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EXPERIMENTAL INVESTIGATION OF HONEYCOMB CONSTRUCTIONAL ELEMENTS

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ABSTRACT

The aim of the present paper is to reviews a novel modular constructional element for the building and construction industries that was patented by Coventry University. Modular elements have been used in the past in the construction of structures in order to speed construction and cut on time and cost. The modular element, the subject of this study, comprises hexagonal elements made of steel or other appropriate material, assembled together to form a constructional assembly of honeycomb form secured by fixings that clamp together the sides of adjacent elements. Concrete, or other appropriate material, is disposed within the elements providing a composite type of action. Reinforcement is also present in the form of bars or tubes, providing extra strength to the assembled element. The novel type of modular construction has potential applications in the building, construction, substructure and highways sectors. It could be used as a permanent or temporary structure for roofs and walls. It may also be used for concrete pavements, tunneling, and retaining wall structures.

Keywords: modular, constructional, hexagonal, honeycomb, assembly, concrete

1. INTRODUCTION

Reducing construction time, and therefore cost, has always been a main concern for the construction industry and much has been invested in that regard*. Sustainability issues have added more pressure and urgency on the construction industry to develop sustainable type of structures where elements may always be reused when the structure reaches its end of life cycle. Examples of such projects include those concerned with ways of optimising construction techniques and procedures through the adoption of standardisation methods aimed at making more efficient and effective use of resources from the feasibility study to the execution stage ([1-3]). Another approach that has become increasingly used in the construction sector was that based on the production of what has become more commonly known as modular construction, thus permitting relatively cheap and fast to build structures

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([4] and [5]). A cost-effective structure (or building) means speed of executing all phases at the lowest possible price without compromising the safety of the structure to be built. The use of modular systems in large projects and, when produced in large quantities, was often found to provide the answer [4]. Obviously, the efficiency of any of these methods relies on an optimal use of resources taking into account any constraints associated with the execution of a particular construction project. The key to such methods is the use of what is more commonly known in the construction sector as “resource sharing” ([6-8]).

The current project is concerned with investigating of the behaviour of a new modular constructional element. Individual hexagonal elements or “cups” are assembled together to form different structural components such as, slabs, walls, columns or even pavements. As is explained in the following sections, the element has some advantages over traditional type of construction in terms of speed and cost reduction. In this research, the hexagons are made of steel and filled with concrete. Additionally, reinforcement is also present to provide the structural integrity of the assemblage but also to give the assembled structure added strength.

2. ELEMENT ASSEMBLY USING THE HEXAGONAL MODULES

The constructional individual element comprises a hexagonal laminar base, each side of the hexagonal base being provided with integral upstanding walls with gaps in between as seen in Figure 1 [9].

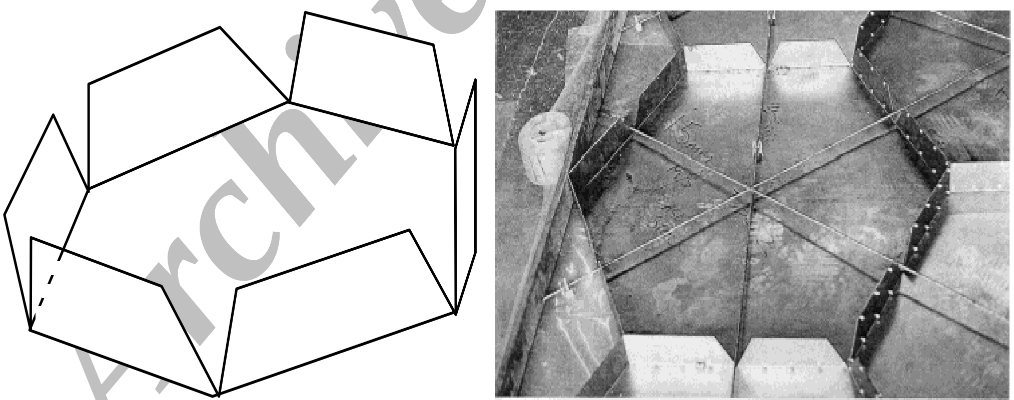

Figure 1. Individual hexagonal module (or “cup”)

The presence of the gaps will allow fluid concrete (or any other liquid material) to flow from one element to another when individual modules (“cups”) are assembled together to form a structure. It will also allow reinforcing bars to be laid across in case the concrete is to be reinforced to provide extra strength (Figure 2).

The assembly of individual elements may be planar (slabs, walls, etc.) or curved to form a domed structures, in this case tie-bars or setters may be used to allow for the slight curvature. Individual elements may be assembled together using rivets or screws/bolts or threaded pipe and nuts. The "cups" may also be provided with additional holes in the bases for passage of liquid material. Thus if two or more such elements are stacked vertically a column or a wall structure could be formed. The assembling the elements vertically or horizontally may be used to produce a wall.

The assemblage of elements using ties could produce curved surfaces that may be used as formwork to curved structures (such as domes or tunnels) or be used to actually build such structures (Figure 3).

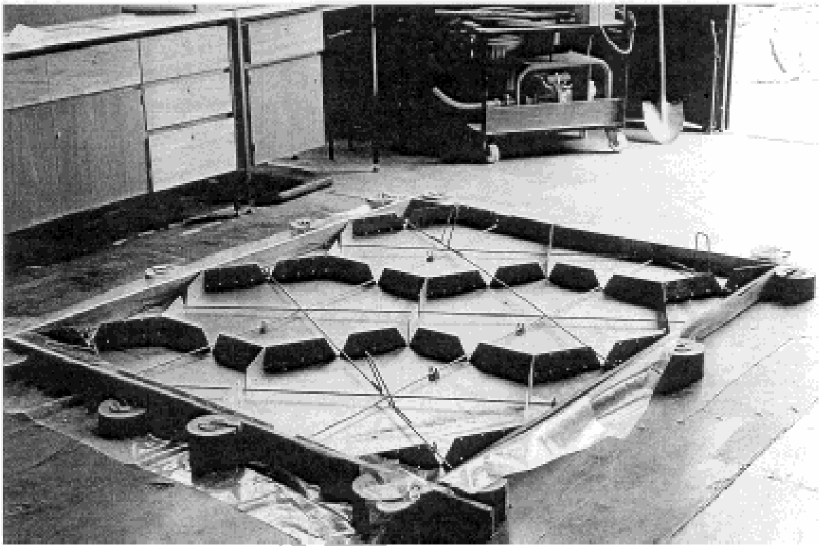

Figure 2. Assemblage of hexagonal "cup" elements to form planar structural elements

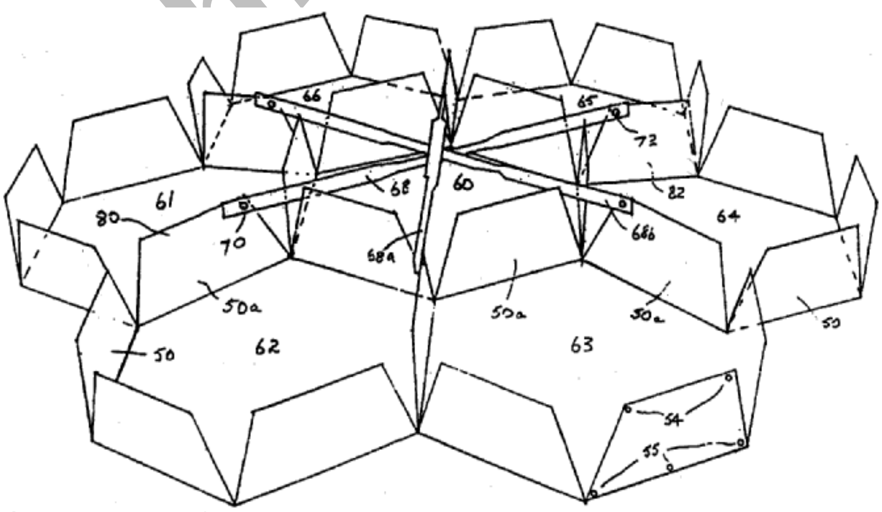

Figure 3. Assemblage of hexagonal "cup" elements linked with ties to form dome-like structural elements

3. POSSIBLE APPLICATIONS

The patented system [9] presented in this paper (see Figure 1) may potentially be used in a number of civil engineering applications using variants of the same component geometry, such as:

- Floors (elements filled with reinforced concrete);
- Roofs;
- Temporary support structures for roofs and floors;
- Walls;
- Concrete pavement for aircraft runways;
- Tunnels.

The new modular system provides a cheap and efficient way of erecting structural elements but also to maintain them in the longer term. The advantage of the system, in addition to its speed of erection and low cost, is that, in a structural situation, only individual modules ("cups") need to be repaired in case of local deterioration if these are filled with concrete for example. Cracks propagation is limited to individual modules and repair is possible. This is particularly important in concrete highways where the cost of repair is very high.

4. TESTING PROGRAMME AND RESULTS

The experimental testing programme is summarized in Table 1. Five specimens were tested to destruction.

A number of static tests were carried out at the Civil Engineering laboratories of Coventry University. Figure 4 shows a typical slab measuring 1.75x 2.17x0.76 m that was tested to failure. The hexagonal elements, fabricated from 1.5mm thick steel sheets, were assembled together using rivets and filled with reinforced concrete (diameter of reinforcement bars = 6mm). The slab is simply supported along its shorter edges and was loaded centrally up to failure. Figure 5 shows the slab deflected under the applied loading.

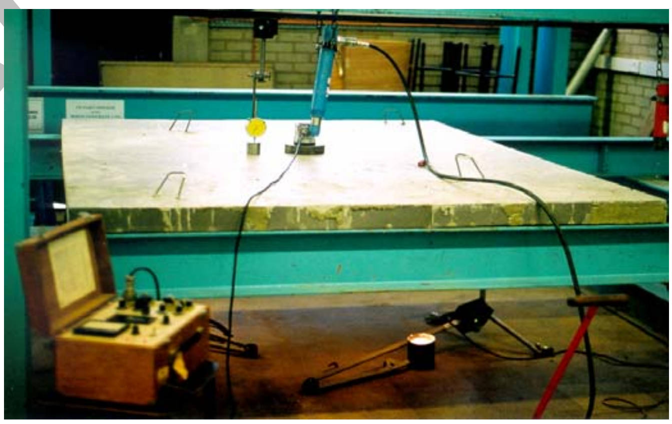

Figure 4. Slab made of hexagonal elements being tested

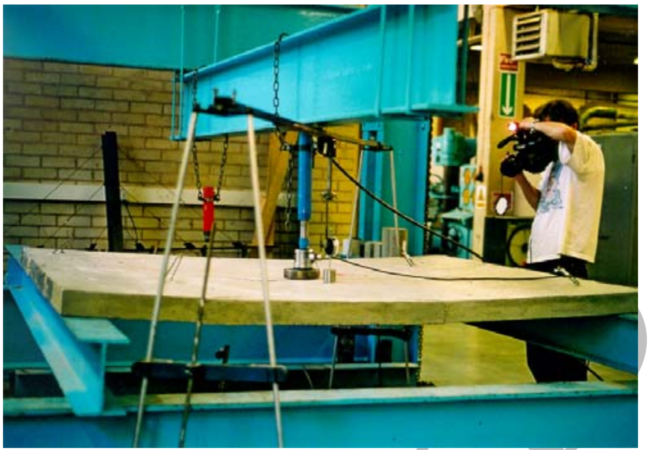

Figure 5. Deflected slab

Figures 6 and 7 show the central deflection and strain distribution diagrams versus the applied central load in the slab. It can bee seen that these are fairly linear, suggesting a linear elastic behaviour up to failure and that the slab with its honeycomb components exhibited very little plasticity and ductile behaviour prior to failure. This, in fact, is typical even in conventional plain reinforced concrete slabs.

Preliminary results on one such slab show that the system performs well compared with traditional slabs. The slab failed at 21kN with a maximum deflection of 14 cm. In addition the failure of the specimen was ductile and not catastrophic. The main cracking in the concrete had followed the lines of the joints between the modules. It was also apparent that some of the rivets joining the modules together had failed as a result of the increased load and deformations.

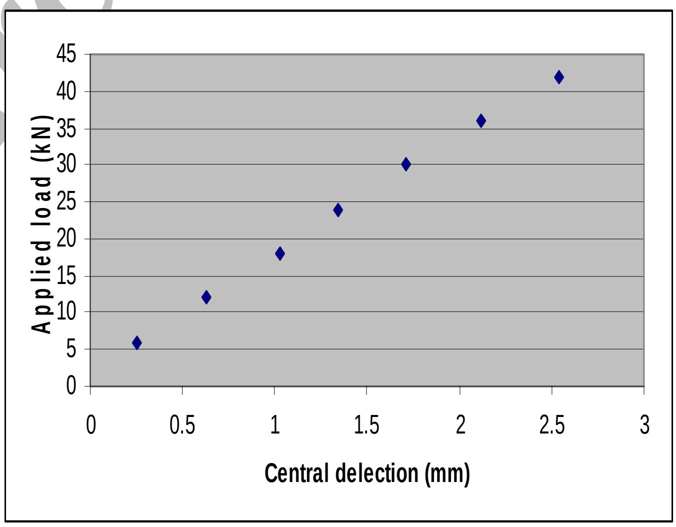

Figure 6. Central deflection in slab

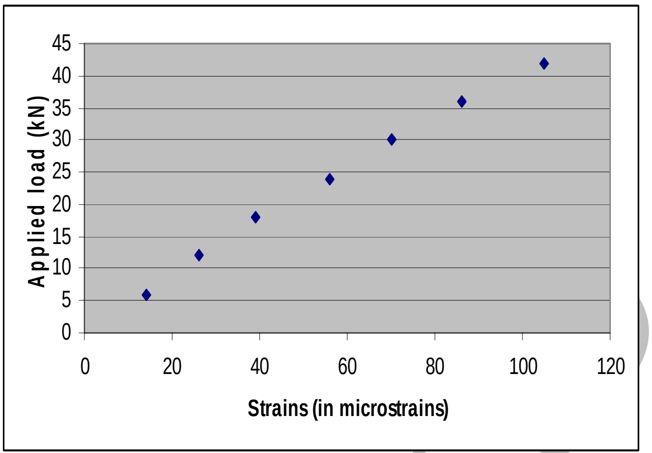

Figure 7. Strain distribution

Areas of improvement are being investigated as the testing programme progresses with the aim of achieving higher capacity for the new system. This includes providing better jointing system between the individual modules and reducing the weight of the assembled structure so that deflections could be reduced. Other improvements regarding the system geometry and reinforcement size and mesh are under review.

Table 1. Testing programme

Test Number	**Test Designation**	**Comment**
T0	Hexagonal assemblage without concrete	
T1, T2, and T3	Hexagonal assemblage with lightweight aggregate concrete	Single point load and uniformly distributed load. Assemblage is made into a rectangular slab (as in Figure 4)
T4 and T5	Hexagonal assemblage with ordinary concrete	

As may be seen from Table 1, the experimental programme included testing slabs made using the hexagonal “cups”. Two kind of concrete were considered: lightweight aggregate concrete and ordinary concrete. The aim of combining these tests is to produce a cheap and strong lightweight structure. Different reinforcement meshes were also investigated for the best design. In the longer term, another series of tests envisaged will be to test the element resistance to lateral loading (for example vertical walls subjected to wind loading). Comparison will be made with traditional types of elements in terms of behaviour at service loads and ultimate strength. The economy of the system will be investigated. It is also envisaged in the future to conduct dynamic testing.

6. MAIN CONCLUSIONS

The system has great potential in construction with possible applications for a variety of structures, slabs, roofs, floors, walls, tunnels, pavements, etc. It may also be used as a permanent or temporary formwork. It is anticipated that the system will represent a speedy and low cost construction process in addition to its cheap maintenance costs. Potentially the system could compete with traditional forms of construction for some applications, especially in large projects. The authors are already engaged in discussions with parties from the construction industry interested in the system.

Current and future work at Coventry University will be focusing on the structural performance of the system through an elaborate experimental and numerical modelling research programme. In the short term, this will consist of static loading for different structural components with varying parameters (type and thickness of material used for the "cups", size of reinforcing bars and mesh, type of concrete used (or any other material used for filling), etc.). In the longer term, dynamic testing will be conducted to study the response of the system to vibrations and earthquake loading.

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