Post-Tensioned, Free Cantilever Diaphragm Wall Project

(Subjet 2)

Curtin, Shaw, Beck and Pope -(W.G.Curtin and Partners)
Liverpool, England

SYNOPSIS. The paper describes the first application of the uncompleted research on post-tensioned diaphragm walls by Curtin and Phipps (ref. 1).

INTRODUCTION.

The Salvation Army needed a hall for religious services in Warrington, Cheshire. The main hall was to be 25 metres long x 15 metres wide x 8.5 metres high as shown in fig.1. The cost budget was extremely tight and it was essential to produce a highly economical solution. It was known, from much experience that a diaphragm wall would provide this but there was a snag. Though the dimensions of the hall were not exceptional (the authors have successfully designed much larger halls using the diaphragm wall technique) the top of the wall could not be propped as the client and architect required a clerestorey window shown in fig.2 running round the top of the wall as well as the roof plane not being constant. Whereas for the propped cantilever wall a base moment of $ph^2/8$ would be adopted, an unpropped one would have to cater for $ph^2/2$ - i.e. 4 times that of a propped cantilever. The stability moment, or resistance moment, at the base is the walls own weight times its lever arm (see ref.2). The solution of increasing the lever arm (thus increasing the overall depth of the wall) was rejected both on the grounds of cost and its unacceptability to the architect. The economic solution, but for the recent research would have had to be the incorporation of a steel frame and cladding. Fortunately the early and satisfactory results of the research (ref. 1) had just been produced at the time of the preliminary design stage of the project and it was decided to design a post-tensioned diaphragm wall.

DESIGN CONCEPT.

The moment of resistance at the d.p.c. of a diaphragm wall is W x a (where W = weight of the wall and a = lever arm). The moment of resistance within the height of the wall is f x z (where f = stress and z = section modulus) W can be

increased by thickening the wall - so can 'a' and Z, but this is uneconomic. But both W and f can be increased by post-tensioning to cope with the quadrupling of the bending moment. The wall does not then need thickening or increased overall depth and structural masonry again can prove much more economic than structural steelwork. (It is perhaps a reflection on the brick industry's lack of confidence or appreciation of the structural properties and economics of its product that far too many of its own buildings are built in structural steelwork).

The normal governing bending value of 'f' in plain brickwork is its pathetically low tensile strength but the application of prestressing can easily increase the bending resistance tenfold (ref. 3). With such an increase in resistance it is simple to cope with the quadruple increase in bending moment. By keeping the wall to the normal overall depth (to prevent rain penetration, provide thermal insulation etc.) it has, easily, a sufficiently high radius of gyration, to reduce the slenderness ratio, so that it can accommodate the axial compressive stress induced by prestressing.

THE STRUCTURAL DESIGN.

The diaphragm wall section as shown in fig. 3 was chosen after consideration was given to the architects requirements at low level in respect of window arrangement (see fig.2) and the particular moments induced by the wind forces for the area under consideration. The introduction of the post-tensioned force created a condition whereby no tensile stresses existed at the base of the wall under full load. The tensile stresses without prestressing were far in excess of the walls capabilities even if full tensile stress were permissable, which is not normally the case at d.p.c. level. The post-tension force was achieved by the introduction of 2 No. 32 mm diameter Macalloy bars positioned within the section of the diaphragm void shown in fig. 4 and anchored as shown in fig. 5. The bars were tensioned to induce a force of 100 kN with the bars positioned concentrically to cater for reversal moments. If post-tensioning to resist moments from earth pressures then the bars can be positioned eccentric to achieve greater economy.

A requirement of the scheme was for the internal structure to be white and light reflecting, so concrete blocks were used internally which also gave a natural surface finish without the need for plastering and ongoing maintenance in respect of painting. This immediately raised a number of problems as clay bricks and concrete blocks have differing

movement characteristics - this was overcome by not bonding the block cross-ribs into the outer leaf of brickwork. The transfer of shear stress etc was accomplished by extensive use of cavity ties which reduced with the height of the wall due to the corresponding reduction in stresses. Movement joints were also placed in the structure at half the centres normal in an all brick construction. The creep characteristics also differ and again the governing factor was the blockwork as this creeps more than brick. Blockwork creep was therefore taken as the governing factor for loss of prestress due to creep.

As is found with normal diaphragm wall design the block and brick strengths were not high, the block strength adopted was $7MN/m^2$ with the external brick skin being dictated by other factors such as resistance to rain penetration and durability.

The adoption of a precast concrete capping beam to the head of the wall shown in fig. 5 created a situation whereby the local bearing stresses from the prestressing force was well within the blocks capabilities, and gave a very adequate bearing platform for the supporting frame to the roof structure.

The tensioning rods as is shown in fig. 6 were protected by treating with Denso paste and wrapped in Denso tape as the wall increased in height. Threaded couplers, as can be seen in fig 6 were adopted to extend the length of the tensioning bars. As is usual this figure also shows the way service pipes such as rainwater pipes can be accommodated within the diaphragm section.

The force required in the post-tensioning rods was achieved by the use of a conventional torque spanner. In this case a Torque Multiplier with a 5:1 Multiplication factor as can be seen in fig. 7 was used to achieve the required torque of 64 kg fm. On completion of torquing up the recessed pockets in the concrete ring beam were concreted solid.

CONSTRUCTION.

The contract value for the hall and ancillary buildings was £200,000. This being a relatively small project it was well within the capability of a small local builder. But building a tall post-tensioned diaphragm wall might not appear to be within the capacity of small building firms - but this is not so in practice. Certainly there is a need to provide the contractor with clear and simple working drawings and a good specification. Guidance is, on the whole, lacking in both these requirements. Experienced engineers, in discussion and co-operation with good builders, should have little problem in providing the site with adequate drawings. There is a problem with the specification. Most specifications only deal with normal brickwork of normal room heights and there is not, to

the authors' knowledge, a comprehensive specification for modern structural brickwork. Fairly certainly there is none for tall post-tensioned diaphragm walls of brick and block construction. The authors practice has, over the years, acquired the knowledge and experience to provide guidance on both specifications and working drawings and will publish this in the near future (ref. 4 and 5).

No problems were encountered during construction, the contract was completed on schedule, within the budget price and with a good standard of workmanship.

CONCLUSIONS.

This first, early (almost premature!) application of post-tensioned diaphragm wall research augers well for the future development of the potential of the technique. It may further encourage cooperation between research and practice.

REFERENCES

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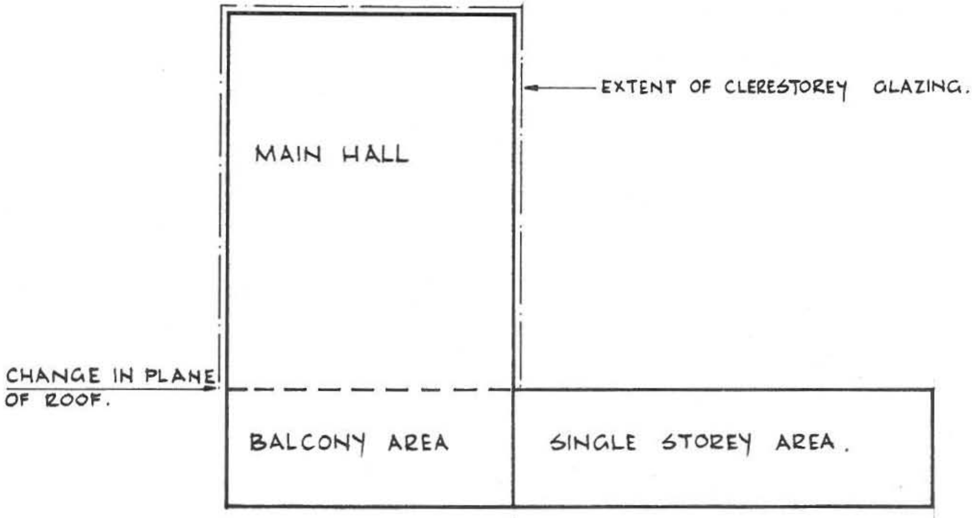

FIG 1 General Arrangement of Building

FIG 2 External View showing Clerestorey Glazing

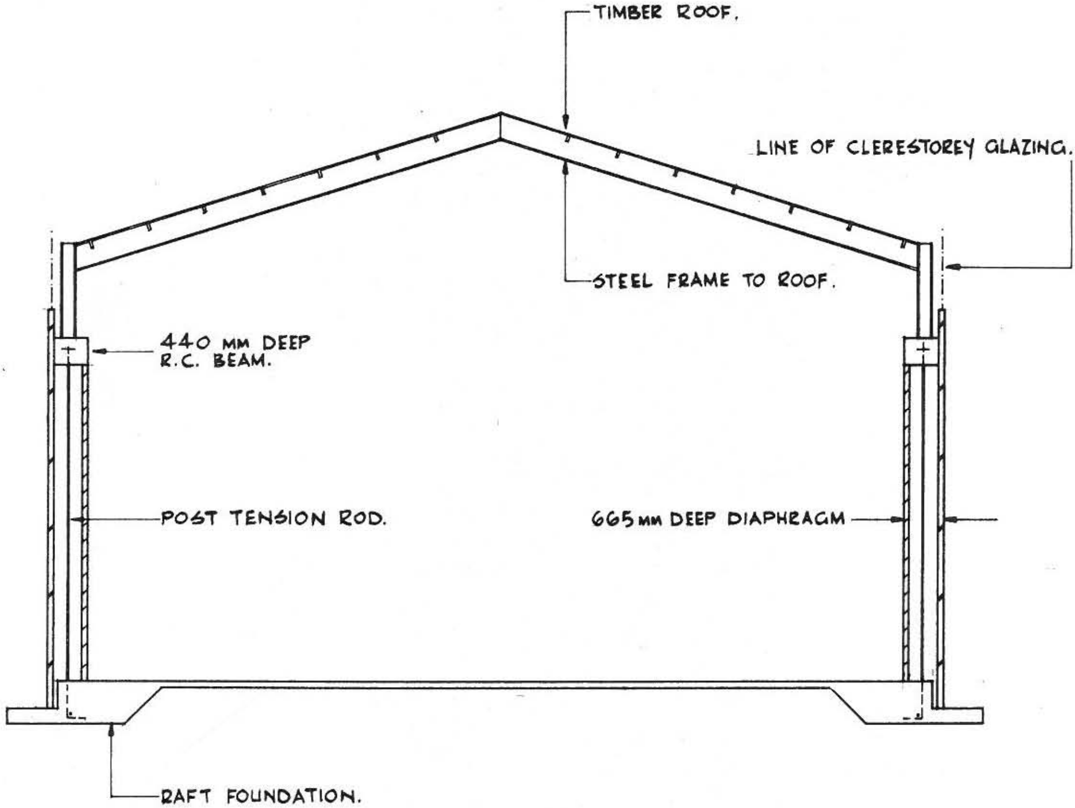

FIG 3 Section Through Building

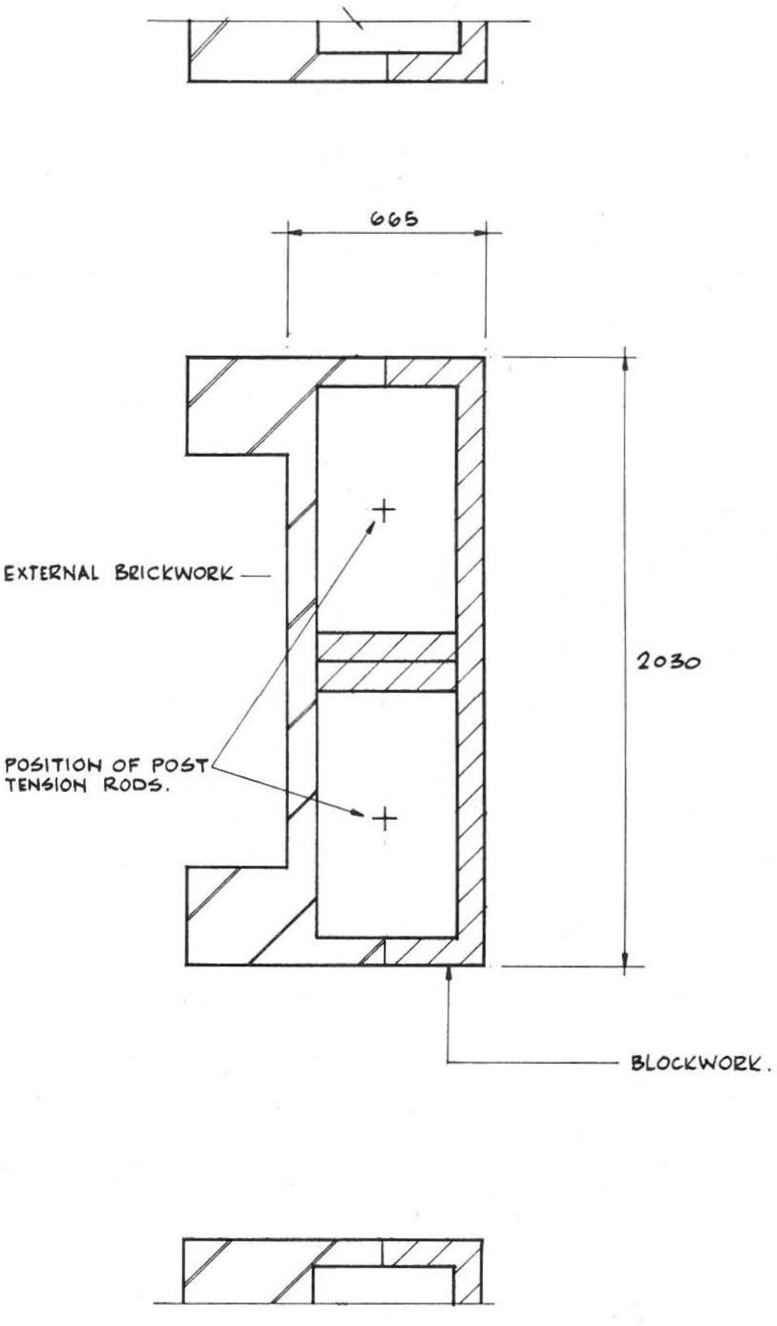

FIG 4 Horizontal Cross Section through Diaphragm at Low Level

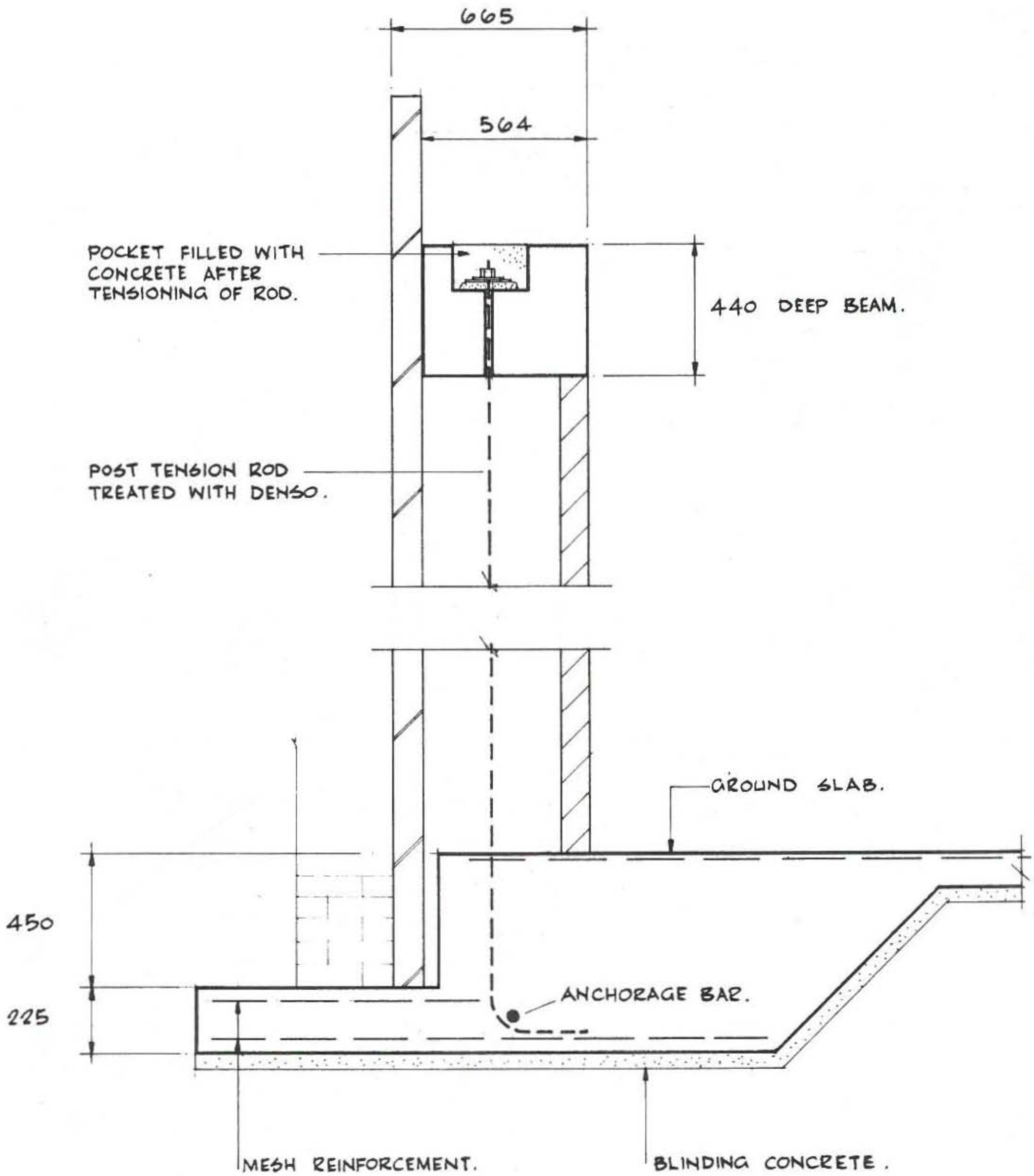

FIG 5 Anchorage Detail to Post Tension Rod

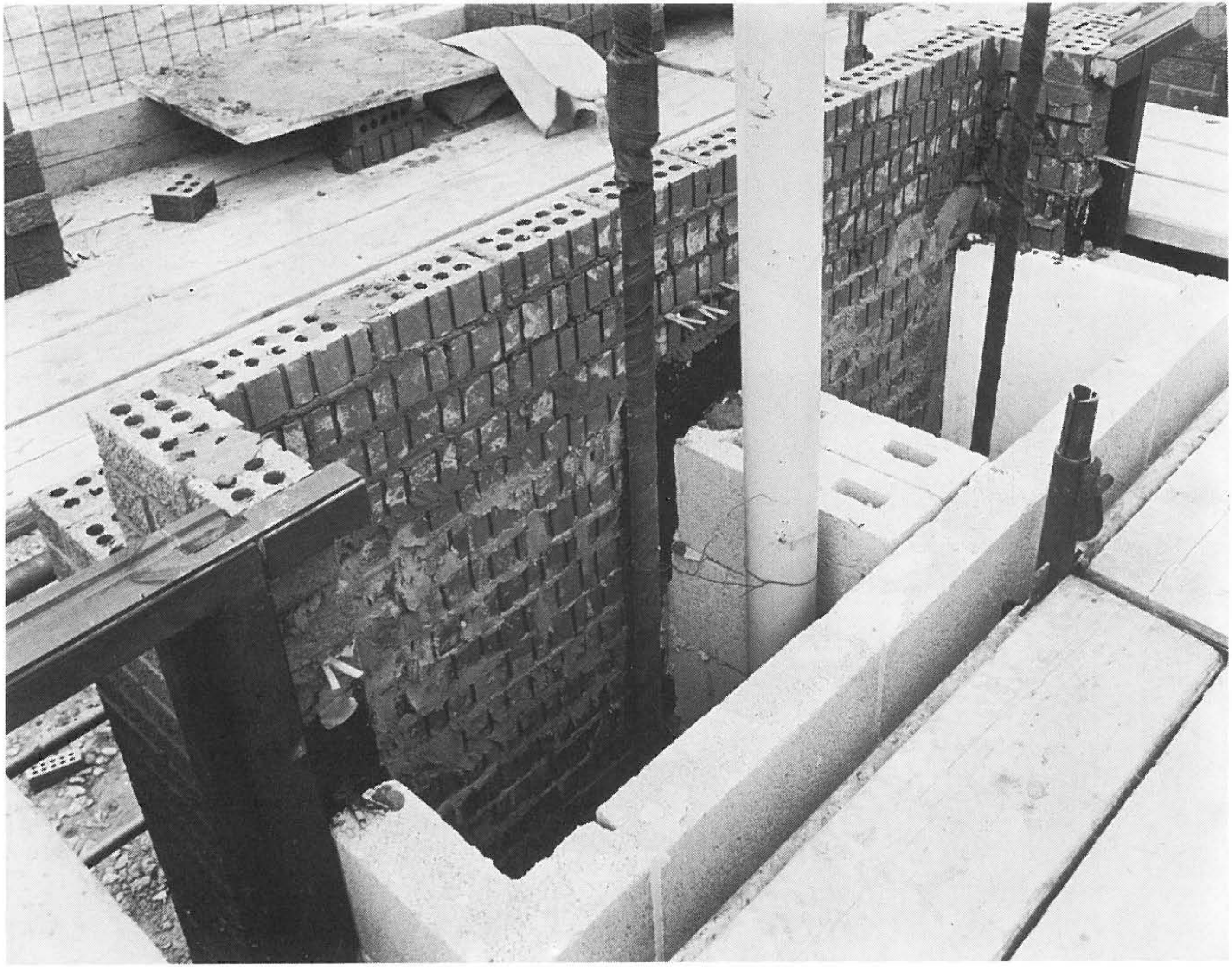

FIG 6 Post Tension Bar with Denso Protection

Fig 7 Torque Applied to Top of Post Tension Road using Multiplier