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Modular Design: a sustainable solution to seasonal flooded areas

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***Abstract:*-- Problem with ever-increasing population has been for an affordable dwelling solution. The situation is even worse, if the areas are seasonally flooded. One such example is Munroe Island, Kerala. Here, due to heavy loads, conventional Reinforce Cement Concrete (RCC) structures are found to undergo settlement in short span of time. Due to poor bear strength of the soil, added with seasonal floods, the people in these areas are abandoning their lands and migrating. However, this is not possible for everyone, and they find it hard to leave their native land. For the economically weaker sections, it is not a feasible option to buy another land somewhere and migrate. This is supposed to benefit the common, economically weaker section in these area, enabling them to reside in their native land.**

Index Terms:- Coastal areas, modular construction, sustainable, seasonal floods.

I. INTRODUCTION

Provision of affordable housing to the burgeoning population has been a challenge in most countries worldwide. The problem becomes severe in areas ravaged by frequent and recurring floods which wipe out many houses and cause irreparable damage to the remaining structures. In such a scenario, rehabilitation of the displaced people is to be addressed in the shortest possible time and building solutions devised to withstand future floods. Modular building construction is the most effective and efficient way of achieving this and a modular building suitable for flood-prone areas is to be developed.

Worldwide, modular housing has been a solution to rising population for some decades now. In modular housing, entire structure or parts are prefabricated as repeating modules, either in-site or in factories. These can be joined using inter-module connection, also called inter-connections, from end-to-end, side-to-side or stacked, allowing a variety of configurations and architecture. Though modular construction has received widespread acceptance in other countries, its implementation in India is limited.

Although introduced as a mass housing solution, modular building construction has a lot of advantages. These address the problems of conventional housing techniques. As mentioned, the main emphasis of modular construction is on easy maintenance and lower investments. Lower time period for construction is also an added bonus.

II. MODULAR CONSTRUCTION

An increasing number of building projects across several markets are using modular construction, the process by which components of a building are prefabricated off-site in a controlled setting and then shipped to the project site and assembled. This approach allows projects to capture the efficiencies gained by integrating the processes and technologies of design, manufacturing, and construction without having to compromise on aesthetic intent.When implemented effectively this approach has been shown to result in a higher-quality building, delivered in a shorter time frame, with more predictable costs, and fewer environmental impacts—for example, through reduced material use and waste. While a range of factors are driving increased use of modular construction, a number of barriers are preventing its wider adoption. Although the planning and design process involved in modular construction is in several ways similar to that of traditional on-site construction, there are some significant differences and a number of considerations that project teams unfamiliar with the modular approach must understand before committing to it.

III. MODULAR MATERIALS

3.1 Glass Fiber Reinforced Gypsum (GFRG) panels
GFRG walls are hollow machined panels made of modified gypsum plaster and reinforced with cut glass fiber (Fig. 3.1). During the manufacturing process, glass fibers of about 300–350 mm in length are randomly distributed inside the panel skins and in the ribs. The fiber volume in the panel is about 0.8 kg per square meter of wall surface area. In building construction, standard large GFRG panels are tailor cut in the

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factory into building components that may have window and door openings. These components are then transported to the construction site and erected in a similar way to the construction of precast concrete panels. GFRG building assemblies have a smaller embodied energy (EE) coefficient and CO2 gas emission (from the manufacturing of panels to the completion of building construction) than any other traditional building construction materials, such as bricks, reinforced concrete and precast concrete panels. GFRG paneling is thus considered to be a green product that helps to save energy and protect the environment. GFRG buildings are a new type of construction to which conventional structural theories and design codes are not applicable. GFRG panels as superstructure will have wall panel of thickness 124 mm.The height of each panel will be 3m.The panels will have reinforcement bars passing through the interior hollow spaces which will later be filled with M25 concrete.

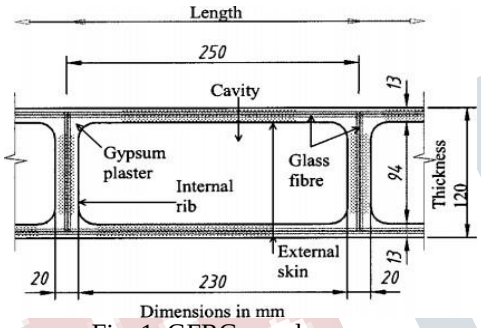

Fig. 1 GFRG panel

3.2 Modular Steel

Off-site prefabrication of volumetric building modules, or modular building, is increasingly popular due to the advantages including improved quality and reduced resource wastage. Modular steel buildings (MSBs) are a type of module which has a structure consisting of a primary steel frame. Connection between the structural elements of MSBs is key to the overall structural performance. MSBs, in comparison with in-situ built structures, incorporate many more connections due to the need to assemble individual elements to form modules, and also modules to form the overall building. In Modular steel, the inter-connections, which form the interface between modules, may provide vertical connectivity (VC), or horizontal connectivity (HC). Alternatively, the inter-connection may provide both vertical and horizontal connectivity (VH).
Hollow steel sections are commonly used for the module columns due to their efficiency in compression and torsion. Bolted connections are used for inter-connections where they are preferred due to the advantages of reduced site work and demount ability. Disadvantages of the bolted connection include the requirements for access, tolerance by slotted holes, slip, and bolt tensioning. Considering construction requirements, the ideal inter-connection should be compact, easy to install on site, address tolerance requirements, and be demountable. In some cases, it is also desirable that connections are reusable which may preclude the use of composite concrete- steel connections, for example. Research into the structural behavior of the existing connection systems is limited. In practice, connection analysis and design typically requires a combination of detailed numerical and experimental investigations.

3.3 Expanded Poly Styrene (EPS)

Expanded Poly Styrene (EPS) is a by-product of the petroleum industry and derived by the expansion process of styrene hydrocarbon polymer (polystyrene) using pentane gas. An EPS bead consists of 2% raw material and 98% of air, which chemically composed of two elements: carbon and hydrogen. Generally, EPS sheets have been used in a variety of applications including impact mitigation packaging, protective helmet, expansion joints, construction filling material, false ceiling, and food packaging material. Diverse structural and geotechnical applications of EPS are also reported namely structural insulated panels, composite structural insulated panels, insulated concrete sandwich panels, lightweight concrete sandwich panels, thermal insulators, soil reinforcement, levee rehabilitation and construction, pavement construction and ICFs.

Research studies about EPS mechanical properties have focused particularly on the density of EPS. In this study, the mechanical properties of EPS were examined with varying parameters of density and thickness.

IV. CASE STUDY: MUNROE ISLAND, KERALA

Munroe Thuruthu, a string of eight islets at the confluence of the Ashtamudi Lake and the Kallada river, Kollam is a typical example for seasonal river floods. The island currently has only 2200 families residing there. The main reason for the evacuation of the rest was due to sinking of houses in a matter of 5-10 years, even if they tried to repair it.

Munroe Island is a delta region and as the people here say, this problem of settlement increased after the construction of Thenmala dam in 1986. The land is under the stress created by the destruction of mangroves, sand mining, delta destabilization caused by the Kallada river due to the construction of Thenmala dam. Another important reason is

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the continuous vibration caused by the passing of train. It is an island created by land reclamation from the delta formed by the Ashtamudi Lake and Kallada River and located at its confluence, hence it is vulnerable to flooding.The settlement of buildings by more than 50 cm is reported and has become evident during field inspection. In certain areas, this is apparently due to construction of structures on the clay layer without proper piling in an area where the soil structure consists of top layer of 2 m thick clay. The difference in elevation of these areas compared to the average river water level/backwater level is less than 30cm in most cases. The clay in the area is getting saturated during the semi- diurnal tides as well as due to the capillary rise. It is noted that the construction with heavy concrete structures are settling faster compared to light weight structures. Earlier the houses here were Kuchha houses, means the load acting too was low. And over time RCC structures were built, which increased the load on the soil and eventually resulted in settling. The flooding due to high tides cause salt water intrusion in to the islands that result in sticking of salt residues to the walls and continuous accumulations leads to crevices in house walls. Panchayat officials reported that shrinking tiny islands ranging from one acre to over one hectare, were inhabited by humans. Due to the recent flood (August, 2018) water level increased and some families had to leave their home.

In the areas of Munroe which were not affected by seasonal floods, the type of foundation, called grid foundation was found. From soil investigation by standard penetration test, the water table was found to be very close to the ground at 0.3m, 0.9m and 1.2m at different bore holes. These indicate the poor quality of soil and the presence of water table which affects the foundation. The bearing strength of the soil was found to be poor and the recommendation for coconut pile driven foundation was made.

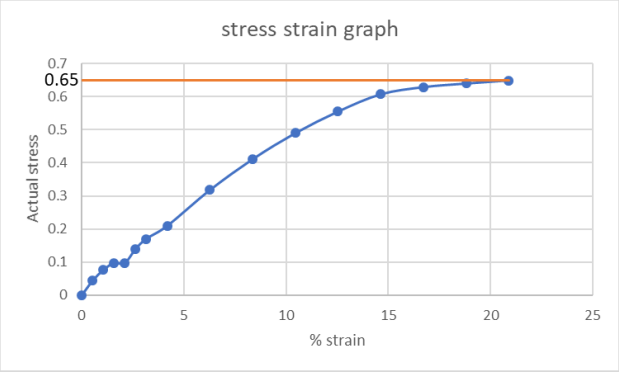

Fig.2 Stress-strain graph from unconfined compression test on Munroe flooded region

Based on the tests done on Munroe soil:

- Effective size = 0.102 mm
- Uniformity coefficient = 2.55
- Coefficient of curvature CC = 0.793
- Unconfined compressive strength of soil = 0.65 kg cm^{-1}
- Angle of internal friction = 0
- Shear strength of soil at failure = 0.305 kg/cm2
- The normal stress at failure = 0.325 kg/cm2
- Cohesion of soil (c) = 0.305

V. DESIGN FOR MODULAR HOUSE

5.1 Foundation

Munroe Island is well known for their frequent settlement of land. Construction in these areas are not similar to that of conventional methods, especially in case of foundations. Also major parts of Munroe Island have soil with low bearing strength; Because of this, the type of foundation seen here is deep foundations like coconut piles.But due to the settlement, and also their unique behavior of tides in the area, Munroe still faces frequent flooding. Along with heavy RCC superstructures and soil with low bearing capacity, even deep foundations do not assure stability of the structure.

5.1.1 Timber foundation

Timber Pile foundation is practiced in Munroe Island. The general purpose of timber piles is to improve the soil through compaction. Though this is basic part of foundation, it transfers the load of the structure into ground on top of which isolated footing is done from the ground level.Piles are basically long slender columnar members which transfer the loads of super structure to the ground through friction or end bearing. A foundation is considered as a pile when its length is more than three times it breadth. So in case of timber piles, timber is the used material. In Munroe Island, coconut is used for the construction of timber piles.

5.1.2 Isolated Footing

The isolated footing is one of the most popular and simplest types of foundation used worldwide. Isolated footings are most commonly used footings for reinforced cement concrete column because it is simple and most economical. Isolated footings are independent footings which are provided for each column. It is seen in the non-flooded regions of Munroe Island. Isolated footing is generally used when columns are not closely placed, loads on footings are less and safe bearing capacity of soil is high. They generally consist of a bottom slab and are of generally three types.

5.1.3 Load bearing wall foundation

This is a soil improvement technique using timber piles.Matured coconut timber piles of 25-30 cm diameter shall be driven dynamically into the ground for a depth of 6m

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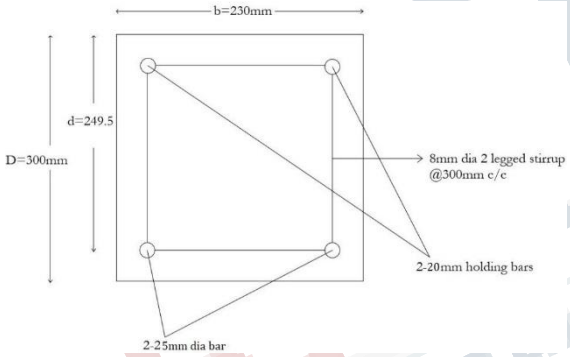
below the existing ground level. The piles shall be driven in a zig – zag pattern along the centerline of the walls and also for an additional width of 1.5m on either side of the center line (3m in total). A spacing of 80 cm center to center is recommended. The tip of the timber piles shall be trimmed so that the pile always remains below the lowest level of ground water table. A minimum depth of 1.2m shall be maintained below the existing ground level. After this, provide a P.C.C of suitable thickness with respect to the loads of the structure as well as the tips of timber pile must be embedded in the P.C.C. Then construct an inverted Tee-shaped Reinforced Cement Concrete(RCC) beam resting on the PCC layer. Width of beam is based on the load values. The beam shall be designed as a grade beam considering load transfer with soil also. In addition to the main columns that may form the part of the super structure, short RCC columns originating from the Tee beam shall also be used to connect to the plinth beam. Space between the tee beam and plinth beam shall be filled with solid concrete block masonry. Brick masonry can be constructed over the plinth beam.

5.1.4 Grid foundation

The grid foundation is made up of interconnected strip



foundation. This type of shallow foundation is appropriate when the columns extend in two directions in an approximately square raster and the foundation beams can be made in two orthogonal directions forming a grid foundation. This ensures a large contact surface and a good connection of the structure in both directions.

5.2 Superstructure

From the modular materials, modular steel cannot be used due to substantial load. Since the soil in Munroe has poor bearing capacity, it has to avoided. Since, GFRG is a more sustainable solution and has other desirable properties of providing cooler interiors and lesser maintenance cost, it is chosen over EPS as modular material for flood- prone areas. Therefore, the most suitable modular material for seasonal-flooded areas is GFRG panels. Also, GFRG panels are easily available throughout India, especially in Kerala. So their maintenance and installation is easier.

Roof slab for the house is to be of the same GFRG material. For GFRG roof panels there are some design criteria. In the design aspect for roof slab, one-third part of the GFRG panel is to be filled with RCC. These will have micro-beams and a screeding of 5 mm thick concrete with gauge mesh

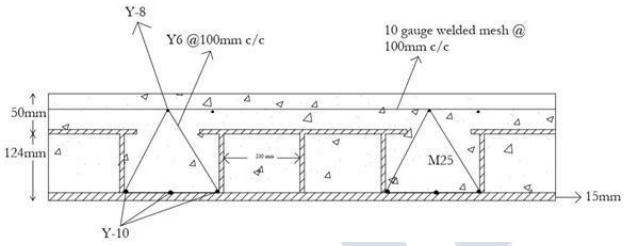


Fig.3 Cross-section of GFRG roof panel slab

.For the design of the slab, reinforced concrete micro beams are provided at every 750 mm in the shorter direction together with 50 mm screed concrete on top of the GFRG panel.Ribs are placed along shorter span and slab is assumed as simply supported. Also it is assumed that the panel essentially acts as one-way slab in the shorter direction.Design is done using codal provisions of IS 456 – 2000

Fig.4 Cross-section of plinth beam

The design of modular house in these areas should be done based on the High Flood Level(HFL) of the region. By identifying HFl, we cn provide sufficient elevation to the plinth area.In the design sample done, a 400 sq.ft. house was designed and the cost analysis was done. The estimated cost for the construction was found to be Rs. 7,70,092, which again proves the feasibility of such a modular design on a massive scale. This also proves the affordability of modular GFRG houses to avoid rehabilitation from one's homeland.

CONCLUSION

Modular design can be a sustainable solution to seasonally flooded areas. With application of modular construction, the rehabilitation of people from their homeland can be addressed to a very good extent. Due to their low maintenance cost and, fast and easy construction, they provide a choice for people to remain in their homeland. Although, the case study and design was based on Munroe Island, it can be applied on a large scale to almost any coastal areas depending on the soil. Only criterion here is to determine the type of foundation, that mainly depends on the type soil. So with enough support, this sustainable method may be adopted world-wide as a sustainable solution in seasonal flooded areas.

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