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Autor: Pryke, John
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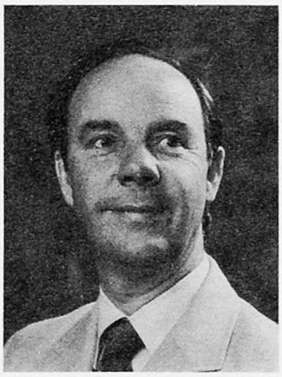
Relevelling, Raising and Re-siting Historic Buildings

Soulèvement et déplacement de monuments historiques

Heben und Verschieben von historischen Gebäuden

John PRYKE
Chairman
Pynford Limited
Waltham Abbey, Essex, England



J. Pryke, born 1928, joined his family business, Pynford Limited, in 1952, as an Engineer after graduating from Trinity College, Cambridge. He has had 30 years' experience in underpinning schemes, foundation and structural design, moving buildings, structural alterations and restoration.

SUMMARY

The Pynford stooling method has proved the key to a simple, safe and systematic method of underpinning a wide variety of brick and stone masonry buildings. The paper describes a selection of underpinning, jacking and moving projects, including raising a 14th century building, moving an 18th century building, both in the U.K., and raising and moving a building in Norway. Proposals for lifting the Leaning Tower of Pisa up 2.25 m and for preserving historic city squares by raising the surrounding buildings are discussed.

RESUME

La méthode Pynford d'étançonnement s'est avérée un moyen simple, sûr et systématique pour étayer une grande variété d'édifices en briques et en pierre. L'article décrit une sélection de projets pour étayer, soulever et déplacer des bâtiments, tel que le soulèvement d'un bâtiment du XIVème siècle, le déplacement d'un édifice du XVIIIème siècle tous les deux au Royaume-Uni, et le déplacement d'un édifice en Norvège. Des propositions pour redresser la tour de Pise et pour préserver des places dans des cités historiques en soulevant les édifices environnants sont discutées.

ZUSAMMENFASSUNG

Die Pynford-Stützmethode ist ein einfaches und sicheres Mittel für die Unterfangung verschiedenster Backstein- und Blocksteingebäude. Der Beitrag schildert eine Auswahl von Unterfangungen, Hebungen und Verschiebungen von Gebäuden, einschliesslich das Heben eines Gebäudes aus dem 14. Jahrhundert, das Verschieben eines Gebäudes aus dem 18. Jahrhundert, beides in Grossbritannien, sowie das Verschieben eines Gebäudes in Norwegen. Vorschläge zur Hebung des Schiefen Turmes in Pisa um 2.25 m und zur Erhaltung der historischen Plätze durch das Heben der umliegenden Gebäude werden diskutiert.

"RELEVELLING, RAISING AND RESITING HISTORIC BUILDINGS"

PRESERVING OUR BUILT HERITAGE. 1. If we are to preserve the wonderful heritage of our older buildings and cities we must not only maintain the fabric by continual care and repair but also maintain their useful occupation. Major expenditure is needed if the foundations fail, or if sites sink or water levels rise causing repeated flooding. Our major cities also need to be modernised if they are not to be deserted and alternatives to demolition and reconstruction are needed. If there is a high risk of earthquakes then important masonry buildings may also need the insertion of structural frameworks with minimum disturbance of the internal appearance.

2. The cost of major structural alterations and repair is a combination of the direct cost of the structural work and the indirect cost of temporary works, protection and reinstatement. It is most important to develop methods that reduce both direct and indirect costs. This paper describes applications of the Pynford stool method of constructing reinforced concrete beams within or under loadbearing brick or stone masonry walls. The Pynford method does not require needles or other temporary external shoring, and it has been used to underpin over 10,000 homes and many larger buildings. The method has also made possible and economically viable many projects for lifting buildings small and large and for moving them to new sites. Thus roads can be widened and car parking or further accommodation can be provided beneath older buildings with reasonable economy and without wholesale demolition and reconstruction. A current project in Norway, described briefly later in this paper, is particularly important. A building is being moved back to facilitate road widening and raised to provide an additional level for parking. The work is a privately financed development project. It has been made commercially viable by the combination of a number of techniques, each of which have lowered costs.

3. The construction of frameworks of reinforced concrete beams beneath walls of loadbearing brick or stone masonry, using a simple, safe and systematic method, is the essential key if projects for raising and moving major buildings are to be completed at predictable cost and on programme. Once the frame and permanent supports beneath it are constructed any building may be lifted. The amount of damage will then depend upon the precision with which the jacks are controlled. With suitable equipment differentials of less than 5 mm can be maintained during lifting and moving even if the supports yield differentially. This will eliminate significant damage. Heavy structures require hydraulic jacking systems to lift them and sliding means such as p.t.f.e. on stainless steel, or grease skates running on accurately constructed tracks to move them. Smaller buildings or monuments may be lifted and moved by crane (Fig. 1) and road trailer.

UNDERPINNING. 4. Underpinning is required when existing foundations are failing or when proposed projects will weaken or remove the support that they provide. If existing foundations are too small then it may be practicable to enlarge them to provide a greater support area and reduced ground pressures. This was the method adopted to stabilise the central tower of York Minster, (Ref. 1). Pynford has proposed that the Leaning Tower of Pisa should be stabilised by enlarging the foundations. It is most usual, however, to provide new and deeper foundations when existing ones fail. Unless a firm stratum can be found within, say, 5 m of ground level, or less if the water table is high, it is cheaper to construct piles beside walls than to dig piers beneath, particularly in non-cohesive soils with a high water table. However, capping and supporting costs are reduced if support is provided directly beneath the loads, and much disturbance and reinstatement cost is eliminated if access is restricted to one side only of the wall to be underpinned. This can be done using the Pynford stooling method coupled with hand excavated piers or jacked in piling.

THE PYNFORD STOOLING SYSTEM. 5. The Pynford stooling system was an important step forward in technique. It eliminated needles and props on either side of

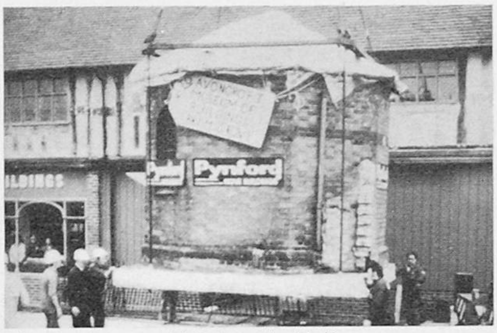


Fig.1. Crane lifting building.

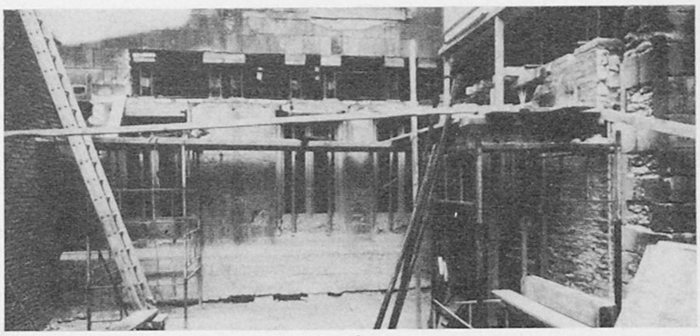


Fig.2. Stools at Trinity College.

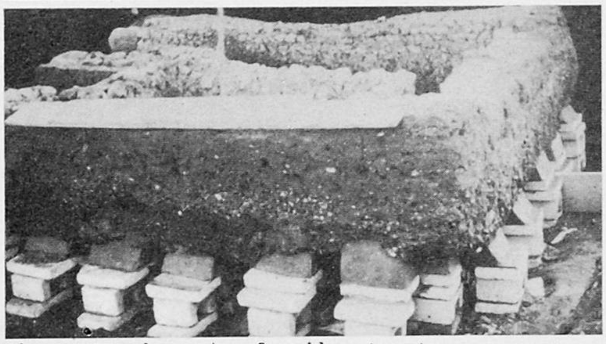


Fig.3. Stools under fragile structure.

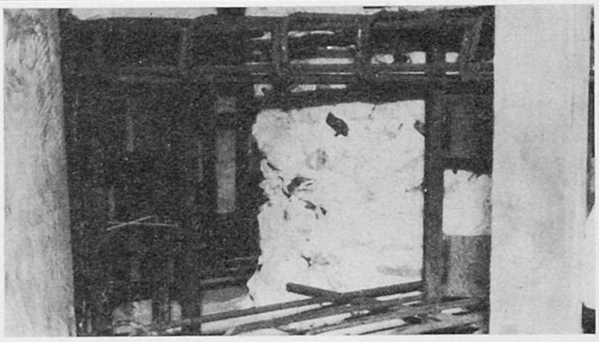


Fig.4. Stools in Winchester columns.

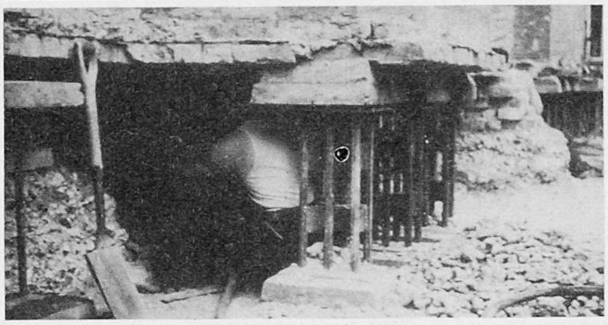


Fig.5. Stools under 400 T pier

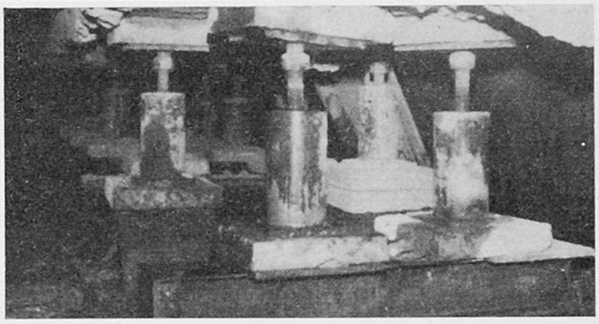


Fig.6. Pre-loading timber piles.

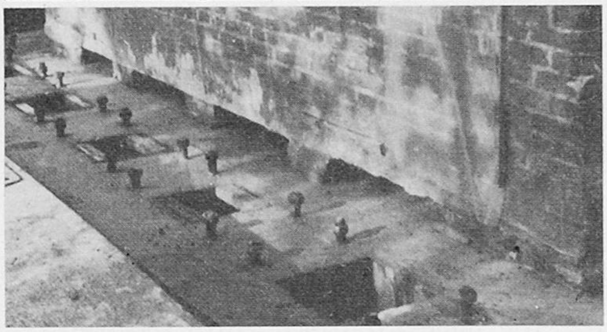


Fig.7. Underpinning Dutch church.

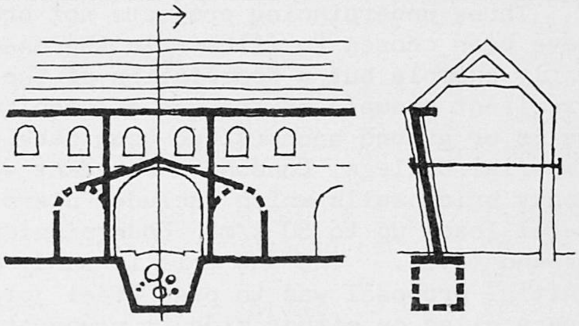


Fig.8. RC frame in mediaeval wall.

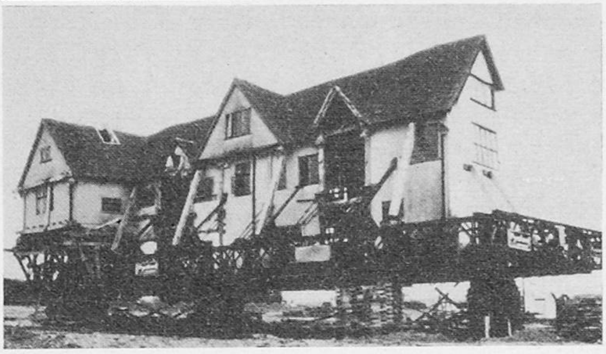


Fig.12. Steel frame under 17th Cent. mansion.


Fig.13. 2500 T being moved - Norway.

the wall by using the existing foundation, or the wall that is to be removed, to support a permanent prop, the Pynford stool, which replaces the needle. The method has been described on a number of occasions by the author and others. (Refs. 2, 3 and 4). It is very safe and offers a controlled method of cutting into loadbearing masonry no matter how weak. As well as the intrinsic safety of the method, the stooling system has many practical advantages. This is demonstrated by the increasing use of the stooling method of cast in-situ underpinning beam construction world-wide.

6. Masonry with a low bearing capacity per unit area is replaced with steel struts which can carry the same load in a very much smaller area. (Fig.2). If the wall is thick, two or more stools may be placed in a row through the wall thickness. If the wall is fragile it is only necessary to cut partially into the wall before the first stool can be fixed so that the weakest walls can be "stooled up". In extreme cases it may even be necessary to clamp the wall above and below the stooling position. An important advantage of the stooling system is that it is very easy to increase the number of supports at little extra cost. In very fragile structures the size of the plates and the spacing of the stools may be adjusted to provide virtually continuous support. (Fig. 3). It is thus possible to construct continuous reinforced concrete beams or slabs less than 1.0 m deep within existing walls, no matter how thick, without cutting away more than, say, 0.3m^2 at any one time. For smaller highly stressed piers, this area can be reduced to as little as 0.1m^2 . Older stone masonry walls are often formed with two outer skins of cut and bedded stonework with a weak rubble infill which often contains considerable voids. On one project, strengthening the columns of Winchester Cathedral, R.C. pads were constructed in the core of the column without propping the arches or removing the stone facing (Fig.4). Because the Pynford stools are permanently cast into the new R.C. beams, the load the stools carry is directly transferred into the new beam. This eliminates another cause of the damage that it is customary to expect during underpinning operations. It is easy to widen the beam by inserting further stools under projections such as chimney breasts or piers. Fully continuous beams can be constructed, although it is important to consider the overall stability of the structure if a significant length of the wall is to be cut away. Care must always be taken to provide adequate lateral as well as vertical support with any shoring system.

7. Three underpinning projects not previously described in the technical press have been chosen to illustrate the use of Pynford beams. The first is a very early example but a description of the work has not been published and it is an excellent example of the use of stooling. The work was carried out before slurry walls or ground anchors had been developed. To begin the redevelopment of Imperial College, London, a basement was required 11 m deep up to the face of heavy brick walls which included piers carrying up to 400 tonnes and foundation level loads up to 50 t/m. Underpinning was required to a depth of 13m below ground level. The sub soil is sandy gravel to a depth of 8 m over clay. The initial proposal was to pass steel joists through the piers supported on temporary piles on either side in preparation for the underpinning. This had two disadvantages. Firstly, the large holes required could not be safely cut through the piers; secondly, needling would have created considerable internal disturbance. Pynford were originally called in to solve the first problem by forming a reinforced concrete bearing pad through the piers which would cantilever on either side on to the needles. This has been done on a number of occasions, a recent example being the A-Kerk in Amsterdam. To solve both problems Pynford proposed a beam below basement level which would act as a needle running on the line of the wall to support the piers. (Fig.5). When excavation was commenced it was discovered that the water table was 3 m above the gravel clay interface, not 0.6 m as expected. In underpinning work it is vital that ground is not lost during excavation as it is providing the support for the rest of the structure. The

author invented and patented an excavation shield for this project which enables piers to be hand dug in waterlogged sand below water table without loss of fines. The Pynford shield has proved invaluable for many subsequent underpinning projects.

8. The Town Hall, Dundee, was suffering subsidence for the common reason that drainage had lowered the water table beneath the building and timber piles supporting the walls were going rotten immediately beneath the foundation. New piles were sunk on either side of the wall. Pynford beams were constructed at foundation level beneath the wall. The timber piles were cut off below water table, treated, pre-loaded by jacking and pinned in place using stools (Fig. 6), to provide temporary support whilst the underpinning was constructed, and permanent support at a reduced load. A combination of new bored R.C. piles and repaired pre-loaded existing piles offered significant cost savings on the project.

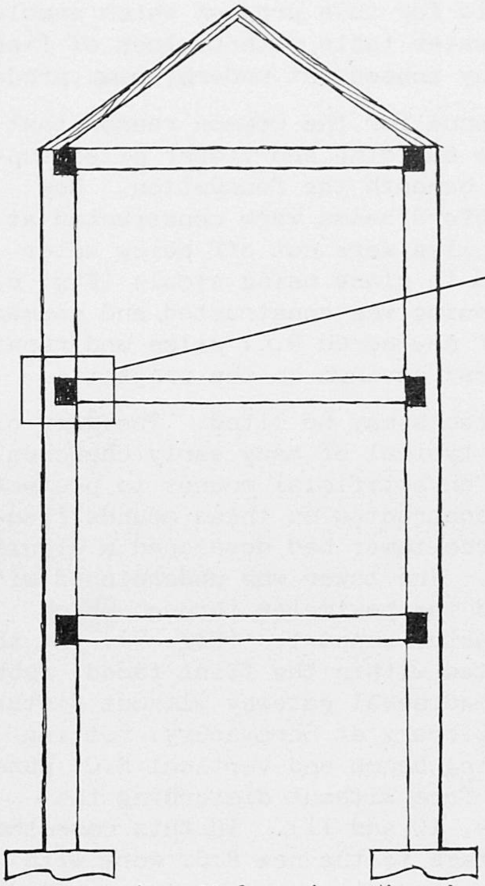
9. Many other examples of the use of Pynford stools may be cited. The very old Dutch brick church at Eenum, near Groningen, is typical of many early churches in The Netherlands. Early settlements were built on artificial mounds to protect them from winter flooding and heavy buildings constructed on these mounds frequently suffer considerable subsidence. The church tower had developed a significant inclination and broken away from the nave. The tower was underpinned with a projecting R.C. slab pierced with holes around the perimeter through which de Waal piles were jacked down to provide pre-tested support. (Fig. 7). At the Kings Gate, Winchester, an R.C. frame was inserted within the flint faced, rubble cored, North wall of this unique church over a mediaeval gateway without disturbing the inner wall face. (Fig. 8). At the Old Library at Shrewsbury, rotting timber beams were removed and horizontal R.C. ring beams and vertical R.C. panels were constructed in the inner loadbearing brick face without disturbing the mediaeval stone facing of the building, (Figs. 9, 10 and 11). In this case the stones were drilled and tied in from the inner face to the new R.C. work with resin bonded stainless steel ties.

JACKING AND MOVING. 10. The earliest Pynford jacking projects were designed to straighten out buildings distorted by subsidence and used large numbers of closely spaced jacks. It soon proved far more economical to relevel the sunken corner of a building than to demolish and rebuild it. This also has the considerable aesthetic advantage that the existing materials are retained. Buildings severely distorted by mining subsidence may tilt at inclinations exceeding 1 in 20.

Such properties are uninhabitable. Such tilting is often accompanied by minor distortion although, surprisingly, the distortion is often less than that caused by subsidence due, for example, to shrinkable clays, where differential subsidence of less than 10 cm will often cause far more damage than tilting due to mining subsidence of 60 cm. It is distortion of the structure that causes cracking and damage. The classic example of tilting without significant cracking is, of course, the Leaning Tower of Pisa. Tilted low-rise domestic dwelling houses can be relevelled and restored for less than two-thirds of the rebuilding cost.

11. Having established a reputation in the UK for both underpinning and jacking enquiries were received for moving buildings. Before large and fragile structures such as buildings can be raised and moved the first requirement is that they be supported by a secure framework or platform. (Figs. 1, 12). Major jacking and moving projects completed in the UK using the methods that have been described include underpinning and raising the 1000 tonne 14th C Shambles in Manchester 1.5 m as part of a major city centre redevelopment project and moving the 800 tonne 18th C Old Academy in Warrington 15 m to release land for road widening.

12. The sloping, derelict, Market Street site in Central Manchester, U.K. contained an important building, the oldest in the city, the partially timber



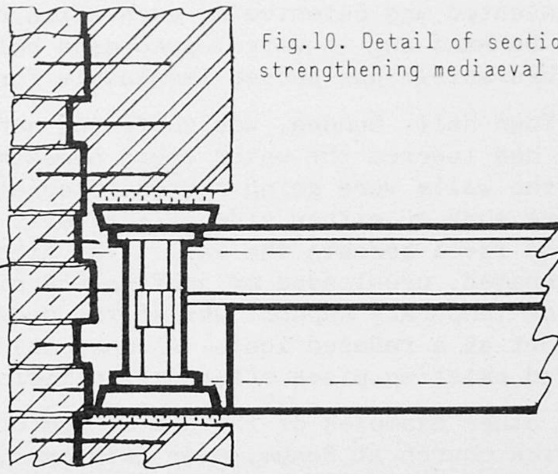


Fig.10. Detail of section: strengthening mediaeval building.

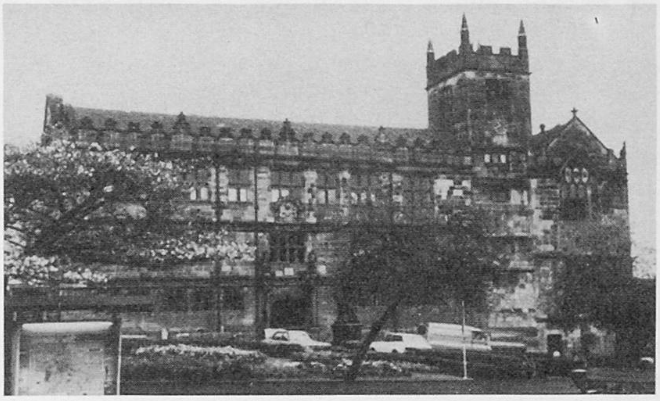


Fig.9. Section: RC frame in mediaeval walls. Fig.11. Shrewsbury Library.

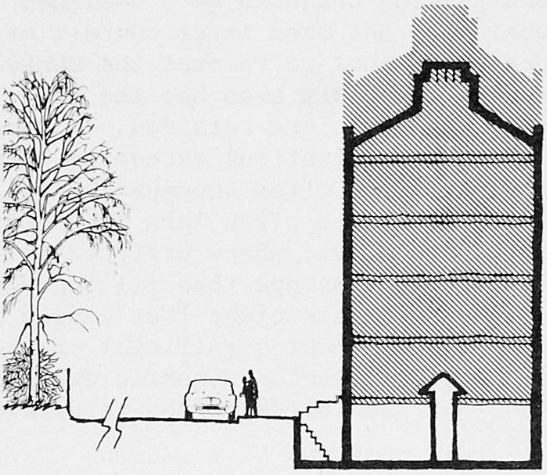


Fig.14. Typical city square.

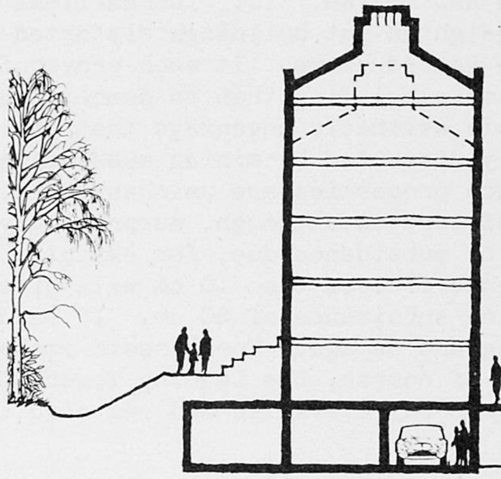


Fig.15. Parking with rear access under building.

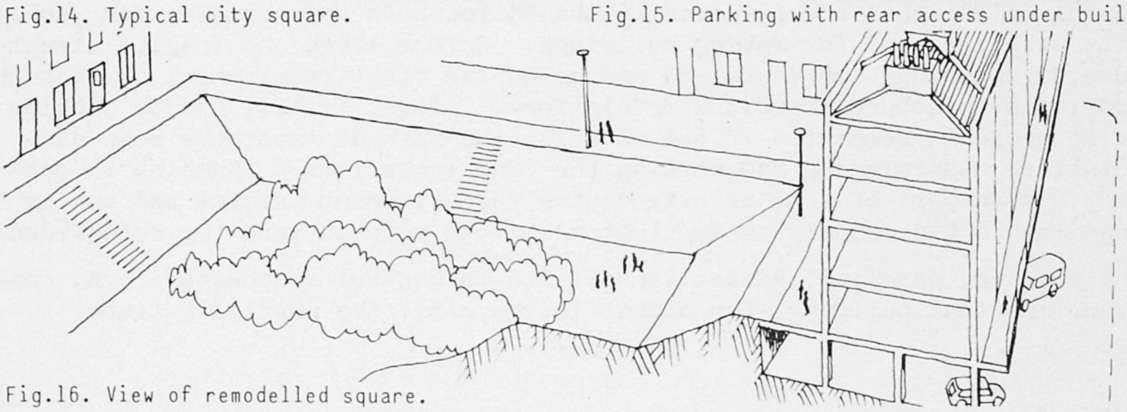


Fig.16. View of remodelled square.

framed and partially brick, Grade II listed, 14th C Shambles, over 30 m long and up to 4 storeys high. The proposed new development included a level pedestrianised area 1.5 m above the ground floor of the Shambles. The whole site was also to be excavated 7 m for two levels of underground access and parking with the entrance ramp passing underneath the Shambles. Pynford detailed and constructed an R.C. frame under the building, dug eight supporting piers 9 m down to the underlying rock and jacked the building up 1.5 m from these to the required new level. The jacking was controlled to within $\pm$ 3 mm to prevent cracking and limit stresses in the R.C. frame during the lift. The whole structure being lifted weighed 1000 tonnes. (Ref. 5).

13. The early 18th C. brick Old Academy in Warrington, UK, stood on the site of a proposed road widening scheme at the north end of the Mersey Bridge in the town centre. It is particularly important for it was the first purpose built non-conformist academy for higher education in the UK. It had been condemned as unsafe. To begin the work, cracked brickwork was injected with epoxy resin and flat steel bars were bonded on. An R.C. frame was then constructed just below ground floor level. Beneath this three further beams were formed to provide a running track and extended onto the new site and linked with cross beams and an R.C. slab to form an inverted cellular raft foundation. Jacks were then fitted in the 400 mm gap left between the upper and lower beams to lift the building 100 mm off the existing foundations. Grease skates running on thin steel sheets were then set under each jack and the building was winched to the new site. The move took about 20 minutes. (Ref.6)

14. At the time of writing Pynford is engaged upon lifting and moving a 2500 tonne building in Norway. (Fig. 13). It is 11 m x 24 m on plan with basement walls and four upper floors that are early examples of reinforced concrete. The walls above basement level are brickwork 3 storeys high and the steep timber framed roof contains the two topmost levels of this 6 storey building. An R.C. raft 0.7 m thick has been constructed 1.2 m below existing basement level and extended 6 m beyond the rear wall. The building will be supported on 42 jacks arranged in 12 groups and lifted 0.25 m. Each jack will then be fitted with a 75 tonne grease skate, a device that can be slid generating frictional resistance of about 0.1% although slight irregularities on the track might increase the restraining forces to over 0.5% of the weight. The building is to be moved back 5 m to release land for road widening and then lifted a further 1.2 m to make space for a basement car park.

15. The insert illustrating the Pisa project and the proposal for raising buildings around a city square, (Figs. 14, 15, 16), are self explanatory. It is safe and practicable to consider lifting and moving the most delicate buildings such as churches or palaces containing many stone columns. Costs are predictable and are likely to be of the same order as underpinning and rebuilding and in some cases may be significantly less. This capability is not yet widely recognised. It may alter thinking about replanning and modernising our priceless and historic city centres, and increase the numbers of buildings that can be preserved, for a reconstructed building is only a pale shadow of the original.

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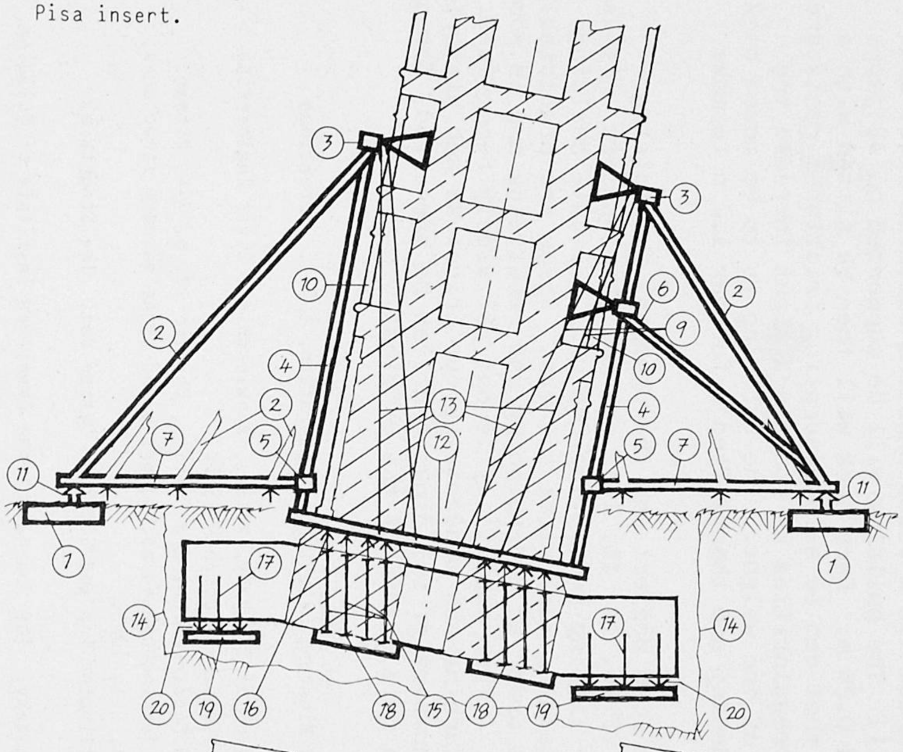
Pisa insert.



1. Construct a ring of shoring foundation (1)

2. Erect raking struts (2) supporting a compression ring (3) from which hangers (4) support a tension ring (5) provide additional struts (6) on low side.

3. Tie the bases of the raking struts with ties (7) to the tension ring and pack between this ring and the drum of masonry (8) forming the base of the Tower. Provide secondary struts (9) between the tower columns (10) at compression ring level and below.

4. Complete the shoring by preloading the temporary foundations with jacks (11) to support the Tower and transfer pressure from the overloaded low side of the foundation to the understressed high side. It is now safe to cut into the Tower foundations.

5. To complete the temporary support construct an RC slab (12) approx 0.75m thick beneath the Tower walls just below original ground level using the Pynford stooling system. Link this to the tension ring (5) with extensions of the ties (4) and with tension cables (13) attached to the compression ring.

6. Stress the cables (13) and increase pressure in the jacks (11) to transfer approx 5000 tonnes to the shoring foundations (1). Note that the Tower is lifted at base level in a steel cradle attached to an RC Base Slab constructed approx 3.5m above the underside of the existing foundations.

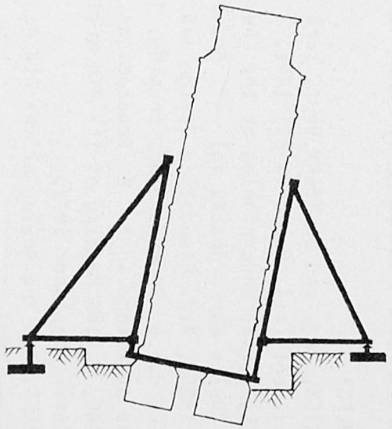
7. It is now safe to construct a new foundation raft approx 3 mm thick to replace the existing foundations and reduce ground pressures to a safe load.

8. Form an impervious ground curtain (14) around the Tower and underpin in sections approx 3 m wide propping the slab (12) with struts (15) pre-loaded with jacks (16).

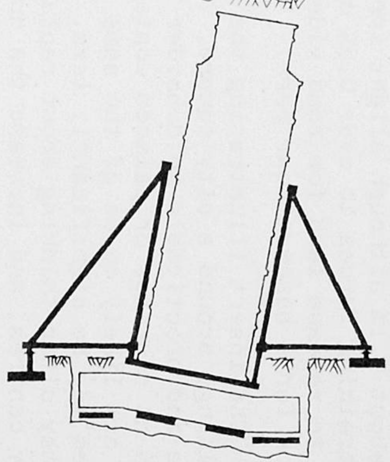
9. The new raft (17) would be of cellular construction bearing partly upon the heavily compressed subsoil (18) beneath the existing foundations and a new RC foundation ring (19) constructed upon the uncompressed soil surrounding the Tower (10). Use jacks (11) and (16) to reduce the inclination of the Tower approx. 2.25 m to ground level as originally constructed, pack up and remove jacks (16).

12. Using secondary jacks (20) load the foundation ring (19) until consolidation becomes minimal, at the same time, reducing the load in jacks (11) to transfer all the Tower weight to the new foundation raft.

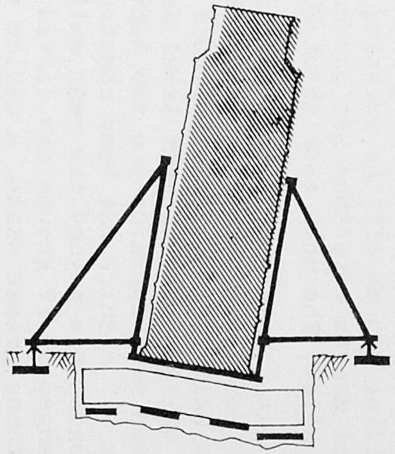
13. Grout the cables (8) to link the Tower to the new foundation. Remove shoring and make good the paving surrounding the Tower.



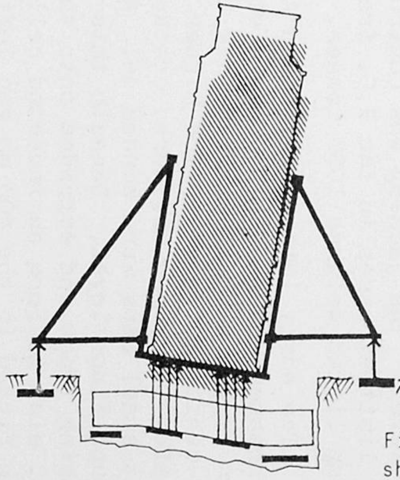
Shore up Leaning Tower.



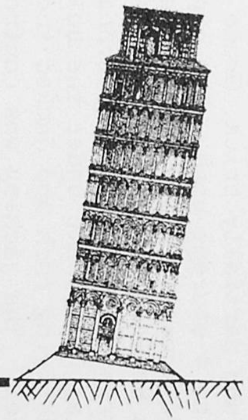
Form raft .



Reduce inclination 1°



Raise 2.25m



Finished:
shoring removed,
paved up to Tower.