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Prestressing in Coventry Cathedral

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ABSTRACT

Coventry Cathedral was completed in the early 1960s and has some prestressed concrete elements to resist lateral thrust from the roof. Other prestressed structures of a similar age have had corrosion problems and this has drawn attention to the fact that there is little publicly available information about the structural system at Coventry. This paper addresses that issue and is in three sections. The first summarises the four different prestressing systems in the Cathedral and estimates the amount of prestress and its purpose in each location. By placing the information in the public domain it will be useful for both historians of church architecture and engineers in future generations who may have to work on the building. Although there is no evidence of corrosion in the building at the moment, it is impossible to inspect the existing tendons, so the second section considers what might happen to the structure if corrosion of the tendons were to occur. It is concluded that very little warning of failure would be given, which would be especially important for the tendons over the baptistry window and those in the nave ties. The final section considers what could be monitored to give as much warning as possible about future problems. The effects of loss of an individual tendon, which would not by itself be sufficient to cause failure of the structure, would cause only very small strains that would be difficult to distinguish from the background strains caused by temperature change. Many of the principles discussed in the second and third sections would be applicable to many other prestressed concrete structures.

1. Introduction

Coventry Cathedral was completed in the early 1960s. It is mainly constructed of unreinforced concrete, with the walls clad in stone and rendered blockwork, but there are some prestressed concrete elements to resist lateral thrust from the roof. The well-publicised problems with the prestressing tendons in Hammersmith Flyover, which was of a similar vintage [1,2] led the Cathedral authorities to be concerned that they might have comparable issues, so the authors were asked to investigate the use of prestressing in the Cathedral. Despite the architectural importance of the building it became clear that there was only a limited amount of published information about its structure. Since society expects cathedrals to be around for hundreds of years, it was felt that the basic structural mechanics of the Cathedral ought to be in the public domain. This paper addresses that issue by describing the prestress in some detail.

The paper also describes how problems with the prestressing might manifest themselves, and also whether anything could be monitored to determine whether corrosion were taking place. These considerations are of more general interest because they would apply to most prestressed concrete structures.

It should be stressed at the outset that no evidence has been found that the prestressing tendons are failing, but since they cannot be inspected, neither can any guarantee be given about their condition. It must also be stressed that no faults have been found in the original design.

1.1. Historical context

The present Cathedral stands on a site of both historic and religious significance. There have been three religious structures here in recorded history, beginning with St.Mary's Priory, dating back to the Middle Ages, of which only a few ruins remain [3]. The second structure was the previous St.Michael's Cathedral, constructed in the late 14th century. It was originally the parish church but became a cathedral when the Bishopric of Coventry was founded in 1918. It was seriously damaged, largely by fire, during a very heavy bombing raid on 14 November 1940 that left the tower and most of the walls standing. The stained glass and other treasures had earlier been removed against just such an eventuality.

The widespread destruction of homes, and the great loss of life, meant that the name “Coventry”, and the Cathedral in particular, came

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to symbolise both the suffering and resistance of the British population. In his "Give us the tools and we will finish the job" radio broadcast on 9 Feb. 1941, Churchill pointed out "*All through these dark winter months the enemy has had the power to drop three or four tons of bombs for every ton we could send to Germany in return. London and our big cities have had to stand their pounding.*" His audience would have been well aware that he was alluding to the attack on Coventry, as he was when he said on 30 December 1941 "*Hitler and his Nazi gang have sown the wind: let them reap the whirlwind*". The symbolism of Coventry remains potent: in the 1980s, when it became clear how much information had been obtained via decrypts at Bletchley Park, there was a furore that Churchill might have known in advance about the raid on Coventry and could somehow have prevented it. It now clear that the decrypts showed only that a major raid was being planned, not its target [4].

The Cathedral was thus far more than a church that had been destroyed in the bombing, so it was unsurprising that after the war there was a move to rebuild it, not just to re-establish it as a place of worship, but also to symbolise the recovery of the country. A commission was set up and a competition held that drew 219 entries internationally [5]. The brief made clear that a traditional east–west orientation was not required, and Basil Spence (knighted in 1960) won the competition with a design that placed the new Cathedral at right angles to the ruins. The central axis of the Cathedral thus lies in a north-south orientation, which is unusual for Christian architecture in Britain [6]. By connecting the new and old Cathedrals he was creating a symbol of reconciliation and forgiveness in the post-war period, which the Cathedral has since enhanced by the foundation of the "Community of the Cross of Nails", a reference to the cross made the day after the bombing from roof nails that were found in the burnt-out ruins. The foundation stone of the new Cathedral was laid in 1956 by Queen Elizabeth II. The funding was to be provided by the War Damage Commission who specified a "plain replacement" and the original estimate was for a "total cost not exceeding £985,000" or about £18m at 2017 prices. However, once the design was complete the estimate more than doubled, which led to cost-cutting [5]. Spence himself raised money for the Cathedral by lecturing in the UK and overseas, and many of the artworks were donated. The building was completed and consecrated in 1962, and is widely regarded as one of the gems of modern British religious architecture, having been one of the first post-war structures to be Grade I listed.

1.2. General description of the Cathedral

Spence designed the new building to be distinctly modern, but also to have aspects of a traditional cathedral. Though not large by comparison with the mediaeval English cathedrals, the interior has a cavernous and monolithic feel without the large columns that typically separate the nave from the side-aisles. From the outside, the Cathedral is relatively simple, unlike historic cathedrals with their extravagant buttressing and carvings. The walls are clad externally with warm-coloured Hollington sandstone, similar to the locally-quarried stone that had been used in the previous Cathedral. The geometric simplicity of the exterior was designed to contrast with the richness afforded by the many commissioned artworks, most notably Epstein's sculpture of "St Michael's Victory over the Devil" at the entrance and Graham Sutherland's tapestry of Christ at the northern end of the Cathedral, leading Spence to describe the building as a "plain jewel-casket" [5]. The Cathedral, which for the most part has a relatively simple structure, was engineered by a team from Ove Arup & Partners, led by Povl Ahm, although Arup himself and Edmund Happold were also heavily involved.

By tradition, the altar is placed at the eastern end of the nave, with a Lady Chapel beyond. The congregation enter the nave through the west front, which is often ornately decorated. In Coventry, the altar is to the north, with the entrance to the south, linking the ruins of the old Cathedral to the new (Fig. 1). To avoid confusion between liturgical directions and physical orientation of the building, in what follows all references to north, south, east and west will refer to geographical directions.

The Cathedral is founded on bored concrete piles to a sandstone layer that is about 10–12 m below the structure; these are surmounted by reinforced concrete pile caps or are directly placed under the walls.

The porch is covered by a barrel vault over the space between the ruins and the new Cathedral, which is entered from the south through a great glass screen that takes the place of the traditional "West Front". This leads to the large, square baptistry area, with a colourful window (Fig. 2a) to the east by John Piper and the Chapel of Unity to the west. There is no screen or divider separating the baptistry and the nave, which tapers to the north, focussing attention on the altar and the Sutherland tapestry. The serrated walls of the nave were faced in concrete blocks as an economy measure and then rendered, which aids the acoustics, and appear not to be punctured by windows, but the south-facing edges of the serrations are glazed to their full height of 23 m, illuminating the congregation from behind and throwing light forward to the altar. The serrations leave triangular spaces at the edge of the nave known as Hallowing Places. A second side chapel, dedicated to Christ the Servant, protrudes at right angles at the northern end of the Cathedral near the Lady Chapel.

The shallow roof spans the nave without internal support, but is hidden from view by a ceiling canopy made from pyramidal timber panels that span between thin concrete beams, which are in turn supported by slender precast concrete columns (Fig. 2b). This separation of roof from ceiling significantly simplified the structural design.

The roof of the baptistry supports a 25 m high lightweight aluminium truss fleche that is surmounted by a "flying cross". Both were lifted into place by a RAF Belvedere helicopter.

1.3. Existing documentation

For a structure as significant as Coventry Cathedral, it is perhaps surprising how little there is in the way of published technical information. Plenty has been written about its architecture, such as Ref. [7], and the architect's own book [5] but apart from some brief articles written during the construction, giving an indication of the design intent of the Arup engineers, [8–12], there are no papers that give enough detailed information to allow an analysis of the stress-state of the building. The project is mentioned in Arup's biography [13] and its superficial condition was reviewed more recently by Ref. [14].

1.3.1. RCAHMS

Basil Spence spent many years at the beginning of his career working in Scotland and the competition entry was designed in his Edinburgh office. After his death in 1976 many of the documents that survived from his practice were donated by Anthony Blee and his wife Gillian (née Spence) to the Royal Commission on the Ancient and Historic Monuments of Scotland (RCAHMS), based in Edinburgh. This archive contains hundreds of categorised folders, photos, scans and drawings relating to the design and construction of Coventry Cathedral. Amongst the many items of day-to-day communication there are some that give crucial engineering information, such as material data, letters between the engineer and Clerk of Works about tendon stressing, and stressing sheets detailing the actual extensions applied to the tendons.

1.3.2. Arup archives

Some documents were archived by Ove Arup & Partners (now simply Arup). They hold two boxes of papers but many are rough calculations with little indication of their context. However, there were enough clear and legible prestressing calculations to inform similar calculations for the rest of the Cathedral.

1.3.3. Cathedral archives

Coventry Cathedral archives contain much information, including