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Renforcement d'une tour d'église, en Angleterre, par la précontrainte

Die Verstärkung eines Kirchturms in England mittels Vorspannung

Strengthening a church tower in England by prestressing (Summer 1948)

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This is only a relatively small work and cannot be compared with all the large constructions shown here, but it may be of interest, since it relates to a novel application of prestressing to walls, whereby Prof. Magnel's sandwich plates were employed for the first time in Great Britain.

Due to mining subsidence the tower of St. Luke's Church, Silverdale, Staffs. had become tilted and the walls were seriously cracked.

In order to prevent further damage due to future settlement it was necessary to strengthen the walls of the tower. The design was prepared by the author in collaboration with Mr. Harold Goldstraw, A. R. I. B. A. and Mr. Harry Mason, M. I. Min. E. whereby the author's system of prestressing was applied. This is a composite construction comprising a concrete member or an assembly of bricks and a cement mortar filler in a groove or chase which contains tensioned steel. The principal idea of this solution is shown in figure 1 according to which beams were constructed within the walls.

Holes were bored in the walls and cement grout injected under pressure, until the masonry indicated by the shaded area was consolidated. Chases (*a*) were cut in both faces of the wall and a recess (*b*) was formed at each end. Wires (*c*), placed in the chases and attached by anchorages (*d*) to 10 in by 8 in steel strongbacks (*e*), were stretched and the reaction was taken by the strongbacks and transferred to the walls by distribution plates (*f*). In the event of further subsidence the compressed beam formed in the walls can act as a simply supported beam or as a cantilever with the risk of tensile stresses occurring in the masonry being considerably reduced.

In the sectional plan of the four walls of the tower (fig. 2) are shown

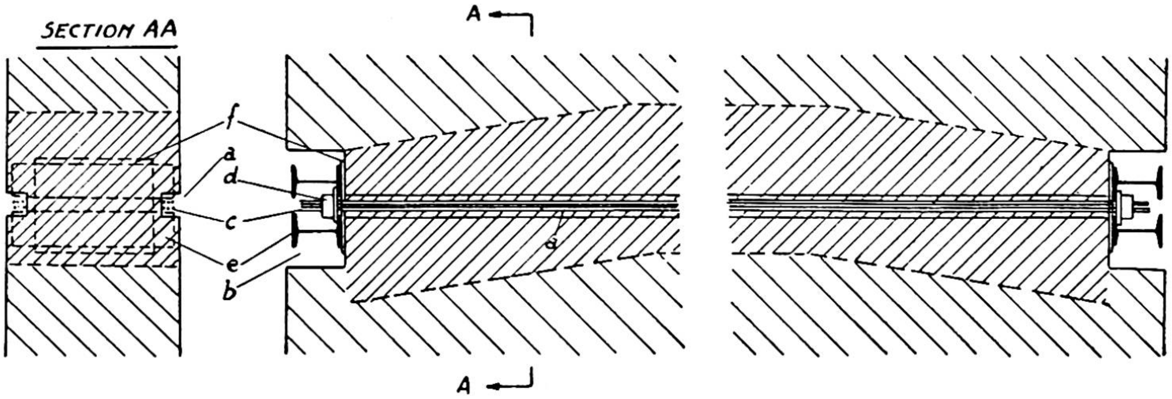


Fig. 1. Diagram showing the formation of a prestressed beam in a wall.

the chases (x) which are at slightly different levels in each wall (see vertical sections AA and BB), the recesses (y) and the openings (z) which were cut through adjacent walls to give access to the stretching devices. The space between the window and the plinth in one wall made it necessary to construct a reinforced concrete sill across the window opening, as seen in section AA, to provide a compression flange for the beam in the wall. A chase in the inner face of one of the walls, in which an arch had previously been bricked up, is shown in figure 3 with the wires in position.

Figure 4 is a view of the outer wall from South showing the chase and the wires before tensioning.

Figure 5 shows the strongbacks which were provided at each end of each wall. The inner flanges were cut off to permit access to the jack and transverse stiffening plates and angles were welded to the joists.

To offset the influence of creep of steel and to avoir any inexactness when reading the manometer the tension was increased by 5 per cent. Further a small extra tension was applied to the wires to offset the slip occurring at wedging, the amount of which was measured. This slip is

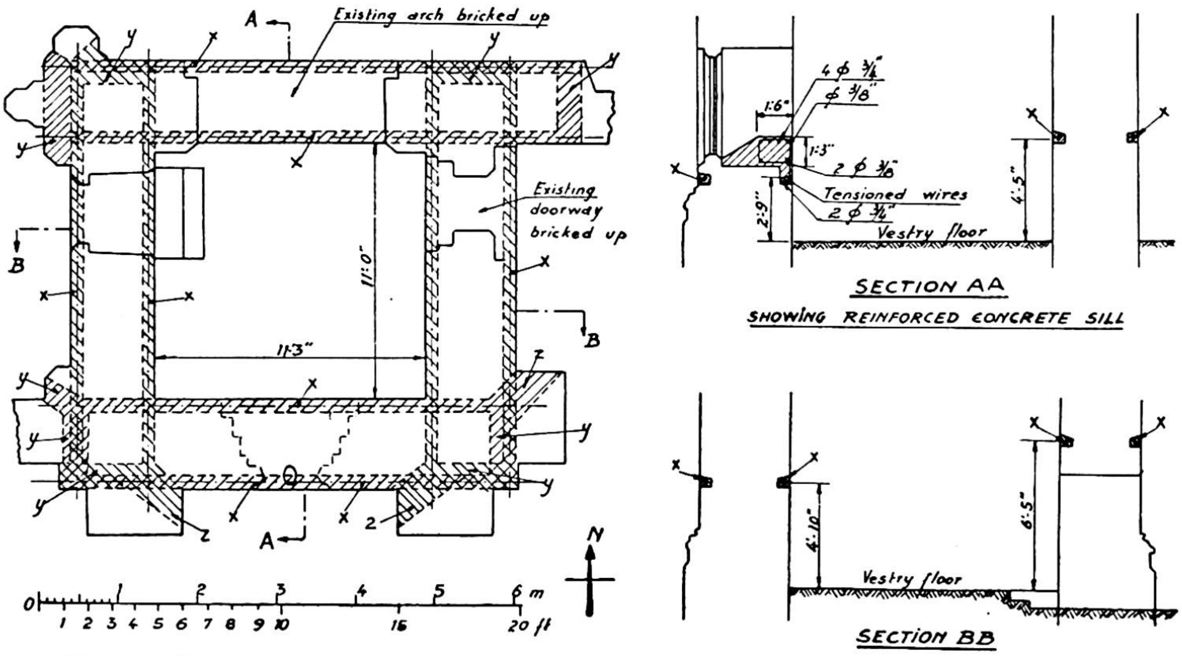


Fig. 2. Plan and vertical section of the church tower to be strengthened.

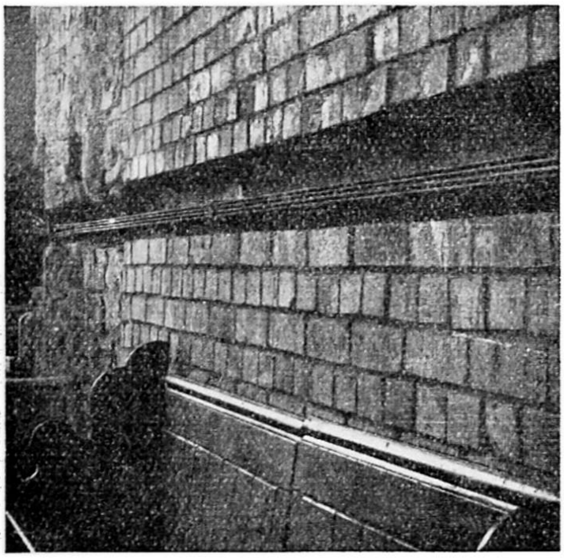


Fig. 3. Chase in the inner wall, where the opening had been bricked up.

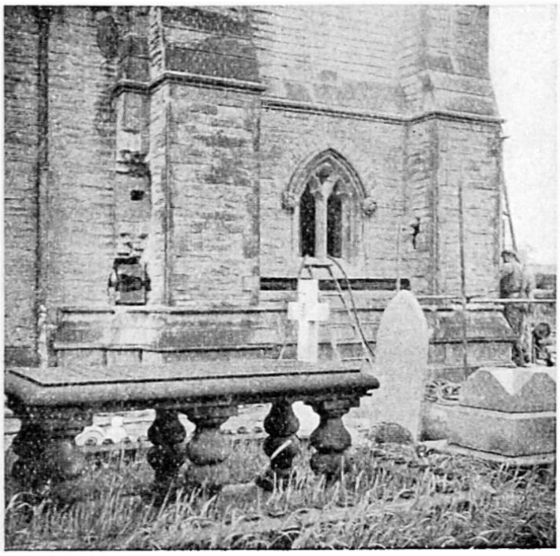
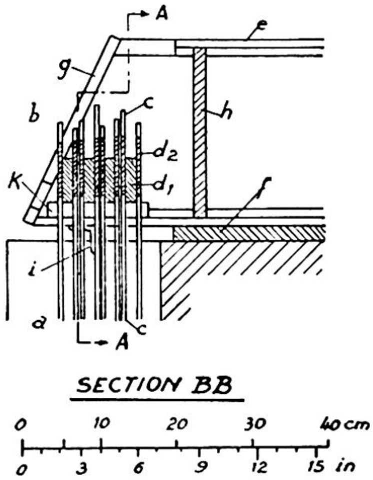
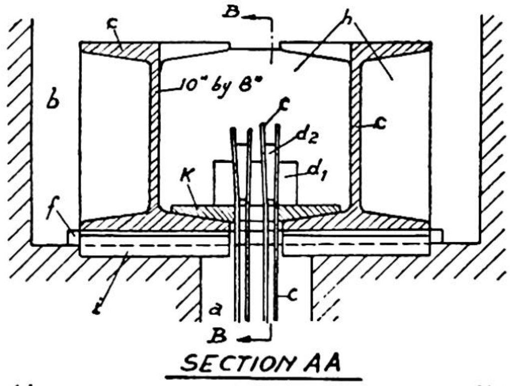


Fig. 4. Chase in the outer wall, with wires before tensioning.

very small and can generally be neglected, but is of some influence in a beam of limited length.

There are 32 wires in each chase and the total compressive force applied to each wall was 128 tons, that is 2 tons in each of 64 wires. The actual force induced in each wire was 2.1 tons. The wires are 0.2 in in diameter and are of hard cold drawn steel having a tensile strength of 100 tons per sq.in. Upon completion of the prestressing operations the wires were embedded in cement mortar that filled the chases.





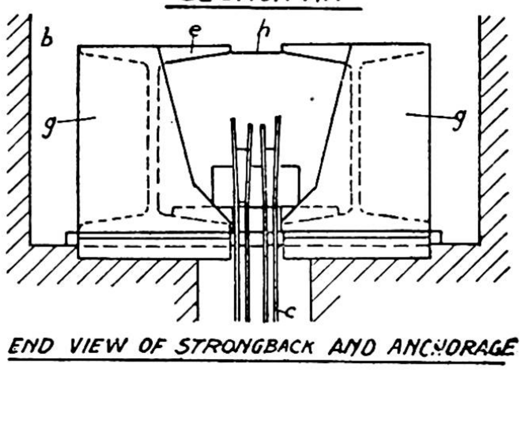


Fig. 5. Srong-backs and anchorages :

a : chase; b : end recess; c : tensioned wires; d : anchorages (d, : sandwich plates; d : wedges); e : steel joist; f: distribution plates; g : end stiffening; h : cross stiffening plates; i : stiffening angle; k : intermediate plate between sandwich plate and flange of steel joist.

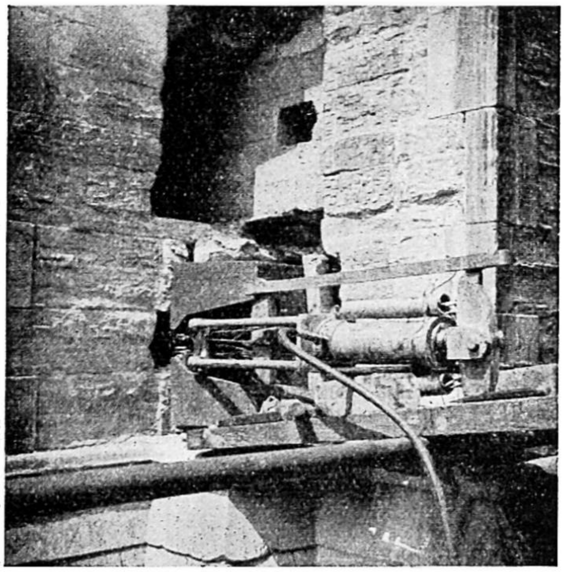


Fig. 6. Jack for tensioning at one end of the chase (see fig. 4).

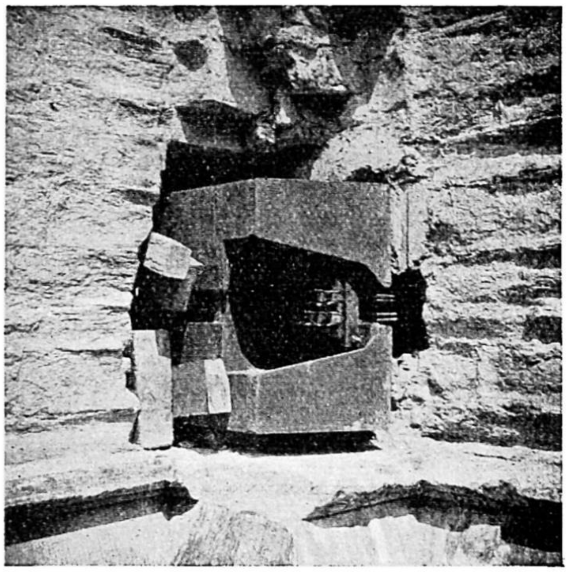


Fig. 7. Strongback with anchorages at one end of the chase (see fig. 4).

Prof. Magnel's method of tensioning 2 wires simultaneously using sandwich plates was employed.

Photo 6 shows the jack in position at the one end of the chase figure 4 whereas in figure 7 the opposite end is seen, the wires being wedged into the sandwich plates.

Photo 8 shows the end of chase, figure 3, after tensioning before the surplus ends of the wires were cut off.

In figure 9 this chase is seen filled with cement mortar, the strongbacks for the other walls being already placed and figure 10 is a view of the outer wall from south corresponding to figure 4. In this figure the stone facing is already fixed and the new reinforced concrete sill mentioned in connection with figure 2 can be seen.

The average width of the « beam » formed in the wall is 3′6″ and total depth about 4 ft. The eccentricity of the 64 stretched wires is about 10 in. The ultimate moment of resistance of the beam, when the stress in the wires is 100 tons per sq.in is 13 440 000 in-lb which is equivalent to the ultimate resistance of two 20 in by 7 1/2 in by 89 lb steel beams when stressed to the yield point stress of, say 40 000 lb per sq.in. The calculated stresses in the concrete due to the prestressing force alone, at the time the prestress is established are 318 lb per sq. in (compressive) at the bottom fibre and 34 lb per sq. in (tensile) at the top fibre. A maximum loss of prestress of only 10 per cent is assumed because the stretching force was increased by 5 per cent to counteract the creep of the steel and because there will be little shrinking or creep of the masonry. If it is assumed that the modulus of rupture is 250 lb per sq.in the moment of resistance when cracking is about to occur is $1/6\ (0.9 \times 318 + 250)\ 48^2 \times 42 =$ 8 550 000 in-lb. Thus cracking may occur at $\frac{8\ 550\ 000}{13\ 440\ 000} = 0.64$ of the ultimate load, and therefore an ample margin is afforded.

This method of prestressing could also be readily applied to creating carrying beams in foundations and to strengthening existing reinforced concrete beams.

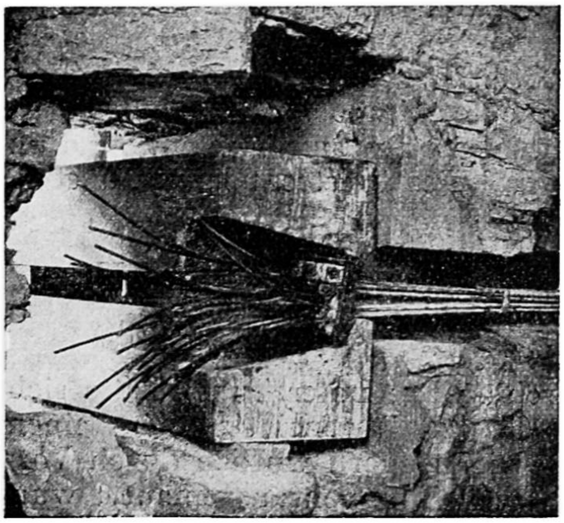


Fig. 8. Tensioned wires at the anchorage at the end of the chase (see fig. 3).

Résumé

A la suite de creusement de galeries souterraines, la tour d'une église anglaise (Staffordshire) s'est affaissée et inclinée et les murs présentaient des fissures importantes. Les quatre murs furent renforcés par la précontrainte, après briquetage et cimentation des ouvertures pour résister à la compression. Pour la première fois en Angleterre on utilisa la méthode du professeur Magnel par plaques sandwich, combinée avec l'idée de l'auteur qui consistait à prévoir aux deux côtés des rainures recevant les fils de précontrainte. Après tension, ces fils ont été ancrés dans les poutres de répartition de l'effort par des plaques sur tout le mur. De cette manière chaque pan de mur constitue, en association avec les

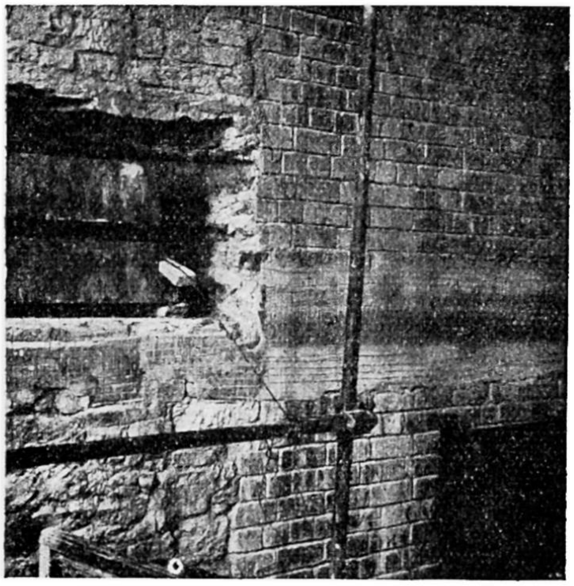


Fig. 9. Chase in inner wall (see fig. 3) filled with cement mortar after tensioning.

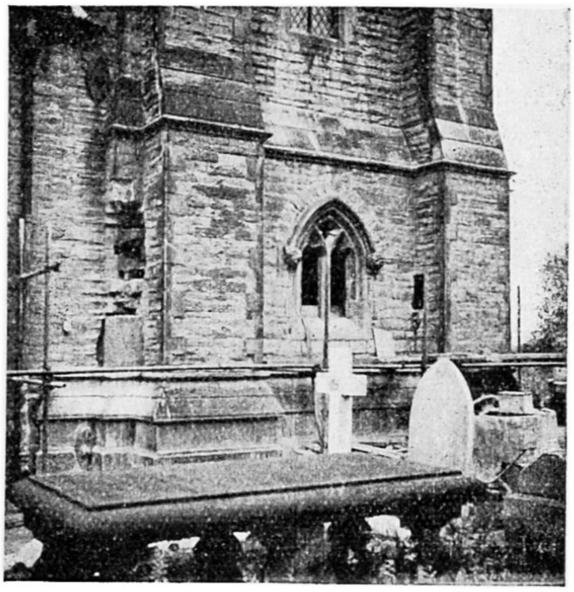


Fig. 10. The South side (see fig. 4) after replacing the stone covering, but before tensioning the wires in the Eastern and Western walls respectively.

fils tendus dans les rainures (bouchonnées après par du mortier de ciment), une poutre sollicitée comme poutre simplement appuyée ou comme poutre cantilever. La charge portante d'une telle poutre, équivalente à une grosse poutrelle métallique, est importante. D'autre part une poutrelle métallique aurait dû être supportée pour l'obtention d'un résultat semblable. Des dessins et photographies illustrent le projet et la réalisation de ces travaux.

Zusammenfassung

Infolge Senkungen (verursacht durch Abbau unter Tage) hatte sich der Turm einer Kirche in Staffordshire (England) geneigt und in seinen Mauern zeigten sich klaffende Risse. Alle vier Mauern wurden durch Vorspannung verstärkt, nachdem einige grosse Oeffnungen ausgemauert wurden und Zementmörtel in die Mauern injiziert worden war, um ihnen die zur Aufnahme des zusätzlichen Druckes notwendige Festigkeit zu geben. Man gebrauchte hier zum ersten Mal in England die Vorspannmethode mittels Sandwichplatten von Prof. Magnel. Ferner wandte man das System des Verfassers an, indem auf beiden Seiten der Mauern Nuten herausgespitzt wurden, in welche man die Drähte verlegte. Diese wurden angespannt und in den Widerlagerbalken verankert, welche durch Verteilplatten den Druck auf die Mauer übertragen.

Damit bildet jeder Mauerteil zusammen mit den gespannten Stählen in den Nuten (welche nachher mit Zementmörtel ausgefüllt wurden) einen Träger, der als einfacher Balken oder als Kragarm wirken kann. Die Tragkraft eines solchen Balkens ist beträchtlich und derjenigen eines schweren Stahlträgers gleichwertig. Zudem hätte beim Einziehen desselben das Mauerwerk unterfangen werden müssen. Zeichnungen und Photos illustrieren den Entwurf und die Ausführung.

Summary

Due to mining subsidence the tower of a church in Staffordshire (England) had tilted and the walls were seriously cracked. All four walls were strengthened by prestressing, after some openings had been bricked up and cement mortar injected into existing walls to make them capable of taking longitudinal compression. Prof. Magnel's method of tensioning using sandwich plates was employed for the first time in Great Britain and the author's system applied, according to which chases are cut at both faces of each wall, wires are placed in these chases, tensioned and anchored to strongbacks which transmit the precompression by means of distribution plates to the walls.

Thus a part of each wall together with the tensioned ties in the chases (which are filled with cement mortar) forms a beam capable of acting as a simply supported beam or as a cantilever. The carrying capacity of such a beam is considerable and equivalent to that of a rather heavy steel joist which would have had to be inserted by underpinning to obtain the same result. Drawings and photos illustrate design and execution.