Monitoring glulam

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Abstract

This paper describes the application of the Leica Electronic Coordinate Determination System (ECDS) to the measurement of the long-term displacements of glulam-framed structures. Following background information for this project, the reasons for choosing ECDS3 are given. Much of the remainder of the paper gives practical details relating to establishing an ECDS measurement programme and a discussion of some of the results obtained is included.

1 Introduction

The use of solid timber, especially for the construction of large buildings, has always been a problem on account of its inherent variability, the limited sizes available and the risk of decay. Timber also has a tendency to produce distortion over long periods of time, a phenomenon known as *creep*.

The introduction of *glulam* (glued laminated) timber overcame many of the problems associated with timber in buildings but, despite all the advantages this is seen to have as an aesthetic, energy-saving structural material, the problem of creep remains. At present, there is little information available as to the magnitude of creep in glulam sections produced for buildings and uncertainty exists as to what allowances must be made for this for design purposes.

In order to provide much needed creep data, the Structural Timber Research Unit (STRU) of the University of Brighton has been carrying out testing of glulam sections in various environments since 1989. All of these tests were done under controlled conditions in the laboratory until 1992 when it was decided to obtain more data by monitoring the behaviour of glulam in 'real' buildings starting from their construction. For this work, it was stipulated that the measuring system should be capable of determining the overall movement of a glulam structure to the order of 1 mm and the movement of individual sections with a precision better than 0.25 mm.

2 Measurement Method

A number of different methods are available for measuring the precise movement of structures, and each of these was considered. However, for this project a theodolite intersection system recording three dimensional coordinates at discrete points on the structure was used and a Leica Electronic Coordinate Determination System (ECDS) version 3 was purchased. Although the cost of the system was high (£45 000 in 1992), the expense was justified for the following reasons:

- ECDS is 'mobile' and can be taken to the structures monitored and then removed. This enables more than one site to be monitored with one measuring system.
- ECDS can take non-contact measurements without disturbing the structure.
- An accuracy of 0.1 mm was theoretically possible for measuring relative movement for the size of buildings envisaged.

ECDS3 was installed by Leica at the University of Brighton in September 1992 and various tests and measurements were undertaken to become familiar with the system and to check that it was functioning properly. The hardware components forming Brighton's system at present are two Wild T2002 electronic theodolites, a Toshiba T6600C portable computer and other items including scale bars and industrial stands.

No detailed description of the theoretical principles and operation of ECDS3 are given here other than to mention that it is based on theodolite intersection and is therefore dependent on the measurement of angles only.

3 Monitored Sites

For this project, three very different structures have been chosen for monitoring.

The first site at which measurements were taken was the Baptist Church in Wokingham, Berkshire. At this site, a complete refurbishment of the original chapel had been started to which an extension was being added along one side of the existing building. This extension was to have a glulam-framed roof above the second-floor, the roof consisting of a series of straight beams pitched at various angles. Allowing for the somewhat complex nature of this structure, 12 beams (rafters) of different section, length and support were selected for monitoring which started in November 1992.

Also in November 1992, permission was given to monitor a second structure which is the roof covering a 25 m by 10 m swimming pool in Shoreham, West Sussex as shown in Figure 1. This building was chosen because the glulam beams forming the roof were to be exposed to a high relative humidity at all times once the pool was fully operational. This has a less complicated but much larger structure compared to Wokingham and measurements started at Shoreham in January 1993 as soon as the roof had been constructed.

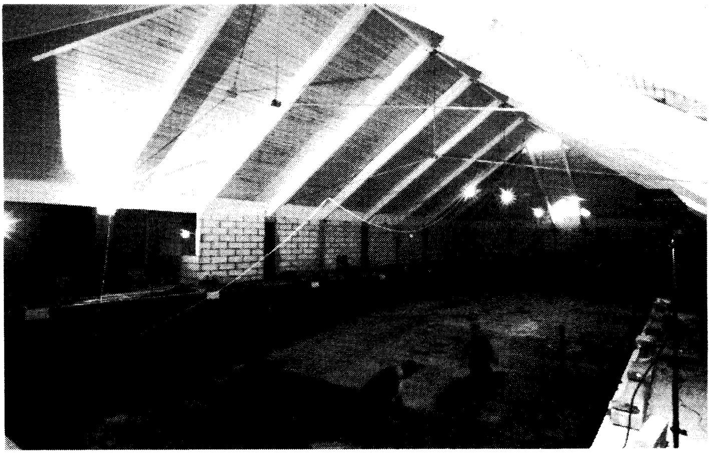

Figure 1. Wadurs swimming pool at Shoreham under construction

The third site at which measurements have been taken (since May 1994) is a Health Centre in Moulsecoomb, Brighton. This is the smallest of the sites and was chosen because it was possible to measure the deflections of some simply supported beams.

4 Targeting

Before any measurements were taken at any of the sites, the problem of targets was considered in some detail. For ECDS, the need for clear, unambiguous and precise targets is vital if accurate observations are to be taken. At Wokingham, the architect responsible for the contract did not want anything to be attached to the structure that was either permanent or obtrusive and after some discussion, it was agreed that 'stick-on' targets provided by Leica were to be used (see Figure 2). These have proved to be a good choice of target as they have withstood a wide range of environmental conditions without deteriorating. For similar reasons, the same targets were used at Shoreham and Moulsecoomb.

Having decided the type of target to be used, the number of targets to be placed on the structure had to be chosen. The critical points to be monitored were both ends and the centre of each glulam beam. At Wokingham, five targets were placed along the complete length of the shorter beams and seven on the longer giving a target separation of about 1 m. Getting the targets in place at Shoreham presented a major problem because of the size of the structure. For this reason, only five targets were positioned between the ends of each beam and these had separations of about 2 m.

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Figure 2. Leica 'stick on' target

Of equal importance as the targets is their illumination, and this has been provided very effectively at all sites by a stand-mounted 500 W halogen lamp. The lamp has enabled targets to be evenly illuminated over distances of up to about 15 m, but the stand needs to be moved frequently.

5 Baseline Selection

When planning an ECDS monitoring scheme, the positions the theodolites occupy in relation to the targets has a major influence on the precision to which coordinates are determined.

Figure 3. ECDS in position for monitoring at Wokingham after construction

Factors affecting the choice of baseline positions are mainly geometrical where distances from targets and the size of intersection angles affect the precision obtained greatly. Another potential problem is the shape 'stick-on' targets appear when intersected. This made it desirable to position the theodolites such that the targets were not too elliptical when viewed.

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Taking account of all the different influences, two baselines were chosen at Wokingham one of which is shown in Figure 3. This particular set-up enabled eight different beams to be observed from one baseline.

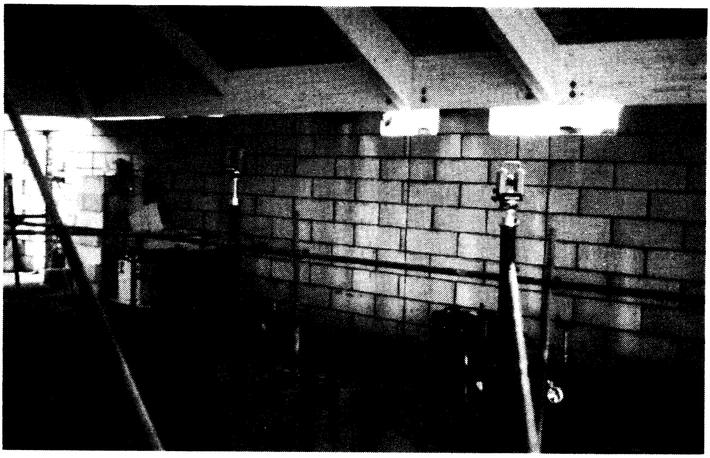

Figure 4. ECDS in postion for monitoring at Shoreham during construction

At Shoreham, unlike Wokingham, only two baselines could be positioned at the ends of the pool, one of which is shown in Figure 4. Fortunately, it was possible to obtain a reasonable geometry and not be more than about 15 m away from the centre rafters at these positions.

At Moulsecoomb, the two T2002's have been positioned in the corners of the rooms in which beams have been monitored as shown in Figure 5.

6 ECDS3 on Site

Each survey has involved loading the equipment at the University and then unloading on site. This has been quite a chore and the minimum time taken to set up ECDS has been about 30 minutes from arrival on site to taking the first measurements. At each site during building, this time has varied depending on work in progress on the day.

In use, ECDS3 has been found to be fairly straightforward. For each survey, a bundle adjustment has been performed following installation using a scale bar and about 10-12 beam targets. Following this, the targets along each glulam section have been intersected. Without any doubt, the on-line facility available within ECDS3 has been very useful when taking these observations as it provides real-time coordinates with an indication of their precision. This has enabled any gross errors to be removed (for example, an operator on the wrong target) and has also enabled poor sightings to be redone. However, despite the advantages of software control on observations, the final results have always relied on the integrity and eyesight of each operator. Interestingly, if the observers were distracted, it was often found that poor results were obtained, particularly for a bundle adjustment, and on some occasions it was necessary to wait and restart without the distraction.

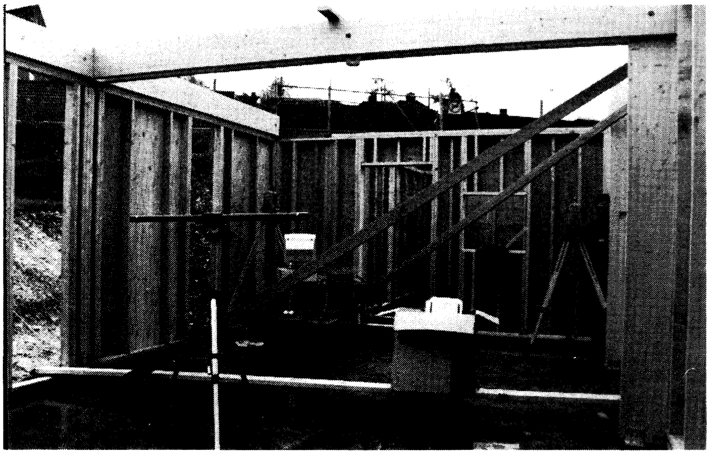

Figure 5. An ECDS set-up at the Moulsecoomb site during early construction. A monitored beam can be seen across the top of the photograph.

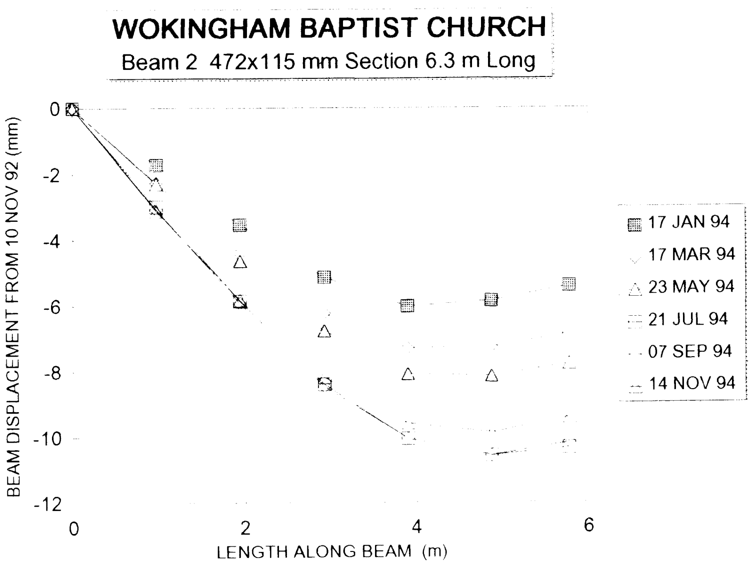

Figure 6. Vertical deflections for beam 2 at Wokingham during 1994

7 Results

For all surveys undertaken it has not been possible to measure absolute coordinates as no reference points could be established on or near the sites which were also enclosed, making it extremely difficult to transfer control into them.

At each ECDS set-up, one of the theodolites has been used to define the origin of a local coordinate system, the X direction of this being defined by the baseline between theodolites. The end result of each survey has been a series of data files composed of X, Y and Z coordinates each based on a different local system.

To date, an analysis of the Z coordinates has been done and the vertical deflection of each beam has been calculated using one end of a beam as reference. The 1994 results for beam 2 at Wokingham are shown in Figure 6 and a similar set can be seen in Figure 7 for beam 3 at Moulsecoomb. Of more importance to creep analysis is a measure of the deflection of a glulam beam with structural movement removed. This can be obtained for the centre of a beam by subtracting half the total deflection at the end from the centre deflection and this is shown for beam 7 at Wokingham in Figure 8.

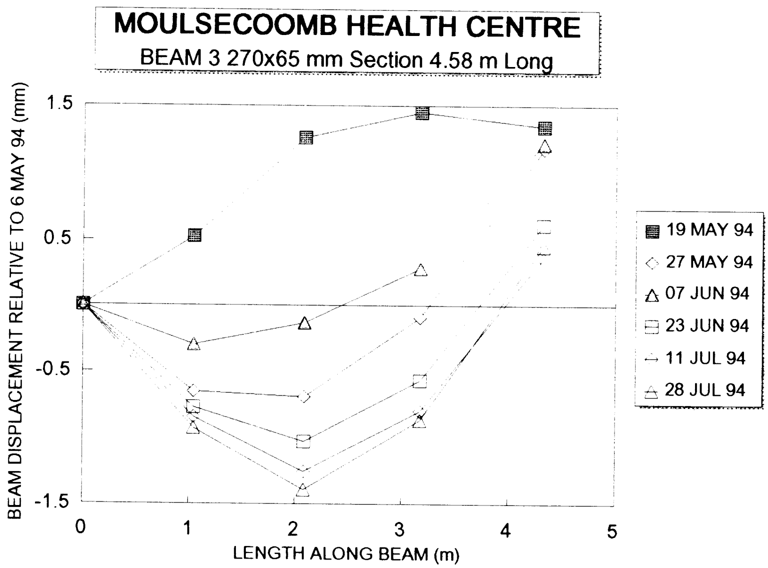

Figure 7. Intial deflections for beam 3 at Moulsecoomb

8 Discussion

From the results obtained, it is estimated that ECDS3 is measuring coordinates that show structural movement has been detected to about 1 mm and creep to

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within 0.1 mm for an individual beam. How this relates to overall accuracy is under investigation but it is felt that the original specification has been met.

All results show a very similar pattern of deformations, the magnitude of which vary in accordance with the size of beam being measured. In addition, all of the beams exhibit what is thought to be 'creep' although the exact nature of this is not known at present.

Future work planned is to continue with measurements at all sites and to commence a detailed study of the results obtained to date. This is to be carried out on the horizontal as well as vertical coordinates and is to be combined with a structural analysis of each site.

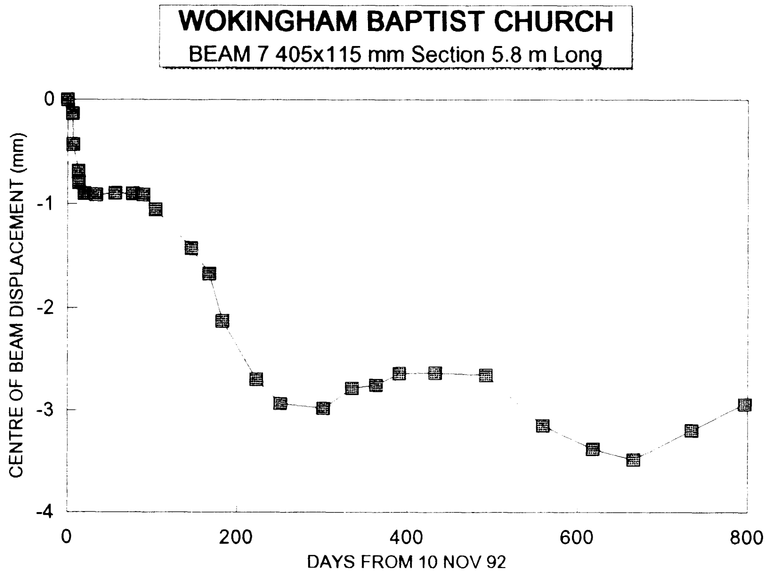

Figure 8. Possible creep characteristic for beam 7 at Wokingham

9 Acknowledgements

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