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Quality Concrete from Crap

Producing good concrete from less-than-ideal materials

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Copyright Page

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Notes

Initially this "book" was scheduled to be completed and published in 2019; however, with the teaching of classes in Haiti, I'm moving that date up. I had a 46-page draft when at the American University of the Caribbean in Les Cayes, Haiti (January 2017). Many of the text boxes are the result of input from students in my classes at AUC and other people I work with in Haiti.

We need to start our final editing by mid-September, and we can start the translation process about mid-October. If we can finish the translation and proofreading by December 1, we can have the book published and have copies available for use as a textbook in January 2018.

Currently we are estimating this will make about a 180-page book, and we are looking at a 6" x 9" formatting. Formatting, other than basic formatting, will wait until many of the blank spots have been filled.

Ideally, we would print an English version and a Creole version and do our best to keep the pagination of the two versions identical. That way when people who are not literate in Haitian Creole come to Haiti to help, they can fully understand the concepts in the book.

We need to find a source of funding for translating the book.

We need to find a source of funding for printing the book.

We need to find someone to draw the pictures for the book.

The document is full of text blocks. These are areas which we need to expand as we are working on the second draft.

Please feel free to send suggestions to HerbNordmeyer@GMail.com.

Notice:

I define concrete as a substance which contains cement paste and aggregate. That means that it includes, but is not limited to:

Ordinary Concrete

Stucco

Mortar

Ferro-cement

While there are differences between the various products, they all have many common characteristics.

The cement paste may be:

Portland cement and water, or

Pozzolanic materials, hydrated lime, and water, or

Other materials which will harden under water and will bond aggregate together, or

A combination of the above.

In this book, we will limit our discussion to Portland cement and water paste, but recognize that Haiti and many other countries have the raw materials to produce a pozzolanic/lime cement. Haiti does not have the fuel to do so.

Plans have been announced to build a 300 M US Portland cement plant in Gonaives, Haiti. The schedule for construction has not been announced, but considering the complexity of the project, it will be a minimum of 5 years to complete the project and more likely 10 years. This will lead to infrastructure changes. Most Portland cement in Haiti is used in the Port-au-Prince metropolitan area, so Route 1 will have to be enhanced. This may lead to placing aggregate plants in Haiti which will produce quality aggregates and improve the quality of concrete in Haiti.

While the techniques discussed in this book can be used for many different uses of concrete, the overriding use discussed in this book is disaster-resistant housing. There are too many examples of houses built with good intentions that have failed with the next hurricane or within five years, whichever comes first.

If I were writing a scientific paper, I would include much more detail. This book is being written for people who are building homes and do not have access to modern scientific equipment and to materials which are certified as meeting ASTM standards.

New page

Acknowledgements

Table of Contents

Foreword

An introduction written by someone besides the author but who knows the author and the contents of the book.

New page

Preface

An introduction written by the author. Normally addresses why the book was written.

When we started this book, we had a working title of ***Quality Concrete for Haiti***. The concept was to write it in English and translate it into Haitian Creole. The book would be used in Haiti.

Then one of the people who reviewed a draft asked if it could be translated into other languages. If we did that, the proposed title would not be appropriate; and if the book were aimed just at Haiti, it might not be well-received in other countries.

We changed our working title to ***Quality Concrete from Crap,*** with the understanding that that would not be the title on the front of the book. In writing we are trying to expand the scope so it can be used in other areas of the world, but to get it translated and published so it can be used as a textbook in January, 2018, we are not going back and changing every little detail. When it is translated into other languages, we should work with someone from that country to rewrite the section on aggregate availability and other areas that tend to be specific to Haiti. As with all my books, this book will remain a work in progress long after it is published and revised. Actually, this is true of all technical books.

Maybe "***Quality Concrete with Limited Resources.***"

Subtitle could be - the perfect ingredients are not always available, but strong concrete is still possible.

The goal of this book is to help people who do not have access to quality concrete-making materials to produce quality concrete so they can build disaster-resistant homes.

Chapter 1

How Long Do You Want Your Concrete to Last?

Until you get paid for the job?

Until the next hurricane?

Until the next earthquake?

Until your grandchildren are old and gray?

Only you can determine that answer and make it happen.

If you build quality structures, you may struggle to get clients because they may not be able to envision a home that is likely to survive the next disaster.

How will you feel when homes you built for your clients fail with the next disaster, or with the passing of five years? How will you feel if a home you built collapses on a child and kills her?

If you sacrifice quality for short-term business, as the years pass you will find it more difficult to get clients, especially if your competitor has adopted a quality mind-set.

While this is the shortest chapter in this book, it is probably the most important. If you do not opt for quality, there is little reason for reading the rest of the book.

Chapter 2

Why Concrete Fails

Following are several photos of concrete failures which have occurred within a few years of the structure being built. Ask yourself, "Do I want my children and grandchildren to see that this is the way I build?"

Try to identify the cause of each failure. Remember, there is often more than one cause.

Photo 1

Photo 2

Photo 3

Photo 4

Photo 5

Photo 6

Photo 7

Now, here are some answers.

Poor Mix

Poor Mix is a common answer, but it means nothing because it covers everything. With this book and the course based on this book, poor mix is not an acceptable answer. We need to know why the mix was poor. Was there too much water? Was there a shortage of Portland cement? Was there too much clay in the mix? Was the concrete not consolidated? Was the aggregate soft? Did chlorides attack the steel rebar? Was the galvanized, painted, or coated rebar dragged to the job site on a motorbike, resulting in the coating being scraped off? These are just a few of the conditions that can be called a "poor mix."

Poor Water/Cement Ratio

One bag of Portland cement needs 15 liters of water to fully hydrate. That is a water/cement ratio of 0.35. But there is a little problem with such a mix. It is unworkable. It can be placed in a mold and hammered into place or vibrated into place, but to handle it with normal concrete-placing tools, it is unworkable.

Adding water to make the mix workable reduces the strength of the concrete. Abram's Law, in Chapter 3, addresses the impact of water on concrete strength.

The easiest way to have enough water for handling but not so much water that the strength of the concrete is impaired is to use a slump cone. The use of the slump cone is addressed in Chapter 6.

Poor Air/Cement Ratio

Ferret's Law is like Abram's Law, but it factors in the absolute volume of entrained air, as well as the absolute volume of water. In fact, Ferret's Law was derived first, and Abram's Law is a simplification. Entrained air is tiny bubbles of air.

Poor Non-Reactive Fines/Cement Ratio

Nordmeyer's Law is like Ferret's Law, but it factors in the absolute volume of non-reactive fines. Those fines can be clay, rock dust, soil, or anything else which is fine in nature and does not participate in the cement-curing reaction.

Poor Mixing

It takes a lot of work to mix concrete by hand. If the particles are not evenly distributed, the qualities we look for in concrete will be negatively impacted. Mechanical mixing is much easier, but sometimes there is such a rush on the job that the concrete is not adequately mixed. Another problem with mechanical mixing: if the concrete is not needed immediately, it may remain in the mixer with the mixer turning. This leads to entraining excess air.

Poor Foundations

Foundations support the building. If they are not adequate, based on the soil conditions where the building is sited, and are not designed to handle the loads which the building places on the foundation, extra stress is placed on the building. If the concrete in the building is not designed to handle that stress, and usually it is not, then the concrete in the building fails.

Poor Reinforcement

Non-reinforced concrete is strong in compression but weak in tension. Reinforcement is added to make the concrete strong in tension. Poor reinforcement can be insufficient reinforcement, poor placement of the reinforcement, or use of a reinforcement which will degrade with time. Since portions of all concrete slabs, walls, and roofs are under tension, this will lead to failure.

Poor Finishing

If the mortar between block is not tooled, water can more easily enter the wall and degrade the wall. If plaster is finished with a wet sponge so it can be leveled easier, the surface becomes porous and allows water to enter. If a slab is wetted so a slicker finish can be developed, the surface will powder in use. Besides the floor wearing out, it allows water to enter if the slab is exposed to water. Also, the more a finish is worked, the more cement paste is brought to the surface and the more hairline cracks will develop in the finish.

Poor Thinking

Pouring concrete is a complex operation, and all parts of it need to be planned ahead of time. Nearly 40 years ago I poured concrete on a job, my father was there watching, and I did not do a final check on the forms to ensure that they were adequately braced. For years, my father ensured that I did not forget that I was not prepared for the concrete pour.

Looking Forward

In the next chapters, we will go into greater depth concerning each of these reasons which lead to concrete failure. Remember, taking care of one problem does not lead to good concrete; we need to take care of <u>all</u> the problems. This slows a job down, but consider which of these is the better deal for the customer:

Building a house for $6,000 US, and it lasts until the next hurricane or for 10 years, whichever comes first.

or

Building a house for $8,000 US, and it lasts through hurricanes and earthquakes and is there when your grandchildren are old and gray.

Following the discussion of producing good concrete, we will address some specific uses of concrete, including the building of disaster-resistant housing. We have published a book on building domes, and the Haitian Government has published a book on building disaster-resistant homes with confined masonry. Now someone needs to step forward and publish books on the other ways which concrete can be used to build disaster-resistant homes.

Chapter 3

Basic Mix Design

Impact of Particle Size Distribution

Formula for the volume of a sphere = $4/3 * 3.14 * r^3$

Formula for the volume of a cube = s^3

Relatively-round gravel with all particles the same size has a void ratio of 47.7%.

It does not matter if all the gravel is the size of baseballs, of soccer balls, or of marbles, if it is relatively round and all the same size, you will have all those voids.

Consider these round balls. They are ceramic grinding media. No matter what we place them in, no matter how tightly we try to pack them, they will always have 47.7% void space. If we were to use them for concrete aggregate, we would have to have 47.7% cement paste to fill the voids. To get workability in the concrete, we would have to use just a little bit more cement paste. Since Portland cement has a higher cost than most aggregate, that would increase the cost of the concrete.

To make strong concrete with uniformly-sized gravel, you need as much cement paste as gravel. If you use less, the concrete will be weak and have holes in it.

Since gravel is cheaper than Portland cement, you want to modify the gravel so there are fewer voids. Then you can use less Portland cement.

If I had a container of baseball-sized round aggregate, I would still have the same 47.7% void space. But if I had a container of baseball-sized aggregate, I could slip a lot of the small round aggregate between the large aggregate.

If we had perfectly round aggregate, we could get the densest aggregate mix by using the Rule of 4. Start with 4 cm aggregate. Fill the void spaces with 1 cm aggregate. Fill the remaining void spaces with 0.25 cm aggregate.

Author's Note: In 1958, as a 17-year-old who knew everything, using a slide rule (a device used before calculators were available), I devised the Rule of 4, and then found that if I had read the literature, it was common knowledge. Lesson learned – Learn from what others have done.

Ideally, the small gravel should have a diameter ¼ the diameter of the large gravel, and the sand should have a diameter of ¼ the diameter of the small gravel. As everyone knows who has spent time in the construction business, IDEAL never is found on a construction site. Do the best you can.

To obtain the strongest concrete with the least amount of Portland cement, we need to devise an aggregate mix so that it is the densest mix possible. The following section shows a way to do this.

Getting the Most out of Aggregate That Is Available

Aggregate needs to be graded so there are as few pore spaces as possible and as few fines as possible that are less than 100 mesh in diameter.

It is possible to mix large aggregate and smaller aggregate and get a denser mix. To get the densest mix possible, it is necessary to do testing. Here is the process. You can use 1-liter containers, 21-liter buckets, or any other container, if the largest aggregate is not more than 1/3 the diameter of the container.

You can get the densest aggregate blend if each size of aggregate is about ¼ the size of the next larger aggregate. For example:

- 4 cm rock,
- 1 cm pea gravel,

- 0.25 cm sand, and

It is better if all the aggregate has the same moisture content as it will have when you start mixing concrete.

You will repeat the testing with each of the sizes of aggregate, so you might as well start with a bucket of each size of aggregate. You can fill each container up to the same level, or your measurements will be more accurate if you fill the containers level-full of the different aggregates.

Measure the amount of water you add to cover the aggregate. If you start with a 21-liter bucket that is level-full and the aggregate is relatively round and all of one size, you will need approximately 10.5 liters of water. Since the aggregate will not be relatively round and all the same size, you will probably need less than 10.5 liters of water.

Record the amount of water used to fill the spaces between each of the aggregates used.

Start with a measured amount of the largest aggregate.

Add an amount of the next largest aggregate equal to the volume of water used to cover the largest aggregate.

Take the volume of water that would fit in the pores of the second-sized aggregate and add that volume of the third-sized aggregate.

To help you understand how it works, following is a chart which assumes that the pore space for each size of aggregate is 40%.

Developing a Dense Aggregate Blend					
Aggregate Number	1	2	3	4	Pore space
					remaining
Volume of Aggregate (liters)	21	21	21		
Volume of water to fill voids (liters)	8.4	8.4	8.4		
Percent pore space	40	40	40		
First blend (liters)	21	8.4			3.36
Second blend (liters)	21	8.4	3.36		1.34

If the aggregate sizes followed the Rule of 4, the volume of the blend of aggregates will be the same as the volume of the largest aggregate used. In the example, we used 32.76 liters of aggregate, and it took up only 21 liters of space. This would result in an aggregate blend that is 56% greater in density than the density of the largest aggregate that was used. The reason it does not take up 32.76

liters of space is that the finer particles are fitting between the coarser particles.

If everything worked right, but it never does, all the aggregate blend would fit into a 21-liter bucket, and there would only be 1.34 liters of pore space remaining.

Test different aggregates and develop a blend that is as dense as possible.

To make concrete, the pore space needs to be filled with cement paste. The lower the pore space, the less cement paste that is needed. Besides having enough cement paste to fill the pore space, you need enough cement space to hold the pieces of aggregate apart slightly. We will cover this later.

Impact of Water/Cement Ratio on Strength

One kilogram of Portland cement needs about 0.35 kilograms of water to fully hydrate. Such a mix tends to be stiff and not workable. More water is added to make the paste more workable. More water makes the paste weaker. Abram's Law expresses the impact of water on the strength of concrete and is expressed as follows:

$$S = K\,[c/\,(c + w)]^2$$

S = Compressive Strength

K = Constant derived from components used

c = absolute volume of Portland cement

w = absolute volume of water

The formula was developed so that if you tested one mix, you could then calculate the strength of mixes with differing amounts of water and cement. In deriving the "K," it can predict the compressive strength in mega pascals, pounds per square inch, or as a percentage of the original test results. In the classroom, I like to use the percentage of the original test results.

For this exercise, the absolute volume of Portland Cement is one cubic foot (28.3 l) (1 bag). It takes 32.9 pounds (14.95 kg) of water to hydrate a bag of Portland cement. That is 0.53 cubic feet (15 liters). If we fix S at 100 (as in 100% strength) and solve for K, we find that K is 234.

Now comes the fun part. Let's assume that we double the amount of water used. The formula becomes:

$$100S = 234 [1/ (1 + 1.06)]^2$$

$$100S = 234 [0.236]$$

$$S = 55$$

The strength of the mix will be 55% of the strength of a mix where we used the minimum amount of water. See how easy it is to weaken concrete. Put in enough water to get the workability needed, but not one drop more.

If you produce a sample, cure it, and break it in a press, you will know the compressive strength. This is usually measured in mega-pascals (MPa) or in pounds per square inch (psi). For example, concrete which would be used for a sidewalk might have a compressive strength of 17.25 MPa or 2,500 psi. Concrete which is to be used for a house slab might have a compressive strength of 27.6 MPa or 4,000 psi.

Knowing the absolute volume of water and Portland cement used, you can develop a K factor for that mix. Then you can estimate the strength of your mix if you vary the amount of water or the amount of Portland cement.

Impact of Air Content on Strength

When mixing concrete by hand, you do not have to worry about adding air content to a good mix. When you upgrade to using mechanical mixing equipment, it is easy to add air content to the concrete. Air is often added to concrete where freezing weather occurs, to keep the freezing and thawing from breaking the concrete. Here in Haiti we do not need to worry about this. There are companies which make water-reducing agents so a better water/cement ratio can be maintained. Some, but not all, of those agents are soap, and they add air.

Ferret's Law treats the absolute value of entrained air in the same manner Abram’s Law treats the absolute volume of water. Ferret’s Law was developed first, and Abram’s Law is a simplification of Ferret’s Law.

Ferret’s Law is written in this manner:

$$S = K [c/ (c + w + a)]^2$$

S = Compressive Strength

K = Constant derived from components used

a = absolute volume of air

c = absolute volume of Portland cement

w = absolute volume of water

Many plasticizers or workability agents that are sold are air-entraining agents. They increase the workability of concrete.

Many water-reducing agents which are sold are air-entraining agents. They do reduce the amount of water used, and the operator thinks the strength of the concrete is being enhanced, but it is not.

If concrete contains more than a few percentage points of entrained air, problems besides reduced strength can result. Water can wick up the concrete due to capillary action. The height of the wicking is determined by the air particle size and the connectivity of the air particles. That means lots of tiny bubbles increase the amount of water that can wick up a wall. This water can then evaporate from the surface of the concrete leaving chemicals behind which were dissolved in the water. If the water contains chlorides, the chloride concentration in contact with steel rebar is enhanced, and the corrosion of the rebar, with the resulting expansion of the rebar, results in the concrete cracking. See the section on **Chlorides and Concrete** and **Addendum B** for a full explanation.

If concrete is not consolidated by rodding, jitterbugging, or other means, there will be large air pockets. These do not reduce the strength of concrete in the same manner as the entrained air does. They have a stronger impact on the strength, but I have not figured out how to reduce it to a mathematical formula, YET.

The big impact on strength comes when you do not have enough cement paste to fill all the voids between the gravel particles. I have seen cases where the absolute volume of air is 3 times the absolute volume of Portland cement. These situations reduce the strength in the same manner as the air voids from lack of rodding or jitterbugging.

Let’s calculate the impact on the strength of concrete if we did not have enough cement paste to fill the voids between the aggregate particles, which results in 0.5 cubic feet of air space (for this example, we are assuming that these voids are only as bad as entrained air; they are worse), and there was air twice the minimum amount of water used.

$$100S = 234\ [1/\ (1 + 1.06 + 0.5)]^2$$

$$100S = 234\ [1/\ (2.56)]^2$$

$$100S = 234\ [0.153]$$

$$S = 35$$

The strength of the mix will be 35% of the strength of a mix where we used the minimum amount of water and filled the spaces between the aggregate particles.

How well would this concrete hold up for a roof if you had another earthquake? Would you be willing to sleep under such a roof?

Impact of Non-Reactive Ultrafines on Strength

Some sand has fines in it. If you stir sand and water up, after a minute or two the sand settles out and the ultrafines turn the water cloudy or muddy. By letting the mix sit for several hours, you can determine what portion of the sand is ultrafines. These non-reactive ultrafines impact the strength in the same manner that excess water or excess air does.

There are fines, such as pozzolans, which react with the Portland cement to form more cement hydrates. These enhance the strength of the concrete.

Author's Note: Back in the 1960s my father determined that adding more pozzolans to a mix than there were receptors for the pozzolan reduced strength of concrete. I determined that when there were non-pozzolanic ultra fines, the same result occurred. So, I carried that testing on through the first decade of the 21st century and developed a modification of Ferret's Law which addresses this problem.

Nordmeyer's Law can be written in this manner:

$$S = K\ [c/\ (c + w + a + d)]2$$

S = Compressive Strength

K = Constant derived from components used

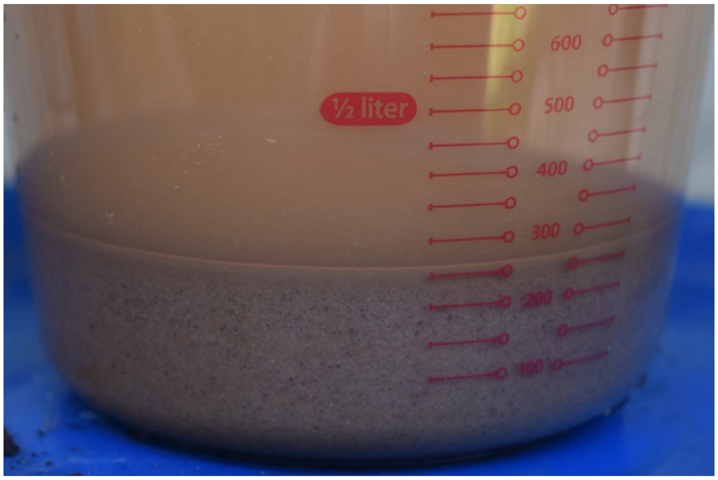
a = absolute volume of air

c = absolute volume of Portland cement

d = absolute volume of fine dust

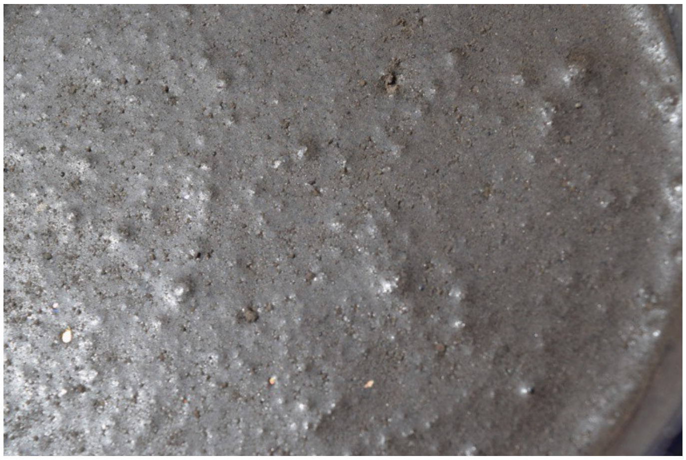
w = absolute volume of water

I have found over 30% clay in some of the sands that are used for mortar and for plaster. They help the uncured mortar to stick, but they reduce the compressive strength of the mortar or stucco. Much of the aggregate used in Haiti is soft limestone. When it is crushed, much of it becomes ultrafines and reduces the strength of the concrete. Nordmeyer's Law addresses particles which are less than 200 mesh. If you mix a water slurry of aggregate, the particles which have not settled within about 2 minutes are the ultrafines. Particles which are a little larger also decrease the ultimate strength of the concrete, but not as much as the ultrafines.



It is easy to estimate the amount of ultrafines in an aggregate mix. Mix the sample up with water and place it in a straight-sided, graduated cylinder or other container so measurements can be taken.

The photo illustrates using a measuring cup. It is filled 250 ml full of sand and then slurried. After about 10 minutes, there is a 10-ml layer of clay on the surface, and the water seems to have lost most of its suspended material. 10ml/250 ml equals 4% clay. Less is better, but this sand is much better than most of the sand I have checked in Haiti.



Sometimes other things show up. Often, organic matter will float to the surface. In this sample, there was oil mixed with the sand, and some of it coated the surface of the water. Oil acts as a bond breaker, so if there is any oil on the surface of the aggregate, the Portland cement paste cannot bond to the aggregate.

Also, some people add clay to the concrete mix because it adds volume to the cement paste. Clay is added to mortar and stucco to give them body and to allow them to stick to a wall. Most clay and other ultrafines do not react to build strength. They act like adding extra air or water.

If the sand had 10% ultrafines, and you were using twice as much sand as Portland cement, then you would be adding 0.2 units of absolute volume of dirt.

With clay in the mix, several additional problems can develop. Over the years, the clay can be washed out of the concrete, stucco, or mortar, and that weakens it even more. The cover photo on this book is an extreme example of this problem. Another problem is that many types of clay tend to hold moisture. If water wicks up a wall, the clay gets wet and keeps the surface of the rebar damp. This leads to corrosion of the rebar. If chlorides are present, this accelerates the corrosive actions. Again, see the section on **Chlorides and Concrete** and **Addendum B** for more details about the corrosive action on rebar.

Ferret's Law and Nordmeyer's Law operate in the same manner as Abram's Law. Rather than remember the three formulae, I prefer to remember Nordmeyer's Law, not because it contains my name, but because when working with mix designs, all the components usually end up needing to be considered.

Aggregates

Types of Aggregate

Stones can be divided into sedimentary, metamorphic, and igneous.

Sedimentary rock are formed from material settling in water, or from the air, or from being precipitated chemically from solution. In time, they solidify enough to form rocks. Limestone is the most common sedimentary rock found in Haiti.

Metamorphic rock are usually sedimentary rock that has been changed by heat, and/or by pressure. The marble in Haiti started as limestone and then gradually changed to marble when exposed to both heat and pressure.

Igneous rock were at one time molten. Besides the difference in the chemical makeup of the magma (lava), the speed of cooling has a great impact on the characteristics of the rock. Basalt is formed when a siliceous magma cools rapidly and becomes amorphous (without crystals); granite is formed if the magma cools slowly and numerous crystals are formed. Basalt and related rock are very common in Haiti. If the magma contains large amounts of dissolved gasses and cools fast, pumice is formed.

Testing Aggregate

Haiti has lots of volcanic rock and lots of limestone. Both can make good concrete, and both can make very poor concrete. First, we will talk about limestone aggregate. Some limestone is hard, while other limestone can be broken by hand. Since concrete cannot be any stronger than the weakest aggregate, we need to eliminate the soft limestone. A second reason we need to eliminate the soft limestone is because when it is run through a crusher, large amounts of ultrafines are produced. This lowers the strength of the concrete that is produced from it.

How do you tell soft aggregate from hard aggregate?

Here is an easy way. Place the aggregate on a large hard stone and have your face about 30 cm from the piece of aggregate. Have someone hit the aggregate with a sledge hammer. If you get dust in your eyes, it is soft aggregate. If sharp pieces of aggregate cut your face, it is hard aggregate. You probably do not want to use this method.

You can break much of the soft aggregate by grinding it with a sledge hammer.

You can also break it by tapping softly with the sledge hammer.

When you break soft aggregate, you usually get ultrafines.

Hard aggregate, when it breaks, usually breaks with a smooth-shiny-surface and sharp edges.

Larger pieces of hard aggregate, when knocked together, produce a ringing sound. Soft aggregate is more likely to produce a thud. If there is an internal fracture in the hard aggregate, it might also produce a thud.

Author's Note: I learned this technique from a man who made rifle stocks and musical instruments from mesquite lumber. When I tried using it on aggregate, I found that it worked.

As you get familiar with hard and soft aggregate, you will be able to judge the relative hardness just by looking at it.

When looking at hard aggregate, there are often sharp edges; or if water-worn, the stones are rounded. Soft aggregate tends to look more eroded.

Sizing Aggregate

Over 50 years ago, I spent some time in southeast Asia, including time at an aggregate plant which was producing aggregate for the US military. There were piles of aggregate, and there were men, each with a round ring, and some with hammers. While there were many men and many piles of aggregate, I will follow one piece of aggregate through the process.

The first pile of aggregate came from the quarry, which we will label **Pile No. 1.** There were stone which were 30 cm in diameter. Most of it was smaller. A portion of it was dust. A man would pitch any piece which would pass through his ring to **Pile No. 2**. Any piece which would not pass through, he would hit with the hammer until it was in pieces which would pass through a 5-cm ring. He would then pitch them to **Pile No. 2**.

On the other side of **Pile No. 2** was a man with a 2.5 cm ring. He did not use a hammer. Any piece which would not pass through that ring, he would pitch to **Pile No. 3**. It was for aggregate which was 2.5 cm to 5 cm in diameter. Periodically the aggregate in **Pile No. 3** was shoveled into a wheelbarrow and hauled away.

The rest of the aggregate went to **Pile No. 4**. On the far side of **Pile No. 4** was a man with a sieve with 0.6 cm holes. Aggregate which would be caught on top of the sieve was 0.6 cm to 2.5 cm aggregate, was thrown into **Pile No. 5,** and was periodically shoveled into a wheelbarrow and hauled away. The aggregate which would pass through the sieve went to **Pile No. 6**.

Aggregate from **Pile No. 6** was shoveled onto an inclined screen, and the fines which passed through the screen were thrown away. Any material which slid down the inclined screen was placed in **Pile No. 7**. This was sand and was periodically shoveled into a wheelbarrow and hauled away.

When **Pile No. 1** was down to fines, it was wheelbarrowed to **Pile No. 4**.

A modern sand and gravel plant is a mechanized system to do the same thing. Since such a plant is expensive, the following paragraphs will discuss a system which is much more efficient than the ring system, but much less expensive than the modern sand and gravel plant.

The basic unit is an inclined screen. It can be one meter wide and two meters long. It should be more than a 50-degree angle (from horizontal) and less than a 60-degree angle. The concept is to allow the aggregate to slide down the inclined screen at a rate of speed so that undersized material can fall through the holes. The frame can be built from angle iron or from No. 3 rebar or other materials. For a temporary system, a wood frame can be built. The legs need to be stronger than No. 3 rebar.

After the frame is in place, horizontal bars should be placed and welded across the frame. No. 3 (1-cm) rebar will work. No. 3 smooth bar, if available, would be even better. For maximum size 5 cm aggregate, the space between the horizontal bars should be 5 cm apart. That is the space between the bars, not the center to center distance. For maximum size 2.5 cm aggregate, the space between the horizontal bars should be 2.5 cm apart.

After the horizontal bars are in place, then vertical bars need to be placed. Ideally, they should be 1.9-cm angle iron, with the angle pointed away from the frame (upward). For the 5-cm aggregate, the space between the vertical bars should be 5 cm apart. The angle iron will allow all oversized material to slide down the screen.

If angle iron is too expensive or not available, then No. 3 smooth bar or rebar can be used.

For the 0.6 cm screen, build one like the 2.5 cm screen, but instead of adding the vertical bars, add 0.6 cm wire mesh.

For the sand screen, build a 0.6 cm screen and then top coat it with screen wire for windows. It will need to be replaced periodically and is slightly on the coarse side, but it is an economical alternative to trying to import screening which would normally be used in a modern sand and gravel plant. If the fines are wet, they will not go through the screen unless they are washed through the screen, thus it is better if the fines are dry. If they are not dry, a system needs to be added so water can be applied to the screen to wash the clay through the screen.

With the fines which are collected, do not use them for concrete, mortar, or stucco. They may be used for fill.

Fly Ash, Pozzolans, and Other Additives

Pozzolans

2,000 years ago, the Romans used volcanic ash to make concrete. They ground it and mixed it with lime putty and aggregate. They made concrete, mortar, and stucco. It took a long time to cure, but some of it remains in good condition after 2,000 years.

In the 1950s and 1960s, I worked for Pozzolana, Inc., and we produced a natural pozzolan from volcanic ash. This product was used to replace 20% of the cement in the concrete in Falcon Dam on the Rio Grande River in South Texas. It was used in the addition to the Galveston Sea Wall and was used in a dam in the Dominican Republic. In 1957 Peligre Dam was completed in Haiti. It used 13,500 tons of our Rio Grande Pozzolan, and as I understand it, is the highest dam in Haiti.

By the late 1960s, fly ash started replacing natural pozzolans because it was cheaper. Fly ash is a by-product of burning coal in a power plant. Now most of the concrete produced in the US contains fly ash.

Metakaolin is clay that has been heat-treated to remove some of the chemically combined water.

Depending on economics, it may make sense to build a fly ash terminal and import fly ash, or it may make sense to investigate the availability of volcanic ash deposits in Haiti and develop a processing plant in Haiti to produce natural pozzolans. The natural pozzolan could be used to replace a portion of the cement used to make concrete. This would lower the cost of the concrete and would make the concrete stronger and more impervious.

Silica fume is also a pozzolan, but requires considerable testing and water reducing agents to be used effectively. It is beyond the scope of this book.

Since much of Haiti is volcanic in nature, chances are there are materials which could be used to produce a natural pozzolan. Basalt rock could be used, but the crushing of it would be expensive. I have not seen any volcanic ash deposits, nor have I investigated whether volcanic ash deposits are present.

Hydrated Lime

Currently, hydrated lime is not being imported into Haiti. It is used for many purposes, including giving mortar body so it will hold masonry units where they are placed, improving the bond between the mortar and the masonry units, reducing water penetration through masonry joints, and improving the workability of stucco so it will stay on the wall or ceiling where it is placed. It is also used for whitewashing of masonry and concrete structures. This reflects light and prevents the sun from heating the building as much, and it protects the concrete surface.

Steps need to be taken to start importing hydrated lime into Haiti and training masons and plasterers to use it.

Depending on economics, it may make sense to investigate the availability of limestone rock deposits in Haiti and to develop a processing plant in Haiti to produce quick lime which can then be hydrated into either hydrated lime or into lime putty. Such a product could be used to produce masonry cement, plasters (stucco), and even concrete, if care is taken.

A processing plant could be as simple as a pit dug in a hillside and fired from below with wood to produce quick lime. Then the quick lime is slaked (mixed with water) and buried in a trench about 0.5 meters wide and a meter deep, so it can cure for 3 to 6 months to produce a hydrated lime paste.

On the other extreme would be a lime plant consisting of a rock crusher, a rotary kiln fired with natural gas, fuel oil, or powdered coal, and a pressure hydrator to produce powdered hydrated lime. This would be followed by silo storage or a bagging plant to bag the hydrated lime powder.

Mortar Fat

Mortar fat is a name that is applied to many different products which tend to do the same thing to stucco and mortar that hydrated lime does. They are also called plasticizing agents and are used in concrete to improve the workability.

One of the more common ones is called KelCrete. It is made of a derivative of guar beans. With KelCrete, only 30 to 45 grams are needed per bag of Portland cement. With hydrated lime, 5 to 10 kilograms are needed per bag of Portland cement.

One of my research projects, which I am currently behind schedule on, is to determine whether guar beans can be crushed and added to mortar and stucco and have the same impact that KelCrete does. If the concept works, then work needs to be done on the best way to process the guar beans by hand and to determine the best dosage rate. If it works, then there is the potential of a small industry to produce guar powder to go into stucco and mortar.

Water-Reducing Agents

If the excess mix water in concrete is eliminated, the cured concrete is stronger. Some agents replace the water with tiny air bubbles which do not help the strength of the concrete. Others work better. These products should only be used after an engineer has designed the mix formula and the components all meet standards.

Accelerators and Retarders

Concrete can become stiff because water has been lost from the cement paste. This may be because of the sun heating the surface and water evaporating, wind blowing on the surface, aggregate which slowly absorbs water, or a substrate which sucks water out of the concrete. In each of these cases, there may not be enough water remaining to fully hydrate the cement particles in the concrete. This results in concrete that is weaker than expected. It may end up powdering or crumbling. This section does not address that problem.

A false set is when non-cementitious reactions, often involving gypsum, cause the mix to appear to set, but no actual chemical hydration of the cement particles has taken place.

Concrete can get stiff because a chemical reaction occurs which causes water to combine with the Portland cement. Accelerators and retarders are designed to impact the speed of the chemical reactions.

For years in cool climates, calcium chloride was added to concretes in winter to accelerate the set. See more on calcium chloride in the next section. Then it was found that the chloride content accelerated the oxidation of rebar so in most countries it has been banned.

The simplest accelerator is warm water. The simplest retarder is cold water.

Where there is a need, there are cements which will set in 2 hours and develop normal 28-day strengths within a day or two. Many, but not these cements, produce a great deal of heat when curing, and care must be taken when using them to prevent thermal cracking from occurring.

Getting into these specialty cements is beyond the scope of this book.

Chlorides and Concrete

For years calcium chloride was added to concrete to accelerate the set, especially in cold regions. Then it was found that the chloride ion caused a deterioration of any steel in the concrete. Now ASTM standards are limiting the use of chlorides in concrete, stucco, and mortar. Admixtures cannot be used if they add more than 65 ppm soluble chlorides.

How much is 65 ppm soluble chlorides?

1 metric ton of concrete

Can add 0.065 kilos of chloride (65 grams).

Each liter of sea water contains 20 grams of soluble chlorides.

Therefore, could add 3.25 liters of sea water without violating that standard.

Each metric ton of concrete contains about 160 kilos of cement.

A metric ton of concrete requires about 80 kilos of water (more is often used).

We are talking about 3.25 liters of sea water per 80 liters of water being all the sea water that you can put in a metric ton of concrete without violating the standard and risking the degradation of the steel.

It is my understanding that most of the water in the lowlands of Haiti is brackish or slightly brackish. That means it has chlorides in it. This can cause deterioration of stucco lath and rebar.

How much chloride content is in the local water? If it is over 800 parts per million of chlorides, you run the risk of causing deterioration of steel. That would be about 1,300 parts per million of salt in the water.

Using the lowest water/cement ratio possible will lower the amount of chlorides added.

Is the chloride content enough to require that rebar be painted before it is installed?

Is there a water source which has lower chlorides?

An alternative is to use reinforcing which is impervious to oxidation and other methods of corrosion. Basalt rebar is discussed in Chapter 8.

Brackish water and sea water do not have as much of a negative impact on concrete as they do on the steel that is used in concrete.

Addendum B is a technical report I wrote on the corrosion of rebar via oxidation and how chlorides enhance that oxidation.

Chapter 4

Concrete Formulae

Author's Note: I define stucco and mortar as forms of concretes; therefore, it is appropriate to add formulae for stucco and mortar in this section.

Formula Notes

Bounce all buckets of Portland cement on the ground several times to get the air out and to compress them, otherwise you will be shorting the formula of Portland cement.

Normally, sand is measured in a loose, damp condition. Sand in this condition is slightly fluffed and takes up about 20% more space than sand that is perfectly dry.

If dry sand is used, often the water and cement paste do not wet it adequately and there are air bubbles that stick to the sand particles. This lowers the strength of the resulting concrete slightly.

If you are not filling the buckets brim-full, mark each one so your measurements will be consistent.

Rounded sand and gravel results in more workable mixes. Crushed sand and gravel results in a stronger concrete which is harder to work.

Foundation Formula

The foundation is designed to transition between solid earth and the building. It does not need rebar, and it does not need to be as strong as the concrete higher up in the building. It does need to be protected from erosion.

Author's Note: In the section on sizing the foundations, the size may seem extreme when compared with foundations for houses built in the US and other parts of the world. A different school of thought is used in the US. The foundations are smaller, but they are engineered with carefully placed and tied rebar and a much higher-strength concrete is used. The larger foundations described in this book are less expensive to build and function as well. If you have a professional engineer designing your structure, feel *free to follow his/her recommendations.*

The amount of water used will depend on the pore space of the aggregate and the moisture level of the fine sand. Decide on the volume needed to get a slump of about 4 inches.

Large stone can be used, but they will not fit in a mixer, so they are added as the concrete is poured into the foundation and rodded. To obtain a better bond between the concrete and the large stone, all dirt and clay needs to be washed off the large stone before they are added to the foundation.

Keep large stones at least 30 cm away from any rebar which is inserted for a column. Since the foundation concrete is weak, it needs to be protected. The best way to protect the foundation is to have it located underground. If that is not possible, it should be plastered when the walls are plastered.

Author's Note: Back in the 1950s in northern Mexico, I observed walls being built with a thin sand/cement paste, and large rock were dropped into the forms after the forms were partially full of the paste. In the 1960s, I saw some of these same walls with the cement paste eroding because the cement paste had such a poor water/cement ratio.

Stem Wall or Plinth Formula

Both terms are used. Some people prefer one term, and some prefer the other. The stem wall is traditionally a wall that connects a footing to the above-ground portion of a building. A plinth is traditionally the base of a column. For this book, we will use the term stem wall.

Ideally, the stem wall should start below the final grade and extend up to the level of the concrete slab.

Two different formulae are supplied for the stem wall or the plinth. One is for when the soil supporting the foundation is firm, and the other is for when the soil is either a sandy soil or a clay soil.

Firm Soil Stem Wall Formula

First, building on a firm foundation, rebar in the stem wall is not needed, but if rebar is desired, it can be added. If rebar is to be added, the medium-sized stone cannot be used because they would tend to knock the rebar trusses out of line and would interfere with the medium-sized stone passing through the trusses and adequately filling the spaces below the top of the trusses.

Follow the formula in the drawing. As concrete is being poured into the forms which have been set up for the stem wall, medium stone should be added, and the concrete should be rodded. As with the large stone for the foundation, the medium stone should be kept at least 30 cm from any of the vertical rebar trusses for columns. The width of the stem wall is the width of the wall that will be placed above the stem wall.

Sandy or Clay Soil Stem Wall

For the stem wall for sandy or clay soil, rebar is required. If the area is subject to steel corrosion due to chlorides, a chloride-resistant rebar should be used (such as basalt, fiberglass, bamboo, or stainless steel) and should be built to provide a minimum of 1-inch concrete coverage for any rebar and a wrapping tie every 20 cm.

Column, Wall Beam, and Roof Beam Formula

This formula is like the formulae which are used to pour stem walls when building in sandy or clay-type soils.

Columns are poured between wall panels of concrete block which have been laid. Boards are placed on each side of the wall panels to keep the concrete in place. Corners are a little bit more complex to form. Ideally, the entire column should be poured at once, but that is not possible when there is a beam installed in the middle of a wall. In those situations, the column form boards should be installed up to the height of the top of the beam. Then the beam form boards should be installed. After that, the beam and the column should be poured at the same time. All the concrete should be well rodded to ensure it is well consolidated.

Slab Formula

If the slab is poured on well-consolidated base, the thickness is based on the needs of the reinforcement. If steel rebar is used, there should be 5 cm of concrete above and 5 cm of concrete below the rebar.

Mortar Formula

Mortar has several functions. It needs to hold the masonry units apart. It needs to bond the masonry units together. It needs to resist the penetration of water. It needs to stick to the end of a masonry unit as the masonry unit is set into place (small unit) or as another masonry unit is set beside it (large unit). It needs to resist erosion. Many formulae will provide some of the functions, but only a few formulae will perform all the functions.

Ideally, the maximum sand size should be less than 1/3 the width of the desired mortar joint.

The mortar should be rich in cement, so it is easier to tool the joints to produce a water-resistant joint.

I prefer a mortar which will hang onto the trowel when the trowel is inverted, but will easily slide off when the trowel is tapped on a masonry unit.

In Haiti, and in some other parts of the world, clay is often used as the plasticizing agent. This results in a weaker and more erodible mortar. Often the clay is introduced as part of the unwashed sand that is used. From time to time I have measured up to 30% clay in the sand that is being used to make mortar. This results in having as much clay as Portland cement in the mix. Other things being equal, the mortar compressive strength will be reduced by about 40%. If clay must be used as a plasticizing agent, use as little as possible.

Stucco Formula

A good mortar will work as a plaster or a stucco. In adjusting the water content, I like to hold the stucco on a trowel that is held at a 45-degree angle. It will stay in place. If tipped to a 60-degree or 75-degree angle, the stucco will slowly slip off. If the trowel is loaded and then flipped so the stucco is below the trowel, it will be held in place by the suction.

Plasticizers for Mortar and Stucco Formulae

Traditionally, hydrated lime was used as the cement in mortars and stuccos. When Portland cement came on the market, small amounts were added to speed the set of the lime mortar or plaster. With time, the amount of Portland cement increased. Then it became common to add hydrated lime to Portland cement to get the preferred workability.

In the 1920s, masonry cement was developed. Traditionally, it was produced by inter-grounding limestone with Portland cement clinker and Vinsol resin. Mixing the three components without the inter-grinding does not produce as good a mix.

There are hundreds of products referred to as mortar fat. Two of the most popular are KelCrete and Easy-Spred.

KelCrete is made from a derivative of guar beans.

Author's Note: I plan to test Guar Beans to see if simple processing can make *them usable as a mortar and stucco addition. If they can be used, this might be a crop that Haitian farmers could grow to add to their income.*

Easy-Spred is reputably made from diatomaceous earth and sodium bentonite. The diatomaceous earth is amorphous silica and is a pozzolan. The sodium bentonite reacts with the calcium ions released when cement hydrates and forms calcium bentonite which adds strength to the mortar.

Author's Note: When I was a kid, my father sometimes burned the spines off prickly pear cactus, diced it, crushed it, mixed it with water, and let it soak for two days. He added it to a Portland cement/sand mix for making mortar and stucco. I need to repeat his process so I can determine the appropriate ratios. He always said that we should not make up more than was needed because after two days it started stinking.

Author's Note: At other times my father burned limestone, hydrated it, and mixed it with a Portland cement/sand mix. He would never let me get close, because during the hydration process, the burned rocks would sometimes explode.

Structural Insulated Concrete Panels (SCIP) Formula

Structural insulated concrete panels are pieces of Expanded Polystyrene (EPS) plastic between two panels of reinforcing. Keeping those panels apart are trusses. While a 20-cm SCIP may react like a 20-cm reinforced concrete wall, it has only 2.54 to 4 cm of "stucco" on each side of the EPS filler.

Author's Note: With several others, I am working on a design in which the EPS can be replaced with another material, such as straw, banana leaves, or plastic bottles.

Author's Note: With the high chlorides in some parts of Haiti, the SCIP system will not work since the galvanized steel would be corroded. With several others, I am in the early stages of developing a SCIP which can be built from native materials and will not contain steel (which corrodes).

Insulated concrete forms (ICF) formula

Insulated concrete forms are sheets of expanded polystyrene (EPS) plastic that are held apart in different ways. Vertical and horizontal rebar are added, and then concrete is poured, using the EPS as the forms. The forms are left in place and act as insulation. The exterior and the interior need to be finished, usually with a stucco.

Sewer Formula

Sewage contains organic wastes. Decomposition of organic wastes develops acidic conditions. Acids attack concrete. Most acid-resistant concrete formulae do not use Portland cement as a base, because when Portland cement hydrates, it gives up calcium ions which are an acid's favorite food.

Author's Note: A noted scientific laboratory tested an acid-proof concrete and determined that it would last for 700 years if it were made as concrete pipe and used to carry human sewage. My testing (I used a different protocol) showed that it would probably last for about 7 years. When the product was made and used, deterioration was noted in 2 years. It always helps to have a test that has been proven to be accurate.

Following are steps which can make concrete made from Portland cement more acid-resistant.

- Do not use aggregate which is soluble in acid. Soft limestone is the worst aggregate which can be used.
- Ensure there is enough cement paste to fill all the voids between the aggregate particles.
- Use a pozzolan, and chemically balance the formula so that all calcium ions produced are tied up with the pozzolanic reaction.
- Keep the entrained air as low as possible.
- Use as little water in the mix as possible, but enough to get a good bond to the aggregate.
- Consolidate the concrete as much as possible.
- Use a long-lasting water repellent.
- Do not re-temper the concrete if it starts to stiffen before being used.
- Mechanically mix the concrete.
- Do not attempt to make acid-resistant concrete unless you have a reliable concrete laboratory available to help develop the formulae and available to provide quality control.

Chapter 5

Concrete Physics

Drying Shrinkage

Concrete, stucco, and mortar are at their largest volume either as they are placed or shortly thereafter, when the cement hydration starts to heat the mix. As the mix cures, water is lost, and the volume shrinks. On a sidewalk without control joints, there is usually a crack every seven steps. You either determine where the crack will be by inserting a control joint, or the concrete will do your planning for you.

If you do not slow down the drying of concrete, the surface will dry faster, shrink, and cause surface cracks. These are places where structural cracks can start to form. They are also places where chlorides and sulfates can get into the core of the concrete and potentially enhance the degradation of the steel rebar or the concrete.

Thermal Movement

When concrete gets hot, it expands. When it cools off, it shrinks. Someone told me that it is always hot in Haiti, so you do not have to worry about this. If sun shines on a concrete slab or on the western wall of a stucco or concrete building, it can get quite hot and cause cracks. Remember the sidewalks and seven steps.

Moisture Movement

It may take a year or more for excess moisture to work its way to the surface of a slab. The more air voids, the faster the moisture will move. If you want to keep moisture from moving from the soil up through the concrete, you need to provide a barrier or eliminate the moisture.

The moisture itself may not be a problem, but if the soil contains high levels of chlorides or sulfates, they may cause the concrete to deteriorate. An additional problem is if people sleep on the floor or if their bedding is on the floor, moisture wicking through the slab can add moisture to their bedding, and this can result in mold growth. To keep ground moisture from wicking up, a sheet of polyethylene plastic is often placed under the slabs and footings.

Concrete Strength

Concrete has excellent compressive strength and poor tensile strength. Steel has excellent tensile strength but is expensive. Stresses always occur on concrete.

When a roof sags, the cracks start on the underside, where the concrete is under tension.

Concrete roofs are seldom as simple as the drawing. If there are internal walls which are supporting the concrete, where the concrete passes over the internal walls, the top of the roof is in tension, so cracks occur on top of the roof outlining the supporting walls.

Since the concrete roof sags, there is a tendency for water to pool over those points of sagging. This adds weight to the roof, and it also accelerates the penetration of water into the concrete.

That water does have a beneficial use. When it evaporates, the evaporation cools the roof, and as a result, cools the structure below the roof. To enhance this effect, dikes are often placed around the edge of the roof to pond more water on the roof. This results in water standing over the tension cracks which occur above the load-bearing walls. This accelerates the deterioration of steel rebar that is used in the roof slab.

Chapter 6

Mixing Concrete

By Hand

Concrete is often mixed by hand on the ground, in a wheelbarrow, or in a mortar box. The problem with mixing it on the ground is that moisture in the concrete may escape into the ground, and the soil may end up being mixed into the concrete, lowering its strength.

If you are mixing concrete by hand, dry-mix before adding water. If you do not, you will need extra water to get the entire mix uniform.

When I was 60 and my father watched me mix stucco in a wheelbarrow, he told me that no one under 75 has enough sense to mix stucco. I used 1.5 cm cuts with my hoe, and he insisted that to get a good mix, one should not use more than 1.0 cm cuts with the hoe.

Use as little water as possible. If you think you need more water, mix a little more before adding it.

After the concrete is mixed, use it within 30 minutes. Microscopic bonds start to form within 30 minutes, and if you move it around after 30 minutes, you are breaking some of those bonds. Once broken, those bonds will not be as strong as they would have been if the concrete had not been moved.

Portable Mixers

Portable mixers may be electric-powered, gasoline-powered, or diesel-powered. They can mix concrete more thoroughly than normal hand-mixing. That and labor savings are their advantage. If one is mixing a less-than-ideal concrete, they can help you arrive at failure much sooner. There is also the tendency to add extra water to the mixer. This leads to segregation of the aggregate and to lower-strength concrete. They also can grow legs and walk off the job. As with any tool, they can improve your performance if used right.

When using a portable mixer, always add most of the water first, about a third of the sand, and then all the fines (Portland cement, pigments, fiber, admixtures); then add the rest of the sand. If more water is needed, add it slowly so the final mix has as little water as possible.

Never believe the manufacturer’s rated capacity. Often, they measure the contents of a mixer by how much water it can hold if filled to the brim. Consider that 50% of the manufacturer’s rated capacity might be a better estimate for the capacity of the mixer.

Ready-Mixed Concrete

In the United States, most concrete is delivered to the job site in ready-mix trucks. The most common kind has a rotating drum so the concrete mixes on its way to the job site. Years ago, most of these trucks were in the 4 and 5 cubic meter capacity, but by adding extra axles and improved roads, many are 9 cubic meter capacity. Maneuvering such a truck through some of the streets of Haiti would be a problem.

There is also a kind which has hoppers for sand, gravel, and cement. At the job site, the components are metered to a mixer, and the concrete is delivered fresh. These trucks are best where small amounts of concrete need to be delivered over several hours. Again, maneuvering such a truck through some of the streets of Haiti would be a problem.

For small jobs, an alternative is a mixer trailer which carries just over a cubic meter of concrete and is towed behind a small truck.

A serious problem with any ready-mixed concrete is that if a poor formula is used, you can quickly make large quantities of poor concrete, and you can be responsible for numerous failed jobs.

Ready-mix trucks need to be filled before delivery of the concrete. This usually requires a plant with a cement silo, an accurate method of weighing the components, and a system for loading the components into the ready-mix truck.

If a ready-mix truck gets stuck, or gets tied up in traffic, and the concrete sets, it is nearly impossible to clean the concrete out and reuse the drum; therefore, the driver needs to have a method of stopping the cement hydration process. The most common method is for the driver to carry a sugar source. Once the sugar is added, the concrete is worthless.

Chapter 7

Foundations

Foundations consist of several parts. They are:

- Footings
- Stem wall or plinth

Besides being wherever there is an outside wall, they need to be wherever a loadbearing wall is located in the building. Before discounting the need for internal loadbearing walls, remember, they are often needed to make a building disaster-resistant.

Foundations support the building. If they are not adequate based on the soil conditions where the building is sited and are not designed to handle the loads which the building places on the foundation, extra stress is placed on the building. If the concrete in the building is not designed to handle that stress, and usually it is not, then the concrete in the building fails.

Engineering a foundation can be complex. If you can hire a competent engineer to design your foundation, do it. If you cannot, and you are building a one- or two-story building, follow the guidelines that are listed here. If you are building a three-story building, whether you can afford it or not, hire a competent engineer.

With building the domes mentioned in this book, they are much lighter than a conventional home, so the foundations do not need to be as massive since they tend to "float" on the soil where they are placed. For them, follow the guidelines listed in ***Homes for Jubilee*** or in ***Kay pou Jubilee***.

Author's Note: I was called in to figure out why the stucco and block walls were cracking on an unfinished building at a major university. The engineer had gone to the literature and determined the soil type and designed an adequate foundation. The contractor had installed it according to the design. What everyone had missed until I pointed it out was that there was a landfill that was not shown in the literature, and money had been saved by not drilling and sampling the soil underneath the foundation. That soil should have been supporting the center of the building, but it was not. The center of the building was sinking.

Footing Width

First, find out about the width and depth of footings on neighboring houses. If there are any signs of settling or shifting, build a wider and/or deeper foundation.

Second, consider the width of the footing. The width is based on the soil type:

Hard soil, such as rock and gravel	Minimum 40 cm wide
Clay soils and clay/sand soils	Minimum 50 cm wide
Sandy soils	Minimum 70 cm wide

Footing Depth

Consider the depth of the footing into undisturbed soil. It should be at least 50 cm into undisturbed soil. It should also extend above the soil line to elevate the building above the surrounding soil levels. As a minimum, it should extend at least 30 cm above the finish grade around the building.

When digging the trench for the footings, there are several things to remember. The footings will carry more weight if the trench has a flat bottom, so dig it with a flat bottom and squared edges. They will carry more weight if the sides of the trench are dug into the undisturbed soil.

If you must dig out soil and then build forms to hold the footings in place as they are poured and cured, they will never hold as much weight. The top of the footings should be level. There are times, such as in sandy soil, when you must dig a wider trench than the footing and then build forms. In other types of soil, it should be avoided. Note that sandy soils require a much wider footing than clay soils. This is part of the reason.

When building on sloped land, it is possible to step the footings. If this is needed, it is better to hire an engineer to help design the stepping.

Reinforcing Anchored in the Footings

If confined masonry or infill masonry building technology is used, vertical reinforcing columns are needed. The trusses are anchored about 5 cm above the bottom of the footing and extend up not less than 60 cm beyond the location of the first-floor roof if a second story is envisioned.

With the type of footings discussed here, horizontal reinforcing is not needed. However, at each corner, on each side of each door, and at each side of each window, a reinforced column needs to be installed. Additionally, if there is any span over 4.5 meters, a reinforced column is needed.

See the section on Confined Masonry for more information on building the rebar trusses to go into the columns, and installing them in the trenches.

With structural concrete insulated panels (SCIP), vertical rebar need to be placed every 60 cm and alternating to each side of the panels. Preferably the rebar should be just inside of the reinforcing mesh on each side of the panels. When the panels are finished, the concrete on the outside of them will be 1.0 to 1.5 cm thick. Each rebar needs to be placed into the footing at least 60 cm and must extend up above the top of the stem wall not less than 45 cm. This will allow the SCIP panels to be anchored to the footings. See more information in the section on SCIP.

With insulated concrete forms (ICF), vertical rebar need to be placed every 60 cm wherever the ICF are to be placed. The rebar coming out of the slab should be centered wherever the ICF are to be placed. Each rebar needs to be placed into the footing at least 60 cm deep and extend up above the top of the stem wall not less than 60 cm. This will allow the ICF to be anchored to the footings. Again, see more information in the section on insulated concrete forms.

Utilities

If the structure is ever going to have utilities coming in underground, it is necessary to install holes through the footings. This is best done by installing PVC pipe a size larger than the lines which will be carrying the utilities, but the maximum diameter of the installed pipe should not be greater than 15 cm.

When installing the PVC pipe, temporarily cap each end and extend the PVC pipe not less than 15 cm on each side of the footings. After the footing is poured, and before the backfill is installed, appropriate lines need to be installed and run to where the surface of the slab is to be located (or higher).

Backfilling

The area above the original grade of the land and the top of the footings needs to be backfilled. When this is done, the backfill needs to be added in layers and then tamped. While it can be tamped by hand, a mechanical vibrating tamper works better. Tamp the soil in tiers of 2 to 3 inches and be sure it is wetted as it is tamped.

Now is just about the only time when building on sandy soil has an advantage. If the sandy soil is wetted as it is backfilled, it will tend to consolidate and require less tamping. Tamp it anyway.

After the stem wall is poured, additional backfill needs to be added and tamped. The final level should be the anticipated level of the bottom of the slab. To keep from wasting concrete, ensure that the top of the backfill is level.

Stem Wall

The stem wall is poured above the footings and provides a place where the masonry units can be laid. For confined masonry, infill masonry houses, SCIP houses, and ICF houses, it should be as wide as the walls and should be a minimum of 30 cm high, except as noted below. It should be formed and poured so the top is flat. With clay soils or sandy soils, the stem wall needs to be horizontally reinforced with trusses.

For SCIP and ICF, the stem walls need to be horizontally reinforced with trusses.

Slabs

Slabs can be placed in two different locations. They can be poured inside the stem walls and plinths, or they can be poured on top of them.

Pouring the Slab Inside the Stem Walls

The advantage of pouring the slab inside the stem walls is that no extra forming is needed; and when the slab is poured, it does not interfere with much of the rest of the construction.

Walls can be erected before the backfill that goes under the slab has been completed and compacted.

Pouring the Slab on Top of the Stem Walls

If the slab is to be poured on top of the stem wall, the process is more complicated.

- Arrangements need to be made to anchor the slab to the stem walls.
- As with pouring the slab inside the stem walls, forms must be built and reinforced if needed.
- After the stem walls have been poured, the forms need to be removed.
- After the stem walls have cured, the areas inside the stem walls need to be backfilled and compacted.

- Then forms need to be added to delineate the slab.
- After the slab has been poured and cured and the forms have been removed, the walls can be erected.

Pouring the Slab and the Stem Walls Together

This pour is more complicated than the previous pours and is not recommended for any crew except those with a great deal of experience.

- Arrangements need to be made to anchor the slab to the stem walls.
- Forms must be built to delineate the slab and the exterior of the stem wall.
- Inner forms of the stem wall need to be shorter than the outer forms by the thickness of the slab.
- Backfill and compact up to the top of the inner stem wall.
- Add reinforcing.
- After the stem walls and slab have been poured, the outer forms need to be removed.
- The inner forms cannot be removed and will in time deteriorate or be eaten by termites.
- After the slab has cured, the walls can be erected.

Chapter 8

Reinforcing

Why Reinforce?

Concrete, while strong in compression, is weak in tension. Most movement of cured concrete places some portion of it in tension. Some of the movement is small and driven by chemical reactions that are taking place within the concrete. Examples would be sulfate expansion and reactive aggregate expansion. Such movement normally causes spalling. This is flaking-off of small pieces of the concrete surface. In time, this can cause massive failure.

Other movement can result in rapid structural failure. This chapter is not a design manual for reinforcement that is needed, just an indication where reinforcement is needed and the types of reinforcement which are needed.

Following is a partial list, with brief explanation, of external sources of movement that can cause structural failure in quality concrete:

Footing Failure

While the footings are often not reinforced, reinforcing in the rest of the building may become ineffective if the footings fail.

Footings fail if the ground moves, if the structures above the footings move, or if the ground below the footings does not have the bearing capacity to hold the weight of the building.

That sounds very simple, but we need to ask, why does the ground move?

Take some wet clay in your hands and squeeze it. Ribbons of clay will ooze out between your fingers. If the clay is only moist, the same thing will happen if more pressure is applied. Remember, the footings are holding the entire weight of the building.

If the soil happens to be clay, or have a high content of clay, changing of the moisture in the soil will often cause it to change in volume. If the soil has been moist and it dries out, it tends to crack.

If there is weight placed on the soil close to the foundation, it may compress some of the soil and put pressure on the footings which may cause the footings to fail.

Most of the readers of this book are in tropical climates. But in northern climates the soil can freeze and expand. Because of this, footings are placed far enough underground where they are not exposed to freezing and thawing.

There are times when the earth moves, such as from an earthquake, and applies stresses first to the footings, and then to the rest of the building. Knowing the likelihood of having an earthquake, and the magnitude of that earthquake in the area where your building is to be located impacts the size of the footings that are needed.

Every building has weight. The heavier the building is, and the narrower the footings, the greater the pressure which is placed onto the soil that is supporting the building. When this happens, the footing may sink further into the ground. If the entire structure sank evenly, which seldom happens, the only problem would be that underground lines for utilities might be broken, but the building would survive intact.

A serious problem is that different parts of the building place different loads on the footings. Then moisture getting to the soil around the footings is not uniform all around the building, thus causing reduced load-bearing capacity in different areas. A few centimeters of settling in one corner of a building is enough to put a big crack in a building.

When wind blows on the building, it causes some portions of the building to push heavier on the footings than when there is no wind. When we are talking about a 1-story or a 2-story building, the stresses are normally minimal. If we are talking about five-story buildings, or more, then the stresses can be much greater. Engineers need to look at anchoring the building through the footings and to the ground, so that the building does not turn over.

An important part of reinforcing a building is to ensure that the footing trenches are flat bottomed, that there are square corners in the trench, and that the footings are poured on undisturbed soil. This ensures that the weight of the building is evenly disbursed along the soil underneath the footings.

Author's Note: I looked at a building recently that had been in place for many years without a problem. When they started landing helicopters on the flat roof, the roof started moving around compared to the columns that were supporting it. A stress had been added that the building was not designed to handle. Every time a person walks across the floor in a building, a little stress is placed on that building. When more stress is placed on the building, the stress is carried down to the footings, and that can cause the *footings to fail.*

Stem Wall Failure

Stem walls are a transition between the footings and the building. Usually, any failure of the stem wall is because of movement either above it or below it.

Slab Failure

Slab failures occur for the same reasons that footing failures occur.

In addition to those reasons, weight may be applied to all or a portion of a slab. An example would be when a vehicle drives on. Or if a heavy piece of machinery is placed on the slab. Or if the heavy piece of machinery vibrates. If the slab is not designed to carry that load, the slab may crack.

Concrete as it cures normally shrinks. If the ends of a concrete slab are anchored, stresses are placed on the concrete as the concrete shrinks. When those stresses are greater than the tensile strength of the concrete, the concrete will crack. Often, slabs are poured after at least a portion of the walls are in place. Often, there is a piece of wood placed along the walls so the concrete will not bond to the walls. This allows the slabs to float freely so stresses do not develop in the middle of the slab, which can lead to cracking.

Slabs also fail when there is a source of moisture under the slab. This could be from a spring or from a broken water or sewer pipe.

If the slab is tied to the wall system, any wall movement can crack a slab.

Wall Failure

Usually, walls fail when the footings and stem walls holding them up move, when the footings and stem walls cannot support the weight of the walls, or when shortcuts are taken when the walls are being built.

If the slab is tied to the walls, anything which will crack the slab may crack the walls.

Wind loads can be powerful. Besides blowing against one side of a building, a partial vacuum forms on the other side of the building. Either of these can lead to a wall failure.

During Hurricane Matthew, a downdraft on a roof caused the roof trusses to exert lateral pressure on the walls because there was not a bottom chord on the trusses. Since then, I have looked at several roof trusses in Haiti and have found that eliminating the bottom chord is not at all uncommon.

Of course, if a vehicle is driven into a wall, a crack is likely to result.

Author's Note: Years ago, I built a straw house and plastered it. Since I did everything right, the building had no cracks, until I hired a man with a skid steer loader to do some landscaping. He drove into one of the walls and cracked the stucco.

If a wall is used as a retaining wall, there are added stresses on it; and in many ways, it reacts like a roof does. All retaining walls in homes should be engineered.

Roof Failure

If a wall fails, the stresses are often carried to the roof. This causes the roof to fail.

If the roof fails, the stresses are often carried to the walls. This causes the walls to fail.

With walls, if there is no reinforcement or if there is inadequate reinforcement, the wall may survive without problems for years. Since the lower side of a flat roof is under tension, except where supported by walls, and concrete has low tensile strength, if not adequately designed, it is a disaster waiting to happen.

A concrete roof that is 3 meters by 3 meters and 10 cm thick will weigh approximately 2,250 kilograms. A slab of this size without reinforcing, even if poured from excellent concrete, will probably fail soon after the supports for underside forms are removed. Most roof slabs in under-developed countries are not poured from excellent concrete.

If the support of the roof is not completely equal, there will be some areas of the roof which are exposed to greater stresses than others. An example would be an inadequate footing which might lead to a section of a wall being depressed a centimeter or two.

Many flat roofs are designed with a rim around the edge to trap water. This water, as it evaporates, cools the roof and thus cools the house. A layer of water on the roof that is 2.5 cm thick on a 3-meter by 3-meter roof will add about 235 kilograms to the weight of the roof. Additionally, the water may seep into the concrete and contribute to the oxidation of steel rebar in the roof.

In adding reinforcement to a roof, it is best to add the major reinforcement over the shortest distance. In other words, if a room is 3-meters by 5-meters, the major reinforcement should be spanning the 3-meter direction.

Stresses on a Concrete Panel

If we were to pour a 30 cm (12 inch) thick concrete slab without reinforcement and support it from two opposite edges and test it, we would develop some interesting results. Gravity would apply stress on the panel.

If you removed the temporary supports holding up the bottom form from under the center of the panel three hours after the concrete was poured, the concrete would collapse immediately. If you waited 3 days and the panel was not very large, it would probably survive for a while. If it was a large panel, it would probably collapse as soon as the temporary supports were removed.

After the forms and temporary supports have been removed, stress on the lower side next to the supports would be negligible. As you moved out from the supports, the stresses would increase substantially. While you might not be able to observe it by laying a straight edge along the underside of the concrete panel, the panel would be curving slightly. When the stress on any portion of the surface of the panel exceeded the tensile strength of the concrete, a hairline crack would develop. This would weaken the panel; and then at the next point where the stress exceeded the tensile strength of the concrete, another hairline crack would appear.

Author's Note: When considering these seemingly harmless hairline cracks, consider the question a doctor once asked me, "How many cholera bacteria do you need to ingest before you come down with cholera?" When I could not answer, he said, "Not as many as you think." It is the same way with those hairline stress cracks on a concrete panel.

If we applied steel to the sides, then the steel would provide the tensile strength and would carry the load. The amount of stress in the center of the panel would become insignificant. The problem with using rebar to provide tensile strength to a concrete panel is that the steel rebar must be covered with concrete that is at least three times the thickness of the steel. If you have an 8-inch concrete panel that is reinforced by Number 4 (1.27 cm diameter) rebar, the rebar must be placed so that it is covered with at least 3.8 cm of concrete. That does not allow the steel to be placed in the areas with the greatest tensile stresses.

Structural Concrete Insulated Panels make use of this concept and will be discussed in the section on disaster-resistant structures.

Placement of Reinforcing

If we wanted to pour a flat concrete roof for a house, we would need to consider where the roof is under tension and where it is under compression. The rebar needs to be in those areas which are under tension.

The underside of the concrete roof is under tension except where the roof is supported.

The upper side of the concrete roof is under tension above where the roof is supported.

Many times, two continuous layers of rebar are used on a concrete roof - one high in the slab and one low in the slab. This results in more rebar being used than is needed. It does ensure that a failure will not occur between the end of the upper piece of rebar and the beginning of the lower piece of rebar. A compromise is to place continuous rebar close to the bottom of the roof slab; and then above the supports, place pieces of rebar that are at least 2 meters long.

Some people think it is a good idea to place the steel rebar dead center in the slab. That would provide very little reinforcement where it is needed and result in premature roof failure.

Instead of building two walls and placing a roof over them, if we decided to build a wall and place a roof over the wall and hanging out on each side about 2 meters, we would have a different problem. It would look like a very large T. Over the wall, the underside of the roof would be under compression and the top would be under tension. If you put rebar in the lower portion of that roof, you would have a roof failure. The rebar needs to go as high as possible in such a roof slab, since the entire lower portion of the roof is under compression and the upper portion of the roof is under tension.

Thus, in designing the rebar placement for a roof, we need to consider where the roof is under tension and place rebar there. This usually results in rebar placed high over walls and other supports and placed low in the spans between walls and other supports.

The steel needs to be protected with concrete. Guidelines vary, depending on the environment and the quality of the concrete. The normal guideline is to cover the steel with an amount of concrete equal to three times the diameter of the rebar. If you are using 1 cm rebar, you need to cover it with 3 cm of concrete.

If basalt rebar is used, the amount of cover need not be as much, since that rebar does not need to be protected from oxidation.

Rebar needs to be lapped and tied where two pieces are joined together. For small-diameter rebar (about 1 cm), lap the pieces about 45 cm. For larger rebar, extend the lap. Use tie wire to tie the two pieces together three times. There should be three ties. Each tie should have the tie wire going around the two pieces of rebar at least 2 times.

When a piece of rebar crosses another piece of rebar, use tie wire to tie the two pieces together. Ideally, if you were strong enough, you could pick up the rebar mat by one corner and the whole mat would come. An alternative is to weave the pieces of rebar together. With anything heavier than No. 3 rebar, this tends to be hard work. It does result in a strong slab.

Concrete does not bond to rebar that is rusty or dirty. If the concrete does not bond to the rebar, you are wasting money on rebar.

If the design places the rebar in the correct locations, can the people who install the rebar place it in the appropriate locations? If they can, will the rebar stay in the correct locations when the concrete is poured and consolidated? Since the answer is often negative to one or both questions, rebar trusses are often designed using four pieces of rebar, and rebar stirrups so that if they are supported high enough above the bottom of the pour, they will provide the needed tensile strength in the appropriate locations.

Deterioration of Rebar

Rebar rusts (corrodes). If it stays damp and has an oxygen source, it rusts faster. If it stays damp, has an oxygen source, and the moisture contains chlorides, it rusts even faster. When steel reacts with oxygen to rust, the rebar increases in diameter. Steel can also react with chlorides in the concrete to form ferrous chlorides; with this reaction, the rebar increases in diameter, but this is minor compared to the oxidation reaction. Any increase in diameter places the concrete under tension, and soon the concrete splits to relieve the tension.

If there are sulfates in the soil and they are wicked into the concrete, the sulfates can react with the steel to form ferrous sulfates.

Once rebar has deteriorated, there are no easy fixes except removing the concrete and starting over.

A common problem in Haiti is that when anticipating an addition to a building, rebar is often left exposed coming out of the concrete roof. The rebar tends to deteriorate faster where it is coming out of the concrete roof. Thus, there is a weak spot where the addition is added. This problem can be solved by cutting the rebar off about 1 meter above the concrete roof and pouring a low-strength concrete around the rebar. When it is time to add the addition, the low-strength concrete can be chipped away.

Alternatives to Steel Rebar

If rebar is subject to attack, there are several ways to protect them. Each method has advantages and disadvantages.

Galvanized Rebar

This is probably the most common factory method of treating steel rebar in a manner so it remains user-friendly. The problem is that the zinc is a sacrificial layer and will deteriorate at some point. Since zinc is highly reactive in an alkaline environment, studies have been performed to determine whether galvanized rebar adds years to the life of rebar. In harsh environments, the results of those studies have been mixed. When galvanized rebar is bent, the zinc coating on the rebar may crack and lower the resistance of the rebar to oxidation.

Painted Rebar

There are several anti-rust paints that can be used on rebar. They can be used on the job site. If they are to be used, the existing rust should be removed as much as possible. Then when they are painted, they need to be placed so they dry without touching anything, so a protective coat can be formed. If two pieces of rebar are touching as the paint dries, when they are separated there will be numerous places where the paint has peeled from the rebar. With paint, the bonding of the concrete is to the paint, and that bond is weaker than the bond between clean steel rebar and good concrete. Often the paint cracks when the rebar is bent. Like galvanization, it will deteriorate at some point, but it does add years to the life of the rebar.

Epoxy-Coated Rebar

They can be epoxy-coated in the factory. This is a more permanent solution, but the bond between the epoxy and the concrete is not as strong as the bond between steel and concrete. Bending the rebar often cracks the epoxy coating.

Cathodic Protection of Rebar

The oxidation reaction which destroys rebar is associated with a very weak electric current. This weak electric current can be neutralized by inducing a direct electric current of the opposite charge into the rebar. This is only used in harsh oxidation environments and is not considered appropriate for use with small structures like houses.

Stainless Steel Rebar

This is a special-purpose rebar and is expensive.

Fiberglass Rebar

Fiberglass rebar, also called glass fiber reinforced polymer (GFRP), is resistant to the oxidation reactions which occur with steel rebar. It is more expensive, and there is a learning curve when using it, since it cannot be bent. Preformed shapes, such as corners, can be ordered and tied to straight pieces of the GFRP.

Basalt Rebar

A new solution is to use rebar made from basalt. Basalt is lava rock. The process starts out like the making of rock wool insulation. It is melted and forced through a tiny orifice. After it is cooled, the similarity to making rock wool insulation ceases.

The strands are coated with epoxy and formed into rebar. The resulting rebar is resistant to any chemical attack which may be found around concrete. It has greater tensile strength than steel rebar. As a result, basalt rebar about half the diameter of steel rebar can replace the specified steel rebar. Additionally, it is extremely lightweight. Basalt rebar for a house slab weights about 11% as much as the steel rebar for a house slab.

Besides making rebar, the strands can be twisted to make rope. This allows for a flexible reinforcement. Since the bond between concrete and the basalt is excellent, and it is resistant to oxidation, the depth of cover can be substantially lower than the depth of cover of steel rebar. As a result, there are situations where much less concrete is needed for a job.

The basalt rope is excellent for reinforcing domes where one can use 5 cm (2 inches) of concrete rather than the 10 cm (4 inches) required when using steel rebar.

Basalt rebar is different from steel rebar. It can be bent into an arch, but as soon as it is released, it returns to its original straight shape. This is referred to as "having no memory." As a result, it can be shipped in coils which are 100 meters long, but are still easy for one man to carry.

This also results in the inability to bend corners and other shapes into the basalt rebar. There are ways to overcome this. Basalt rope can be used to reinforce corners. In using basalt rope to reinforce a corner, keep in mind that per equal diameter, the basalt rope is half as strong as the basalt rebar.

My friend Van Smith builds permanent scaffolds by wrapping joints in the metal aluminum pieces with basalt rope and then painting them with epoxy.

Basalt rope is not to be used as one would use other types of rope. It is only permanent if it is encased in concrete or in a substance like epoxy. If you wiggle it back and forth, the pieces of basalt fiber will come loose. If you do this in a unidirectional light source (sunlight), you can often see the fibers separate and float away. If you slide the rope through your hands, you can end up with the tiny fibers embedded in your skin. Wear gloves when working with basalt rope, or learn to avoid running it through your hands. By running it through my hands, I learned not to do that anymore.

Currently, basalt rebar is more expensive then steel rebar, but the price will come down as it becomes more common. The extra price is often offset by the reduced amount of concrete that is needed. Basalt rebar is not attacked by any of the corrosion problems that beset steel rebar, so if you are building a structure you want to be permanent, this is an excellent choice.

Bamboo

Bamboo, if it is processed right, can make an acceptable reinforcing rod. While I have not worked with bamboo, I spent time with a gentleman who did considerable testing concerning bamboo as reinforcement.

The bamboo stalks need to be mature. That is three years old. If younger, they may be more likely to be weaker and more likely to rot.

Reinforcing strips need to be dried. Bamboo changes size with moisture changes, so it needs to be as small as possible when placed in the concrete.

The concrete used needs to be as dense as possible to keep the moisture level of the concrete constant and thus the moisture level of the bamboo constant.

Bamboo does not have the tensile strength of steel, so about five times as much cross section of bamboo is needed to replace the cross section of steel in the concrete.

An investigation needs to be done to determine which species of bamboo work best for reinforcement of concrete.

Plastic Bottle Rebar

Sometimes someone makes a stupid remark to me, and then several weeks later I think that maybe it was not so stupid.

Currently, we are bringing basalt rope and basalt rebar into Haiti and using it where steel rebar will not hold up. My friend said we should replace the basalt rebar and the basalt rope with plastic bottles.

It would be easy to design a cutter which would cut a 1/8-inch strip of plastic bottle. Then the strands of plastic could be braided to make a rope. That rope could be used to replace the basalt rope. Would it be strong enough? Add another strip of plastic if it were not. A nice thing about the plastic rope is it would not tend to slip like the basalt rope does. We would need to tie it fewer times.

If we dipped the plastic rope in epoxy, we could make plastic rebar.

Since most plastic used to make water bottles will melt at about 260 degrees C, it might be possible to pass the rope through a heat chamber and allow enough of it to melt to stiffen it. Most plastic when burned gives off toxic fumes, so it would be necessary to experiment to determine whether the process could be done at a temperature where toxic fumes were not given off.

There are questions which need to be answered.

- What would be the economics of making plastic rope and rebar?
- How could we suspend the plastic rebar while the epoxy dried?
- How well would the concrete bond to the plastic rope and rebar?
- How much concrete cover would we need to bond the rope and rebar to the concrete?

Basically, for the cost of a bottle cutter, and a simple rope-twisting machine, a family could be in the plastic-rope-making business.

Chapter 9

Concrete

Base Material Under the Concrete

You do not want to use any more concrete than necessary. So, you need to fill in the low spots and compact it. You do not want to have thin areas of concrete, so you want to cut down the high spots. If the concrete is going to have vehicle traffic, a layer of crushed limestone is often added and compacted in lifts of 5 cm (2 inches) until the desired thickness is reached. This protects the concrete from some of the minor earth movement.

With one slab I remember well, we were going to pour 5 cm (2 inches) of basalt-reinforced concrete. I was not watching the compacting and final leveling. When we started pouring the concrete, one of the workers told me, “There are some areas where we need 12 cm (5 inches) of concrete to make it level. You need to order more cement and gravel.” Remember, compacted base material is much cheaper than concrete.

Forms

Forms should be built and installed before you install the rebar mat. Use something that is handy to build the forms. Lumber, concrete block, whatever you have that is available can be used. Ideally, you want to contain the concrete and have a level surface to screed it smooth. The forms need to be reinforced enough to stay where you placed them. Years ago, I was pouring a base for a piece of mining equipment. I was running behind, and the ready-mix truck was on time. As it drove up, my father drove up and watched as my carefully-built form failed. After that, whenever there was the possibility of him watching a pour, I always overbuilt my forms and had them completed a day early!

You want the forms to come off easily when the concrete has set. While there are lots of form-release chemicals available, used motor oil or used transmission fluid is hard to beat. Each time you use the forms, apply more oil. Each time you remove the forms, scrape any concrete off that is sticking to them.

To keep ground water from wicking up into your concrete, especially ground water containing chlorides and sulfates, place a layer of plastic in the form. Then build your rebar mat. The mat may contain wire mesh as well as rebar.

Pouring

If the pour is too large to do in one day, plan where you will end one day's pour and begin the next day's pour. Cold joints are a fact of life. Cracks often develop where cold joints are located. If you must have a cold joint, add extra reinforcement in the area and slope the concrete so the joint can be wider. Use a concrete bonding agent before you start pouring the next day.

Before starting the pour, ensure that the rebar mat is in the position you need it to be in. Block it substantially so it does not move as you walk on it. When you pour a house slab or other item from concrete, better results are achieved if it is done in one continuous pour so there are no cold joints.

As the concrete is being added, it needs to be rodded and/or jitterbugged to ensure that the concrete reaches to the bottom of the forms and is well consolidated. If we were to give human emotions to the concrete, we would say that the concrete loves to separate so the gravel is in a different place than the paste. We would also say that the concrete loves to get caught on rebar so it does not have to fill columns that are there to reinforce the structure.

After the form is full, screed it off so it is even with the tops of the form boards.

Use a float to remove the screed marks.

Finishing

Back off and wait until the concrete is ready to finish. This is often seen by some of the mix water coming to the surface.

Depending on the use of the concrete, you may select one of several different finishing techniques. If it is for the floor of a residence, you may want to trowel the surface very smooth. Colored earth or pigments may be dusted on to add color to the concrete.

If it will be a driveway, you may want a broom finish. Trowel it smooth and then pull a broom over the surface to add a little texture. Broom finishes can be light or heavy.

Sugar interferes with cement hydration. If after you trowel the surface smooth, you spray it with Coca-Cola or other sugary drink, the surface cement will be retarded. The next morning, when the deeper concrete has set, you can hose off the surface and have an exposed aggregate floor. Normally a sugar-and-water solution is cheaper, but I prefer to see the expression on people's faces when I suggest they spray Coca-Cola on their concrete to kill the hydration process.

Keep the surface of the concrete moist for at least 3 days and preferably 7 days. An easy way is to lay burlap or vegetation on the surface after the initial set and keep it wetted.

After the concrete has set, the forms may be removed. I have seen this done within 4 hours of a pour, but one to three days is a lot better if you do not want to chip corners.

Concrete takes a long time to cure. Conventional wisdom says that ordinary concrete reaches about 90% of its ultimate strength in about 28 days. Conventional wisdom also says that it reaches 75% of its 28-day strength in 7 days. Conventional wisdom often is wrong. Temperature impacts the speed at which concrete cures. Thickness of the concrete impacts how much heat builds up in a pour, since cement particles give off heat when they hydrate. Anytime an additive is added to the concrete, either on purpose or inadvertently, it may change the way the concrete cures.

Chapter 10

Masonry

Foundation

If you do not have a stable foundation under the masonry units, something may move and cause a problem. If the foundation cracks, it will probably crack the wall. If a portion of the foundation sinks, it will cause a diagonal crack across the wall. The width of the foundation wall needs to be based on the anticipated load (weight of the building) and on the load-carrying capacity of the soil under the worst possible conditions. Have you ever grabbed a handful of damp clay and squeezed it and had streams of clay come out between your fingers? Such soil cannot support much weight. There are ways to test the soil for its load-carrying capacity and to engineer the foundation needs. See Chapter 7 for a simplified way of sizing foundations.

Mortar

Mortar has two major functions. It holds the masonry units apart, so irregularities in the units do not interfere with building the wall, and it bonds the masonry units together so the wall becomes, as much as possible, a monolithic unit.

If a Portland cement/sand mortar is used, it does not have enough body to hold the units apart. See the Mortar Formula section of Chapter 4 for mortar formulae.

If mixing by hand, the dry components of a mortar need to be well-mixed before any water is added. Use only enough water to give it the workability that you need. The mason is the best judge of how much water to use. He will judge how the masonry units absorb water from the masonry units and end up with a mix which contains enough water for good hydration of the cement particles after the masonry units have sucked some of the water out of the mortar.

With time, the mortar gets stiff. More water can be added, but to prevent loss of bond strength, use the mortar as quickly as you can. I prefer that it be used within one hour of the time it is mixed.

The stiffer the mortar becomes, the less mortar can enter the pores of the masonry unit. This substantially reduces the bond strength.

Now we have an interesting problem. Keeping the water/cement ratio low results in higher-strength mortars, but increasing the water/cement ratio usually increases the bond strength. The mason (not the engineer, the building contractor, or the architect) needs to determine how much moisture should be added to the mortar.

Masonry Units

Masonry units include concrete block, brick, and stone. Each has advantages and disadvantages. If the units are good quality, each will function well in a wall.

Much of the concrete block that I have seen in Haiti tends to be weak. While there are tests, there are few facilities in Haiti which could test the quality of a concrete block. Tests address compressive strength, resistance to erosion, consistent size, and other parameters. A simple test that does not meet any standards is to hold a block at chest height and drop it onto a grass-covered area. If the block breaks, it is poor quality. If it remains in one piece, it is good quality. One of the major problems with this test is that the block are heavy, and there is a tendency to hold the block close to one' chest. This results in the block landing on, or very close to, one's toes.

Author's note: When working with a brick plant in northern Mexico about 30 years ago, the man in charge of quality control told me that a number 1 brick was in one piece, a number 2 brick was in two pieces, and that they did not try to sell the number 3 brick. When he saw I was about to rip his standards apart, he started laughing and said they had discarded that system several years before.

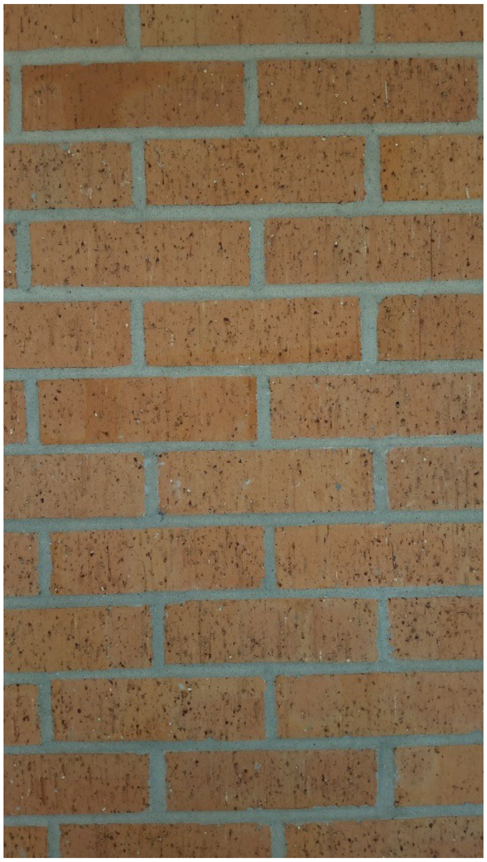
Concrete brick should be tested like concrete block.

Fired clay brick should be banged together. If they have a ring to them, they are normally well-fired and will hold up. If they produce a dull sound, they are either cracked or under-fired.

To determine the quality of stone, go to the section on aggregates in Chapter 3.

Placing Mortar

If the masonry units are dry when mortar is placed on them, they will suck water from the mortar, and there will not be enough moisture in the mortar for it to hydrate properly and develop strength. If the masonry units are too wet, then the mortar cannot enter the pores of the masonry unit, and an adequate bond will not form. Normally, the block should be well-wetted the day before they are laid.



With smaller masonry units, the units can be hand-held and mortar smeared on them. Concrete block are too heavy to handle this way. The usual practice is to place mortar on the top of the wall and on the webbing of the block which will be receiving the block. Then mortar is buttered on the end of the block to be laid. The block is then placed into position and tamped to ensure it is level and in the correct place.

Laying

If the block must be picked up and repositioned, it is best to remove all mortar and start over.

After the block is in position, the trowel needs to scrape off all excess mortar.

After several block have been laid, the mortar needs to be tooled. Tooling does several things. It makes the mortar joint look good; but more importantly, it densifies the mortar and reduces the likelihood that water will penetrate at the mortar joint.

Developing a Water-Resistant Wall

Two photos are shown of masonry work. One is laid with a good mortar, using graded sand, laid for even mortar joints, and tooled at the proper time. This wall will resist the penetration of water when hurricane winds and rain blow against it. The other photo was laid by a person who was not interested in whether the wall survived. One can see that the joints were not tooled, and that the mortar did not bond to the masonry units. This wall will let water enter the wall and pass through the wall.

After the mortar has reached its initial set, the wall should be moistened to keep the mortar from drying out before the mortar hydrates.

Keep water out of the cavity after the wall has been laid. If water enters the cavity before the mortar has set, it can weaken the mortar or cause it to erode. If it enters the cavity after the wall has been placed into service, it may lead to water entering the structure. This can be done in several ways. The cells of the masonry units can be filled with grout or a beam can be poured over the masonry wall.

As with insulated concrete forms, both horizontal and vertical rebar can be placed in a concrete block wall. After the rebar is placed, grout (thinned mortar) can be poured into the cavities. This rebar/grout combination helps the wall resist tremors from earthquakes and provides a wonderful point to tie the roof to the wall. It must be well rodded to get it to the bottoms of the cells.

Some years ago, I ran a study concerning water passing through brick walls. I found that the water seldom passed through the brick, even though some of the brick tested would absorb large amounts of water. The water passed through the cracks between the mortar and the brick. By improving the bond strength of the mortar, the walls would become more water-resistant.

With concrete block, the situation is different. Water will pass through most concrete block. When concrete block are used for building a home, the block should be plastered both inside and outside.

Chapter 11

Stucco

Probably the best book on stucco that has been published is ***The Stucco Book-The Basics.*** Even though I am the author, I am sure that I am not biased. Currently it is available only in English.

Plastering on Concrete Block

Some people like to stucco concrete block walls. Reasons range from aesthetics to serving as a moisture barrier. If the block are weak because they contain an excess of clay or because they were not vibrated during the manufacturing process, the wall may need to be plastered to keep it from failing.

If a decision is made to stucco a block wall, the mix design should be sand, Portland cement, and something to give the stucco body and the ability to stick to a substrate and hold on to it. That could be hydrated lime, plaster fat, or what I used as a kid (ground-up cactus – after the thorns had been burned off). Basically, it is the same formula used for mortar for laying the concrete block wall.

The day before the wall is to be plastered, it should be wetted down at least twice and then repeated within an hour before applying the stucco. Before the stucco is applied, the wall should be dried so there is no water sheen on the wall.

If the block are in good condition, there is no need to use lath; in fact, a better job will be accomplished if the stucco is applied directly to the concrete block. In the US and some other countries, a water-repellent or sealer is applied to the block during the manufacturing process. If this happens, the plaster will not bond well to the block. In that situation, block should be ordered which do not have the sealer, or lath should be applied to the wall to receive the stucco.

If the block are weak, then even though a stucco coat is applied and the wall looks good, it may not be structurally sound enough to handle a hurricane or an earth tremor. Before using low-quality block, ask yourself, "Would I want to be in this building with my family if we had a hurricane or an earthquake?"

See the section on Masonry Units in Chapter 10 for a simple test for determining the quality of concrete block.

The stucco can be applied with a trowel or with a sprayer. If applied with a trowel, a throwing action will result in a better bond to the substrate than if it is pasted on with a trowel. A sprayer will throw the stucco at the wall so it will end up tight against the wall.

The first coat should be less than a centimeter thick. As it cures, the mortar lines between the block will probably show through the stucco. This is known as telegraphing. Wait 48 hours before applying the second coat. If you don't, the mortar lines will continue to telegraph through the stucco.

A second reason for waiting 48 hours before adding the second coat is that if the first coat of stucco cracks after the second coat is applied, the second coat will crack as well.

The second coat is about as thick as the first coat. It can usually go on smoother and flatter than the first coat since the suction of the wall has been evened out by the first coat of stucco.

On a block wall, the total thickness of the stucco should be about 1.25 to 1.5 cm. The third coat can be the finish/texture coat and is usually much thinner than either of the other coats.

Plastering on Lath

Lath is used in many different situations. Here are a few of them:

Over a substrate with wood framing behind it,

Over masonry where a good bond cannot be developed to the masonry,

Over open framing where the lath is hung directly on wood or metal studs.

If there is not a firm substrate to apply the stucco to, often lath is applied. In many cases a felt paper or building paper is applied before the lath so water cannot penetrate through the stucco and enter the building. Since water usually gets behind the stucco at windows and other openings and at cracks in the stucco, a system needs to be installed so the water can drain out.

On the downwind side of a building, there is a suction. The suction gets stronger as the wind blows harder. If the lath is not attached firmly, it can be peeled off the wall. How strong is “strong enough?” ASTM C1063 (Standard Specification for Installing of Lathing and Furring to Receive Interior and Exterior Portland Cement-Based Plaster) speaks of every 178 mm along each framing member when being attached to wooden framing members (studs). Those studs are usually spaced every 41 cm. That is one fastener every 730 cm^2. That is 12.7 fasteners per square meter. In areas of anticipated high winds, more fasteners are often required.

When using lath over concrete block, the lath reduces the pressure with which the stucco is pressed against the block; and as a result, one should not depend on any bond that might develop, even if there is no sealant on the block.

Plastering on an Airform

Plastering on an Airform is different. More information can be found in the book ***Homes for Jubilee*** (English) or ***Kay pou Jubilee*** (Haitian Creole).

After the Airform is in place and inflated, it needs time to stabilize. This is usually done by maintaining the air pressure overnight. It needs to be coated with a bonding agent. This helps the concrete or stucco to bond to the slick plastic of the Airform.

Starting at the foundation, a coating of stucco needs to be applied that is about 1.9 cm thick. Thickness is hard to judge, so take a piece of wood which will easily fit into your hand and drive a finishing nail into it so the nail protrudes 1.9 cm from the wood. This makes a handy gauge for measuring the thickness of the stucco coating.

Spraying the stucco on is better than troweling it on. There are some people who can apply the stucco by throwing it on with a trowel or shovel. The only troweling of the surface is to knock down high spots. If the surface is rough, better bond will be established when the second coat is applied.

Keep working your way up the side of the Airform. Do not put weight on the Airform and do not let the pressure drop. Both will cause cracks in the stucco. After the stucco has gotten stiff enough so it can be dampened without washing any of it off, start dampening the stucco. The concept is not to add water to the stucco, but to keep the surface moist so moisture does not evaporate from the stucco.

After the first coat has been applied and cured overnight (keeping it moist), the dome should be wrapped with basalt rope or other approved material. Then a second coating of 1.9 cm of stucco should be added.

Again, it should be kept moist.

The following morning a third coat of approximately 1.9 cm should be added. This coat can be troweled so it is smooth or finished in whatever manner one desires. Stucco should be moist-cured for at least 48 hours.

Curing

Stucco needs water to cure. If it does not have enough water, the stucco will not form chemical bonds to the substrate.

During the curing process, keep the surface of the stucco moist for at least 2 days. The concept is to keep the moisture from evaporating from the stucco so the internal moisture can react with the cement particles in the mix.

If the stucco turns from the rich gray color when it is first applied to a light gray color, that means that it has been allowed to dry out. Don't let that happen.

A light mist on a regular basis is much better than a hard blast of a hose periodically.

Limitation of Stucco

Stucco should not be considered a structural layer. If the building is not designed to survive a disaster, a coat or two of stucco will not help. The exception to this is when building a dome or when using the stucco as part of a ferro-cement structure.

Author's Note: Following Hurricane Matthew, I examined several buildings which were supposedly disaster-resistant, that consisted of a metal frame, then wood was attached to the metal frame, and then lath was attached to the wood. Both sides of the lath were plastered. Since some of the stucco contained excess clay, the bond of the stucco to the lath failed. Since undersized nails were used to hold the lath to the wood, in many areas the lath tore away from the wood. Since the same people poured the concrete floor for these houses as applied the stucco, two of the concrete slabs washed away.

Chapter 12

Roofs

Non-Concrete Roofs

After numerous concrete roofs collapsed after the 2010 Haitian earthquake, there are many people who will not consider living under a concrete roof. The problem is not concrete roofs, but the poor quality of many concrete roofs

Whatever type of roof is to be used, there needs to be a concrete bond beam all the way around the building so the roof can be solidly anchored to the walls. There needs to be a method so that each roof truss or rafter is firmly anchored to the bond beam.

Since non-concrete roofs do not offer the bracing between opposite walls that a concrete roof will offer, steps need to be taken to install bracing. It can be in the form of concrete bond beams. It can be in the form of concrete bond beams on top of dividing walls within the building.

While wooden trusses can be built which will reduce the pressure applied to the walls below them, they are not as good as concrete beams in my opinion. That being said, sometimes there is no choice, for example in a church where a large open space is desired below the roof. In that case, buttresses can be built on the outside of the building to provide bracing. Gothic cathedrals in Europe use buttresses and later they used what became known as flying buttresses. There were ornamental structures which also provided support to the walls.

Metal trusses can be built which are much stronger than wood trusses.

Author's Note: Following Hurricane Matthew in Haiti in October, 2016, I examine a Catholic church which lost its roof, and one wall was seriously cracked. The gable roof did not have a bottom chord, and there was a downdraft. The roof was pushed down, and that made the ends spread. Since one wall was weaker than the pressure on the roof truss from the downdraft, the wall and a supporting column cracked.

Author's Note: In the 1950s at a cemetery outside of Roma, Texas, was an entrance structure consisting of two brick columns and a very low arch between them. The columns were one brick wide. Each time we would pass

> *it, my father would ask me to explain why the structure did not collapse, since there was more lateral pressure from the arch than a column of brick could resist. The first time I was driving past the cemetery without my father, I stopped. There was a thin stainless-steel wire just below the brick arch tying the two columns together. It could not be seen from the highway. Be innovative, but address all stresses which are likely to be placed on the roofs and walls of any building you help construct.*

Dutch roofs with short eaves are probably the most disaster-resistant and easiest to build non-concrete roof to place on a disaster-resistant home. With these roofs, if the building is square, the roof is peaked and the same slope is used on each side of the roof. Each side of the roof is identical. If the building is rectangular, there is a ridge line, and the slope for each side and end of the roof is identical. The reason the overhang at the eaves should be limited is so wind cannot get under the eaves and tear the roof off.

The next best roof is a Dutch hip roof. It looks like a hip roof, but there is a vent at each end of the ridge line. This can be developed by extending the ridge line or can be developed by having a flatter slope on the two ends. The advantage of the Dutch hip roof is it allows ventilation in the attic space which keeps the attic cooler and thus keeps the building cooler.

Gable roofs normally provide large areas at the ends where hurricane force winds can tear the roof off. If a gable roof is used, the overhangs at the eaves and the gable ends should be limited so wind must work harder to tear the roof off.

The worst non-concrete roof is a shed roof. Even with a short overhang, the force lifting the roof on the upper edge is tremendous if the wind is coming from that direction. Remember, depending on where the eye of the hurricane is located, the wind can come from any direction.

Flat Concrete Roofs

Flat concrete roofs are easy to build, but are easier to build wrong. When supported by the walls of the structure and not providing a substantial overhang, most of the reinforcement needs to be in the lower portion of the roof slab.

A 10-cm-thick flat roof on a 6-meter-by-6-meter house will weigh about 9,100 kilograms. This requires substantial support. If it is poured in one piece, it requires a substantial frame to support it while the concrete cures.

A flat concrete roof should never be flat. It should have a slope to it. Different people have different recommendations, but most of them are based on the concept that once the concrete has shrunk, there will be areas where water will pool. The slope should be enough so these pools will drain. 2 cm per meter is normally adequate. If the concrete is porous, the shrinkage will be greater and the likelihood of water seeping through the roof slab is greater.

Conventional Flat Concrete Roof Construction

Conventional flat concrete roofs are simple to construct. They are even simpler to construct so that they will fail.

A concrete roof can be constructed so it stops at the walls which are supporting it, or it can be constructed so that there is an overhang which protects the exterior walls. Building with an overhang produces stresses on the roof that are not present when a roof is built without overhangs.

The first step is to determine the length and width of the roof and where the permanent supports will be located. Plan to have a concrete beam wherever a permanent support is located.

While the entire process needs to be planned before any work is done, this includes having an engineer design the reinforcement for the roof.

Following are the steps that must be done to build the roof and are listed in the approximate order in which they should be done.

Install the trusses for the concrete beams which are resting on the support walls.

Install the decking which will support the roof while it is being poured. Normally this is plywood. Boards need to be attached on the underside to hold the pieces of plywood together. The plywood needs to be supported. Vertical 2x4 lumber can be used. A block needs to be placed under each piece to spread the load on the slab. Between the top of each piece and the plywood, a block needs to be placed to spread the load on the plywood. Having a piece of 2x4 poke a hole in the plywood leads to serious problems.

Tree limbs can be used for the vertical supports. Each needs to be tested to ensure that it will support the weight that is placed on it.

After the decking is in place inside the building (and extending outside the building if the roof is going to extend past the walls), the decking needs to be coated with a bond breaker. Polyethylene plastic is one option. Coating the plywood with used motor oil is another option.

Now the reinforcement across the short span of the roof needs to be installed. Reinforcement only needs to go where the concrete will be under tension. That means high over supporting walls and low between supporting walls.

The amount of reinforcing materials could be limited if one could be sure that it stayed in the correct location as the concrete is poured. On small jobs it often does not.

An option is to build trusses from the reinforcing material and attach those trusses to the reinforcing materials in the beam trusses. Ensure that the lower chord of the reinforcing truss is at least 2.5 cm above the bottom of the roof slab and that the upper chord of the reinforcing truss is at last 2.5 cm below the top of the roof slab.

Another option is to place continuous reinforcement where the bottom chord of the trusses would go and then add shorter pieces which are tied to the beam trusses and extending out from them to ensure that there is reinforcement wherever the concrete slab will be under tension. An engineer designing this is well worth anything you have to pay him.

Above the reinforcing trusses a lighter-weight reinforcing should be placed at right angles. These can be placed on the upper chords of the roof trusses, or if the upper chords are not continuous, they may be supported so they remain in place. The trusses are there to carry the weight. The right-angle reinforcing is there to reduce the cracking of the roof slab due to temperature variation.

At this point, everything should be checked and rechecked. Once the concrete pour is started, there is not time to make changes. Ensure that there are enough materials to produce all the concrete needed. Ensure that there are enough people to mix and transport the concrete to the roof. Ensure that there are enough people to rod or jitterbug the concrete to ensure that it is well consolidated.

It is a common practice to place concrete block in between the reinforcing to take up space so as much concrete is not needed for the pour. This procedure usually leads to problems a few years down the road. It is better to use the system listed later in this chapter to build lightweight block from lath and a little stucco.

Once the concrete pour has started, do not stop until it is finished. Having an extra mixer is important. Having extra of everything is important.

After the concrete has been poured and the water rises, it should be finished. Keep it moist for at least three days. Keep the support posts and decking in place for at least seven days.

Lightweight Concrete Roof Construction

The Blondet Manual shows a lightweight concrete roof using lightweight hollow clay tile. Such tile is not made in Haiti and would be too expensive to import. Several paragraphs are included which give concepts for ways of replacing the lightweight tile. The final one is a tile that we developed made from stucco lath and a little stucco. The lightweight roof consists of alternating beams and tile with a slab poured over the top of it.

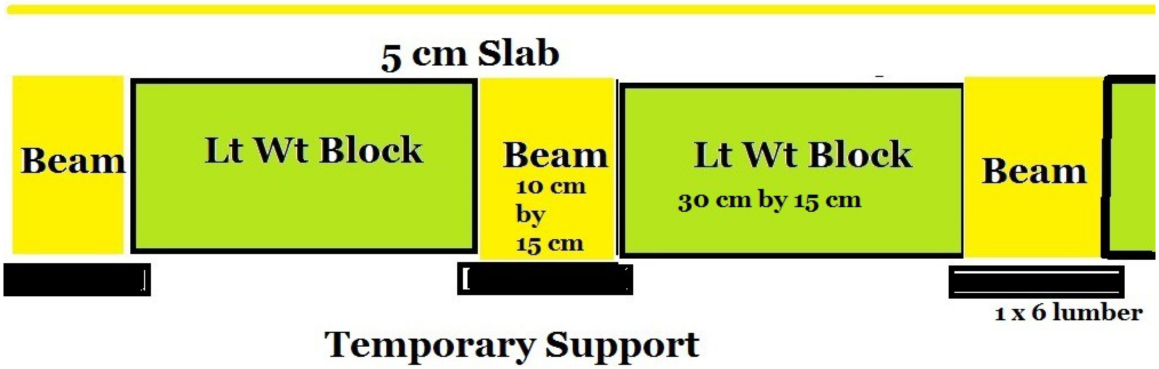
The beams are 10 cm wide (4 inches) and 15 cm high (6 inches),

The lightweight tile are 30 cm (12 inches) wide and 15 cm high,

Over the top of the beams and lightweight block is a 5 cm (2 inches) continuous slab.

Rebar are placed as needed, based on the spans between walls.

Solid decking can be installed, or an acceptable way to proceed is to use strips of decking. If that is done, lumber that is at least 15 cm wide can be laid on supports on a 40-cm center-to-center basis. This allows each block to rest on at least 2.5 cm (1 inch) of the boards. Care must be taken to not inadvertently move the lightweight block before all the concrete is in place. In the following depiction, rebar are not shown.



A continuous pour is used to pour the perimeter beams, the roof beams, and the 5-cm slab, so there are no cold joints. During the pouring of the beams, walking boards are placed on the lightweight block to support the crew pouring the concrete.

Styrofoam could be used to replace the lightweight blocks if it were available. It would moderate the temperature inside the home. If it were used, we would need to add lath under it so the ceiling could be plastered. So far, we have not identified a Styrofoam expander in Haiti. When I checked in 2013, it was illegal to produce plates, cups, and similar items from Styrofoam in Haiti. Now I see lots of Styrofoam trash, so the law has apparently changed.

Cardboard could be used and sprayed with Thompson’s Water Seal so it would not soften when the concrete is poured next to it. Are large enough pieces of cardboard readily available? Will it hold up with the weight of the crew while the concrete is being placed?

Paper Crete is another option. Waste paper and cardboard are slurried and poured into molds and allowed to dry. It provides insulation which would moderate the temperature inside the home.

We could make box forms from lath and use wood to reinforce them, or lightly stucco them to reinforce them. They need to be strong enough to hold their shape when a board is laid on them and one or two people walk on the board. Then they need to be strong enough to support a two-inch layer of concrete over the top.

Lath is 69.6 cm (27 inches) wide. The blocks need to be 15 cm (6 inches) high and 30 cm (12 inches) wide, so pieces of lath 108 cm (36 inches) long (plus lap) could be cut and formed into block that are 69.6 cm (27 inches) long. Wood could be used to brace the block. If that is done, notches need to be cut in the wood so pipes and cables can be fed through the block. If block were coated with half-inch stucco on all sides, they would weigh 40 pounds each.

Is there a need to coat the top and the bottom of the block with stucco? Half-inch stucco on the sides would support the men pouring concrete. Wood braces on the ends would keep the block from deforming and collapsing, but even better might be folding 3.8 cm (1.5 inches) of lath on each end. That would make a 60 cm (24 inches) block and would provide rim on each end 3.8 cm (1.5 inches) wide to stucco. That should be strong enough to hold the men pouring concrete if the lapped stucco were wire-tied at each of the 8 corner laps.

Such a block would weigh just over 13 pounds and would have a designed cavity for running electrical and other lines through the block. With a microloan, a business could be set up so this type of block could be produced and furnished to the builders.

Roof Produced from Concrete Strips

Rather than trying to pour a complete roof with one pour, one can pour strips of reinforced concrete and hoist them up to form the flat roof. If the strips were 20 cm thick, 30 cm wide, and 3 meters long, each one would weigh about 440 kilograms. With enough people, these can be lifted and slid into place. Then a 5-cm slab is poured over them to ensure that water does not enter the building through the gaps between the strips.

There are a couple of problems.

1. Due to movement of the strips, cracks develop in the 5-cm slab and let

water in.

2. During an earthquake, the strips can shift and fall into the building below.

Unless there is a secure way to tie the strips to the walls, unless the walls are strong enough to handle the lateral movement, and unless one can ensure that there will not be any earthquakes or tornados, this roofing technique should not be used.

Ferro-cement Roof Channels

This is a way to build lighter-weight roofs, but without all the support structure. Ferro-cement, mentioned earlier, is used to form channels, which as you recall are stronger than a flat piece of concrete.

Essentially, a semi-circle mold is used which is as long as the roof is wide. The mold is about 80 centimeters wide and about 40 centimeters high. The mold is covered with plastic as a bond breaker and then coated with a centimeter of stucco. Wire mesh is laid over it, and the stucco is built up until it is about 2.5 cm thick. A channel that is 6 meters long and covers a span of 80 cm will weigh about 450 kilograms. A roof for a 6-meter square house would weigh about 3.5 tons, about a third of the weight of the 10-cm thick flat roof, and would be much stronger.

There are companies which make molds and vibrators to make the Ferro-cement roof channels.

I have not done any long-term testing of Ferro-cement roof channels using SpiderLath as reinforcing. SpiderLath does not deteriorate in less-than-ideal concrete like metal lath does. This is something which should be investigated.

As with the concrete strips, with enough people, these can be lifted and slid into place. A 5-cm slab does not need to be poured over them to ensure that water does not enter the building through the gaps.

During an earthquake, the strips can shift and fall into the building below. Unless there is a secure way to tie the channels to the walls, unless the walls are strong enough to handle the lateral movement, and unless one can ensure that there will not be any earthquakes or tornados, this roofing technique should not be used.

Arched Roofs

An arched or vaulted concrete roof is harder to build, but it can be built stronger than a flat or gabled roof. Since there is an outward pressure, the walls of the structure need to be built to withstand that outward pressure. The higher the arch or vault, the less the outward pressure. Rather than build the walls thicker to handle the outward pressure, buttresses were added in Gothic buildings. Steel wire and rods can also be used to tie the two walls together. Remember, steel rusts and corrodes, so stainless steel has a greater chance of surviving.

To build an arched roof, a form as wide as the span of the roof and about 1.5 meters long, is often built from plywood. It is positioned and shimmed. After the concrete arch is built over the form, the shims are removed and the arch is moved down about 1.5 meters, re-shimmed, and the next section of the roof is built.

A problem with using this method is that every 1.5 meters there is a cold joint in the concrete. Adequate reinforcing needs to be added, so adjacent segments of the roof can be tied together.

A balloon form can be constructed and inflated to provide the support for building the arched roof. The problem is ensuring that the area below the balloon form is airtight.

Chapter 13

Building Disaster-Resistant Homes

This chapter is a survey of several different types of structures which can be built to be disaster-resistant.

Be Prepared for Disasters

Hurricanes and typhoons are a fact of life in many coastal areas.

Wherever fault zones occur, earthquakes may occur.

Tornados frequent the Great Plains of the US and other areas of the world.

Forest fires and prairie fires can also bring about disasters.

Wherever rain falls, floods may occur.

If you live in an area which experiences periodic disasters, it is appropriate to build to withstand those disasters.

Think about the whole structure and how it will react to a disaster. In California, many homes with fire-resistant walls and roofs have burned because embers entered the attic through soffit vents. The wood in the attic was very dry so it was easy to start a fire. If the soffit vents with finer screens had been used, the houses would not have caught fire.

With floods, the easiest way to avoid them is to build above the highest known flood line. In the US, most water courses have been mapped to determine the maximum expected flood in 25 years and the maximum expected flood in 100 years. Periodically, events occur which demonstrate that those are just best estimates from known data. Hurricane Matthew in Haiti and Hurricane Harvey in the US demonstrated this. Both stalled out and brought more rain and thus more flooding than was anticipated.

When homes are destroyed by one of these events anyplace in the world, there is an effort to rebuild. All too often, the rebuilding is to the same standards that were used to build the structures that were destroyed.

In 2008, Hurricane Ike destroyed expensive houses on Galveston Island and on the Bolivar Peninsula in Texas. Even though there was a SCIP home that survived without damage while other houses were destroyed, people rebuilt so the next major hurricane would wipe them out again. Hurricane Harvey, in 2017, was the next major hurricane.

Building hurricane-resistant and earthquake-resistant homes is not much more expensive than building homes that will be blown away within the next 10 years. Would you like to learn the secrets of building disaster-resistant homes?

The Disaster Experts

Ken Luttrell and Joe Warnes probably know more about disaster-proof homes than just about anyone else. I know them from World of Concrete (an international concrete trade show with seminars, workshops, and panel discussions), where all three of us have been speakers. A few years ago, I spent an evening with them, along with three others who are as knowledgeable about things concrete as I am. Also present were:

Dave Stevenson from Advanced Structural Panel Industries, LLC, who is an expert on Structural Concrete Insulated Homes,

Jesse Lilligren, who has built in disaster areas all over the world, and

Nolan Scheid, owner of MortarSprayer.com.

While we all are considered experts in our little niches, we found that Ken and Joe knew much more than we did. They explained that one should not develop specifications for building earthquake-proof structures and another specification for building hurricane-proof structures, or another specification for building fire-stormproof structures. If a home were built to resist a Class V tornado, it would resist all other disasters except for a meteor strike, a direct atomic blast, or the earth opening and swallowing the house. This results in having one design standard, which simplifies the design and construction process.

A Tornado-, Hurricane-, and Earthquake-Proof Home

Ken and Joe’s method of achieving a tornado-proof house is simple: build a six-sided reinforced concrete box that is tied together. Walls need to be a minimum of 10 cm (4 inches) thick and have considerable internal bracing (interior concrete walls).

To do this, one should establish a ground anchor. This will usually be a slab with footings under it. It should be built to withstand the loading of the walls and roof, as well as the added loading that can come from the wind. In most cases, you do not need to worry about the wind turning the structure over, but if it is extra high and the slab is not tied to the earth, that could be a problem.

If you do not have a concrete slab, but a dirt or gravel floor, you can still build a tornado-proof home. You simply need to dig enough holes, dig them deep enough, and fill them with concrete and steel to provide the ground anchor. Often it is easier to install an adequate slab.

The concrete walls need to be tied to the ground anchor. This is usually done by tying rebar that extends up into the walls to the rebar mat of the slab.

The concrete roof needs to be tied to the concrete walls. This results in a monolithic six-sided box.

Holes are left in the box for windows and doors. Even if all the windows and doors were to be destroyed, the structure would still stand and resist the disasters that nature can throw at it.

Little things can make it a lot better. Provide drainage. Water should flow away from the house. If it collects around the house, and the water gets deep, you have water in your house. Moderate the eaves. If you have long eaves, that gives the wind something to hold onto and try to break the connection between your roof and your walls. Adding storm shutters can protect any window glass that you may have.

In talking to several structural engineers, they suggested that a better term than “disaster-proof structure” would be a “disaster-resistant structure.” Typhoon Omar in 1992 wiped out 75 to 90 percent of the homes on Guam. That is when the US government went in and started building homes which would handle storms with over 200 mph winds. Since tornados have winds well over 200 mph, disaster-proof is not an accurate term.

Many houses in Haiti and other parts of the world are built from concrete, but most are not fastened together to make them disaster-resistant. That would require a few changes. Would you like to have the reputation of the contractor who builds disaster-resistant houses?

Here are a few other methods of building a concrete home that is disaster-resistant.

Domes

The domes we are talking about are concrete structures which do not have any straight sides. As mentioned before, strength can be developed by having a curved surface. While there are several ways to build domes, the easiest way is to inflate a balloon (Airform), then add rebar and concrete. The rebar and concrete can be added to the inside and the Airform remains in place as waterproofing, or the rebar and concrete can be added to the outside and the Airform is removed and used again. Normally, larger domes are plastered from the inside, and smaller domes are plastered from the outside. Both systems have advantages and disadvantages.

The books ***Homes for Jubilee*** and ***Kay pou Jubilee*** contain information on building domes where the concrete is placed on the outside of the Airform and then removed and used again.

With the larger domes, a urethane foam is often applied to the inside of the balloon before the rebar and stucco are placed. This results in the internal temperature of the dome approaching the temperature of the earth under the dome - never as hot as a conventional home in summer and never as cold as a conventional home in winter.

With a concrete slab and with the dome tied to the slab, these structures weather all the disasters with ease. Problems which are periodically mentioned are that they do not look like conventional houses and that the space next to the walls may not be fully usable if they are not designed right. David South with Monolithic developed the Monolithic Dome, which is formed by erecting an Airform and first spraying urethane foam on the inside and then concrete. The Airform stays in place and protects the urethane foam. He also developed the EcoShell which uses an Airform, and the concrete is sprayed on the outside. The Airform can then be removed and used again for up to about 100 times.

Several years ago, a company developed a modification of the dome-building system that adds a front to the building that makes it look more like a conventional home, but it still has the disaster-resistant qualities of the concrete dome. I have not seen any advertisements concerning that company lately.

There is a learning curve to building a dome, but it is not a difficult process. A 15-year-old grandson decided he needed to move out, so on his parents' property he is building a six-meter diameter dome.

Domes, while they do not look like conventional homes, are the most economical of the disaster-resistant building techniques.

Structural Concrete Insulated Panels (SCIP)

Wire mesh is on both sides of the wall. The wire mesh needs to be imbedded in 2.5 to 3.0 cm of stucco. Wire trusses provide tensile strength between the sheets of wire mesh. The interior concrete for the wall can be replaced with foam insulation board.

A panel with 6 cm of stucco and 24 cm of foam insulation board behaves like a solid reinforced concrete wall that is 30 cm thick.

The panels can be used for walls, roofs, and upper floors on multi-story homes. The insulation helps keep the home cool. About 20 years ago I inspected a subdivision built with the system in 1970. 30 houses were built. On 29 of them I could not find any cracking. The 30th house had been too close to the cliff edge, and during one of the California mud slides, it slid 25 meters down the cliff. When it came to rest, the doors would still open and close.

SCIP structures are very robust. So far, no matter how shoddy the workmanship, I do not know of a single SCIP structure which has failed.

Homes can be built so they are disaster-resistant. I inspected a SCIP home following Hurricane Ike on the Texas Coast. Other homes were destroyed except one that was protected from the wind by the SCIP home. One home broke free from its foundation and crashed into the SCIP home. It broke into pieces. The SCIP home survived with minor damage.

While many standards call for these homes to be coated with a shotcrete (a concrete that is sprayed on, and has a compressive strength of at least 17.25 MPa), testing has shown that if the coating is at least 6.9 MPa, the homes are disaster-resistant. It is harder to make a plaster that has such a low compressive strength than to make one with the higher compressive strength.

Most of the plants around the world which produce SCIP cost more than five million dollars US to install. There are plants in the Dominican Republic, Central America, Mexico, Venezuela, Africa, and Asia.

Dave Stevenson, Advanced Structural Panel Industries, LLC, has designed and has completed the installation of a plant in Southern California that can be built for about 1.3 million dollars.

It is an ideal technology for building disaster-resistant houses. The panels, usually 122 cm wide, are assembled in a factory. Picture a piece of rigid insulation with wire mesh on each side and with wires stuck through the foam insulation at different angles. The wire mesh on each side is not tight against the insulation but out from it about a centimeter or two.

The building process is straightforward. A slab is poured, with two rows of rebar sticking up every 0.5 meters. The panel is placed between the rebar, and the wire mesh is wire-tied to the rebar. Each panel is wire-tied to the next panel with a strip of wire mesh bridging the joint between the panels. The roof is tied to the walls with wire mesh bridging the joints. Panels are braced and then stuccoed. While some will apply stucco with a trowel, often a stucco sprayer is used. In areas where one does not want to invest the money to purchase a contractor-grade stucco pump and sprayer, MortarSprayer.com has a handheld sprayer that is operated by compressed air and filled by dipping it into a wheelbarrow of stucco.

Because of the way the panels are assembled, the stucco applied to them does not have to be very thick. Most panels are coated with between 2.5 and 3 cm of stucco on each side. The insulation between the sheets of wire mesh may be from 5 cm thick to 30 cm thick. As a result, the inside of the house tends to approach the ground temperature under the house.

There are people who put a conventional roof on a SCIP home, but most such homes are no longer disaster-resistant.

Dave Stevenson, whom I mentioned before, is developing a 60-square-meter SCIP kit home that:

1. Can be delivered to the building site on pallets,

2. Is disaster-resistant, as discussed above, and

3. Can be assembled and finished with a crew of nine people in one week.

Jim Farrell has developed the Met-Rock System. It consists of a trailer-mounted jig and press so the panels can be assembled right on the job site from wire mesh, Warren trusses, and expanded polystyrene. Since Jim is an expert on spraying concrete, he and his staff have designed their system to be easily coated with concrete. The wire mesh has screed points built in so it is easy to apply the right amount of concrete (stucco) to the wall.

A problem with using SCIP in Haiti is that many portions of Haiti have high chlorides in the water and the soil. The high chlorides would lead to oxidation of the galvanized wire mesh used to provide structural integrity. In areas where chlorides are not a problem, SCIP would be a good choice.

A friend of mine, Mark David Heath, is working on technology to build SCIP panels without any steel. My father used to say, “The Impossible Just Takes a Little Longer.” So, one of these days Mark will be talking to me about writing a book about his new technology.

Mark David Heath and I are discussing developing technology so rather than using expanded polystyrene in the SCIP, recycled plastic water bottleswill be used.

Insulated Concrete Forms

These are a fun product to work with. Picture large block, often consisting of two sheets of foam insulation board that are held apart by braces. They may be the size of two or four concrete block or even more.

A slab is poured with rebar coming out of the slab every 0.5 meters or less. The first layer of blocks is usually placed on a bed of mortar, since the slab may not be level. Then additional block are stacked and locked together. Rebar, both horizontal and vertical, are placed in the cavity. Concrete is poured into the cavity, and, if nothing goes wrong, you have a reinforced concrete wall. If something goes wrong, it is usually the failure of one or more of the block or because the concrete did not fill all the cavities that it should have. The causes are:

> The concrete was poured too fast,
> The concrete was rodded too aggressively,
> The concrete was vibrated too aggressively,
> The concrete was not rodded aggressively enough, or
> The concrete was not vibrated aggressively enough.

If the area where the ICF structure is being built has a chloride problem, the steel rebar can be replaced with either basalt rebar or with fiberglass rebar.

I like to complain about insulated concrete forms because:

1. From a thermodynamic standpoint, the insulation is in the wrong place to do the most good. SCIP uses the insulation to a greater benefit.

2. The rebar is in the center of the concrete, so it is not in the ideal location.

3. The outside of the structure needs to be coated to protect it from the elements.

4. The inside of the structure needs to be coated, because if there is a fire, toxic fumes will develop.

5. If care is not taken, there are voids in the concrete wall.

All that having been said, it is a good building system, and disaster-proof homes are regularly built using this technology when time is taken to take care of the details.

Confined Masonry Construction

The most common method of concrete block construction in Haiti and many parts of the third-world is known as Confined Masonry Construction. Following the information provided in Chapter 10 on masonry construction does not result in a disaster-resistant structure, but by incorporating that technology into a confined masonry building, disaster-resistance can be achieved.

After laying out the building and before pouring the foundation, vertical rebar columns need to be placed. Each column consists of four No. 3 rebar that are joined at specific intervals by No. 2 rebar stirrups.

The rebar stirrups should be placed at each corner and at critical points within the structure. Critical points include at each location where two walls intersect, where a wall ends, and on each side of each doorway and window. Additionally, the rebar columns should not be placed more than 4.5 meters apart.

When laying up the units in the wall, they should be laid with a running bond pattern and each end should be toothed so the concrete which is poured will have a better bite. After the wall is laid, forms are added around each rebar column, and concrete is poured and rodded to fill the space.

Beams need to be poured about halfway up the wall (just below the windows) and again at the ceiling/roof line. These beams should be reinforced with not less than four pieces of No. 4 rebar which are tied at specific intervals with No. 2 rebar stirrups.

The beams in conjunction with the roof slab need to be poured monolithically, and the rebar in the beams and the rebar in the roof need to be tied together, then the roof needs to be poured monolithically. (See the section on lightweight concrete roofs for an alternative to pouring the entire roof monolithically.)

The problem with confined masonry in parts of Haiti with high chloride levels is that steel rebar is used for reinforcing. When the rebar oxidizes, the structure fails.

I developed a truss fabricated from basalt rebar and basalt rope to be used in columns and in beams. It is triangular rather than square in cross section, so it is a little more difficult to get good penetration of the concrete into the beams and columns. I have not had the time to develop a jig for forming square trusses from basalt rebar and basalt rope, but that will come.

Chapter 14

Measuring Strength

Why ASTM

American Society of Testing and Materials (ASTM) standards were developed so buyers, sellers, engineers, and others could know specifically what was being bought, sold, used, specified, etc. In recent years the standards have gone worldwide so international trade can be enhanced.

If you need to measure the strength of concrete, there are ASTM procedures to follow and special equipment that is needed. The ASTM system has been developed so that no matter where a product is tested in the world, all the results will be very close. As a result, the process is expensive. If you need certified results, this is the only way to go.

This chapter explains how, for a relatively reasonable amount of money, one can get a **reasonable estimate** of the strength of a concrete, stucco, or mortar. What I would call a guesstimate.

When working for Pozzolana, Inc., in the 1950s, we needed to test the compressive strength of cement mortar with the pozzolan we were producing. One of the quality control tests was to mix the mortar paste, place it in wooden molds we had made and soaked in waste motor oil, cure the samples for 3 and 7 days, and then break the cubes. The press we used was a hydraulic jack that was mounted in a frame. A pressure gauge was attached to measure the oil pressure. A needle was advanced as the pressure increased and remained in place after the sample broke until we reset the needle to zero. It served our needs.

We then upgraded to metal molds which were tinned. I ran a series of tests comparing the wood molds to the metal molds and found that I got higher compressive strength breaks from the wooden molds. Many years later I concluded that the wooden molds absorbed some of the moisture in the paste, which gave the paste a better water/cement ratio.

ASTM requirements for compressive test machines and molds were enhanced every year or two. We ended up being required to use brass molds which cost about a week's wages and had to be recertified every few years.

At one point a hand-pumped compressive test machine was acceptable, but now the rate of increase in pressure needs to fall between very tight limits. The reason – Increasing the pressure rapidly can give higher readings. Increasing the pressure very slowly can give lower readings. The standards are needed, they are good, and they are expensive.

A Nail, a Credit Card, & a Magnifying Glass

Most people who do testing of mortars, stuccos, and other concretes are asked to go out into the field and figure out why a job went bad. For the last 40 years when inspecting stucco and mortar jobs, I usually carry a 16d nail, a 10X magnifying glass, and a credit card.

If I can scratch well-cured stucco or mortar, the material is very weak. If I can mark it with the nail, but not scratch it, it has an appropriate strength. As I get older, I cannot scratch as hard so the test is not as reliable. 10 years ago, I found that being able to mark the mortar but not scratch it indicated that it was about 10 MPa.

If I spot a crack, I rub a finger over it to see if there is any displacement. If there is, the problem is more complicated than a drying shrinkage or plastic shrinkage crack.

Most credit cards are about 0.075 cm in thickness. If there is a crack that the credit card can just barely fit in, if the area is marked, one can return to see if the crack has expanded. A credit card will not go into most drying shrinkage and plastic shrinkage cracks.

The magnifying glass allows me to look for signs of efflorescence, staining, etc., and to inspect the bond between the masonry unit and the mortar. The most important use of the magnifying glass is to intimidate the contractor. Many contractors will answer questions based on how they know the job should have been done, not on what was actually done. If I exam a wall for 5 minutes with my magnifying glass and say, “Hmm,” and comment, “Strange,” several times, and then write something in my notebook, the contractor will usually be nervous. If I then ask a question, I often get an honest answer.

Molds

Molds come in several different sizes. They are available with the English system of inches and with the metric system of millimeters. For simplification, we will only address the metric system

Common cube molds are 50 mm and 150 mm. Cements, mortar, and stucco would be tested in the smaller molds, and concrete with aggregate up to 50 mm would be tested in the larger ones. These are heavy metal precision molds.

Plastic cylinders are available for making concrete cylinders to test. Standard sizes include:

5-cm x 10-cm

10-cm x 20-cm

15-cm x 30-cm

The maximum aggregate size is one-third the inside diameter of the plastic cylinder.

Compressive test strengths are meaningless unless dimensions and ratios, are specified. The larger the mass of the concrete, the higher the strength. The taller the specimen related to the cross-sectional dimensions, the lower the compressive strength.

Always stay with the accepted sizes of the cubes or cylinders.

Author's Note: Years ago, one of my employees tested a concrete cylinder without taking it out of the plastic cylinder mold; that increased the apparent strength considerably.

Filling the Molds

With concrete in the field, a slump test is usually used to determine the consistency. It is also an indication of the amount of water that is in the mix, but if the mix is allowed to set for a while, the mix will get stiffer and the slump will decrease.

The slump test device is a truncated cone 30 cm in height with both ends open. Concrete is added and rodded, and then struck off level at the top. The slump cone is removed and the amount that the concrete slumps without the support of the cone is the slump. It is usually measured in inches. Concrete with a slump of 1 inch would be very stiff. With a slump of 8 inches, it would be very soupy.

For mortars and stuccos, a flow test is used, since most mortars and stuccos are designed to hold their shape. It is essentially a variation of the slump test. A short-truncated cone is filled, rodded, and struck off. The cone is removed, and the table the sample is sitting on is lifted slightly and dropped 25 times. The flow is the percent that the base diameter of the specimen expands.

The molds are then filled in lifts and rodded in a specific fashion. For 50 mm cubes, the mortar needs to be tapped 32 times to ensure that it is well-consolidated.

If these preliminary tests were not required, people could reduce the amount of water for the tests and have results that show that the concrete had much greater strength than it actually had.

Compression Test Machine

A compression test machine which will give reasonable results can be built for a fraction of what an accurate and certified machine would cost to purchase. By building and using one of these, many decisions can be made before paying for certified tests.

Protection

First off, when a cube or a cylinder breaks, often chunks of concrete are thrown with great force. The higher the compressive strength, the greater the force that they can be thrown. Build a protective barricade before you lose an eye.

Force Needed

Decide on what you are going to be breaking and the anticipated strength of the samples.

Example: to break 50-mm cubes that have a maximum compressive strength of 5,000 psi, 20,000 pounds of pressure would be needed. That would require 10-tons of force.

Example: to break 100 mm cylinders that have a maximum compressive strength of 5,000 psi, 62,800 pounds of pressure would be needed. That would require 32-tons of force.

If 20 tons of force are needed, a bottle jack may be more economical than a port-a-power. When higher forces are needed, then a port-a-power may be the only option.

The Jack Stand

The jack stand needs to have a stable base. And needs to be tall enough so the power source and the sample can be inserted. Ideally, the space where the sample is placed to be tested should be adjustable.

Author's Note: Extra space comes in very handy. I have a test machine that I was going to be using for testing 50 mm cubes and 50 mm x 100 cylinders. Then I decided to test the pull-out strength for screws and bond strength.

> *This required my machinist to build some jigs for me which were taller than what I ever dreamed of needing. My machinist had anticipated that I would want to do something weird and had added an extra 15 cm of space that I had not requested.*

If the upper and lower surfaces, called platens, which compress the test specimen are not perfectly flat against the upper and lower surfaces of the sample, the tested compressive strength will be lowered. This is taken care of by placing a steel ball, from a ball bearing, above the upper platen and another below the lower platen. Ideally the steel balls should be about a 1-cm in diameter.

To keep them in place, a shallow hole can be drilled in the center of each platen.

The platens should be thick enough so they do not bend or deform when pressure is applied.

The oil pressure of the jack or the port-a-power needs to be measured. A pressure gauge can be inserted into a special port on some of these units. This is not the oil fill port. The gauge needs to be sized for the anticipated oil pressure. This is done by taking the maximum pressure and dividing by the cross section of the jack cylinder.

Example: With a 10-ton jack (20,000 lbs.) and a cylinder of 1 inch, the cross section would be 0.785 sq. in, and the oil pressure at that load would be 25,477 psi. If the cylinder were 2 inches in diameter, the oil pressure at that load would be 6,370 psi. If there is a choice, go with the largest diameter cylinder available.

A digital gauge is easier to use and usually more accurate. If you go with a regular pressure gauge, look for the largest diameter one that is available, and has a needle that will show the maximum pressure recorded.

Chapter 15

How Long Do You Want Your Concrete to Last?

Until you get paid for the job?

> You have now learned that that is shortsighted.

Until the next hurricane?

> You know that hurricanes are coming on a regular basis so you do not want to be known as a person who can build a family a home on the same property 5 or 6 times during his career.

Until the next earthquake?

> You know that you do not want to have to live with people dying because you built a concrete roof that collapsed.

Until your grandchildren are old and gray?

> Having your grandchildren look up to you makes your old age much better.

Only you can determine that answer and make it happen.

If you build quality structures, you may struggle to get clients because they may not be able to envision a home that is likely to survive the next disaster.

How will you feel when homes you built for your clients fail with the next disaster, or with the passing of five years? How will you feel if a home you built collapses on a child and kills her?

If you sacrifice quality for short-term business, as the years pass you will find it more difficult to get clients, especially if your competitor has adopted a quality mind-set.

In the final analysis, build quality homes because that is what your clients want.

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Addendum A

Conversion Chart - English to SI

Since the United States uses the English system, you may end up hearing the English system units used, so a brief conversion chart is included. To convert from the English units to the SI units, multiply by the conversion factor given. To convert from SI units to English units, divide by the conversion factor given.

Unit	Symbol	Multiply Times	Equals	Symbol
Volume				
Pint	pt	0.473	Liter	l
Quart	qt	0.946	Liter	l
Gallon	gal	3.785	Liters	l
Cubic inch	ft^3	16.4	Milliliters	ml
Cubic foot	ft^3	28.32	Liters	l
Cubic foot	ft^3	0.02832	Cubic meter	m^3
Cubic yard	yd^3	0.7646	Cubic meter	m^3
Length				
Inch	in	25.4	Millimeters	mm
Inch	in	2.54	Centimeters	cm
Foot	ft	30.5	Centimeters	cm
Yard	yd	0.9144	Meter	m
Mile	mi	1.61	Kilometers	km
Area				
Square inch	ft^2	645	Square millimeters	mm^2
Square foot	ft^2	0.0929	Square meter	m^2
Square yard	yd^2	0.836	Square meter	m^2
Acre	ac	0.4047	Hectare	ha
Density				

Ounce	oz	28.35	Grams	g
Pound	lb	454	Grams	g
Pound	lb	0.454	Kilogram	kg
Ton (short)	tn	0.907	Tonne	Mg or t
Pressure				
Pounds / sq inch	psi	6.895	kilopascals	kPa
Pounds / sq inch	psi	.006895	megapascal	MPa
Temperature				
Degrees Fahrenheit		$C^{o} = (F^{o}-32)$ x 0.556		

Addendum B

Deterioration of Rebar

This explanation will probably make the eyes of most readers glaze over, but if you are working in an area with moderate or high chlorides, it is mandatory you address the problem.

The Basics

Non-reinforced concrete is high in compressive strength, but low in tensile strength. Reinforcing is added to concrete to increase the tensile strength. The most common method used is to add steel rebar. In most situations, this is adequate. The two most common problems with the use of steel rebar is when chlorides are present, as when salt (sodium chloride) is added to a roadway for deicing, and when water can get to the rebar.

The Chemistry

When chlorides are in contact with steel, and there is enough moisture present for a chemical reaction to take place (enough moisture to dissolve some of the sodium chloride), several chemical reactions take place. First, when the salt dissolves in the water, the ability of the water to carry an electrical current is increased. This increases the ability of the oxygen that is dissolved in the water to react with iron which is in the steel rebar. In the process, ferrous oxide, ferric oxide, ferrous chloride, and ferric chloride can be formed. The oxidation state of the iron (ferric or ferrous) and whether a chloride or an oxide are formed are not germane to this issue, since each of those chemical compounds increases the volume of the iron in the steel which was the precursor for those compounds.

The Physics

When the rebar expands as these compounds are formed, stress is developed until that stress is greater than the tensile strength of the concrete. This causes the concrete to crack. The cracking of the concrete allows more water and oxygen to come in contact with the rebar and the chlorides which are present. This accelerates the process.

The stresses the concrete has been under usually weaken the concrete in areas around any of the cracks which occur.

As the chemical reactions continue, the tensile strength of the rebar decreases. This causes the tensile strength of the concrete to decrease.

When a concrete beam or slab is suspended between multiple supports, it flexes very slightly. At a point between any two supports, the bottom side of the beam is under tension and the upper side is under compression. Above any of the supports, the top of the beam is under tension and the bottom of the beam is under compression.

As a result, a flat concrete roof will often crack above any supports and will sag between those supports. The cracking above the supports increases the moisture entering the roof and accelerates the deterioration.

Accelerants

In the Gonaives, Haiti, region where I work, there are several other factors which contribute to the problem:

The water used for mixing much of the concrete is often brackish. This provides the chlorides to increase the oxidation of the steel.

Much of the aggregate used contains clay. Tests I have conducted have shown up to 29% clay in concrete sand on our jobs. The presence of clay requires more water to be added to make the concrete, stucco, or mortar workable. The increased amount of water needed increases the amount of chlorides which are available to catalyze the oxidation reaction.

The concrete is often porous due to aggregates used which are not well graded to increase the density of the concrete mass.

The concrete is often not well-consolidated, leaving air pockets in the concrete as reservoirs of oxygen and water.

The clay in the concrete acts as a reservoir for the chlorides, so the chlorides can initiate a chemical reaction whenever the moisture content of the concrete is conducive to the oxidation reaction.

Conclusion

Chlorides do not directly harm the Portland cement paste or the hardened Portland cement paste. Chlorides catalyze the oxidation of the chemical element iron, which is a major component of steel rebar and metal lath. The oxidation process weakens and/or destroys the tensile strength of reinforced concrete and stucco. Expansion of the metal components can, and often does, crack the concrete or stucco and thus accelerate the deterioration.

Avoid chlorides

Addendum C

The following topics will be addressed in a separate book or books.

Special Situations - Lining Sewers with Concrete

Include information about:

open sewers and storm drains,

anaerobic conditions,

early failures that have been observed, and

techniques for making concrete more resistant to acidic conditions.

Add drawings of the V-channel or U-channel drain and of the straight-sided channel drain.

Ferro-cement - Concrete Without Forms

Traditional Ferro-cement was several layers of wire mesh bound into an armature and then stuccoed. A plasterer would be on each side, and they would try to force the stucco into the mesh between them. Some ships used in WW II were built with this technique. Then water-reducing agents and plasticizers were developed so a stucco mix that would develop great strength could be sprayed. Now sculptures, water tanks, thin columns and shapes, and much more, are made from Ferro-cement.

Meet a 13-foot dinosaur who stands in front of the Witte Museum in San Antonio, Texas. He was built in a week as a project for a decorative concrete show.

If you put a curve into a Ferro-cement panel, it becomes stronger. In the US, engineering students at different colleges participate in a concrete canoe competition. These canoes are not necessarily practical boats, but they challenge the students to think of ways to build strength while using as little material as possible. Several of my friends and I have consulted with several of these teams. One of the regional winners found that using SpiderLath (a fiberglass cloth) gave much greater strength than metal lath.

Concrete Block Manufacture

To test the quality of a block, drop it from chest height onto a grassy area. If it breaks, the block are not strong enough for building. Caution: hold the block away from your body so you do not drop it on your toes.

Mix design

Vibration

Cure

Storage

Memory jogs to ensure they have been covered.

Block made with Excess Clay

Clay vs. Portland Cement

Aggregate Quality

Concrete can be no stronger than the weakest aggregate.

Aggregate attacked by the environment will result in failure of the concrete.

Failure to consider stresses when placing reinforcing

Poor or inadequately sized foundations

Insufficient Concrete

Low-Grade Concrete in Beams

Poor locations

Moving after initial set

Acid Attacks

Sulfate Attacks

Water Attacks

Index?

About the Author

Herb Nordmeyer was homeschooled in chemistry and cement chemistry. Even though he went on to earn degrees in biology, chemistry, and aquatic ecology, he considers his real education that homeschooling. After following a career track based on his formal education for a few years, he got back into the construction materials field where he specialized in product development and forensic analysis of failures (usually, but not always, other people's failures). Since his retirement in January, 2010, he and his wife own and operate Nordmeyer, LLC, a consulting, writing, and publishing company. He is a partner in HerbCrete, LLC, a company which develops specialty stuccos.

He has been very active in ASTM, serving on Committees: C 1 (Cements), C 11 (Gypsum and Related Products – including stucco), C 12 (Mortar for Unit Masonry), C 15 (Masonry Units), and C 27 (Precast Products).

In September, 2013, Herb made what he thought was his first and last trip to Haiti. Pastor Benoit showed him the need for earthquake-resistant and hurricane-resistant housing. He challenged Herb to find or develop technology to build earthquake- and hurricane-resistant housing for Haiti, especially the slum called Jubilee, which could be built for a materials cost of $1,000 US. In November, 2013, Herb was back in Haiti where he agreed to go at least four times per year, as long as his health and finances held up.

Besides teaching in the slums, in January, 2017, he taught a 4-semester-hour course in disaster-resistant construction at the American University of the Caribbean in Les Cayes, and plans on being back in January, 2018, to teach another course.

Herb is a prolific author, but a poor writer and speller. His wife, Judy, has to drip red ink over everything he writes. Besides numerous peer-reviewed papers in ASTM and other scientific journals, he is the author of ***Stucco Handbook for Builders*** (out of print), and ***The Stucco Book–The Basics*** (2012).

Homes for Jubilee and the Haitian Creole edition, ***Kay pou Jubilee,*** interfered with the publication of ***The Stucco Book*** series of books. He is planning on publishing ***Quality Concrete for Haiti*** in both English and Haitian Creole by the end of 2017.

When not involved in building, or in building materials, or in writing about them, Herb adopts granddaughters and with several of them has published several books, and he enjoys taking people kayaking.