Structural interventions in English Cathedrals

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ABSTRACT: The paper is an overview of the structural interventions made to English Cathedrals. It reviews some of the most common problems and disasters and looks at how they have been overcome with reference to particular events.

1 OVERVIEW

I aim to give an overview of structural interventions that have been made to our Cathedrals in England. Clearly this is a huge topic worthy of many volumes but I shall attempt to sketch a flavour of the some of the key historical events and the common structural problems with reference to some particular case histories.

Many of our Cathedrals in England were built, and in many cases rebuilt, during the period of great activity in the 1100 and 1200’s. As architectural fashions changed, new prelates were appointed or local saints beatified, there was a tendency to refashion the Cathedrals in the latest style. The growing wealth of the church made all this possible, but excited the envy of the English monarchs. This led to Henry VIII abolishing the monasteries and acquiring their wealth in 1536, at which point many of these fine buildings became stone quarries for the locals. The depredations continued during the civil war in the 1640’s, when most of the art work and fine interiors were stripped and the buildings were sometimes used as stabling for Cromwell’s forces. During the Victorian period, in the latter part of the 19th century, there was a massive programme of repair, renewal and restoration in our Cathedrals. This was funded by public donation, much from very wealthy individuals. Repair schemes included dramatic tasks such as the saving of the east end of Winchester Cathedral, by the underpinning of the foundations by the diver Robert Walker. The work often went well beyond restoration, with Gilbert Scott making many “Improvements” for example at Chester Cathedral.

Many of the restorations at the end of the 19th and early 20th centuries made use of the “magic new material” reinforced concrete. A typical example being the tieing together of the towers and nave of Lincoln Cathedral with concrete beams and frames, together with the tieing of walls with phosphor bronze rods and extensive cement grouting.

2 DISASTERS

The Cathedrals have survived earthquakes, fire, flood and man’s depredations over their 900 year history and survive today as superb examples of man’s endeavours and his wish to glorify God.

The structural designs often pushed the limits of structural knowledge and collapses were not uncommon, a list just of some of the major spire and tower events is instructive.

1107 Winchester Walkelin’s central tower fell and the present one built...
1170 Gloucester South tower to the west front collapsed
1175 Worcester Western tower fell into the river Severn
1185 Lincoln The whole building collapsed during an earthquake
1210 Chichester West tower collapses
1238 Lincoln Central tower fell
1248 Wells Central spire fell in an earthquake
1272 Norwich Spire burnt down during rioting
1322 Ely Central tower removed before it fell
1362 Norwich Replacement timber spire blown down in a gale
1407 York Central tower and Spire collapsed
1463 Norwich Second replacement spire destroyed by lightning
1548 Lincoln Timber spire (524 ft high) destroyed by lightning
1561 Old St. Paul’s Timber spire destroyed by lightning
1615 Ripon Central spire collapses
1635 Chichester West Tower collapses again
1640’s Durham West Tower demolished by Cromwell’s army
1642 Lichfield Central spire demolished by Cromwell’s army
1704 Canterbury Central spire removed due to storm damage
1786 Hereford Central spire removed after collapse of west front
1807 Lincoln West front spires demolished as unsafe
1832 St. Albans Spire removed as unsafe
1861 Chichester Central tower and spire collapse
1880’s Peterborough Tower replaced to prevent a collapse.

This is by no means an exhaustive list as it not does not include many of the major fires that have caused untold loss to the Cathedrals, but does show the determination to recover from disaster.

3 LONG TERM WORRIES

Over this time the buildings were subjected to much repair, renovation and alteration and we know, as did our forefathers, of the value of constant maintenance and the dire consequences of its omission. We have records of many of these campaigns of repair and alteration and it is fascinating to find that many of our current concerns are merely the continuation of worries of the past generations.

I have personal experience of two very clear examples of such ongoing concerns, one which, so far, has required no intervention, but a second which resulted in significant works.

The retro choir at Wells Cathedral is a vaulted area between the high altar and the Lady Chapel, the supporting columns are very slender and support an unbalanced vault onto which are imposed large loads from flying buttresses. On visual inspection one is immediately worried that the vault is in tension and that the slender columns are undergoing excessive bending.

I have investigated these carefully and can show that they have a factor of safety greater than 1.0 which is just as well as they have been standing unchanged for 900 years. On searching back through the archives I find that every Cathedral Architect, Engineer, and before that the master masons, were all expressing concern about the retro choir and all setting up their own monitoring systems – just as I have done! Indeed the Victorians had a series of specially fabricated props which were kept close to the retro choir for instant installation if any cracks appeared. My own advice is that if cracks appear everyone is to run, as there will probably be localised and fast compression failures! It gives one a profound sense of historical continuity to find that we share the same worries as our forbears.

Another fascinating case is that of the Deans Eye window at Lincoln Cathedral. This is one of the top five rose windows in Europe with fabulous 1220 stained glass and a very ambitious form.

The companion window, the Bishop Eye collapsed within 50 years and the archives show a long history of repairs to the Deans Eye, some successful and some a failure. A constant theme in Clerk of Works records over the centuries is how to keep the window stable. This was initially by adding cramps and lead filling to the joints as they moved, then by bracing across the central opening and latterly by adding major cross bracing behind the window. Until by the year 2000 no

Figure 3. Chichester spire collapse.
more patching was possible and replacement was the only option. A complete reconstruction of the stone tracery was required and the opportunity was taken to include some hidden strengthening so that the internal and external cross bracing which had disfigured the window was no longer needed.

4 THE LAST 50 YEARS

In the latter half of the 20th Century there has once more been a significant round of repair and renewal, with priming funding from English Heritage, but with the majority raised from appeals. As opposed to the Victorian repairs this time there was little “improvement”, the emphasis being upon conservation and restoration.

There were major interventions to stabilise the structure of these great buildings and four typical examples are:

1 Improving existing foundations by some means of underpinning, such as at York Minster.
2 Tieing elements together with concrete ring beams at roof, clerestory and triforium levels and adding tie rods through towers and facades. Ely Cathedral being a good example.
3 Stabilising towers and spires with concrete or steel frames, such as Salisbury Cathedral.
4 Reconstructions after fires, several examples unfortunately and York Minster suffered more than most.

5 YORK MINSTER

York Minster is built on an historic site and overlays previous constructions including a roman basilica. The Minster was started in 1100’s but its present form was finished in 1472 – much of it having to be rebuilt after the central tower collapsed in 1407 whilst attempting to remodel the tower piers.

5.1 Underpinning

In 1956 a detailed survey showed a number of instabilities in the building. The central tower had differential settlement of 225 mm that was continuing and investigations showed severely damaged foundations, the east wall was 600 mm out plumb and still moving and the building was suffering a number of other similar problems. A major programme of works was undertaken of which the underpinning of the central tower piers was probably the most significant. The intention
of which was to halve the bearing pressure below the foundations to approx. 300 Kn/m², given that the supporting soil is poor it is no wonder that it was still settling.

The principle employed was to join the footings below each of the central piers to their adjacent nave and transept columns making one large footing twice the size of that existing. The masonry footings were surrounded by new concrete and the whole post-tensioned into a single composite foundation. In order to ensure that the new parts of the foundation would carry load, additional footings were cast below the new areas, with flat jacks between them and the new foundation. The jacks were then stressed in order to consolidate the soil below these areas, when this had happened and all movement ceased then the gap and jacks were grouted.

This was a massive and complex task which was undertaken successfully and has ensured the future of the minster.

5.2 Restoration after the fire

The instabilities were not the only problems at York. In 1984 a major fire resulting from a lightning strike destroyed the South Transept. A significant reconstruction was then needed.

6 ELY CATHEDRAL

In the early 1970’s inspections showed that the stonework in the West Tower at Ely Cathedral was loose and decayed with many cracks through the tower. The tower in common with many others is effectively two almost separate shells, so that over time they move independently, resulting in cracking and loss of stiffness.

More detailed research showed that in the 1860’s Gilbert Scott had carried out major repairs which included the installation of massive wrought iron bars, 125 mm by 30 mm diagonally across the belfry and four 60 mm diameter wrought iron ties across the tower at two levels, plus the inclusion of many other wrought iron ties and straps throughout the tower. These were now exacerbating the problem as some of them corroded.

The work was carried out under the control of Jacques Heyman and was in several parts.

1 The external wrought iron ties and strapping that was corroding, and damaging the stonework, was removed, whilst all the internal ties that were still in good condition were not disturbed.

2 The lower two thirds of the tower have been reinforced by stitching with stainless steel bars and grouting. It having been found that the core to the walls was loose in areas with some voids. The stitching effectively created complete ring beams at each of four levels tying together the two shells of the tower.

3 The geometrical stability of the tower was further assured by the provision of three sets of stainless steel ties passing from face to face of the tower and connecting together the corner stairs. One of these replaced some of Scott’s work and the others were additions.

4 The octagonal belfry, which is of a lighter construction than the main portion of the tower was
strengthened at its top by a new reinforced concrete ring beam, with stainless steel cables inserted and pre-tensioned at a lower level.

This is an excellent example of the progression of repairs to Towers in English Cathedrals. As we have seen there were numerous collapses of towers relatively soon after their construction or alteration and there was little that could be done with the technology available at the time to save them. They were often significantly under designed.

As the centuries passed by the continuing settlement of overloaded ground below the central piers caused ongoing cracking of the major towers and this resulted in loss of stiffness which caused further redistributions of load. This often increased the load on the piers, with an ongoing racheting increase in cracking and movements. Sometimes this was added to other interventions such as the removal of the choir screen at Chichester which ultimately caused the failure of the spire. In other cases the inclusion of wrought iron ties and strapping alongside the repair of crumbling stonework was sufficient to maintain stability.

Figure 10. Ely Cathedral – strengthening of the West Tower.

However, as is so often the case, whilst the intervention was successful it introduced other difficulties that in time also needed remediation. So that whilst in the original construction of these massive tower walls timber ties were sometimes included to hold the walls together, these rotted and the towers began to lose their integrity. So the wrought iron ties, in their turn, decayed and needed replacing.

7 SALISBURY CATHEDRAL

A different approach was undertaken at Salisbury Cathedral where there were serious concerns about the stability of the spire in the 1970s. Salisbury spire has a series of bands of open stonework at several levels in its height and the lowest level of stonework was decaying such that there were serious fears as to its ability to continue to carry the wind loads and weight from the spire. It was not possible to individually replace the stones as it was highly likely that the spire would collapse with the removal of some of the stones. Various options were considered including the dismantling and rebuilding of the spire – though needless to say that was thought of as a last resort.

The successful solution was to introduce a stainless steel frame inside the spire which effectively transmitted the load from the upper part of the spire into the frame and bypassed the open section. The frame was then jacked against the upper spire, to ensure that it was taking some of the load from the open section.

8 REPAIR AND MAINTENANCE

Alongside these major interventions there is an ongoing need for constant repair and renewals. All
Cathedrals have a long programme of stone replacement, working around the exterior over a 100 year cycle replacing eroded stone. The work can vary from the straightforward on nave walls, to the complex on flying buttresses, to the difficult on towers.

Wells Cathedral central tower requires replacement of areas of heavily eroded stones and other repairs on roughly a 120 year cycle; this being about the period by which time pieces of stone are falling off to the danger of the public below. In 1998 it was time to carry out such a task. The biggest difficulty was getting the access to all faces with a working scaffold as there is no access to the ground below any face. A flying scaffold had to be used supported from the transept, nave and choir wall junctions, with an access bridge along the ridge of the south transept from a lift/stair tower on the south transept gable.

The sequence in which the stone replacement is carried out is important as with some areas requiring extensive repairs it is vital to ensure adequate load transfer at all times to avoid local overstressing.

As well as these major works, repairs and replacements there are always new constructions happening at Cathedrals which impact upon the existing fabric. Many Cathedrals are improving their facilities such as by the addition of choir rehearsal spaces, storage, education rooms, visitor centres and refectories. These all need to be close to the main building and often structurally impact upon, it. Added to which are the difficulties with the foundations, as invariably these new buildings will be located over areas previously built upon, so with important archaeological remains below the surface. The foundations become a game of finding any spaces that are clear for support and then trying to carry the building from these points.

9 FINALLY WHAT OF THE FUTURE?

All over Europe we have repaired, strengthened and stiffened our major masonry buildings with concrete. Is this a good thing? Is it durable? What happens to our lovely flexible masonry buildings in the next 900 years after they have been stiffened and tied together? That has to be the subject of a future paper.

REFERENCES

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