The Earthquake Strengthening of Single-Storey Unreinforced Block Masonry Houses in Trinidad and Tobago Using Ferrocement

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by

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DISCLAIMER:

The retrofitting scheme presented herein is based on good engineering practice. When executed properly, it is believed to achieve collapse-proof (but no proof against damage) houses in earthquake intensity up to MM VIII. However, the authors will not be responsible for any adverse consequences occurring in the field for any reasons whatsoever.

Cover Picture: A Mason applies mortar to layers of mesh in fabricating a ferrocement skin.

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Introduction

Trinidad and Tobago is an earthquake-prone region. It is believed that strong earthquakes occur in the region with such statistical regularity, that buildings in Trinidad and Tobago must be designed to withstand them.

Knowledge of the effects of earthquakes on buildings is continually expanding and this is reflected in the increasing refinements of the structural design codes of practice which state the criteria that must be met for the satisfactory performance of buildings. However, since the incorporation of the effects of earthquakes on buildings began only in the 1920s, this aspect of structural design can be considered to be relatively new, with greater emphasis being placed on commercial multi-storey buildings built with reinforced concrete or steel. Detailed study of masonry buildings began much later. There is also a time lag between the acquisition of the knowledge, and its practical application in building construction. Therefore, it takes some time for the latest findings to be incorporated into the local Buildings Regulations.

Modern commercial buildings in Trinidad and Tobago are professionally designed using the latest structural design codes of practice which cater for the effects of earthquakes. However, the houses are typically unengineered buildings - they are constructed based on local technologies which have evolved over the years. As such, given its low cost and ease of use, most of the existing houses in Trinidad and Tobago utilise unreinforced hollow clay or concrete blocks to build the walls that support the roof. Through the observation of the effects of earthquakes on such buildings worldwide, as well as by structural testing in the laboratory, it is acknowledged that such materials are inadequate for regions which are prone to strong earthquakes. This implies that all such houses in Trinidad and Tobago must be strengthened if collapse is to be avoided during a strong earthquake - a procedure known technically as *seismic retrofitting.*

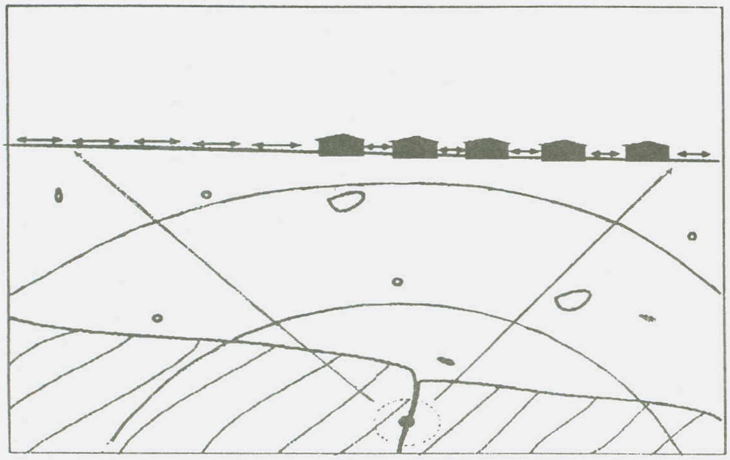
Though there are several approaches which can be used for the earthquake strengthening of houses, the choice to the most appropriate method is based on factors such as cost, convenience, aesthetics, and the psychology of the people. The authors believe that the method most suited to Trinidad and Tobago must be such that the appearance of the house is changed as little as possible, and the construction technique must be sufficiently simple that most of it can be implemented by the homeowners themselves as a home improvement project, assuming that they have no previous experience in construction. These criteria can be met by using the material called *ferrocement.*

This Booklet describes to the homeowner how to seismically strengthen the house themselves using *Ferrocement.* An additional benefit of the ferrocement based seismic retrofitting described here is that the house should also be significantly strengthened against hurricanes as well. Attention is paid to the avoidance of too many technical issues and jargon. The Booklet is limited to single-storey houses. The recommendations made by the authors are based on technical studies conducted locally which included laboratory testing and computer analyses. The details of these studies are presented in the companion booklet entitled **"The Structural Design Methodology for the Seismic Retrofit Recommendations for Unreinforced Masonry Houses in Trinidad and Tobago using Ferrocement".** This Booklet, as well as the computer software developed for the analyses, are available at the Engineering Institute, Faculty of Engineering, The University of the West Indies, St. Augustine Campus, Trinidad.

Proper House Behaviour during an Earthquake

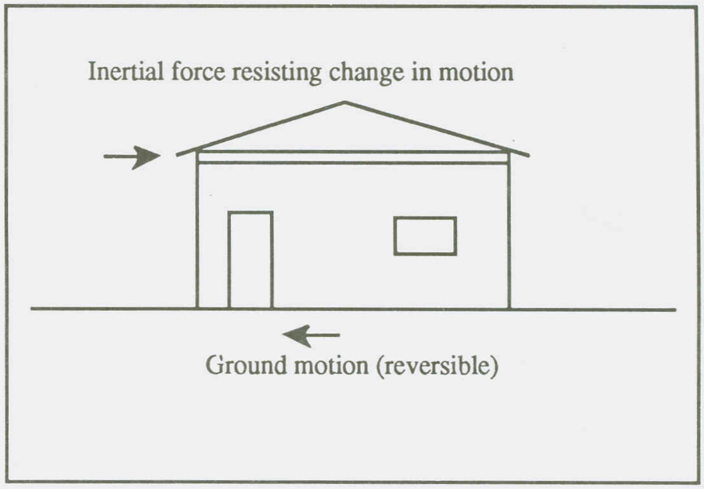
A simplified description of the way a house properly behaves in response to an earthquake is as follows:

1. Far below the earth's surface large plates of rock float on top of liquid rock. Two such plates are moving in opposite directions but are locked together. They eventually slip and like the releasing of a stretched rubber-band, a tremendous amount of energy is emitted. This energy moves like a wave from its source, through the layers of soil, then to the surface of the earth. It travels along the surface for



some distance shaking the ground backwards and forwards, and up and down, until it eventually dies away. The well-known "Richter magnitude" of the earthquake is a measure of the energy released at the source. However, the intensity of the shaking of the ground at any point on the surface depends on the distance from the source and is measured subjectively by the observed effects of the ground shaking on the objects located at that point on the ground (using the *MM scale* which is shown on the inside of the back cover). The intensity of ground shaking is measured objectively in terms of the *ground velocity or acceleration* using a special device called an *accelerometer.*

2. A typical house has two main directions: the directions of the longer and shorter sides of the house. The shaking of the ground on which the house stands, takes place in both these directions, as well as vertically, all at the same time. For simplicity, let us look at what happens on the shorter



side, neglecting the up and down movement also. What does the earthquake do to the house? The earthquake causes the ground motion but the house rests on the ground. All matter: trees, birds, your hand, etc. tends to resist any change to its state of motion and this characteristic of matter is called *inertia.* For example, when a car is suddenly accelerated, the car moves forward but the passengers initially move backward. The larger the mass, the greater the *inertia.* The mass of the house taken as one body, in the direction of the ground motion, is concentrated at the roof level. Therefore, the horizontal ground motion causes the force due the *inertia* to push horizontally on the house, mainly at the roof level. As indicated above, the direction of this inertia force is opposite to that of the ground motion. As the ground motion is a back and forth motion, the inertial force is also a back and forth motion.

3. The inertia force acting on the house is not fundamentally different from any other type of force that the house must safely resist, such as the weight of the roof, which acts downwards. A structure is safe when it can adequately resist all forces applied to it. A structure adequately resists the forces applied to it if there is a suitable path for the force to follow, from the source of the force at its point of application, to the soil below the foundations. This force path can be likened to a flow of water from a tank, through a set of connecting pipes, then finally out through one pipe. If on its way, there is no path along the set of connected pipes that the water can follow to reach the outlet pipe, then you cannot get

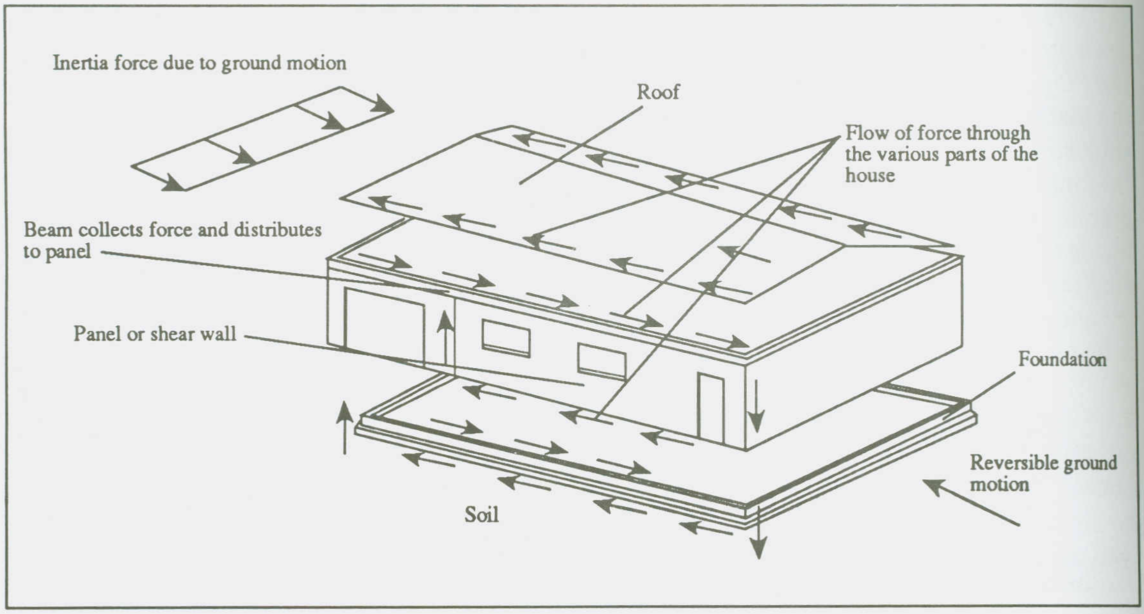
the water. Similarly, if there is no means of transferring the force from its point of application, through the structure, and finally to the soil, then the integrity of the structure is compromised, and the structure is regarded as being unstable. Therefore, for the proper behaviour of the house during the earthquake, such a path must exist in each direction of the house.

This path is provided by the various parts of the house and implies that they must be well connected together. In resisting the earthquake-induced *inertia* force, the path taken is: from the roof, through the connections linking the roof with the external walls at the top of the walls, through the beam along the top of the wall to the various panels that make up each external wall, through the connection between the wall panels and the foundations to the foundations, then through the interface of the foundation with the soil, to the soil itself. This is indicated on the diagram below for the case of that part of the inertial force that acts in the longer direction of the house.

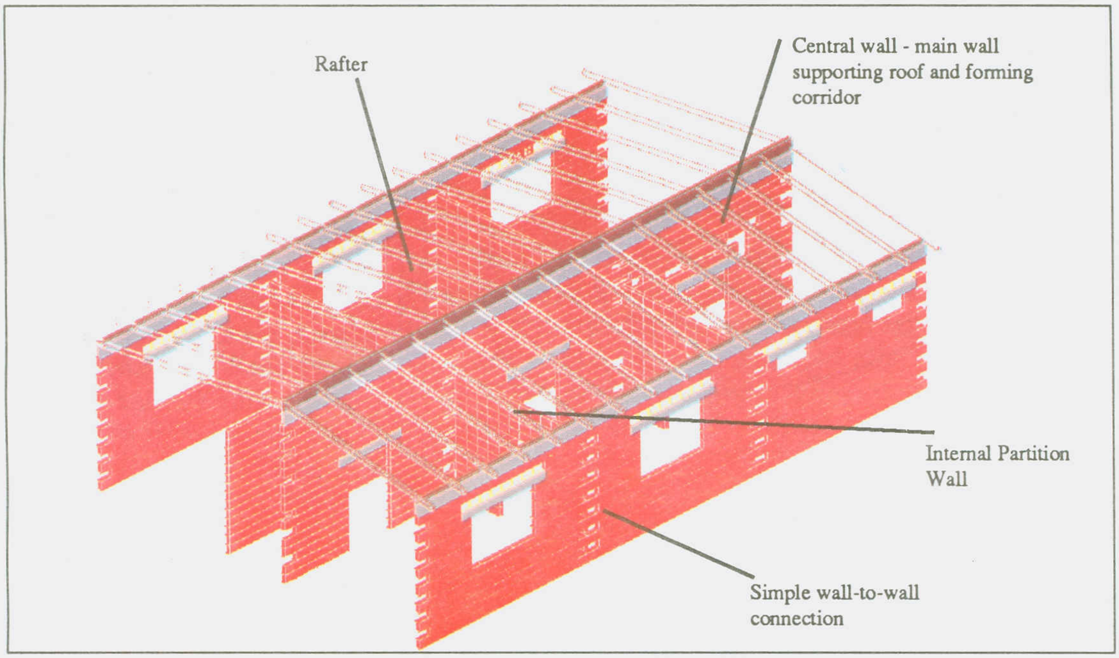
Apart from having a suitable load path, each part of the house, that is, all the various connections - the walls, the foundation and even the soil, must be sufficiently strong to withstand the effects of the inertial force as it is transferred to them. As the parts of the house which provide the load path for the inertial force, is the same as the parts of the house that support the roof, if any one of these parts cannot sustain the effects of the inertial force, then at least one section of the house can collapse, and even possibly the entire house.

Unfortunately, to enable the various parts of the house to withstand the inertial forces due to a strong ground motion without any damage being done to them, would require that these parts be very large. For instance, the walls would probably need to be at least four times thicker than they are now. However, the magnitude of the inertial force can be very significantly reduced if the parts of the house that resist it can be made to be *ductile*. Something is ductile if it is able to "give" before finally breaking. The opposite of ductility is brittleness. For example, if you take a piece of thin steel wire, place it between your first and second fingers, then press at the center with your thumb, the wire will bend without breaking, and remain in its bent shape when you stop. If you do this with a match stick, it just breaks in two almost immediately after you begin. The wire is ductile and the match stick is brittle. After a while, for the same level of force applied to the wire, the atoms within the wire are being rearranged while the wire itself is bending (which is why it does not return to its original straightness if you stop). Only after this, does it break. A brittle material cannot do this - when it takes as much as it can, it just breaks.

Masonry blocks, as well as hardened concrete, by themselves are brittle materials. However, the steel, which is ductile, can be placed in them at certain places so that the relevant parts of the building (the walls, beams and columns) achieve a sufficient level of ductility. Unfortunately though, to use the ductility of the steel rods, the brittle material will develop large cracks, so the building will not be repairable or usable after experiencing the largest earthquake it was designed to withstand, but the building will not collapse. This approach to the design of buildings for earthquakes is the most widely used approach throughout the world today.



Conditions under which the recommendations apply

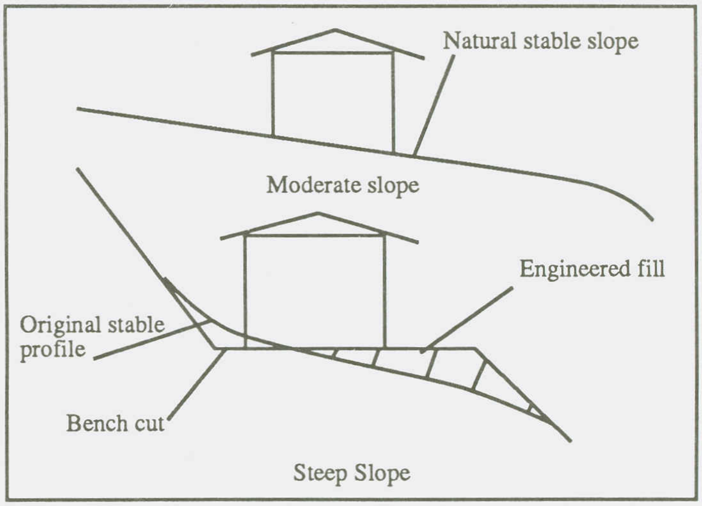


The recommendations presented in this booklet apply to your house only if a certain set of conditions are met, under which your house was built. This is necessary for two reasons. Firstly, from a survey of 200 houses, a generalisation of the typical house in Trinidad and Tobago was made hence it is unavoidable that there will be those cases, in the minority, which are different from this presumed typical house. Secondly, there are cases where the house is poorly located and therefore beset by other types of problems, within the context of earthquakes, which retrofitting will not be able to alleviate.

The main structural features of the typical single-storey house in Trinidad and Tobago, built with unreinforced masonry hollow clay or concrete blocks is shown in the diagram below. Within the context of this Booklet, the type of roofing is of secondary importance. What is more important, is the question of the supports for the roof. The roof is typically supported by 3 walls which run parallel to each other - 2 external walls, and one wall which forms the central corridor of the house. These walls are not necessarily of the same length. The other two external walls (not shown in the diagram) in effect do not support the roof because they are not bolted or nailed to the roof's rafters, and because they are constructed after the roof is built. Therefore these walls, and all the other walls in the house, serve no structural purpose but they are used to enclose the house, and form its various rooms. This Booklet applies to houses of the type shown above.

If your house is situated on any of the following types of site, then the recommendations of this booklet are applicable:

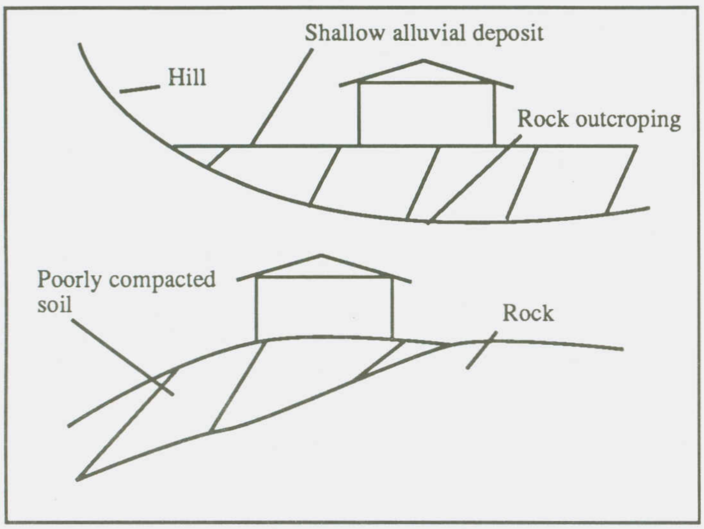
1. Firm natural sites - flat or moderately sloping
2. Bedrock
3. Stable hillside slopes
4. Dry, consolidated earth deposits underlying firm material
5. Engineered land fill



GOOD

If your house is situated on any of the following types of site, then the recommendations of this Booklet are NOT applicable:

1. Organic fills (peat)
2. Landslide prone areas
3. Swamps
4. Ocean cliffs and bluffs
5. Loose shifting soils at the base of hills



NOT GOOD

What is Ferrocement and How it is used to Strengthen your house

Ferrocement is composed of steel wire mesh that is completely penetrated by a mortar that is rich in cement. It is not a type of cement. The wire mesh is very thin and the wires are closely spaced, a typical example being the well-known "chicken wire". Several layers of the mesh are used. The term "mortar" refers to sand mixed with cement and water, where the largest particle of sand is no bigger than about 5 mm. In Trinidad and Tobago, the type of sand used for ferrocement construction is called "sharp sand". On the other hand, concrete, which is qualitatively similar to mortar, in addition to the sand, cement, and water, uses particles that are much larger, typically 25 mm. If steel rods are used to reinforce concrete, the result is called reinforced concrete. Beside the chicken wire, the other types of mesh used for ferrocement construction are: square-welded mesh, woven mesh, and expanded metal (known locally as "hi-rib"). In Trinidad and Tobago, the most common types of mesh suitable for ferrocement construction are the chicken wire, and the square-welded mesh.

When steel is used in the form of the meshes, the result is that the material behaves very differently than if rods are used. If rods are used, then when the material is severely damaged it has large cracks and the concrete can fall out in large pieces. If meshes are used, then the cracks are very small, and occur later. The distribution of the steel meshes into the brittle mortar imparts more of the beneficial properties of the steel to the mortar hence the name "ferrocement" which means "a cement-based material that behaves like steel". Since more of the steel's properties are imparted to the material for ferrocement than for reinforced concrete, ferrocement is a superior material than reinforced concrete. It was first developed by Lambot in 1847, even before the reinforced concrete with which we are generally more familiar. However the concept died for a while presumably due to the difficulty in making mesh as compared with making rods. The concept was revisited by Nervi in the 1940s and it is now used worldwide for making boats, tanks, houses, etc. Another important feature of ferrocement is that to make something with it, you do not need formwork (the timber or steel members that give the shape to the desired item). The meshes themselves provide the shape and being so closely spaced, the mortar does no fall out when applied.

In this project, it is the high ductility of the ferrocement that will be exploited. However, to better understand how this will be done we will need to appreciate what will likely happen to your house without the ferrocement, if a severe earthquake was to occur, given the concepts of proper house behaviour and the layout of the typical house, which were presented earlier. The main deficiencies of the unreinforced single-storey masonry houses in Trinidad and Tobago can be listed as follows in decreasing order of severity:

1. The walls supporting the roof are not tied to their foundations
2. The external walls in the shorter direction of the house are not tied to the roof
3. The connections at intersecting walls are poor
4. The walls are too thin and too lightweight
5. There is no continuous member connecting the roof to the top of the walls

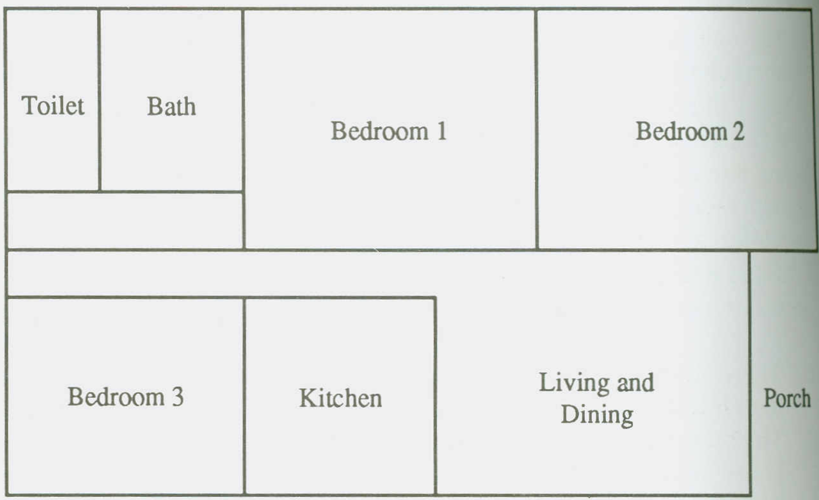
What would happen to the house due to a severe earthquake? A house built with the brittle unreinforced masonry can withstand a moderate earthquake, given certain properties as sufficient wall thickness and weight. Relatively recent findings show that such walls can resist the earthquake by the rocking of their cracked portions thereby enabling the walls to continue supporting the roof. However, due to the first 3 deficiencies in the last paragraph, the walls will slide arbitrarily, then they will separate from each other and then, the 3 walls in the direction of the longer side of the house will topple sideways, taking the roof with it. The lack of a connection from the roof, to the top of the external walls in the direction of the shorter side of the house, means that there is no reliable way for those walls to resist the inertia force from the roof and the force cannot be adequately transferred to them. The internal partition walls that intersect with the walls in the direction of the longer side of the house, cannot assist since their connection to those walls is too inadequate for the force to be transferred, and even so, since they are not tied to their foundations either, they would slide. Even if all the walls were to be properly anchored and the roof properly tied, the walls would not have sufficient capacity to withstand the earthquake since they are too thin and light and would topple over. Although we are focusing on one type of unreinforced masonry house in this Booklet, this analysis of what would happen in a severe earthquake also applies to all other types of unreinforced masonry houses as well, including the common two-storey houses where the unreinforced masonry walls are built on reinforced concrete slabs and frames.

How can the ferrocement help the situation? Basically, by providing a ferrocement skin to the surface of the walls, its ductility and higher strength are imparted to the wall. Even so, the ferrocement skin cannot do its work if the walls to which it is applied are not anchored to the floor. In addition, the roof-to-wall connection for the external walls in the direction of the shorter side of the house, cannot be adequately improved without incurring a high cost. Therefore, the internal partition walls that intersect with the walls in the direction of the longer side of the house, will be relied upon to resist the force in the direction of the shorter side of the house.

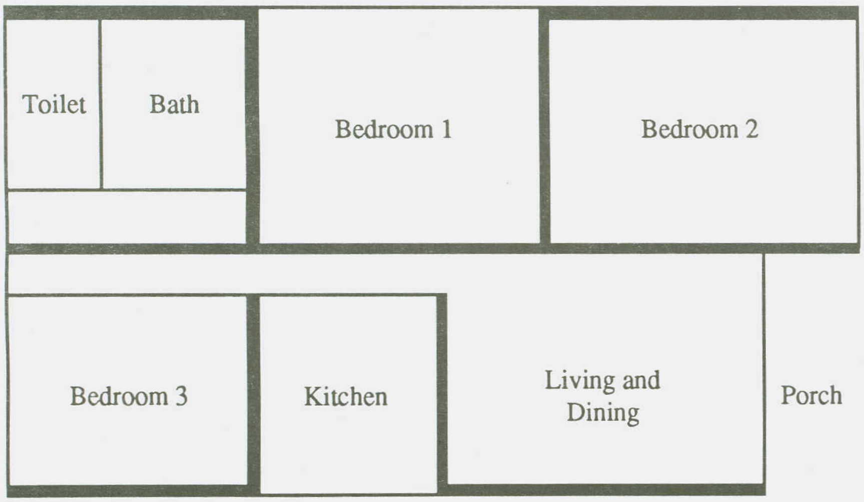
How to Identify the Walls for Strengthening

The rule to remember is this - for the 3 walls that support the roof, strengthen the full length of the middle wall, and the outer portions of the other 2 walls; for the internal partition walls in the other direction, strengthen 4 of them that meet with the external walls, such that 2 are on each side of the central wall that supports the roof.

Let us illustrate this with an example. Say the layout of your house is like this *(the sketch is not to scale):*



The walls that you strengthen are the ones with the thicker lines shown below:



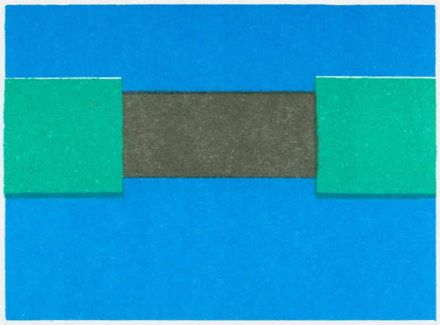
It must be pointed out that this recommendation represents the least amount of strengthening, and hence lowest cost, that is required to ensure that the walls which support the roof do not collapse. However, the unstrengthened portions of these walls, and the end walls in the direction of the shorter side of the house, can fall out. As any of these walls is not light, it can cause serious injury if it falls on someone. Therefore for maximum safety, they can also be strengthened.

How much Mesh Reinforcement and Where to place it for each Type of Wall

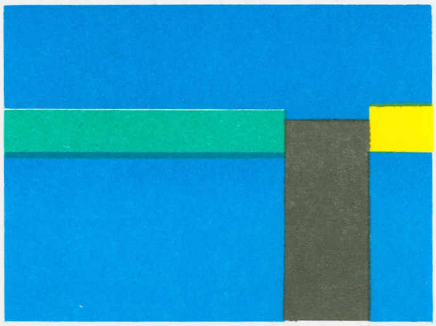
The term "type of wall" refers to the openings in the wall. There are 7 main types of walls in unreinforced masonry houses in Trinidad and Tobago. The effect of an opening is that the wall develops a weak point at the corners of the opening.

The following diagram tells you where to place the mesh reinforcement for each of the 7 types of walls, and for each of two types of mesh reinforcement: square-welded mesh, and hexagonal mesh (also known as "chicken wire"). Please note carefully that the mesh reinforcement is to be placed on both sides of the wall.

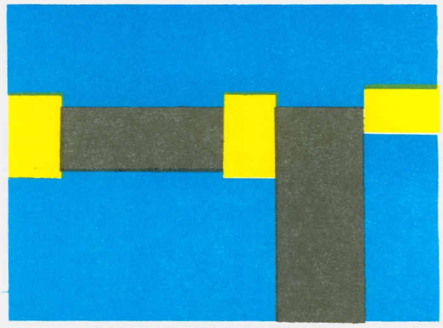
FOR SQUARE-WELDED MESH:



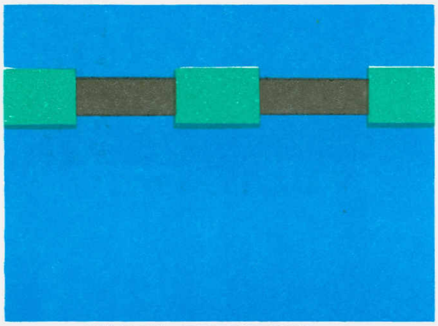
WALL TYPE NO. 1



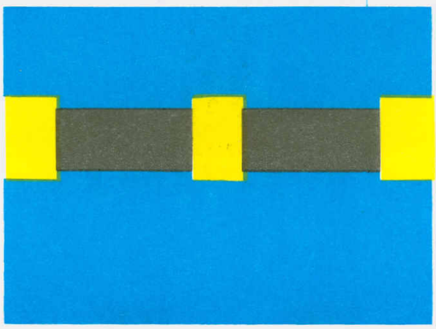
WALL TYPE NO. 2



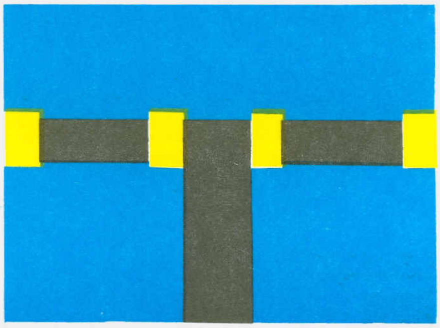
WALL TYPE NO. 3



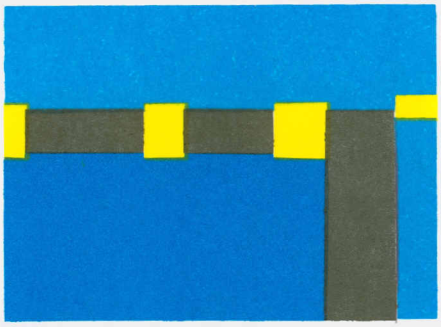
WALL TYPE NO. 4



WALL TYPE NO. 5



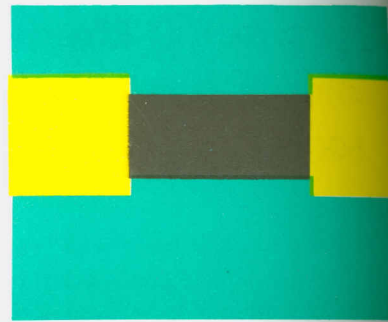
WALL TYPE NO. 6



WALL TYPE NO. 7

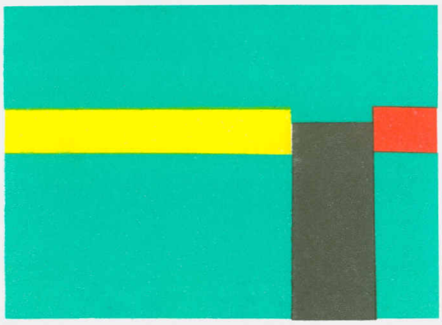
LEGEND:

- If the wall has no openings, use 3 layers throughout
- If the wall type is not one of the types shown, then use 4 layers throughout
- As shown in the above diagrams, at the corners of all openings, the meshes extend by 350 mm (14 in.).

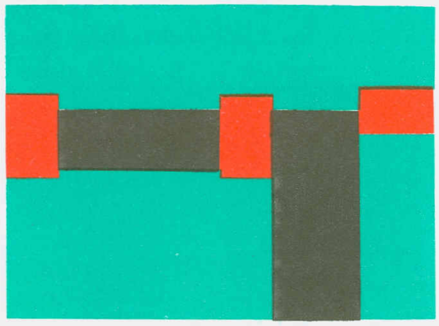


WALL TYPE NO. 1

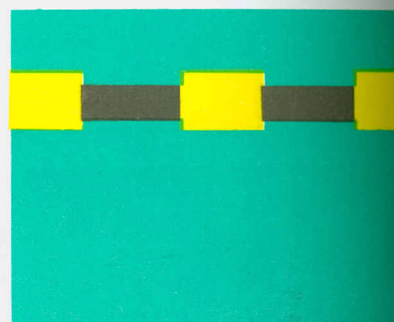
FOR HEXAGONAL MESH ("Chicken Wire"):



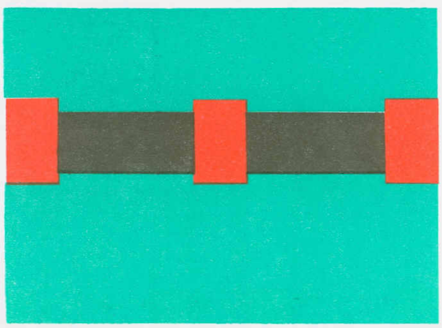
WALL TYPE NO. 2



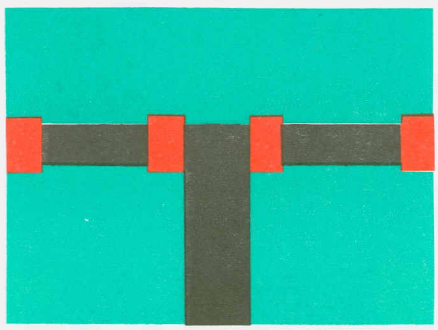
WALL TYPE NO. 3



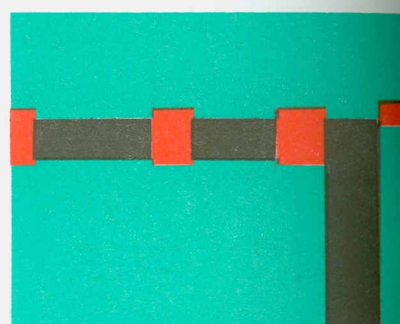
WALL TYPE NO. 4



WALL TYPE NO. 5



WALL TYPE NO. 6



WALL TYPE NO. 7

LEGEND:

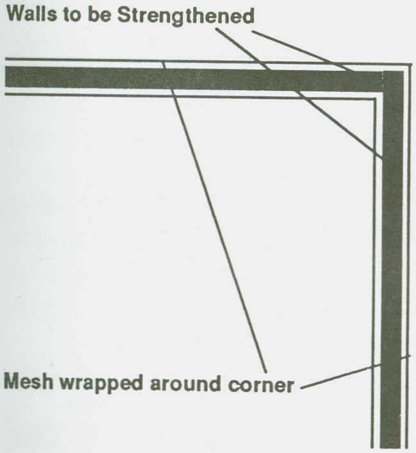
Opening | 2 Layers | 3 Layers | 4 Layers | 5 Layers

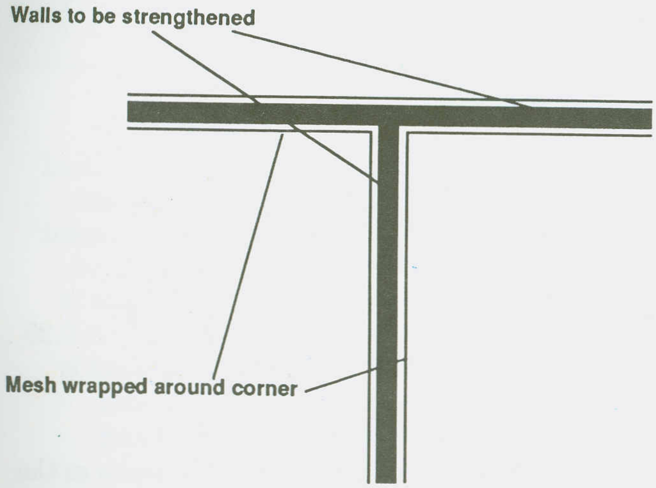
- If the wall has no openings, use 3 layers throughout
- If the wall type is not one of the types shown, then use 5 layers throughout
- As shown in the above diagrams, at the corners of all openings, the meshes extend by 350 mm (14 in.).

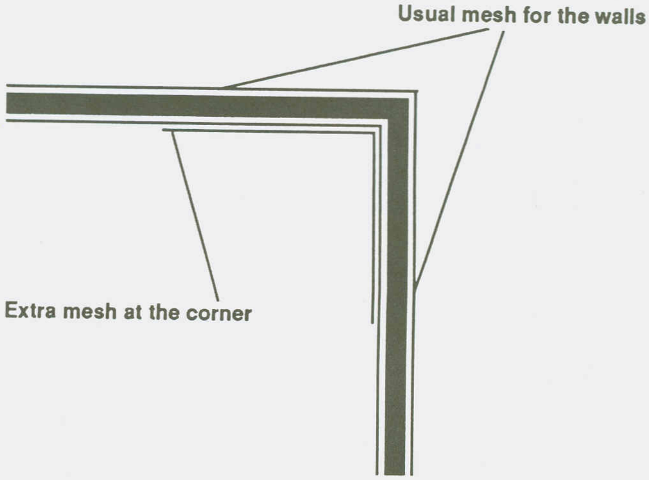
The Wall Intersections

Apart from the strengthening of the relevant walls, the intersections of those walls with each other must also be specially reinforced. This is necessary if the walls in the direction of the shorter side of the house are to perform as intended.

From a bird's eye view, the 2 types of wall intersection look like the letters "L" and "T". To reinforce any of these, you must ensure that at the corners, you wrap the layers of mesh for the walls around the corner, from one wall to the next. This is indicated in the diagram below.







If one of the walls requires more mesh than the other, then wrap the extra layers around the corner and onto the other wall, for a distance of 1.0 m (about 3 feet) from the corner.

Finally, when you have finished placing the mesh for both the walls, place an extra layer of mesh at the corner, such that it extends a distance of 1.2 m (about 4 feet) from the corner, along each wall. This is shown above for an "L" intersection.

The Construction Procedure

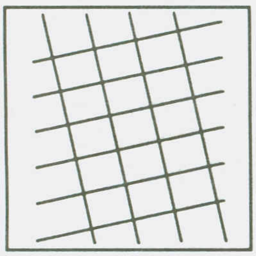
Now that you know where to place the mesh, we will look in detail at the whole procedure that is to be carried out in constructing the ferrocement skin, and all the materials and tools needed to do the job. We will consider one typical wall.

The Materials and Tools Lists

MATERIALS

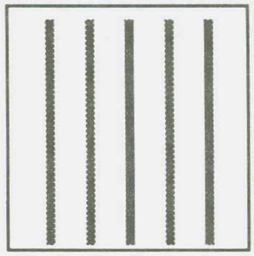
The required materials are as follows:-

1. **MESH**



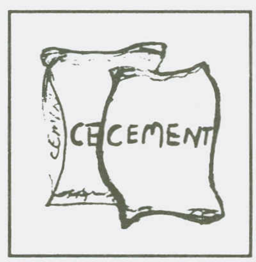
The hexagonal and square-welded wire mesh are recommended based on availability in Trinidad and Tobago. The hexagonal wire is called the "half by half by 22 gauge hexagonal or chicken wire mesh" and it is generally more readily available than the square-welded mesh. The square-welded mesh is called the "half by half by 19 gauge square-welded mesh". Both types of mesh are typically sold in rolls that are either 0.91 m (3 ft.) wide by 45.73 m (150 ft.) long, or 1.2 m (4 ft.) wide by 30.5 m (100 ft.) long. The hexagonal mesh is cheaper, and the wire is thinner than the square-welded mesh but the square-welded mesh performs better therefore, as shown in the previous section, you need to use more layers of the hexagonal mesh than the square-welded mesh. As a result, there is a constructional advantage of using the square-welded mesh rather than the hexagonal mesh. Since more of the latter is generally required, it is more difficult to get the mortar to penetrate the mesh completely, especially in regions where the meshes overlap. For maximum economy, you will need to work out the mesh cost for each type of mesh separately. There is no general way of knowing which would be cheaper since each house has different types of walls which require different amounts of mesh for each type of mesh. However if you prefer not to do any calculations, then you may wish to use the requirements for the most common type of wall, the wall with one window opening, as a guide. In this case, using the hexagonal mesh is more cost-effective, you would need about 1.4 rolls for a 0.91 m wide roll, or 1.7 roll for a 1.2 m wide roll.

2. **STEEL TIE RODS**



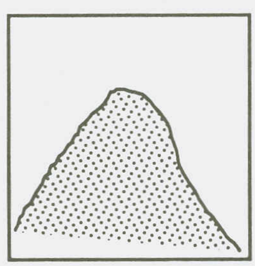
The Steel Tie rods are used to hold the meshes in place on the wall. Each of these rods is 6 mm (1/4 in.) in diameter, 175 mm (7 in.) long and goes right through the thickness of the wall. Each rod therefore projects about 30 mm (1 1/4 in.) from each face of the wall. Hence 30 mm from each end of the rod is threaded to accept a nut and washer. The rods are spaced 300 mm (1 ft.) apart in both the horizontal and vertical directions. The intention is that the meshs are held in place by bolting them to the wall. The fabrication of the tie rods is one of the few areas that the homeowner would not be able to do themselves - a workshop would have cut and thread the rods for you. To minimise the cost, the homeowner can purchase the rods, nuts and washer, at a hardware store, then carry them to the workshop. A wall that is 2.44 m (8 ft.) high by 3.66 m (12 ft.) long would require 4 lengths (about 24 m (80 ft.) of the 6 mm rod, which includes extras.

3. **CEMENT**



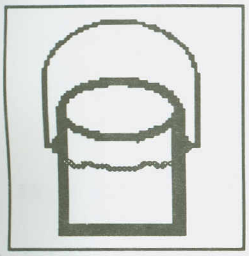
About 7 bags of cement are required for a typical wall. One bag of cement weighs about 45 kg (99 lbs.). The type of cement to use is called "ordinary portland cement".

4. **FINE AGGREGATE**



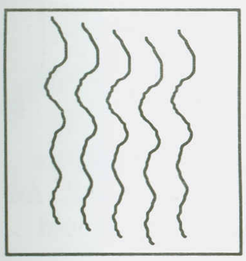
The fine aggregate is required for making the ferrocement mortar, along with the cement and water. In Trinidad and Tobago, the fine aggregate is called "sharp sand". About 0.25 cubic meters of sharp sand is required for a typical wall. However, in Trinidad and Tobago, aggregate is still sold in imperial units so the amount you need is about 1/4 cubic yard, which at the hardware store is called a "quarter yard of sharp sand". Since you will have to pay a transport cost, it is better to order the amount required to do all the walls instead of just one. A truckload carries about 8 cubic yards of material therefore if you intend to strengthen say 15 walls, you will need about one half of a truckload, which includes some extra material.

5. **WATER**



The amount of this ingredient that is used severely affects the strength of the mortar. The more water that you use, the weaker the mortar. However, the less water that you use, the "stiffer" the mortar hence making it more difficult to get the mortar to penetrate the meshes, especially in any regions of overlapping meshes. In a home environment, it is difficult to know exactly how much water to use, so this is typically done by adding a bit at a time so that the minimum amount of water that is required for the mortar to penetrate the mesh is used. As a guide, if you use a construction bucket (available at any hardware store) to measure out the water, then about 5 buckets of water is the amount required to do both sides of a wall that is 2.44 m (8 ft.) high by 3.66 m (12 ft.) long. This amounts to about 3/4 buckets of water to 1 bag of cement.

6. **TIE WIRE**



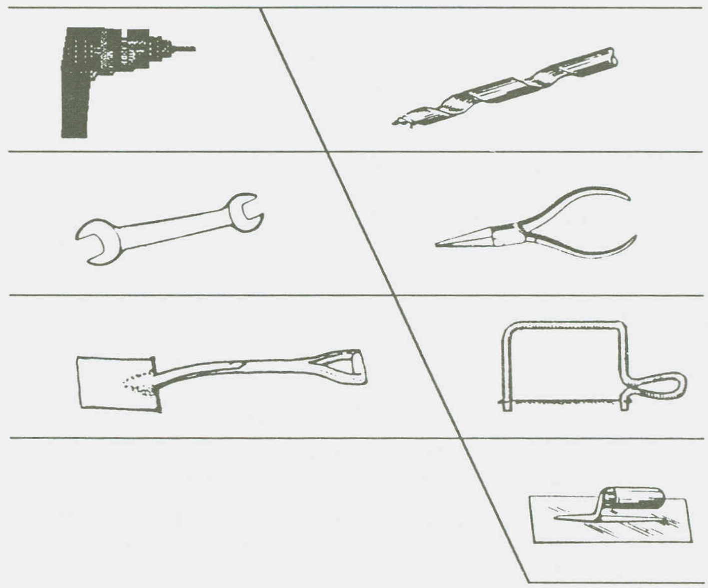
This is needed when tying the layers of mesh together before mounting them on the rods in the wall. It is sold at the hardware store by weight and comes in a roll. A 7 kg amount should be enough for all the walls.

TOOLS

The following tools are required for the strengthening of the walls using ferrocement:-

1 household electric drill with a 6 mm bit and a 16 mm carbide bit; a chalk line; a 6 mm spanner; a 12 mm spanner; a 16 mm spanner; a construction measuring tape; 1 pair of wire shears; 1 pair of pliers; 1 bolt cutter or a hacksaw; 2 construction buckets; 1 pencil; and 1 shovel and trowel for each person helping on the project.

TOOLS

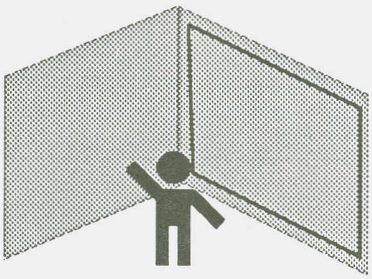


Placing the mesh

To place the mesh on the wall, carry out the following steps (The example of a wall with a single door opening is used throughout):-

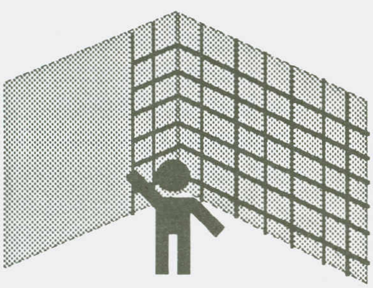
1. Remove the strip of wood or metal that is attached to the wall for supporting the ceiling, and remove the row of ceiling tiles which are closest to the wall. That is, give yourself room to work on the wall remembering that the mesh is placed from the very top of the wall where it meets the roof, down to the floor.

2. Using the chalk line put a long line along each edge of the wall, as close to the end of the wall as possible.

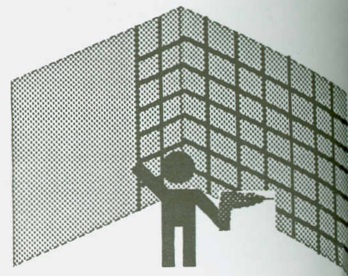


3. Use a pencil and measuring tape and mark along the lines at 300 mm (1ft.) intervals. Do the same thing on the walls that intersect with the wall, and which you intend to strengthen next. However, on these walls, you only mark out an area 1.2 m (4 ft.) from the corner. This is done because as stated in the section called "The Wall Intersections", the mesh must wrap around the corner of intersecting walls that are to be strengthened.

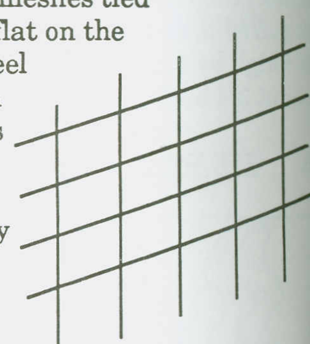
4. Use the chalk line to form horizontal and vertical lines across the entire wall, and the area of the intersecting walls, using the outer lines and tick marks from steps 2 and 3. You should now have a grid of chalk lines spaced 300 mm apart.



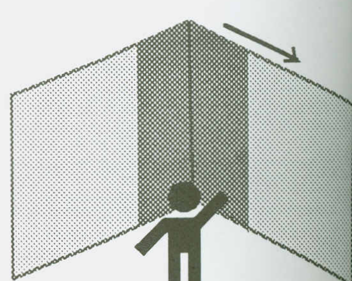
5. Use a drill and a 6 mm (1/4 in.) bit to drill holes through the wall at the chalk line intersections. However, do not drill at the likely locations of plumbing pipes or electrical conduits which may be present in the wall. How do you know where they are? Look for electrical outlets and do not drill horizontally at the same level as the outlets, or vertically at the same location of the outlets. The plumbing pipes are usually more obvious but examine the layout of the pipes from the connection at the mains, to the sinks and sanitary facilities. Also, drill holes at the edges of any openings, and vent blocks, but not too close (about 50 mm away) to damage the edges. Do not be alarmed if you notice that on the wall face opposite to the face that the drill first pierces, you do not get a neat hole. Also, please note that you must drill through the concrete ring beam also (use concrete drill bit).



6. Now you are ready to prepare the mesh. The idea is that you prepare the meshes on the ground as one mat of meshes tied together, place them flat on the wall, and push the steel tie rods through them and through the holes closest to the corners of the mat so that the mat can then stand by itself on the wall, supported on to the steel ties. Find a suitable flat work area where you can prepare the meshes before placing them on the wall. An area about 3 m by 3 m (10 ft. by 10 ft.) should be sufficient.

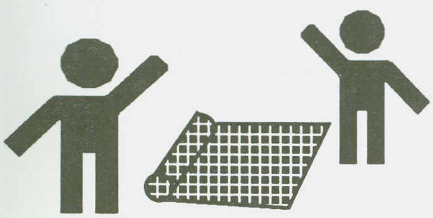


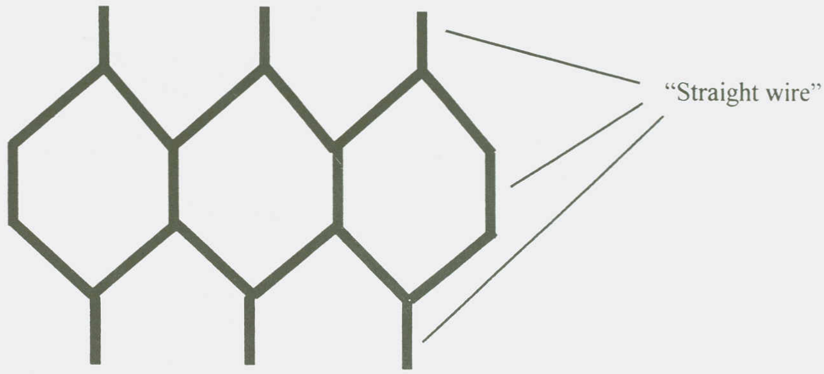
7. There are a few things to remember at this point: (i) if you are using square mesh, the basic number of meshes is 2, but the basic number of meshes is 3 for the hex mesh; (ii) you begin on an intersecting wall, then onto the main wall to be strengthened, continue along that wall, then finally onto the other



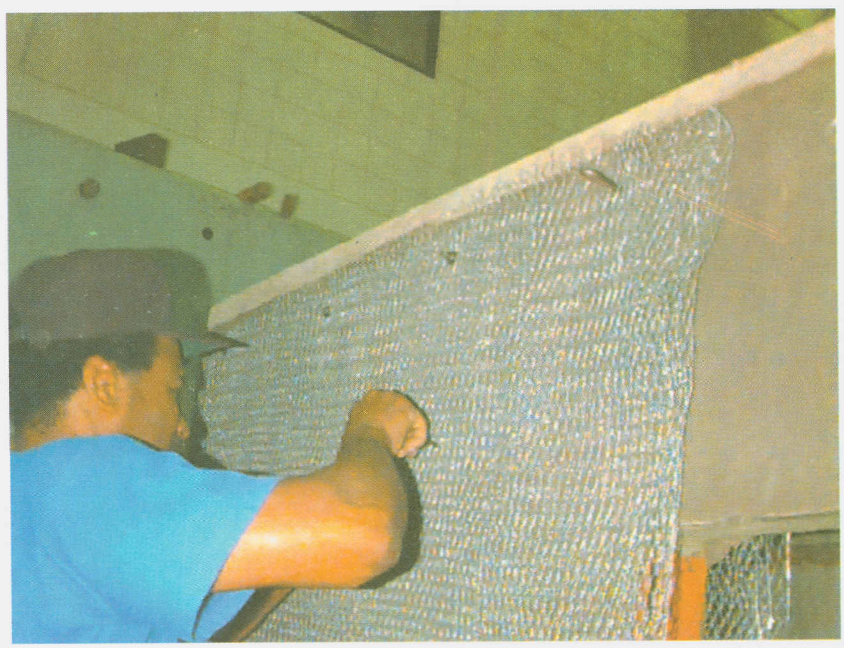
intersecting wall, if any; (iii) the mesh mats are placed from the top of the wall to the bottom, and (iv) you must place the mesh on the front and back of the wall at the same time so you can bolt them together using the steel rods. Note that if the wall you are doing is not your first wall, then the meshes for the wall intersection may already have been placed so you can just continue onto the areas without any meshes placed as yet, for the wall you are doing.

8. Now you prepare the mesh mats. Measure from the top of the wall to the bottom. Roll out the mesh by this amount and using the shears, cut 2 pieces if you are using square-mesh, or 3 pieces if you are using hex mesh. Place these pieces on top of each other, and tie them together using the tie wire so that they are as close together as possible. The idea is that they must be as if they are just one layer of mesh. Make another mat the same way, this one being for the area behind the wall (remember you must do the front and back of the wall at the same time). Of course, for the area where there is an opening, the vent blocks, an area you do not want to cover, you measure and cut the appropriate size mesh. An important point to remember is that since the width of the roll is only 0.91 m or 1.2 m, it takes several mesh mats to cover the wall. To ensure that the mats act integrally, <u>you must overlap adjacent mats by no less than 300 mm (1.0 ft.)</u>. Knowing this, you can now measure the entire length of the wall (for both front and back), and prepare all the mats, making allowances for the overlaps. Alternatively, you can do one piece at a time, and measure out the last piece when you reach it. Lastly, if you are using the hex mesh, the "straight wire" must be vertical when you place the mat on the wall. The way the roll of mesh is usually manufactured is such that this is so when you cut from the roll as described above. This is very important since hex mesh is stronger in the direction of the "straight wire". The "straight wire" is shown below.

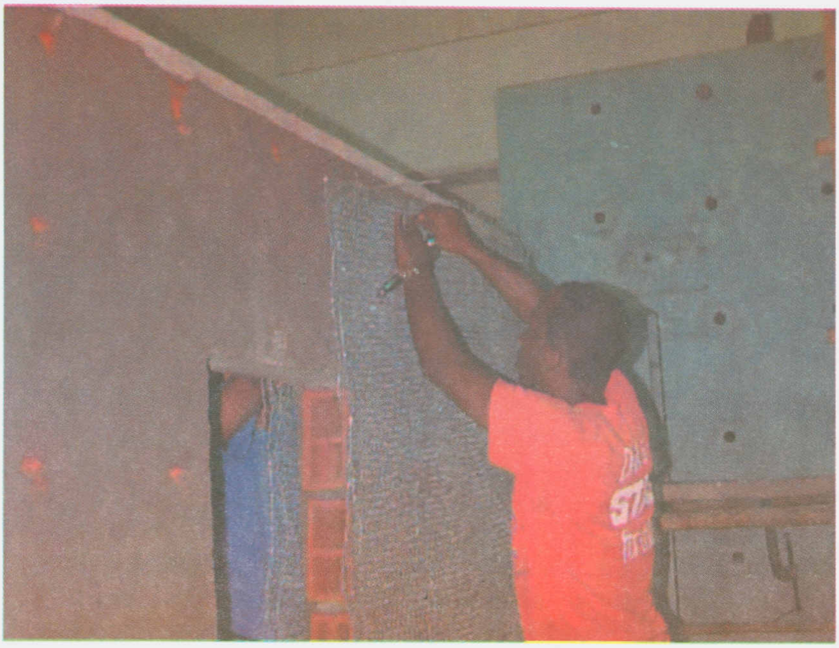




9. To place any pair of mesh mats on the wall (on the front and back faces), take some of the threaded steel tie rods and put them in your pocket or close at hand, hold one mesh mat against the front of the wall in the position that you want it (remembering the one vertical edge must overlap with the previously placed mat), while your Assistant does the same thing on the back face of the wall. Take the steel rods and insert them through the mat and the wall, at the top of the wall. You and your assistant then put the washers and nuts at each end of the rod and



tighten the nuts. The mesh mats can now stand on their own against the wall, and you now continue to place and tighten the remainder of the rods.



10. You then continue placing the mesh mats for the entire wall, front and back. However, the mesh mats have only the basic mesh reinforcement. In the previous section which showed how to place the mesh for each type of wall, it is observed that in certain regions, especially at the corners of openings, and in the region between openings, additional layers of mesh are required. For the wall type that you are working on, you now place these additional layers. Firstly, cut the required size from the roll, for the front and back of the wall. Then, undo the nuts on the bolts in the region where this additional layer will go, slip the layer of mesh over the bolts, put back the nuts, and tighten.

11. Remember that in the section on the wall intersections, it was stated that an additional layer must go on the inside of all corners. Place this additional layer now, as you did in the last step.

12. At this point, you have applied all the required meshes for a particular wall. You can now either repeat steps 1 to 11 for all the walls that you intend to strengthen, or you can mortar this wall now, and re-do the process for the other walls in turn. However, before preparing the mortar, each steel tie rod will have a little extra length protruding beyond the nut. Cut the extra length off with a bolt cutter, or hacksaw blade, for all the tie rods on both faces of the wall.

Mixing and Placing the Mortar

1. How much mortar to mix at one time is determined by the length of time it will take for you to place it on the wall. This is because after a while the mortar begins to harden and it becomes unusable. Some masons adopt the improper practice of adding more water to soften the mix when it hardens. But, this weakens the mortar too much so we won't be advising that this be done. As a basic rule, all the mortar must be applied (within an hour) after mixing. Therefore, for each person who will be helping apply the mortar, use the following ingredients: 1 construction bucket of cement to 2 construction buckets of sharp sand.

2. With a shovel, mix the cement and sand together at a convenient location (the back yard) with a tap nearby so that you can easily clean up when finished. Next, you add a little water carefully and mix it in with the sand and cement. Add a bit more water and mix it in. Stop when the mix is just fluid enough that you think it will penetrate the spaces between the meshes. It is important to remember to use as little water as possible.

3. Put some of the mortar on a piece of old plywood sheet or sheet metal, or whatever you can use to move some of the mortar to the base of the wall.

4. You are now ready to apply the mortar to the wall. There is nothing special about the procedure - simply pick some up with a trowel and dab it onto the wall, pressing it in with the trowel to get it to go between the spaces. You can even use your fingers to try and force the mortar into the spaces but remember to use rubber gloves if you want to do this since the cement in the mortar can damage your skin.

5. You do not have to worry about the outcome of your endeavours if you have no previous experience in construction - ferrocement is a very forgiving material that gives excellent results for first-time builders. This was one of the reasons the authors chose ferrocement in the first place. The photographs below show first time ferrocement builders applying the mortar.

6. A typical wall (both sides) should take you about 16 hours per person (hence 8 hours for 2 people) so it is unlikely that you will do a whole wall in one sitting. This is not a problem. You must remember however that before you

resume, take a steel-hair brush and brush away all loose mortar from the edges of the hardened section.

7. It is unlikely that when you have finished, the surface will be as smooth as before. At this point you will need to acquire the assistance of a professional mason. This is one of the few areas of the project which you will not be able to do yourself, and it deals with the aesthetics of the wall, and not its functionality - the ferrocement skin can do its work without it.

The mason is needed in order to put a thin (10 mm) layer of ordinary plaster over the ferrocement skin. Use a bonding agent to ensure that the plaster will adhere securely to the ferrocement mortar. In Trinidad and Tobago, "poly-vee" is typically used for this purpose. When the mason is finished, the wall's total thickness would have increased by about 57 mm (2.25 in.) due to the ferrocement skin and the new outer plaster. At this point, most of the work is finished - only the installation of the wall's anchors to the flooring remains.

Anchoring the Wall

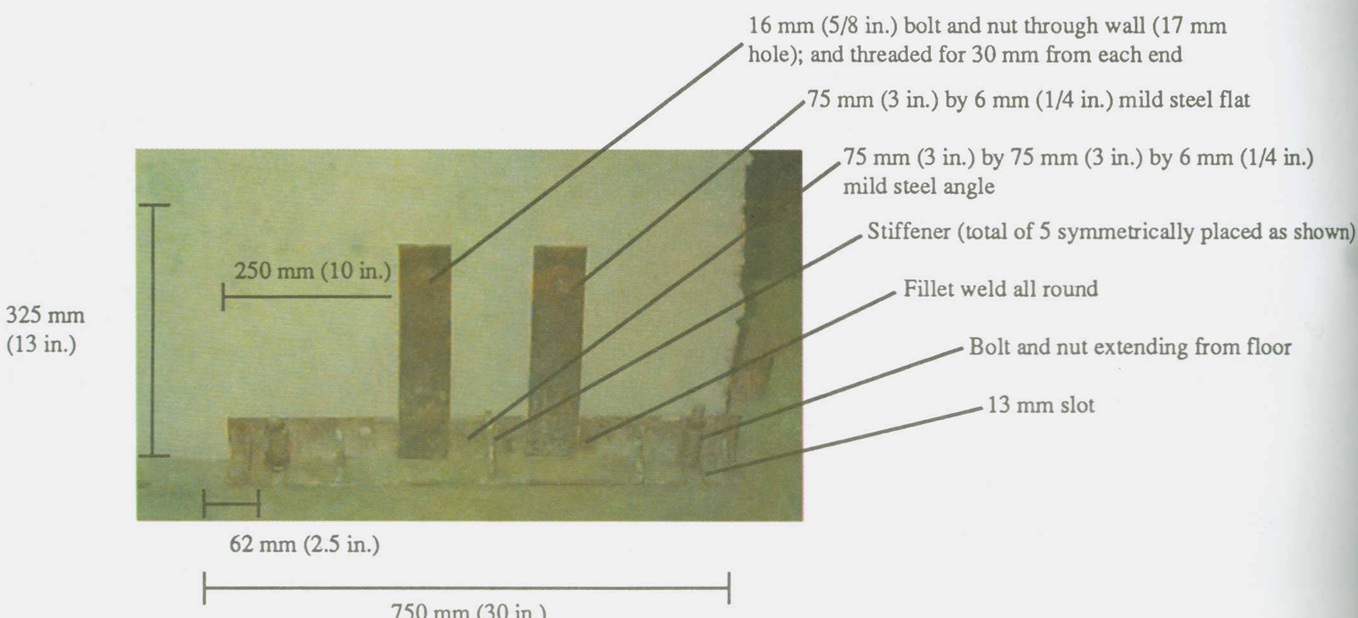
1. The term "anchoring the wall" refers to the procedure of attaching the anchors to the base of the wall. An anchor is fabricated from steel members and welded together to form one unit. An anchor is composed of basically 2 sections - the section that is attached to the wall, and the section that is attached to the floor. Without the anchors, the wall would not be able to transfer the inertial force to the foundation, and the wall, even with the ferrocement skins, would slide or topple over. The anchors are therefore essential. You would need to hire a Workshop to fabricate the anchors for you, but you can install them yourself. The first step therefore, is to call a Workshop and ask a mechanical engineering technician (MET) to visit you at the house. Explain to them what you are doing, and show them the walls where the anchors are to go.

2. The MET will need to measure each wall and determine exactly where each anchor will go. To do this he needs the following information:

   - an anchor is to be placed as close to each end of the wall as practically possible
   - the type of anchor recommended is used in pairs: one on each side of the wall
   - the spacing between each anchor along the wall be not less than 1.2 m.

3. In addition to this information, the MET needs to know the dimensions of the anchor, and the steel members that the anchor is made of. Give the MET a copy of the diagram on this page.

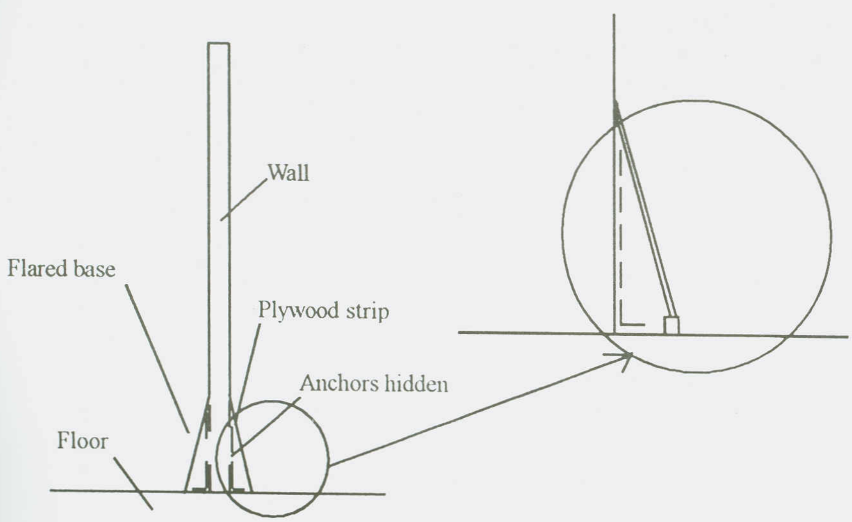
4. The idea behind the design of this anchor is



4. The idea behind the design of this anchor is simply that as the wall tries to lift or slide, it pulls on the 16 mm steel rod that goes through the wall, which in turn pulls on the steel flats, which pulls on the stiffened angle. But the stiffened angle is bolted to the ground, so the wall is restrained and the force is transferred to the foundation. In the photograph above, to bolt the angle to the floor, bolts were placed in the ground beforehand, and which each passes through the 13 mm slot, are used. This was for the case of the test walls. For your walls, there will be no such bolts, which would have had to be placed while the floor was being constructed. Instead, you will use special anchor bolts.

5. At this point, you may be asking "when the anchors are attached to the wall, won't this now make the wall appear ugly?". To cater for this, the anchors are to be disguised as an architectural feature of the wall, by hiding them behind a plywood strip which runs along the wall. This strip makes the wall appear flared at its base, as indicated below. The strip is nailed to another plywood strip which lies on the floor, and which in turn, is nailed to the floor. The ends are blocked off using triangular pieces of plywood.

6. This part of the project can be easily handled by a Carpenter. The top half of the plywood strip can be painted the same colour as the wall, and the bottom half can be painted black. However, this part of the project is the last part. You first have to install the anchors when they are completed by the Workshop.



7. To install an anchor, first place it in position and using a pencil mark the area to be drilled through the wall for the 16 mm bolts, as well as the area to be drilled for the special 12 mm floor anchors. Drill the holes in the wall for the anchor. (Please note here that the Workshop can be given the job for the preparation of the 6 mm steel tie rods, the 16 mm bolts for the anchors, as well as the anchors themselves. To complete the project as quickly as possible you can contact the Workshop before you fabricate the ferrocement skin. The 16 mm bolts and the anchor bolts were not previously discussed since they are parts of the anchor which is treated separately).

8. The special anchor bolts recommended by the authors are the "HILTI QUICKBOLT half inch by two and three-quarter inch by 2400 psi bolts". These bolts are available locally. To use them you must first drill a hole into the solid concrete, then you hammer the bolt into the hole. The bolt has a bulb at the end which expands in the hole as the bolt is pulled on. In this way, the bolt becomes wedged in the hole, thereby resisting pullout.

9. Follow the manufacturer's instructions for preparing the hole for the HILTI bolts, and putting them in place.

10. Put the anchor in place, using the slot to position the anchor as close as possible to the wall.

11. Insert the 16 mm bolts in the hole through the steel flats and through the wall, and finally attach the nuts to the 16 mm bolts and the HILTI bolts, and tighten them. The anchor is now in place. Repeat steps 7 to 11 for the remaining anchors for all the walls.

12. Lastly, call the Carpenter and ask him to build the plywood closure for the anchors.

YOUR EARTHQUAKE RETROFITTING PROJECT IS NOW COMPLETED.