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# Prefabricated Foundation System for Single Storey Houses

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Prefabrication technologies have been used in the building industry since the 19th century. The technologies vary from the innovative materials to novel techniques of construction and the prefabricated systems range from individual components to the entire structure. The major prefabrication technologies prevalent today include sandwich panel walling elements, hollow core slabs, light gauge steel frames as well as modular housing. Even though prefabrication technologies have been widely used in slabs, beams and columns, prefab foundation system is still a relatively new concept. The construction of foundation is the most important part of building process and hence a sound prefabricated foundation system is the need of the hour. In this paper, an attempt has been made for construction of a portable prefabricated reinforced concrete foundation which can be used in buildings up to three storeys.

**Keywords:** Prefabrication, Foundation, Reinforced concrete.

## Introduction

Prefabrication technologies have gone through a number of changes since its inception. A lot of advancements have been made in the prefabricated technologies corresponding to the superstructure. However, studies regarding prefabricated foundations are scarce. As it is widely known, prefabrication technologies have a number of advantages including efficient resource utilization and faster construction; therefore, a prefabricated foundation system will be instrumental in improving the performance of the building industry. The current research addresses this gap and proposes a prefabricated portable foundation system, designed for a one storey building. The advantage of this system is its flexibility, as it can be fabricated partially or wholly on-site as required depending upon the machinery available for erection. The paper consists of a comprehensive literature study on prefab foundation systems, followed by the description of the proposed foundation system and the methodology followed. The scope of future studies has also been outlined in this paper.

## Review of Prevalent Prefabricated Foundation Technologies

A comprehensive literature research has been carried out to study the prevalent prefab foundation systems across the world. Studies published indicate that even though prefab techniques have been applied to the superstructure (modular framing system, panel system, tunnel and box-form construction and use of different lightweight alternative materials to traditional construction methods etc. (Girmscheid 2010), the substructure is still built according to conventional methods. Only a few innovations have been made in this area. One such technology is a foundation system using a number of concrete panels patented in 2003 (Davis 2008). The panels of rectangular shape are positioned end to end forming a wall-like structure

around the entire perimeter of a prefabricated structure. The lower surfaces of the panels are supported by precast posts and the upper edges are locked together to avoid any displacement from their position; thereby providing a stable platform for the superstructure. The joints between the panels are sealed with weather guard material. A modified prefab panel foundation technology employs lightweight element for construction of strip foundations in Denmark (Rasmussen 2007). The elements are made of Expanded Polystyrene (EPS) boards glued together to serve as strip foundation for buildings up to two storeys. The EPS element is designed such that the strip foundation represents the base of a traditional double-brick wall together with the ground deck, a traditional wood-stud wall, or combinations of lightweight concrete, brick and wood-stud walls with insulation. Instead of an excavation depth of about 900mm as needed for conventional foundation, an excavation depth of 400mm is sufficient for this element (Figures 1a, 1b, 1c). The process of its installation is described as follows:

1. Material up to a depth of at least 350mm underneath the top soil surface is dug up.
2. The excavated area is covered with a capillary breaking layer of gravel which is stamped in order to form the stable base for a building.
3. The strip foundation is mounted, fixed together with comb-shaped pieces of plastic and outer support of stamped gravel. 300mm of EPS in two layers is mounted inside the strip foundation working as insulation underneath the concrete floor slab.
4. Before casting the concrete, iron is mounted, as a net, preventing shrinkage crack development, inside the strip foundation and as wires along the moat formed by the two vertical boards of EPS in the prefabricated elements.
5. Wires of stainless steel rods, 5 mm in diameter are put through the inner vertical boards of the prefabricated elements of EPS every 600mm, in order to attach the concrete in the moat to the concrete floor slab.
6. Concrete is cast and levelled and after a few hours, when the concrete becomes stable in shape, the outer vertical boards of the prefabricated elements of EPS are removed exposing the outer surface of the concrete moat as the outer plinth.
7. The removed outer vertical boards of EPS are used as the outer insulation on the ground around the plinth.



*Figure 1a):* Prefabricated elements, made of EPS boards glued together and forming an element, are mounted as the strip foundation, fixed together with comb-shaped pieces of plastic.



*Figure 1b):* 300 mm EPS, mounted as two layers on top of the base of stamped gravel bordered by the strip foundation, working as the insulation layer underneath the concrete slab.



*Figure 1c):* Iron is mounted, as a net inside the strip foundation and as wires along the moat formed by the two vertical boards of EPS in the prefabricated elements before concrete is cast and levelled.

Similar types of prefabricated foundations using panels (concrete or EPS (This old House 2013)) with concrete studs have been in vogue under various patented systems of different companies catering prefab technologies all over the world. Precast pile foundations and precast rectangular foundation blocks have also been used as foundation systems. The process constitutes of driving the precast pile foundations in the ground after which reinforcing steel bars are inserted into the piles by drilling holes. The outstanding portion of the reinforcing bars is then fitted either in concrete pedestals or in beams (simple and post-tensioned beams, as the case may require) with in situ grouting by pouring concrete in the through holes of these elements; thereby connecting the elements in an integrated foundation system (Precast concrete piles. (n.d). retrieved 2016). The precast foundation blocks can also be used without piles in some cases, depending on the soil conditions. The tie beams are slotted in the wedges made in the foundation blocks and in situ grouting is carried out for connecting the elements in a monolithic system (Figure 2a-2f).



*Figure 2a):* Precast Foundation block.



*Figure 2b):* Foundation block placed in the trench.



*Figure 2c):* Precast foundation with Tie beam slotted in place.



*Figure 2d):* Soil filled till top of the foundation pier.



*Figure 2e):* Plinth beam inserted in the reinforcement slots over the foundation pier.



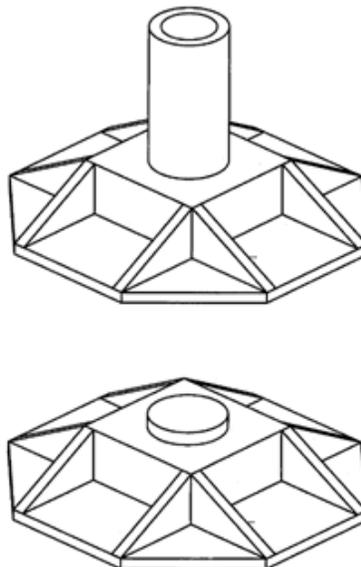
*Figure 2f):* Insitu grouting in the slots to make the system monolithic.

Reinforced concrete being heavy, the precast rectangular pedestal units are modified to manage the weight for ease of installing and handling. Hence, partial prefab foundations are used during installation and the remaining portion is cast in situ while connecting it with other elements to form a monolithic structure. This type of prefab systems have been used via a number of patented shapes like ring-shaped or rectangular box framed with reinforced hollow panels, where in situ concreting is done (See Figure 3).

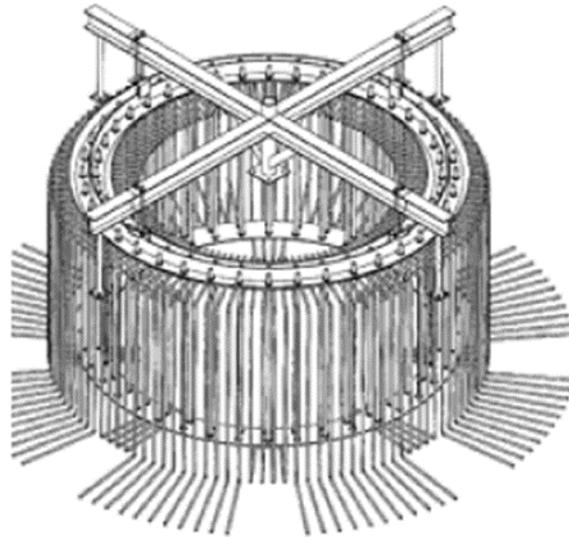


*Figure 3:* RCC rectangular box framed Express Foundations: courtesy Contech Engineered Solutions (Solutions, C. E. (n.d.). EXPRESS Foundations, retrieved 2016)

A partial prefab modular foundation system has been developed for specialized applications to wind turbines, patented in 2008 (Phuly 2007). It consists of a central pedestal, a bottom support slab, and a number of prefabricated radial reinforcing ribs. The pedestal and support slab are poured in situ at site. When the concrete cures, the support slab is united to the prefabricated ribs and the ribs are also united to the pedestal. The result is a continuous monolithic foundation wherein loads are carried across the structure vertically and laterally through the continuous structure by doweled and spliced reinforcing steel bars which are integrally cast into the pedestal, ribs and support slab (See Figures 4 & 5). The slab thus behaves structurally as a continuous slab reducing deflections, improving fatigue conditions and increasing the stiffness of the foundation as well as allowing for the benefits of an economical design.

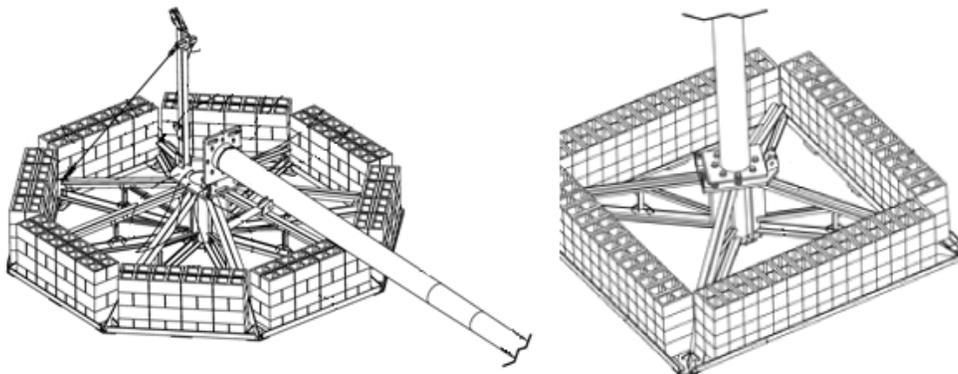


*Figure 4:* A perspective view of pedestal and ribs with (for offshore applications) and without pier, respectively.



*Figure 5:* A perspective view of the foundation.

A modular foundation for monopole tower has also been developed and patented in 2012 (Clifton 2012). It is utilized to support a monopole, a central assembly with a number of legs. A proximal end of each removable leg is attached to the central hub. A mounting bracket is attached to a distal end of each leg and connecting members are secured to adjacent mounting brackets to form a perimeter around the hub. The connecting members are configured to receive ballast or other stabilizing mechanisms to stabilize the foundation to allow the monopole and the attached equipment to be raised and lowered. This invention also includes a lifting mechanism that attaches to both the modular portable foundation and the monopole to raise and lower the monopole and the attached equipment (See Figures 6a & b).



*Figure 6a & b):* Perspective views of portable and modular monopole foundations of different shapes.

Therefore, some of the prevalent prefabricated foundation presented indicates that the main principle is the reduction of manual labor, ease of handling and speedy construction. Similarly, areas where heavy cranes are not possible, the weight of the prefab elements is also to be taken care of. These underlying principles are followed in the proposed foundation system and elaborated in the following section.

## Prefabricated RCC Hollow Spider Foundation

The proposed system of foundation consists of a reinforced concrete pedestal, cast in 4-legged spider projections from the central hollow column. The remaining part of the rectangular footing is a steel cage, over which in-situ concreting may be done. The pedestal is attached to a monolithic hollow column, interlaced with reinforcing bars which are protruded above (Figures 7a and 7b). In order to connect it to the precast column above, in situ concreting is done to fill the hollow portion, and simultaneously, the extended bars are embedded into the continuing column, thus making it a monolithic/unified construction.

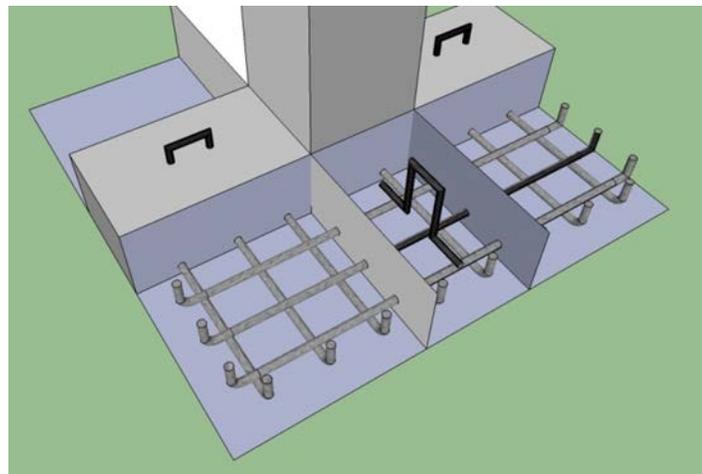
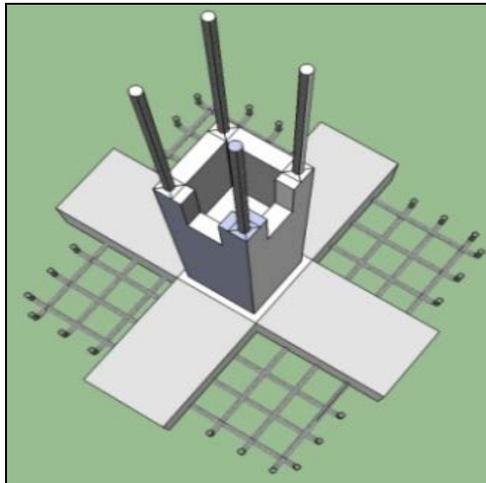


Figure 7a & b): Schematic views of the precast foundation system visualized in Google Sketchup.

### *Procedure Description*

Firstly, the proposed system is modelled analytically and the design is done according to the Indian Standard Code for reinforced concrete design. Consequently, mix design of M25 grade concrete was prepared and tested according to the provisions prescribed by Indian Standard Codes. In the third step, the mold of the spider foundation was fabricated using plywood and finally the foundation was ready to be cast. After the casting of the foundation as an isolated component, it was necessary to build the other parts of the system and hence, various alternatives were considered for the plinth beam, columns, walling and roofing systems. The best fit of the alternatives of each element has to be considered for the test bed. However, although the design and visualization of the elements has been done, the connection details and fabrication of the entire system is yet to be completed. This section presents the details of the methodology followed till date.

### *Analytical model and design*

A one-storeyed precast model room of size 3000 mm x 3600 mm (inner dimensions) has been considered at CSIR-CBRI, Roorkee. An analytical model of this room was prepared using SAP2000 software and the various forces obtained in the results of the analysis have been used

for designing the precast elements according to the provisions of the Indian Standard Code IS 456-2000.

### *Mix Design*

The precast foundation is cast in-situ using M25 concrete and reinforcement of 10mm diameter steel bars of grade Fe415 @ 150 mm c/c. The loading and the design are done according to the provisions of Indian Standard Code IS456-2000. The mix design details of the M25 grade concrete used for casting of the precast pedestal is shown in Table 1, the provisions of IS 456-2000 and IS 10262-2009.

Table 1

#### ***Mix Design Details***

W/C ratio	0.5
Maximum water content	208
Water content	178.88
Cement content	357.76
Volume of C.A.	0.6
Volume of F.A.	0.4
Volume of concrete	1
Volume of cement	0.114
Volume of water	0.18
Volume of admixture	0.0016
Volume of all in aggregate	0.71
Mass of cement	357.76
Mass of C.A.	1122.40
Mass of F.A.	735.56
Mass of admixture	1.7888
Slump in mm	85-90
Ratio	1:2.06:3.14
Reduction in water content by mixing super-plasticizer	14%
Super plasticizer	0.5
Maximum size of Aggregate	12.5

### *Tests for strength and workability*

Consequently, the sample (cube of size 150mm x 150mm x 150mm) is checked in accordance to the various tests as prescribed by Indian Codes viz. IS 516-1959 for the 7- day compressive strength test and IS 1199-1959 for the slump test for workability. From the results obtained, it has been seen that M25 grade concrete with ratio 1:2.06:3.14 is most suitable for casting the precast components of the prefab model room because it is the best fit considering the properties of strength and workability. The results are shown in Table 2.

Table 2

**Results of tests conducted for workability and compressive strength**

Grade	Mix	Slump (mm)	7 days Compressive Strength (N/mm <sup>2</sup> )	% of Admixture by weight of Cement	W/C ratio
M25	1:2.11:3.51	Nil	24.45	1.0	0.43
M25	1:2.13:3.53	Nil	26.43	0.3	0.43
M25	1:2.08:3.47	10-15	24.78	0.5	0.45
M25	1:2.06:3.14	85-90	16.55	0.5	0.5
M25	1:1.63:3.22	20-30	20.91	0.75	0.4

*Foundation details up to plinth level*

For casting of foundation up to the plinth level, a unique formwork has been prepared using plywood, battens, steel plate, hinges and nut bolts. The formwork is used for casting of the spider legged foundation as well as the hollow pedestal. The following figures show the schematic diagram and formwork preparations on site at Rural Park CBRI, Roorkee, respectively:

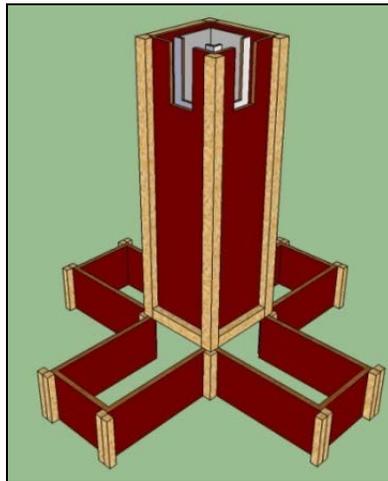


Figure 8: Schematic Diagram of the formwork.

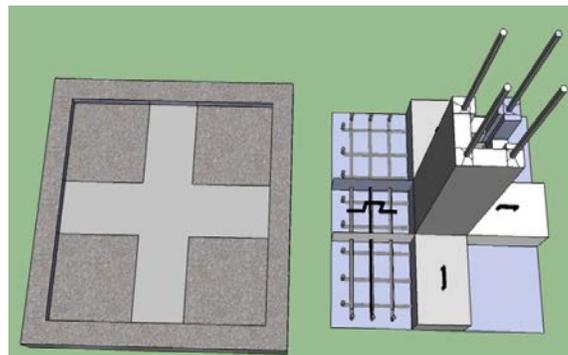


Figure 9: Formwork preparations on site at Rural Park CBRI, Roorkee.

The pedestal system consists of footing and a stem column portion which is to be used for the foundation system of the prefabricated model room. The footing portion consists of a cross base which have four handles on each wing for placing the pedestal in the trench safely and easily. The pedestal system has to be placed manually in the trench. The following figures show the visualized and final product respectively:



*Figure 10:* Isometric view of the Foundation system.



*Figure 11:* Schematic Diagram of the foundation system up to PL.

Since the pedestal system has to be placed in the trench manually, therefore the weight of the pedestal should be less. Hence a number of different alternatives had been considered in order to complete the handling with maximum ease. Apart from the one described above, another alternative was where the hollow pedestal portion had been used with fully cast footing. The footing portion of the pedestal casted fully with dimensions of 1250 mm x 1250 mm x 200 mm and the walls of the hollow stem column were of 75 mm thickness. As the weight of the pedestal in this case is very high, therefore further modifications are being done in the previous partially precast pedestal system for situations where the machines will not be available. Similarly, different alternatives of the precast hollow pedestal have also been considered.

### Precast Plinth Beam

The plinth beam is provided on the levelled ground and serves as the connecting point of substructure and superstructure. The ends of plinth beam are provided with anchorage bars which are to be inserted in the notch provided in the stem column pedestal. The hollow portion is to be filled with in-situ concrete of M20 grade. The precast members are made of M25 grade concrete as they have to bear the higher stresses. The connection details of the stem column to the plinth beam are given in Figure 12. However, this portion has not yet been cast on-site and the schematic visualization has been shown in Figure 13.

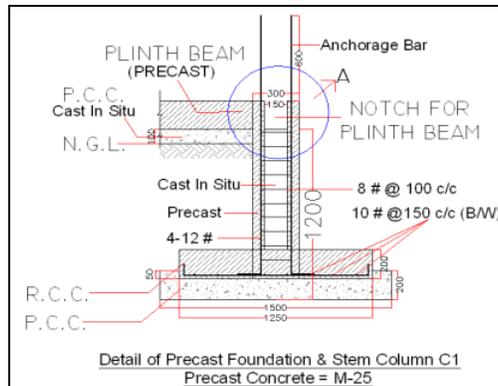


Figure 12: Joint details of the pedestal stem column and the plinth beam.

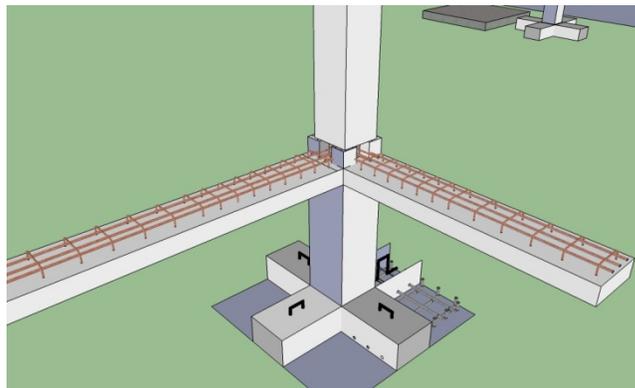


Figure 13: Schematic diagram of the foundation, column with the plinth beam.

### Precast Plinth Beam

The precast system from the plinth to the roof consists of columns, walls and roofing elements, which has not yet been cast but only visualized. The connection details are also to be worked out.

**Columns:** Columns are provided to support a frame structure by transferring the load from the slab to the foundation. The precast column, 250 mm x 250 mm dimension is to be adopted with different wall thickness of the hollow column. The system consists of the hollow column are made of cross section of 250 mm x 250 mm and 75 mm wall thickness. As the weight of the column in this case is on a higher side, further modifications need to be made in the column

formwork. Of all the alternatives considered, the weight of the column in this case is less than the other two alternatives, so this can be used for construction.

*Walls:* The walls are to be made by using light weight fly-ash blocks and hollow concrete blocks of dimensions 600 mm x 300 mm x 150 mm and 300 mm x 300 mm x 150 mm. The roofing unit will consist of precast RC planks and joist system. Dimensions of the precast RC planks are 300 mm wide, 60 mm thick and up to 2.4 m long. It is to be used for economical and faster construction of floors and roofs of single and multi-storeyed buildings. The floor / roof will be constructed with precast RC joists and precast RC planks. The components are to be produced on a casting platform at construction site. As soon as the walls reach the floor / roof level, the components will be erected, assembled and partly filled up with concrete to form the floor / roof. This scheme results in saving 20% in overall cost, 25% in cement and 10% in steel as compared to conventional R.C. slab floor / roof.

## Conclusion

In this paper, we have discussed the work done related to the prefabricated spider foundation system. However, the system is not yet complete and further studies are in progress. The future scope of work includes full scale casting of the Test Bed (Model Room) described above in CSIR-CBRI, Roorkee campus. This also includes the design of the different precast elements, preparation of formworks for different precast elements like plinth beam, columns, roof joist and working out the details of the connections between the elements. Also, full-scale testing of the entire system shall be carried out and validated with the analytical results for performance compliance satisfying Indian Standard Codes.

In addition to this, details of other non-structural elements/components in conjecture with the whole structure shall be worked out for the final fully prefabricated model room. It can also be envisaged that this study will prove to be useful to the countries in the Asia-Pacific regions having similar geo-climatic and socio-economic conditions.

## *Acknowledgement*

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