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FERROCEMENT GEODESIC DOME SHELTER FOR EARTHQUAKE RESISTANT AFFORDABLE HOUSING

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ABSTRACT

Housing, which is the basic infrastructure necessity for any nation, has been becoming a highly challenging task, not only for the developing countries, but also for the developed countries, due to rapidly fluctuating economic situations prevailing all across the globe. The worsening economic conditions are dumping millions of families to become home-less. In this context, apart from offering remedial economic packages, the governments have to come-out with innovative technical solutions of affordable disaster resistant housing, particularly for the displaced families.

Geodesic dome homes are not new for North America. But, ***'Ferrocement Geodesic Dome Shelter (FeGeDS)'*** is an innovative construction system, which provides not only affordable housing but also earthquake resistant homes. This type of housing is also effectively multi dimensionally disaster resistant, as they are fire resistant, cyclone resistant and flood resistant. Hence, this disaster resistant construction technology is also highly suitable for rehabilitation and reconstruction phase in post-disaster situations.

The paper illustrates and projects FeGeDS construction as a simple technology with the combination of precast ferrocement panels and cast-in-situ assembling technique for the construction of earthquake resistant geodesic dome home. These ferrocement geodesic domes are highly durable and requires nominal maintenance, unlike conventional wooden / synthetic / plastic / fiber reinforced plastic (FRP) geodesic domes. As FeGeDS is built of a special type of concrete, known as ferrocement, they last for decades and even beyond a century, with minimum maintenance.

This technology offers many advantages. The long list of advantages starts with economic, materialistic and labour related savings. Even the maintenance cost will be much lesser, when compared to other types of housing. All these economic advantages are brought-out in this paper. For this type of technology,

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the foundation required will be very simple, because its dead weight will be relatively very less, when compared to reinforced cement concrete (RCC) / masonry / steel buildings. The architectural advantages and structural advantages are highlighted. This paper also projects the FeGeDS not only as one of the green building technologies, but also as greenery promotion housing.

The social acceptability for this geodesic dome type housing may not be a problem in the long run of time, say with in a period of few years. If, its very important advantages of affordability, durability, disaster resistance, green building concepts, etc., are intensively promoted by series of seminars, demonstrations and other relevant technical activities, its social acceptability may catch-up like a wild fire. More and more people may also exclusively like its geodesic shape.

The only limitation with this type of dome is that, it can not be suitable for multi-storey construction. Hence it is not recommended for urban housing, where the real-estate value of land may be very costly and thus multi-storey apartment housing only may be affordable. However it is highly relevant and most suitable for rural housing, where the land cost may be cheaper and the construction cost is to be economized without compromising on durability and the structural stability.

Introduction

Fe*rrocement* ***Ge****odesic* ***D****ome* ***S****helter* ***(FeGeDS)*** is a geodesic shaped dome, built of ferrocement construction technology. The geodesic dome is made of assemblage of series of intra matching triangles. A standard size of 6m. diameter geodesic dome offers total plinth area of about 28sq.m., to accommodate a family size of three to five people, under basic and essential living conditions. However, the bigger diameter geodesic domes offer larger plinth areas, for spacious living conditions. Ferrocement is a versatile form of reinforced cement concrete(RCC) made of cement mortar and wire mesh reinforcement. The combination of geodesic dome and ferrocement construction technology is innovative application for affordable rural housing, with effective disaster resistant features. FeGeDS is a simple technology with the combination of precast ferrocement triangular panels and cast-in-situ assembling method. This type of housing is not only fire proof because it is built of non-combustible ferrocement material, but also cyclone resistant because of its better aero-dynamic shape. Its inherent capability of earthquake resistance is justified with reference to its monolithic / three dimensional structural stability, relatively lighter dead weight and broader structural base. Its construction system is envisaged to be simple and easy. This technology requires no special equipment for construction. Nor, it requires any special shuttering. The FeGeDS construction is quite fast, as its construction can be completed with in a week. It is quite economical, as it consumes minimum quantities of cement and steel. This technology can also be claimed as 'Green Building Technique', since it saves lot of cement and steel, the materials which consume very high energy during their manufacturing stage. Further, this green building technology also conserves natural construction materials such as the clay soil by minimising utilisation of bricks and stone is conserved by minimising the usage of concrete aggregates. One small limitation of FeGeDS is that, its interiors may be relatively hot in the tropical environments where the temperature rises above 35^{o}C. This limitation may be turned-up as an additional greenery advantage, if few creeping plants (such as money plant) are grown-up on the surface of the geodesic dome. The green creeper plants on FeGeDS surface top will also make it to appear as the real green home. *With this introductory back-drop, it can be summerised that FeGeDS technology offers affordable, highly durable, green building and disaster resistant housing system, which is to be advantageously utilised by all the countries.*

Geodesic Dome

The geodesic dome is a semi sphere shaped unique dome, without any curved surfaces. Because, a geodesic dome is composed of series of intra matching plane surfaced triangular panels. Hence it is a special dome, without any curvature on its surface, which is assembled with series of triangle panels. Each triangle will have three edges of straight lines of specific lengths called as struts. Depending upon the shape and size, a geodesic dome consists of number of sets of different sized triangle panels and number of sets of struts of different lengths.

The geometrical design of geodesic dome is designated with a specific number, which is called as frequency. The frequency of any given geodesic dome ranges from one to any full number, say 'n'. The minimum frequency being one, theoretically the maximum frequency may not have any limit. But, practically the frequency of any general geodesic dome may be limited to highest single digit only. Because the higher the frequency of geodesic dome, its shape becomes more and more complex with the composition of more and more triangle panels.

The lower the frequency of geodesic dome, the simpler will be its assembling technique. But, low frequency dome consists of relatively large area triangular panels, which may be difficult to handle during assembling stage of dome. On the other hand, the higher frequency geodesic dome needs complex assembling procedure, with more and more triangular panels. For a given radius of geodesic dome, higher the frequency number, higher the number of total triangle panels and shorter the strut lengths. Hence, the high frequency domes are composed of relatively smaller area triangle panels. Though its assembling becomes little more complex, it will be relatively easier to handle the smaller triangle panels for construction of larger sized geodesic domes. Hence, for a geodesic dome of larger radius (say more than five meters), higher dome frequency of four and above are to be adopted.

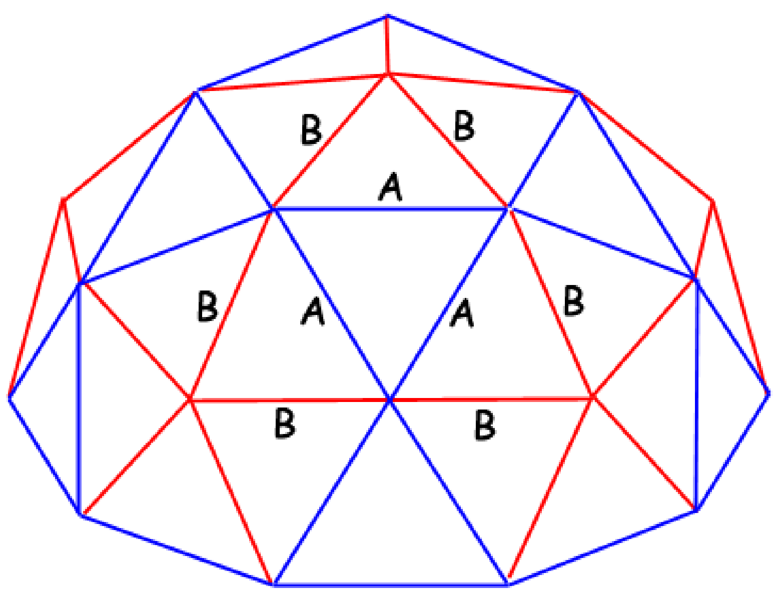

Figure 1. Geometric shape of frequency-2 geodesic dome

In this paper a standard size of 3m. radius geodesic dome of a very simple frequency two, is considered for typical affordable rural housing. This size dome offers total plinth area of about 28sq.m., to accommodate a family size of three to five people, with the basic living conditions. The geometric design and the shape of the proposed geodesic dome house are shown in figure-1.

As a dome of frequency-2, it is made of two different types of struts called A and B. The strut lengths are calculated using strut factors, with the formula – *strut length = dome radius X strut factor*. For the freaquency-2 dome, the strut factor of A-strut is - 0.61803 and the strut factor of B-strut is – 0.54653, as per the standard geometric design of geodesic domes. Being frequency-2 dome, this dome is composed of two sets of triangular panels known as AAA and ABB. The full geodesic dome of frequency-2 requires total forty numbers of triangular panels. This freaquency-2 dome is composed of ten numbers of equilateral triangles-AAA and thirty numbers of isosceles triangles-ABB, with the sub-assemblages as shown here, in figure-2.

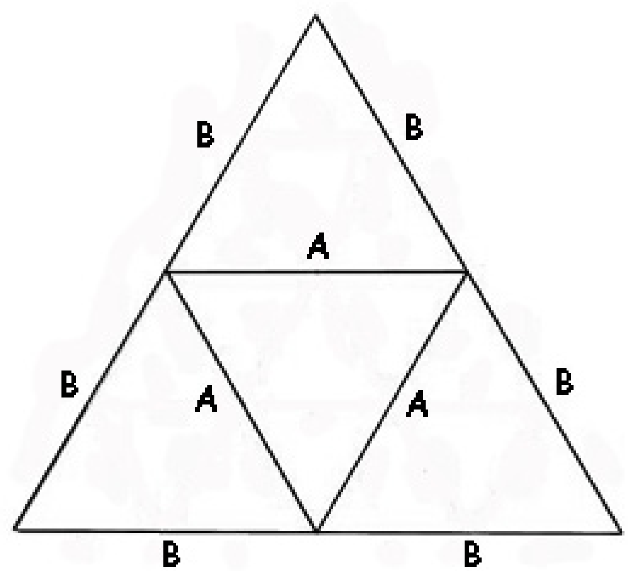

Figure 2. Sub-assemblage of geodesic dome

The Advantages of Using a Geodesic Design

1. Geodesic dome offers the strongest form of architecture. Because, geodesic forms follow a spherical surface without any curvature, as a unique shell. The example of the strength of the shell of an egg confirms the strength of a spherically based structure.

2. A geodesic form creates the largest volume of space covered by the least area of surface, thereby least amount of material is consumed. Hence, it is the most efficient use of material to cover a given volume of space. Thus it forms an efficient and economical shelter.

3. The largest unobstructed spans can be created using geodesic geometry.

4. Geodesic structures provide the most efficient form for the purposes of heating. Hence, it is ideal for living purposes in the cold countries. Similarly, as dome interior cooling may also be done with more efficiency, geodesic domes may also be claimed as less energy consuming shelters in tropical weather regions of the globe.

5. Spheres, particularly geodesic domes, are aesthetically pleasing form of architecture.

Ferrocement Construction Technology

Ferrocement is a highly versatile form of reinforced cement concrete(RCC) built of cement mortar plastered onto wire mesh reinforcement. Rather, ferrocement can also be simply termed as, 'mesh reinforced cement mortar section'. Unlike RCC, in ferrocement the mesh reinforcement replaces the steel rods and cement mortar replaces the concrete made of course aggregate. When compared to RCC, the ferrocement construction dose not call for any shuttering arrangements. Nor, it requires any high technology machines such as, concrete mixtures, concrete pumps, vibrating systems, etc.. This type of ferrocement construction possess unique qualities of strength and serviceability.

The major advantages of ferrocement construction are:

- Structures can be thin and of light weight, when compared to RCC
- They can be easily pre-cast, without the necessity of shuttering
- They are amenable to repairs in case of local damage
- Considerable saving in formwork particularly for complex shapes
- Overall savings in cost of the structure

The ferrocement construction technique is simple and the workmen can be easily trained for construction of ferrocement structures. Many academic institutions and research organisations of various countries have been doing pioneering research on ferrocement, in many parts of the world. A number of products have been developed using ferrocement, which can be economically used for housing projects. With this back-ground of development and to take advantage of economical / structural / construction features, the ferrocement technique of construction is recommended for the proposed geodesic dome.

Construction Sequence of Ferrocement Geodesic Dome:

The name FeGeDS is derived from the first (few) letters of its title words known as "Ferrocement Geodesic Dome Shelter". The combination of geodesic dome and ferrocement construction is innovative application for affordable rural housing, which exploits the unique advantages of both dome shape and ferrocement material. Hence, this innovation has also got additional built-in disaster resistant features. Its construction system is envisaged to be not only very simple and easy, but also practically adoptable and feasible to execute in rural conditions, where both the resources and talents available may be practically limited.

The ferrocement section of the dome is of 3cm. thickness. This section is made of rich mortar - 1:3 mix of cement and sieved fine sand, plastered on to the cage of reinforcement consisting of two layers of 26-gauge(g) – 13mm X 13mm chicken wire mesh tied on either side to a central layer of 10g X 10g – 15cm X 15cm welded wire mesh.

The geodesic dome of frequency two, consists of total 40-triangles. Leaving one equilateral triangle to serve as entry door, initially the welded wire mesh is to be cut to total number of 39-triangles. This set of-39 triangles consists of 30 isosceles triangles of ABB and nine equilateral triangles of AAA. The length of side A is 1.85m. and side B is 1.64m.. For all these welded mesh triangles wrap two layers of the above said chicken wire mesh on both sides of its surface. Now to precast the section of 3-cm. mortar thickness and to keep this mesh skeleton in the mid of the section thickness, first, cast a layer of about 2-cm. thick cement mortar on a plain floor with waste oil applied on the surface of floor. Now set the mesh reinforcement evenly on this mortar, with a little press to maintain it in the centre of total thickness. Further, apply remaining section of 1-cm thick mortar and finish the surface. While precasting each of these triangles, there should be all around 10cm. wide outer peripheral border left without cement mortar casting to leave out the reinforcement for assembling of geodesic dome with cast-in-situ jointing.

As a start of the super-structure construction, these partially precast triangles are to be assembled in the first layer on the ground above the plinth made of simple foundation system. On all the sides of each triangle, where it joins with the other adjacent triangle, tie a over lap of reinforcement (weld mesh plus two layers of wire mesh) with the width of 10cm + 10cm centrally bent to the angle of joint between two adjacent triangle faces of geodesic dome. This over lapped joint is to be cast-in-situ with the uniform section of 30mm. thick cement mortar, keeping reinforcement at the middle of section. After finishing first layer construction, the second layer of triangles is to be erected on its top, along with the overlap reinforcement joint.

Figure 3. Prototype Ferrocement Geodesic Dome Shelter (FeGeDS)

To hold these second layer of partially precast triangles in position, temporary supports or a sort of simple make-shift scaffolding system is to be arranged to take-up the in-situ casting of joints at this level. After completing the second layer construction, the third and final layer forms a pentagon of roof. With the cast-in-situ jointing method, adopted for the previous two layers, this third / roof layer is also to be built. While precasting the geodesic triangular faces of the second layer, a small triangular frame of ventilator provision is to be set in all of the equilateral triangles. This provision will offer suitable ventilation and day lighting for the house. Of-course, the provision of only one equilateral triangle open space for adding the door for the home will be less than required. But, it needs to be added on, with additional bottom space taken by about 50-cm. from plinth height of the house.

Economical Advantages of Ferrocement Geodesic Dome Shelter (FeGeDS) :

1. For the given plinth area of construction, this technology consumes minimum amounts of essential and energy consuming construction materials such as cement and steel, when compared to the other conventional construction systems.

2. This technology conserves natural construction materials, such as the clay soil by minimising utilisation of bricks, and stone is conserved by minimising the usage of concrete aggregates.

3. The construction can be very fast with this technology, as it can be finished with in a week.

4. As its construction is simple and fast, the labour costs are relatively lesser for this technology. Hence, it economises on labour costs too.

5. This technology requires no special machinery or equipment for construction. Nor it requires any special shuttering / centering system. Unless it is to be produced in mass by mechanization / automisation process, this technology dose not call for any additional investments.

6. As the super structure is comparatively very light and only weighs by a fraction of the weight of conventional construction, it requires simple and nominal foundation system only. Thus, FeGeDS economises foundation cost also.

Architectural and Structural Advantages

1. FeGeDS is a three dimensional (3-D) structural system, and derives its structural stability and strength due to its complex 3-D shape. Further, the ferrocement material properties make it not only stronger, but also highly durable, with nominal maintenance.

2. The dome's broadest structural base on the plinth level, and its in-situ construction connectivity adds to its structural stability, with monolithic structural effect.

3. It is fire proof house, because FeGeDS is built of non-combustible ferrocement product.

4. It is cyclone resistant, because its shape is aero-dynamic, and also because it is monolithic.

5. It is earthquake resistant, basically for two reasons. One is that, it is light-weight and attracts lesser earthquake inertial forces and the net seismic force acting on FeGeDS will be much less when compared to conventional house. Another reason is that, the ferrocement is more ductile material, when compared to conventional construction materials such as RCC or

masonry. Further, its broadest base gives it additional structural stability against seismic vibrations, during earthquakes.

6. Another unique structural advantage of FeGeDS is that, it is neither light enough to be blown away by any cyclonic winds, nor it is heavy enough to be got crushed by the devastating vibrations of killer earthquakes. Hence, FeGeDS is to be rationally and scientifically claimed as effectively disaster resistant housing system.

7. FeGeDS offer the advantages of green building technology, as it consumes relatively very less cement and steel, and it also conserves natural materials such as soils and stone. Its carbon foot-print will be relatively much less, when compared to that of conventional housing.

8. Either the interior heating, or air-conditioning process can be more efficient in FeGeDS, as its construction surface area is minimum. Hence, it offers less energy consuming housing. Thus, FeGeDS accumulates more and more carbon credits in its life-span.

9. The creeper plants grown-up on the surface of FeGeDS offer thermal comfort in the interiors of FeGeDS, located in the tropical climates. Hence, it promotes plantation and thereby it encourages environmental interests.

10. FeGeDS also serves as a highly economical roof-top spare house / pent house, over the top most floor of multi-storey buildings in urban environments.

Comparative Studies and Quantitative Advantages of FeGeDS

To compare and prove the quantitative advantages of FeGeDS, with reference to conventional construction system, a study of detailed designs and estimates of building materials has been undertaken. Conventionally in most of the Asian countries, low-rise buildings with load bearing masonry walls and flat RCC roof slab are very popular. Hence for the present study, this type of conventional rectangular box type house with 28 sq.m. plinth area (that is equivalent to the plinth area of 3-m radius geodesic dome) is considered, whose external dimensions are fixed as the length = 7.0m and width = 4.0m. For comparing with the disaster resistant FeGeDS, this conventional building is also hypothetically designed with disaster resistant features such as floor, lintel and roof level RCC bands, and vertical RCC elements in all the corners and on the either side of all door and window openings. This comparison building is assumed to be situated in the most vulnerable earthquake zone with high importance factor and bad soil conditions. International Association of Earthquake Engineering (IAEE) guidelines of earthquake resistant specifications are considered for adoption in this conventional building design. Other major specifications of this conventional building design are:

- Shallow strip footings with the plain concrete bed and two step brick masonry foundation.
- 0.6m. height basement above the ground level is considered for this building.
- All the four main walls are built of 20cm nominal thickness, with the modular bricks (of size 19cm X 9cm X 9cm). Few windows, a door and a ventilator are provided in the walls.
- Its masonry is designed with relatively rich cement mortar of 1:4, based on the IAEE earthquake resistant guidelines. Also for plastering, same 1:4 cement mortar is considered.
- The roofing is built with RCC slab of 12cm. thickness and designed reinforcement.

The comparison is basically done for civil and structural works of FeGeDS, with that of conventional building. Hence, in this study the plumbing and electrical materials are not considered for the comparative estimates. Further, the internal partitions are also not considered, as they are assumed to be similar in both the cases of FeGeDS and conventional buildings. Only external and periphery structural covering of construction surface alone is considered for the comparison of both the cases. The results of this comparative studies are expressed in the following table, which will explain the quantitative advantages of FeGeDS :

Details / Description	***Conventional Building***	***FeGeDS Structure***	***Economic Advantages and Remarks***
Cement Consumption	5520 kgs.	1568 kgs.	- 71.5% saving of cement - Green building advantage
Steel Consumption	277 kgs	92 kgs	- 66.8% saving of steel - Green building advantage
Bricks Consumption	11250 nos.	2600 nos.	- 76.9% saving of bricks - Conservation of natural soils
Aggregate Consumption	8.83 cu.m.	2.1 cu.m.	- 76.2% saving of aggregates - Conservation of natural stone
Sand Consumption	12.76 cu.m.	4.04 cu.m.	- 68.3% saving of sand - Conservation of natural sand
Total Dead Weight	99.5 tons	25.38 tons	- 74.5% lighter than conventional building - Seismic vulnerability reduced by 74.5%
Mason days	36 days	17.5 days	- 51.5% saving of labour component

The above table makes it clear that FeGeDS is highly economical, to the extent of more than 60% to 70%, when compared to the conventional building cost. There is a rational justification, which may support this very high figure of economy. This justification calls for quantitative comparison of construction surface (total roof and walls) area required for FeGeDS, verses that of conventional building, for the same plinth area coverage in both the cases. FeGeDS needs only 52.41sq.m. area of walls cum roof of only 30mm thick section of cement mortar, as construction surface, for covering the given plinth area of 28sq.m. Whereas, for covering the same plinth area, the construction surface requirement of conventional building needs 66sq.m. of walls of 200mm thick masonry with both sides plastering of minimum 12mm thickness on each face, plus 28sq.m. RCC roof slab of 120mm thickness with reinforcement rods and weather proofing course on top. This construction surface comparision of 52.41sq.m. (with relatively very thin section of only 30mm thickness) for FeGeDS, verses that of 94sq.m.(66sq.m. masonry + 28sq.m. RCC slab) for conventional building obviously explain the high economic characteristic of FeGeDS.

Conclusions

FeGeDS technology promotion offers highly feasible economical housing, along with added advantages of disaster resistant features. FeGeDS construction is very easily adoptable in any corner of the world, due to its technical simplicity and for the sake of following advantages:

1. FeGeDS is quite economical housing technology.
2. It is fire-proof, cyclone resistant and earthquake resistant technology.
3. Its construction is relatively very fast.
4. Its simple construction technology is easily adoptable in rural areas.
5. As it conserves lot of natural construction materials and consumes relatively very less cement and steel, it can also be considered as an effective green building technology.

Hence, the FeGeDS is not only affordable and disaster resistant, but also a green building technology. A series of FeGeDS promotion programmes put-up in the form of technical seminars, construction demonstrations, building of model FeGeDS villages, special building bey-laws, etc. will popularize this greenery promotion housing in a big-way. This technology can be easily perfected by training the local masons in any country, to offer safe shelter and green buildings across the world. Hence, the housing ministries of all the nations are invited to exploit this simple innovative FeGeDS housing, for promoting the environmental interests and towards their national disaster mitigation efforts. FeGeDS being effectively disaster resistant, the governments should also utilize this fast construction technology, especially for rehabilitation and reconstruction programmes, immediately after major natural hazards / calamities / terrorist attacks / wars.

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