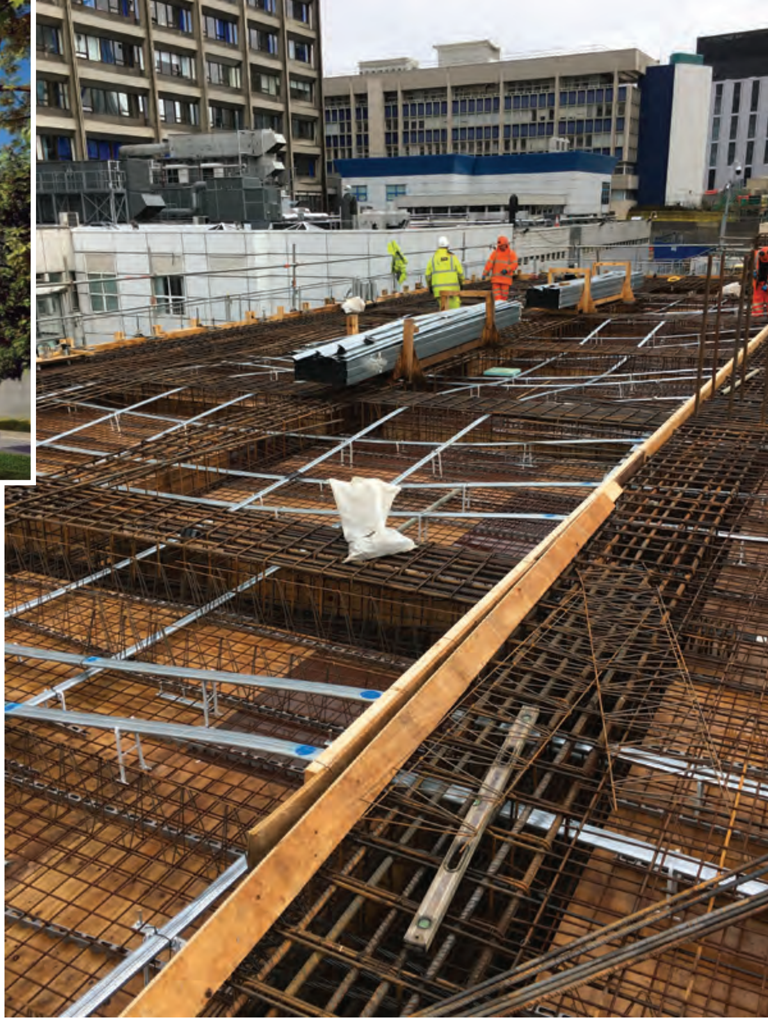
Post-tensioning provides the right solution for complex cancer centre build

***Radu Trancau** of **CCL** discusses the post-tensioned slabs installed at the new Clatterbridge Cancer Centre in Liverpool, the engineering challenges involved and the benefits post-tensioning (PT) offered in meeting the project's performance specifications.*

The Clatterbridge Cancer Centre is one of the UK's leading cancer centres, with a main hospital in the Wirral, a satellite facility in Aintree, Liverpool and a number of chemotherapy clinics in Cheshire and Merseyside.

The latest addition to this estate is the custom-designed Clatterbridge Cancer Centre Liverpool, located adjacent to the New Royal Liverpool Hospital and connected to it by three link bridges. Due to open to patients in 2020, the 11-storey hospital will provide treatment for patients with blood cancers and solid tumours, with the accommodation arranged floor-by-floor by cancer type and the heavy linear accelerators for radiotherapy located in the basement.

Designed by architectural practice BDP and engineered by AECOM, the building has been constructed by Laing O'Rourke and the main contractor has worked collaboratively with CCL and other delivery partners to develop a detailed design for the post-tensioned slabs that answers the very specific loading, deflection and vibration criteria of the design, without detracting from its considerable aesthetic impact.



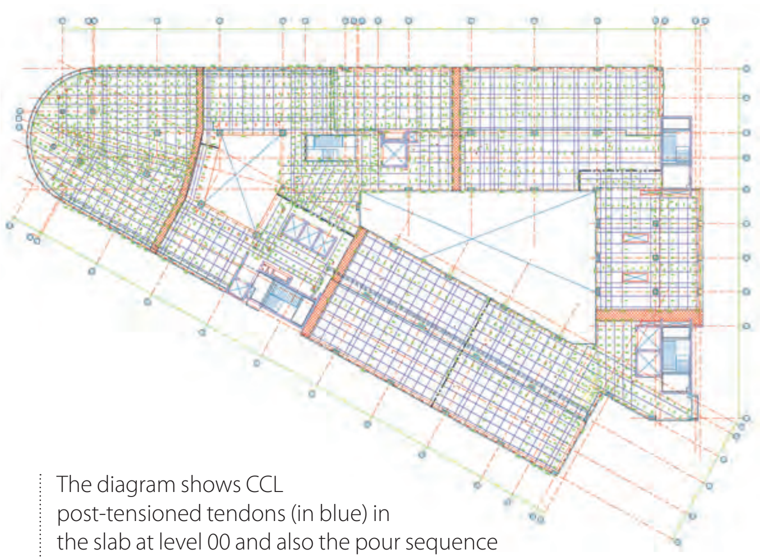
Above and left: Artist's illustrations of the completed Clatterbridge Cancer Centre.

MRI area showing PT tendons and location of deep orthogonal beams.

Slab strategy

Occupying a sloping site, the new Cancer Centre is an unusual triangular-shaped building with a unitised glazed façade and a stepped terraced roof where patients will be able to relax in the outdoor space during their treatment. At the front of the building there is a curved cantilevered section that extends from the main building by around 8m, supported by huge raking columns.

The viability of different slab strategies was explored by the project team at the early concept stages of the project, with traditional reinforced concrete (RC) slabs, precast concrete, post-tensioned concrete and steel frame all considered as potential options. This analysis led to the decision to use RC slabs for the basement and ground-floor levels, while the remaining storeys, including the stepped cover slab, have all been designed and installed with PT.



The diagram shows CCL post-tensioned tendons (in blue) in the slab at level 00 and also the pour sequence used to build the slab. The red hatches show the pour strips that were designed in order to release the slab from the restraints of the vertical cores and the black dotted lines show the day joints necessary in order to control the volume of concrete cast at one time. The diagram also shows level 00 slab footprint.

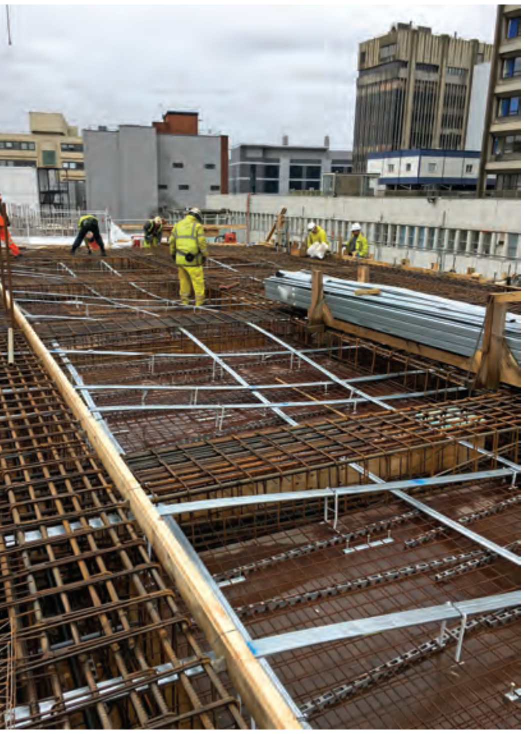
Unlike many projects where RC slabs are switched to PT to achieve a thinner slab depth or enable larger spans, PT did not significantly reduce the amount of concrete required and the 9m maximum spans could have been achieved by using conventional RC slabs just 25mm larger in depth.

However, the use of PT significantly reduced the level of steel reinforcement required by increasing the tensile strength of the slabs and reducing deflection in critical areas, ensuring that the required criteria were achieved.

Vibration and loading

There are two key reasons why the vibration criteria were so strict on this project. First, the MRI equipment that will be installed on level zero is extremely sensitive and the hospital has been designed to allow for an additional MRI scanner at a later date. Second, there is a pharmacy located on the top floor where chemotherapy infusions and other treatments will be custom-prepared to precise requirements for patients and the equipment used here is also very sensitive.

To provide sufficient concrete mass for the required vibration resistance, the depth of the slab was increased to 450mm, as opposed to the 325mm depth required for the remainder of the slab. The vibration control provided by the slab thickness was further enhanced



PT tendons in the MRI area where deep orthogonal beams are located.

The prow of the building showing the cantilever slab, inclined columns and the orthogonal beams.

by stiffening in the critical areas with a set of deep orthogonal beams.

While the slab depth below the MRI scanner and proposed future scanner was increased only for the specific area affected, for the top-floor pharmacy the depth across the whole slab is 525mm, as compared to the 325mm of the building's standard PT slabs. Additional tendons and anchors were required for these areas to enhance the slab's tensile strength but the use of PT avoided the onerous level of steel reinforcement that would have been required to support a conventional slab of this mass.

The extensive plant requirements of the specialist facility also affected the engineering of the slabs. There is a plant room on each level in a repeated pattern rising up the building and for this section, rather than increasing the thickness of the slab, the building has been designed on a smaller grid size.

However, on the roof, where there is complex plant to service, the pharmacy, along with air-handling units and other equipment that is mission-critical for the whole hospital, the slab design had to take account of heavy loading, with varying loads in different locations, and the horizontal forces created by large service openings for ducting and flues etc. In addition to requiring an increased slab thickness, the cover slab also had to be cast to falls to aid water management. Close collaboration was required between CCL, the construction team and the MEP provider to co-ordinate the location of the PT tendons and anchors.

Design co-ordination

Indeed, design co-ordination has been one of the key challenges of the project, requiring close collaboration between delivery partners to address the specific requirements of each floor. Each level of the building has its idiosyncrasies in terms of specification and design: the cores are a mix of in-situ concrete pours, slipform and precast concrete, each of which had to be tied into the PT slab. To create the outdoor terraces on the stepped roof areas, the exit point has been cast as a traditional RC slab for around the first 500m^2 of each terrace to enable a smooth transition from indoor to outdoor space and this has then been tied into the remainder of the PT slab.

The raking columns below the cantilevered section at the front of the building also had to be tied into the PT slab and the design of the slab here had to take account of the significant horizontal forces created by the size of the cantilever and its unusual shape.

This not only required PT design expertise in terms of slab depth but also a load path had to be established using a strut-and-tie analysis. This was done to ensure that the forces through the slab were evenly distributed, minimising their impact on the concrete cores.

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The impact of horizontal forces was also a design consideration for the level two slab, where a large atrium meant that the forces from the steel structure of the atrium at the void had to be incorporated in the slab design. Here, an edge beam has been installed around the perimeter of the void to help manage the forces and control the deflections.

An edge beam was also installed as part of the solution for managing deflection and enabling a neat finish for the unitised façade. There is no raised access floor at any level of the hospital, so the fixing brackets for the façade have been recessed approximately 150mm into the slab and the CCL team worked closely with the construction team and the façade designer to co-ordinate the location of the PT anchors and tendons with the façade fixing brackets. The edge beam on each floor has been used to control deflection as thickening the slab at the perimeter was the only viable solution for achieving this important criterion. The edge beams will be concealed in the ceiling void at each level, providing a robust structural solution with no visual impact either inside or outside the building.

Innovation

The Clatterbridge Cancer Centre project has been on-site in Liverpool since November 2016 and the building is now structurally complete, with the façade installation nearing completion and the services installation well underway. The complexities of the building's design and construction are an apt metaphor for the complex cancer treatments it will pioneer, creating a symbol of endeavour and innovation. ■