1. St Thomas' Hospital – CFRP plates bonded to concrete

Introduction

The reinforced concrete hospital building was undergoing major refurbishment to three floors, which included the introduction of many more services penetrations through existing concrete slabs, especially near columns (i.e. in hogging regions). The use of CFRP strengthening to replacement cut existing reinforcement allowed holes to be cut without locating or avoiding existing reinforcing bars.

Step 1.
Type of Structure

St Thomas' Hospital building North Wing located in Lambeth, London, is a 13-storey reinforced concrete building built in the 1970's.

Step 2.
Design conditions

As part of a major refurbishment works, holes were being cut through into the existing floor slabs. The holes were to be generally 100mm or 150mm diameter cores, with some 200mm diameter cores. The floor slabs were variously 250 or 300mm thick. Assessment by others had identified that if cores happened to cut multiple reinforcing bars, the slab capacity would be reduced below acceptable values.

Most floors in the building remained in use as hospital, with only one or two floors available for the refurbishment works at any one time. Access to working areas was only permitted via an external cage lift on the outside of the building, and there was limited access for cranes close to the building. CFRP had been identified as a preferred strengthening system for reasons of ease of delivery of the materials that could be carried in the lift.

Step 3.
Initial testing and investigation

The original construction drawings were available. In addition, the engineers supervising the project had worked on the original design and construction of the building and therefore had some information.

Step 4.
Material selection

Pultruded carbon fibre strips with epoxy as matrix was selected - it had been used before on a similar project and had performed satisfactorily. For commercial / contractual reasons, material from a particular supplier (Sika) was preferred.

Under the proposed classification scheme the strips would be classified as PBU/1/C.
CFRP pultruded strip
Young's modulus, E – 150kN/mm^2
Ultimate tensile stress – 3000N/mm^2

Step 5.
Partial factors

The following partial factors were adopted, in accordance with the recommendations of TR55:

Strip for flexure

Material type factor	- 1.4 (carbon)
Method of manufacture factor	- 1.1 (pultruded plates)
Young's modulus factor	- 1.1

Step 6.
Design calculations

The design was based upon the recommendations of TR55, which had been published just before the design calculations were undertaken. These

recommendations are compatible with BS8110. The design of anchorage and checks against debonding failures were as specified by TR55.
Calculations were undertaken for various generic situations, which covered combinations of hole size and existing reinforcement in the slab (and therefore number of bars that may be cut). In a few special cases relating to the largest size holes in most heavily reinforced slab it was necessary to specify that hole setting out be undertaken after locating bars and avoiding cutting more than a critical number.

The generic cases examined were:

Type	maximum core diameter	maximum reinforcement cut	Note
A	150mm	none	Top of slab strengthening
B1	100mm	1 x 25mm	
B2	200mm	2 x 25mm	
B3	100mm	1 x 32mm	
B4	150mm	1 x 32mm	
D	200mm	2 x 25mm	Soffit strengthening

Maximum reinforcement cut referred to reinforcement that may be cut, since CFRP was installed before coring, and holes were set out disregarding existing reinforcement.

Step 7.
Design conformance check

Since the input data were all selected from manufactures data sheets dimensions, material properties are satisfied once the loading requirements are met. Maximum stress and strain limits are all satisfactory as they are checked as part of the design process. The level of strengthening is also achieved given that it is one of the input parameters.

It was recognised that in many cases, the generic cases approach was likely to result in conservative design - for example many of the smaller holes actually did not cut bars when they were eventually cored. However, it was advantageous to the programme of works to adopt this method, since most of the strengthening design and approval could be completed before hole setting-out was finalised.

Step 8.
Prepare specification

Specifications for strip installation were prepared and issued to the client.

The strengthening scheme required numerous strips crossing over previously installed strips. The specification included particular requirements relating to the sequence of operation and method of forming the crossing, including build-up of ramps either side of previously installed strips so that subsequent strips followed a smooth profile. The specification included details of timing in operations to ensure that subsequent works at a particular location did not cause damage to previously installed strips.

Since the works were to occur in phases as floors became available, the testing was specified ‘per phase’ as well as on a material consumption basis, to ensure that a full representative set of testing was available for each area of work, and regardless of whether the contractor changed operatives between floors.

Step 9.
Specific material selection

As discussed in Step 4, the specific material to be used in the scheme was already defined and the particular parameters used in the design calculations, so this step is not applicable to this structure.

Step 10.
Method Statement for application of reinforcement

The contractor (Structural Renovations Ltd) prepared a Method Statement that gave details on surface preparations, mixing and application of the adhesive and the cleaning up operation after installing the strips. The contractor also highlighted the skill level of the operatives and the required test that will be undertaken during the operation.

Step 11.
Site activities prior to installation

Since the site was an established refurbishment site, and the CFRP strengthening was completed by a specialist sub-contractor, there were no particular issues prior to the strengthening works.

Step 12.
Surface preparations

Tony Gee and Partners (TGP) undertook a site inspection after the surface preparation for the first set of strips to be installed. In addition to confirming that the contractor had prepared the surface adequately for bonding, TGP inspected and commented on the contractors arrangements for delivering material, and QC arrangements for handling, preparing, setting out and installing the strengthening material. The contractors proposals for QA testing and records were also reviewed.

Of particular importance were the contractor's arrangements for controlling dust. The CFRP works were undertaken simultaneously with other works on the same floor which included breaking-out and chasing in concrete and plaster surfaces. Since all partitions had been taken down, the contractor had to establish tented dust-free zones using polythene sheeting fixed to floor and ceiling, and control access in and out of these zones. TGP reviewed and commented on the arrangements after observing the effectiveness of the arrangements.

Pull off-tests were undertaken prior to bonding and the results were satisfactory.

Step 13.
Application of composite materials system

CFRP installation was completed in accordance with the specification and method statements. TGP witnessed the first batch of strips installed, and two other randomly selected installations, but the majority of strip installation was undertaken with the contractor completing the QA and QC required.

At a few locations the designed strengthening could not be installed due to clashes with remaining parts of the structure or previously completed works. Where these were identified on site, the designer was notified and the contractor did not commence works in the vicinity until an alternative special arrangement was produced by the designer (in accordance with steps 12 - 13.5 - 6 on the design activities flow chart). This avoided any reworking of non-compliant installation, but was only possible because the designer could produce such special arrangements very quickly after being notified of the issue.

Step 14.
Final QA checks, inspection and approval

Tap testing of the bonded regions were continuously undertaken as the CFRP installation proceeded. In one instance a region was found have voids and resin-injection into the voids was undertaken and the region retested (in accordance with Steps 14 - 15 - 14 on the design activities flow chart).

Inspection / maintenance and monitoring
Since all of the FRP material is applied to the top surface of slabs and subsequently covered by cementitious screed, direct inspection of the CFRP material is not possible. However, the locations of all material is recorded in the H&S file, so the CFRP could be exposed in future if the structure shows signs of distress and the performance of the reinforcement is questioned.