



PREFABRICATED BRICKWORK – A REVIEW OF RECENT APPLICATIONS

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ABSTRACT

In recent years there has been an increased awareness for the need to improve both the brickwork construction process and quality achieved on site. The old idea of prefabrication as a means of achieving more predictable construction standards and a more reliable process is once again prevalent.

Currently very little use is made of prefabricated brickwork and the vast majority of brickwork is constructed using traditional skills employed directly on the building or engineering site. However, prefabrication does hold out the opportunity for significant improvements in overall building construction efficiency, quality and greater economy over traditional site constructed work.

A small number of one-off projects have recently demonstrated the technical feasibility of providing both loadbearing and cladding brickwork elements through the use of industrial production techniques employing either off-site factory production or on-site prefabrication. The Inland Revenue Building at Nottingham and the Powergen Building at Coventry are good examples of each approach. This paper reviews recent applications of prefabricated brickwork and the corresponding implications for future work.

Key words: Prefabrication, Masonry, Panels, Manufacture, Economics.

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INTRODUCTION

Masonry has been used for centuries as a building material due to its durability, insulation properties and fire and weather resistance. Unfortunately traditional bricklaying methods are slow and laborious, requiring the skill of trained masons and over the last few decades, other materials such as steel and concrete have become more and more popular. In recognition of this situation, there has been an increased interest into looking for alternatives and improvements in the construction of brickwork and one solution is the widespread use of prefabrication.

TECHNIQUES FOR PREFABRICATION

In 1973 the National Concrete Masonry Association produced a paper observing how pre-assembled concrete masonry wall panels were suitable for a variety of construction jobs ranging from simple screen fences to high-rise buildings. The paper discusses two methods for the production of these panels: -

- 1) Built manually i.e. using masons to place the bricks into position.
- 2) Built mechanically i.e. the bricks are laid by machines.

When using the manual method, one approach is to position the bricks without mortar to form several panels adjacent to one another, which are then reinforced and grouted. A three-man crew is employed for this task and is capable of producing 1,800 square feet per day. The benefit of manual construction is that it can be done at the building site (providing there is space) and is adaptable to particular design requirements. The mechanical method involves the use of a 'wall machine' located in the factory. The machine is programmed to lay the bricks into position and complete the necessary work required for the formation of joints and the appropriate reinforcement. In theory, the machine would be capable of laying walls up to 3.7m by 6.1m (12 feet by 20 feet), sixteen times faster than manual workers doing the same job. Whichever method is chosen, once complete the panels need to be transported to site. The paper describes how this is made possible using standard trucks with slight modifications or specially designed low bed trailers. At the site, the panels are lifted into position using cranes, set and braced into place and then wall and floor joints are grouted. The whole procedure is relatively quick with only a minimum amount of staff required.

REASONS FOR PREFABRICATION

In 1979, a paper written by Takahashi Y et al examines some of the reasons for the introduction of prefabrication into brickwork. One of the issues brought to light was the decrease in numbers of skilled masons on site, which in turn lead to longer construction times and failures occurring due to bad workmanship. The paper discusses how the use of prefabricated brickwork could lead to improvements in the quality of brickwork and decreased construction times and costs. The authors highlight how, using methods of construction as described in the 1973 NCMA paper, pre-assembly can eliminate the

need for skilled bricklayers and reduce both the quantity and time needed to use scaffolding.

In 1991, Klein U. and Kohler W. also highlighted the main reason for needing prefabrication i.e. the lack of skilled masons and the unlikely event that this will improve in the coming years. The benefits of prefabrication completed under factory conditions are listed, including uninterrupted work independent of weather conditions, productivity increase and humane workplaces. It is also mentioned that pre-assembly will produce a product of 'optimum quality' as work can be constantly supervised, a task that is quite difficult on the job site.

OPTIMISING PREFABRICATION

Using pre-assembly techniques can make the whole process of brick-laying more complicated, but despite this many people believe it is worth the effort. William D. Palmer wrote a paper that continues to emphasise the numerous benefits pre-assembled brick panels have over conventional brickwork. He talks about another method of prefabrication which involves using masons to build walls by hand, as they would on site, but within the factory using electric scaffolds which enable masons to be constantly working at waist height and without the problems of adverse weather conditions. This method has an advantage over the previously described 'pre-cast' methods because every panel is handmade and therefore each one can be different. Pre-cast panels are better when bulk supplies of the same format are needed, if each form had to be different the price would be unacceptably high. Due to the design flexibility of hand pre-assembled panels, complex shapes such as sloping sills, arches etc. that would cause great difficulty on site, can be produced very easily in the factory. They can be erected in most weather conditions and using panels can practically eliminate the need for scaffolding on site, as mentioned by Takahashi Y. et al, as they are lifted into position by crane. Prefabricated brick panels can also prove to be much more cost effective on 'tight sites' where there is very little room as they can be delivered using the 'just in time' principle, leading to less congestion on site.

Palmer writes about two additional advantages of pre-assembled panels. Firstly, prefabricated panels have the benefit of being reinforced which allows the wall to perform as a structural element, unlike typical brick veneers. Secondly, the panels can be attached in such a way as to remain isolated from the building frame, which is excellent for structures built in areas prone to earthquakes!

The last point to be made by Palmer is that for a project involving prefabrication to run smoothly, good communication between the parties involved is essential and the contractor should be involved from the very beginning. This is a point echoed throughout many different papers.

ADVANTAGES AND DISADVANTAGES OF PREFABRICATED MASONRY

In 1992, Fisher wrote a paper in which he discusses the three known methods for pre-assembly, which have been mentioned previously: -

1. Horizontal Casting – Bricks are placed into a horizontal mould and a thin grout poured/pumped over the back of the bricks.
2. Vertical Casting – Bricks are tightly clamped between vertical faces as grout is poured in from the top to fill the joint spaces.
3. Jig-Laying – Traditional brick laying methods are employed with the additional help of jigs to improve productivity.

Fisher suggests the major advantages of using these methods and of prefabrication in general:

- Work is protected from changeable weather conditions.
- Design features that may be too costly or labour intensive on site can be carried out in the factory.
- More control can be exercised over materials used and construction work carried out to ensure superior quality.
- Project time is shortened due to speedy erection of wall panels leading to earlier occupancy of the building.
- No need for storage on site as panels can be delivered ‘just in time’.
- Need for scaffolding is reduced dramatically.

And he also points out some of the disadvantages:

- To date there has been no published data to show that the economy of construction desired has been achieved.
- The use of prefabrication is currently limited to certain types of construction, such as cases where repetitive panels are used.
- Traditional brickwork on site allows alterations for size variations in bricks and other components to be carried out easily by adjusting joint thickness. When using prefabrication, other elements such as floor slabs can be built to achieve accuracy’s not usually possible on site, which doesn’t allow much scope for change.

Despite these disadvantages, a few specialised companies throughout the world have had some success with prefabrication using manual methods. Work in several countries continues towards improving the manual techniques as well as advancing the robotic wall laying machines and Fisher includes brief reviews of work carried out in some of these countries. In the USA, companies such as Vet-O-Vitz Masonry Systems which specialise in prefabrication work use a system based on single leaf brickwork with suitable reinforcement and steel sections to provide connections. Construction tends towards the manual method of using bricklayers, but in factory conditions with

electronic jigs. In Holland, Sterk Bedrijven at Rossum also uses a manual system of prefabrication, by laying the bricks out horizontally on tilting tables and filling in joints using a mobile hopper. The maximum panel size produced is 9m by 4m (30 feet by 13 feet), which is cured for a minimum of three days and then transported to site. A trial plant was set up to produce the Keybrick system, based on an Italian patented system, where the walls are erected dry and filled with a liquid grout. In Holland, mortar was eliminated altogether through the use of glued joints, obtaining the effect of brickwork mortar joints through the profile of the unit.

In Australia the 'Panelbrick' system has been adopted, which involves using a tilting table combined with robotic laying, steel reinforcement and a super-plasticised mortar mix. Denmark showed interest in robotic labour and Peterson had developed a panel-making machine. A rate of 1000 bricks per hour would be deemed satisfactory and in 1992 a rate of 900 bricks per hour had been achieved. However, the machine still needed further developments to make it acceptable for commercial use.

COST AND STRUCTURAL EFFICIENCIES

In 1998, Treppke D. addressed the issue of cost efficiency with respect to prefabrication. By itself, even the most flexible pre-assembly system will only make a small contribution to the overall cost-efficiency of construction, unless other factors such as the building team and building parameters are constantly kept in mind. By involving the whole building team, which would include architects, consultants and contractors in the early stages and through careful consideration of the building parameters and uses of prefabrication, there can be considerable cost reductions made whilst at the same time improving the construction process.

The importance of the early involvement of all parties is vital for two main reasons. Firstly, 80% of the construction costs are determined in the planning phase of a project. If all architects, consultants and contractors are present, then it allows them to voice their opinions and expertise and help determine any feasible cost reductions that can be made at this time. Secondly, with everyone involved from the beginning there is less need for repeat meetings and double processing and thus making the planning process more efficient. Together, early integration of the building team and increased flexibility in prefabricated elements can reduce the amount of work carried out on site, allow construction sequences to run more smoothly and make an important contribution towards increasing the productivity and overall cost efficiency of construction.

Another area in which efficiency is becoming more prevalent is in the actual design of the structure with clients wanting buildings that offer maximum efficiency in terms of volume and available floor space. In January 2000, Acker Van A. wrote a paper observing some of the factors contributing to the increased demand for modernised techniques and materials in the construction business. As well as increased financial and

structural efficiency there is the need for structures that are flexible in use and adaptable for change in the future. Certain buildings need to be flexible enough to allow for many changes during their lifespan, such as offices, but future building design will also need to be easily adaptable to allow for any structural changes that may need to occur. Increasingly, demolition will be replaced by renovation in order to preserve the environment and reduce waste. Optimum use should be made of materials and techniques available. Instead of producing buildings made of the same material, there is now a tendency to use materials and techniques best suited for the job and that provides a higher standard of quality and endurance.

Prefabrication has the potential to succeed in the modern market, not only through speed of construction and reduction of waste, but also through the use of new high performance materials and the production of hybrid structures (combination of prefabricated concrete with one or more other type(s) of structural element in the same structure).

CURRENT PROBLEMS ASSOCIATED WITH PREFABRICATION

In contrast to many other papers written, Giovanni Peirs wrote a paper in 1998 which suggests that prefabrication techniques are not yet evolved enough to provide a realistic replacement for traditional bricklaying. As the title of the paper suggests the author looks at some of the areas of masonry that need improving in order for it to remain the popular choice in construction materials. There is the acknowledgement that traditional brick laying is slow and uneconomical with plenty of room for improvement, but at the present time prefabrication is more of a hindrance than help. The biggest problem with pre-assembled panels is the creation of joints, which can leave buildings more vulnerable. There is also a point made that at the moment the use of large wall panels doesn't actually solve any cost problems and is unlikely to do so in the immediate future. Until vast improvements are made in mechanical bricklaying, prefabrication is not the practical option.

CASE STUDIES

Prefabrication is still not the perfect solution for many construction jobs and it is accepted that adjustments and improvements need to be made in order to get the process running smoothly. However, despite the reservations of some critics there have been a number of successful cases involving the use of prefabricated masonry panels in construction. A recent project carried out by Andrew Fanning at the University of Teesside, UK, highlights case studies of buildings constructed using full pre-assembled or part pre-assembled methods. The studies discuss the type of work carried out, the contractual agreements used, design and specifications required of the brickwork, procurement arrangements, construction techniques, transportation and erection facilities needed and the supply chain interaction. As with all construction work, each job had its own requirements and design specifications, but interestingly the reasons for choosing pre-assembled brickwork were very similar to those highlighted in earlier papers.

Prefabrication has the main advantage of being carried out within the protective, controlled environment of the factory and remains unaffected by the weather, allowing work to continue 24 hours a day, in dry, warm, well-lit working conditions. The elements can be stored and taken to site when required using either flatbed or A-frame trailers. Building off-site in a factory also means that construction can progress at a much faster rate as the brickwork could start almost straight away and in some cases be completely removed from the critical path. The faster productivity results in downstream benefits including shorter duration times for overall construction. Panels are moved into place on site through the use of cranes, thus helping to reduce or eliminate the need for scaffolding and create a reduction in overall site waste. These benefits of time saving, less scaffolding and less waste help compensate for the higher costs of the prefabricated elements.

It is important to note that whilst prefabrication produces quicker results, there is no reduction in the quality of workmanship or lowering of standards. In fact the quality is raised due to the improved working conditions of the factory environment. To ensure an accurate finish the process relies heavily on standardisation, which is necessary to ensure that all units fit together perfectly when placed on site. The prefabricated panels are often used as a benchmark of quality when conventional brickwork is also included on the project.

Among the case studies are two successful projects carried out in Britain which show how well prefabrication systems can work. The first study looks at the Inland Revenue Centre, Nottingham, UK (see figure1) with Trent Concrete acting as specialist contractors. The large office development provided a brief that required value for money and the flexibility to provide for the changing needs of the client and other possible owners in the future. There was a preference for a green solution and the architects' Michael Hopkins and Partners provided a design able to provide excellent energy efficiency due to the inherent thermal capacity of the construction materials. Ove Arup & partners were chosen as project engineers and decided that, although there was enough time to build the solid brick piers on site, due to possible hold ups caused by weather and scaffolding delay it would be better to have them prefabricated off-site. The pre-assembled units could perform several functions and had no applied finishes, which not only influenced the design but also reduced cost and kept in time with the project program.



Figure 1. Inland Revenue Centre, Nottingham

The piers were built off-site at Trent Concrete's factory using traditional bricklaying methods combined with profiles, jigs and other sufficient lifting apparatus enabling the bricklayers to achieve a high standard of accuracy ($- + 7\text{mm}$ tolerance). Each pier was built around a steel lifting bar attached to a steel base plate and the finished piers were left to cure. Pre-cast concrete saddle-shaped sockets were produced simultaneously elsewhere and attached to the tops of the piers. When placed on site the lifting rod eye was removed and the void grouted to provide a connection between the floor, pier, cap and slab. A-frame trailers were used to transport the piers to site and they were lifted into position using mobile cranes.

The supply chain for the pier construction worked in a similar way to methods used for on site production. Brick orders were placed and cancelled as required directly through the manufacturers allowing resources to be monitored and waste to be recognised and controlled.

Although the higher cost of prefabricated elements may give the impression that the project cost will be greater, the outcome in relation to total project duration shows that this method of brickwork is actually cost effective and a proven success.

The second study looks at a partial pre-assembled masonry project developing the Powergen Headquarters in Coventry, UK, where prefabrication methods were used to build post-tensioned stack bonded panels, constructed within a tented area on-site.

Like the Inland Revenue project, the reasons behind choosing pre-assembly were unpredictable weather conditions, project duration and the risks involved with conventional brickwork. The architects (Bennetts Associates) stated that not only did prefabrication allow for the brickwork to be removed from the critical path but it also allowed for a controlled monitoring system to ensure high quality workmanship.

Although work was carried out during the winter months (a factor that led to the decision of pre-assembly) good weather conditions and pressing completion dates meant that some of the final panels were built in-situ, proving that prefabrication has the flexibility to work in conjunction with conventional methods. No problems were encountered when reverting back to conventional brickwork as the workforce had a full understanding of acceptable production standards.

The overall project duration was from May 1993 to Sept 1994 with work on the super structure lasting from July 1993 to April 1994. Pre-assembly allows for work to continue throughout the winter months, which enables speedy construction and continuous employment for the workforce.

Unfortunately, even though both projects were highly successful the prefabrication systems were dismantled as soon as each job had finished. This leaves the U.K without any permanent pre-assembly works, making it difficult to determine whether or not the

construction industry could benefit from widespread use of prefabrication. However, there is a small group of companies throughout the world that produce prefabricated elements on a more permanent basis and, like the projects in Britain, achieve success with their work. With a few more adjustments made to current and possible future methods of manufacture, prefabrication could become a serious contender in the construction market place.

CONCLUSION

Through study of these past papers and projects, the following conclusions about prefabricated masonry can be made: -

- Fewer skilled masons will be required
- Construction times are reduced
- The need for scaffolding is lessened and in some cases eliminated
- Decrease in congestion on site as panels can be stored in the factory and delivered 'just in time'
- Panels can be reinforced allowing wall to act as a structural element unlike typical brick veneers
- The overall cost of the project can be lowered
- Reduction in waste material
- Prefabrication is flexible enough to work along side with conventional masonry methods.

Prefabricated brickwork can be constructed indoors under factory conditions, which means: -

- There will be no more delays due to weather conditions, allowing work to be carried out at any time of the year.
- Working conditions for the labourers will be improved, including electric jigs to keep work at waist height, better lighting and protection from the weather, leading to higher productivity.
- Supervision of construction will be made easier, resulting in a higher quality of work.
- Features that may be too difficult or expensive to build on site can be produce with greater ease.

But it should also be noted that: -

- Pre-assembly techniques aren't fully developed enough yet for prefabrication to work on every construction job.
- Work still needs to be carried out on improving mechanical 'wall laying' machines to make them suitable for commercial use.

Finally, for a prefabricated project to run smoothly, it's essential that all parties in the building team i.e. architects, consultants and contractors, are fully involved from the very beginning. This ensures everyone knows exactly what's happening and reduces the need for repeat meetings and double processing.

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