

FOUNDATION ENGINEERING HANDBOOK

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22 UNDERPINNING

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22.1 INTRODUCTION

Underpinning structures is the introduction of additional support to the foundation of a structure to deepen or increase its bearing value. If done because the foundation is inadequate it is called remedial underpinning. Deepening or enlarging a foundation because of deeper new construction adjacent to the building is called precautionary underpinning. The latter is the most common type of underpinning, although the history of underpinning started with remedial underpinning.

Although many of the early large structures had foundation difficulties, no remedial work was performed since the technique of underpinning was not generally known. The Tower of Pisa is a classical example of an inadequate foundation that has been settling for 600 years and unless corrective work is done, will collapse in 50 to 100 years (Spencer, 1953b). Many of the great cathedrals built in the Middle Ages, such as the Cathedral at Ely, England, and Bauvais in France, collapsed and were not reconstructed. One of the first large underpinning projects was at the great cathedral in Winchester, England, which settled for 900 years until it was underpinned in the early twentieth century by a diver who singlehandedly installed bags of concrete into pits dug under water through peat and silt to a gravel layer (see Fig. 22.1 and Hammond, 1955). Visitors to the cathedral will find a plaque memorializing this feat.

Remedial underpinning dates back to efforts to correct mistakes in foundation construction and was performed in early days by the Romans on their structures and by the French on the fortification walls of XIII Century Carcasonne but it was not until this century that the technique of underpinning was developed and greatly stimulated by subway construction in New York City. Earlier subways had been built in European capitals but the ground conditions and type of subways constructed did not require underpinning.

In New York underpinning was necessary in order to construct deep subways in downtown Manhattan next to heavy buildings. The streets were narrow and the subsoil was varved silt which is very difficult to dewater, making it a problem to excavate open piers without loss of ground. It became necessary to jack piles or sink compressed air piers to eliminate this pit work. In 1917 the Pretest pile, developed by Lazarus White and Edmund A. Prentis, was designed to prevent the rebound of jacked piles and to transfer the load from the structures to the piles without settlement. The Nassau Street subway was an example of the magnitude of underpinning required. Here the subway

was constructed adjacent to very heavy masonry buildings which were underpinned by Pretest piles and heavy concrete retaining walls (see Fig. 22.2). This method is still in general use in water-bearing ground on such important structures as the San Francisco and Washington, D. C., subways.

In the course of early subway work it was necessary to underpin literally hundreds of buildings of a great many types and sizes and other new techniques were developed. The greatest improvement was made in shoring and temporary support techniques prior to underpinning. In many buildings, particularly large ones, it was discovered that it was possible to dig small pits under the footings to install piers or piles, making it possible to eliminate shoring or temporary support. The loss of support under the foundation for a short period could be tolerated until the underpinning support elements were installed.

In recent years the amount of underpinning work has increased due to large, deep structures and the large volume of construction of subways throughout the world. Under-

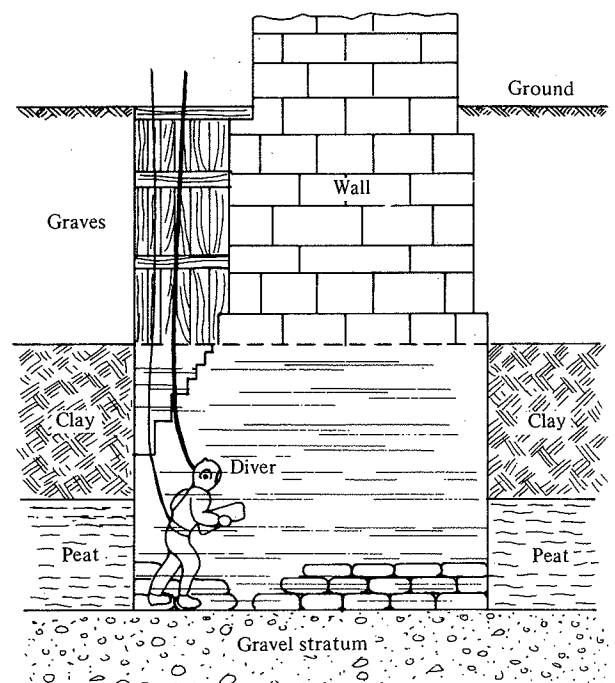


Fig. 22.1 Winchester Cathedral, England. Concrete-filled bags for underpinning installed by diver. (After Hammond, 1955.)



Fig. 22.5 Collapse of small building due to improper underpinning and lateral support.

essential to have adequate, properly made borings available, preferably with samples that can be examined, consolidation tests, groundwater-level observations and grain-size analysis. Test pits are also useful for determining the location and condition of existing footings or wood piles supporting the structure. Any previous experience in the same area should be investigated. With proper information and with a sound understanding of the soils engineering involved the best-suited underpinning methods can be selected. The type of soil that supports the underpinning as well as the weight of the building will determine the size of concrete piers or the capacity of piles that support the building. It is standard practice not to consider the weight of the concrete pit underpinning in designing the underpinning. This is done on the theory that the weight of the concrete at 150 lb/ft³ is not too much heavier than the earth dug out at 120 lb/ft³ and the excess weight is supported by the side friction of the pier against the ground.

It is a common error to underpin a structure to just below the subgrade of the excavation of the structure instead of founding the underpinning on a suitable bearing stratum. The load of the building may be transferred using this criteria from a hard upper crust to a soft layer and cause dangerous settlement of the underpinned building. This problem is magnified when piles are driven in the excavation adjacent of the underpinning.

The most important consideration is to determine the extent of underpinning. Usually adjacent excavation influences the outer foundations of a building that is within a 1-on-1 slope from subgrade. Softer materials such as silt or clay may require underpinning along a flatter slope, such as 2 horizontal to 1 vertical. Experience in underpinning hundreds of buildings during the construction of the New York subways has shown that underpinning the front walls of the

building is sufficient and that it is usually not necessary to underpin interior columns that are within the 1-on-1 slope line. This is true for many types of ground ranging from good sand to moist silty sand. The use of the 1-on-1 slope allows a reasonable safety factor because the normal zone of horizontal disturbance of an earth bank is roughly one-half the vertical depth of cut. Soft clay material and running wet material may require support for interior columns. The extent and success of underpinning will also be determined by the care taken in other phases of the work such as the lateral bracing of the underpinning, general excavation techniques, sheeting of the excavation, and pumping methods used on the project.

Experience has shown that there is a great inclination to skimp on underpinning of small structures and that most underpinning failures result from this cause. The underpinning of large structures is more carefully engineered because of the size of the structure involved. Damage to a small building can be very costly because of factors in addition to the physical damage to a structure such as legal fees, loss of use suffered by businesses or stores that may have to be evacuated, and other intangible expenses. An example is a building in Michigan which completely collapsed due to faulty underpinning and lack of proper lateral support (see Fig. 22.5).

22.3 PIT UNDERPINNING

Of the many methods of installing underpinning, the most common is concrete pit underpinning. Plain concrete pits are installed by excavating sheeted pits by hand under existing structures to the proper depth and to a suitable bearing strata, and filling the pit with concrete and dry packing be-

tween the pit and foundation to transfer the load into the new concrete piers. This method is basically limited to dry ground because it is difficult to dig below groundwater level without loss of ground causing settlement of the building to be underpinned. It is possible to install 30"-wide pits, but 36" is the optimum width of a pit for ease of installation and economy. The breadth of the pit may vary from four to five feet, although larger pits may be dug, if necessary.

Pit underpinning requires careful and skilled work as loss of ground will cause settlement of the building. The usual procedure is to dig an approach pit 3' wide and 4' long to a depth 5' below the bottom of the footing in front of the footing to be underpinned. This approach pit is then extended under the footing so that the underpinning will be

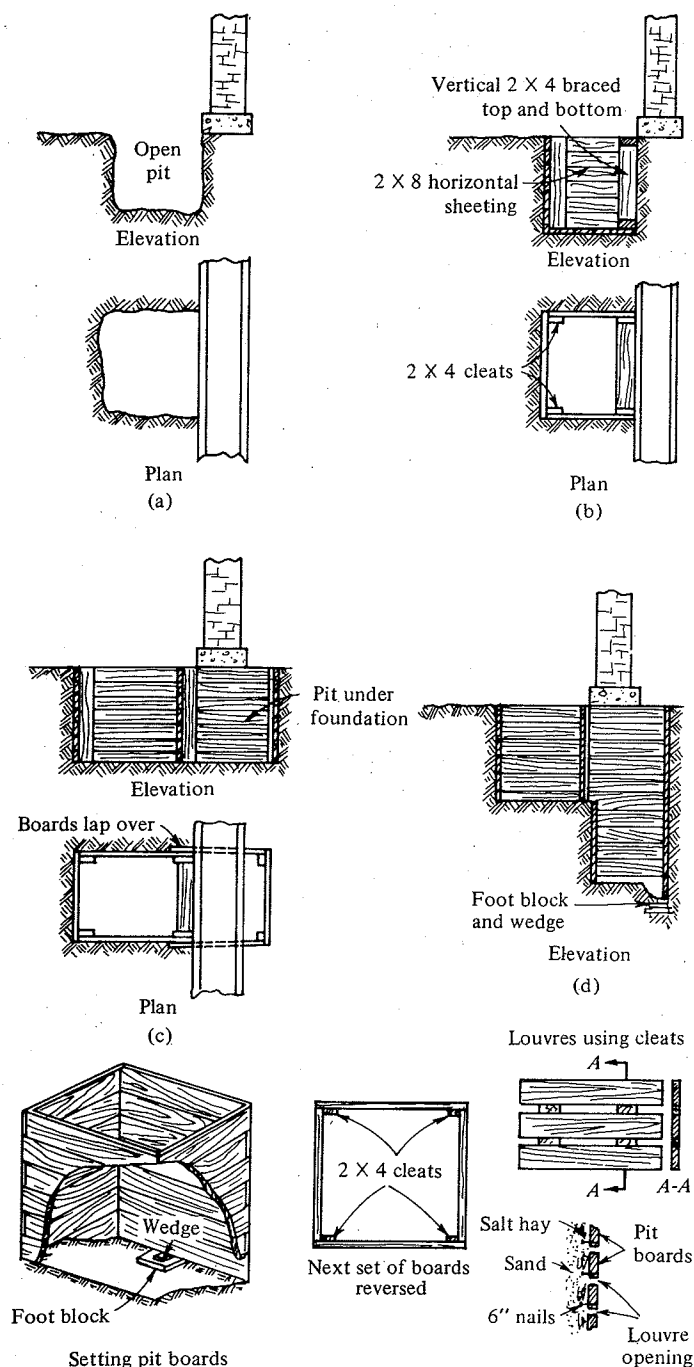


Fig. 22.6 Details and methods of installing underpinning pits.

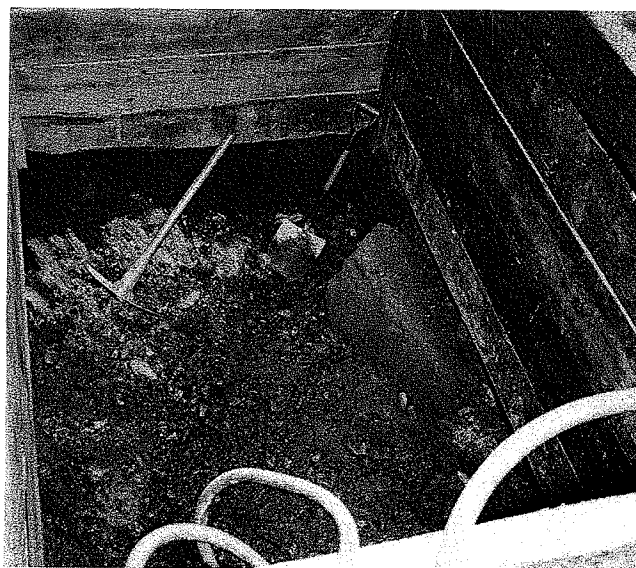


Fig. 22.7 Horizontally sheeted underpinning pit.

centered under the footing. The pit is completed by deepening until it is several feet below subgrade of the new excavation, provided the bearing capacity of the ground is adequate on this level. All pit work is sheeted with 2" X 8" untreated horizontal timbers as excavation proceeds. The 2"-thick sheeting can be used for deep pits as the load against the planks is greatly reduced by the arching of the ground and the pressure does not increase with depth. Horizontal sheeting is installed because vertical timber is difficult to handle in a confined 3' X 4' pit and it can be installed at the same time as the digging (See Figs. 22.6 and 22.7). The boards are wedged against the sheeting already installed with the corners of the pit nailed with 2" X 4" cleats. Two-inch louvres between rings are often used, as these louvres provide drainage and prevent the building up of water pressure against the pit boards. The louvres also provide a place to pack hay or sand behind the boards to insure contact between the ground and the horizontal sheeting.

When the pit has been excavated to the required depth, a form is built across the approach pit and the pit is concreted to within 3" of the underside of the footing. After the concrete sets overnight the pit is dry packed with a mixture of one part sand and one part cement with just enough water to make it hold its shape when a handful is squeezed. The drypack is placed into the 3-inch space, thoroughly tamped in place with a short length of 2 X 4, and pounded with an 8-lb hammer, resulting in a complete filling of irregularities to assure full bearing (see Fig. 22.8). The dry pack sets up rapidly and as the thickness of the drypack is small there is practically no shrinkage or settlement of the building. Experience has shown that special nonshrink grout mixtures do not make enough difference to warrant their considerable additional expense. Wedging and jacking of pits are not necessary because of the large mass of the pit and side friction of the concrete against the ground makes this operation difficult. Liquid grout is sometimes used by pouring it through a hopper and keeping a head on the grout until it sets up. High Early Cement may be used to speed operations.

Concrete piers may be intermittent or they may be installed next to each other to form a continuous wall. This is determined by the load of the structure being underpinned and by the bearing value of the material under the

packed to complete the wall. It is not necessary to have formed keys between pits because the side surfaces after stripping have very rough surfaces that act as keys. Reinforcing should be avoided in underpinning pits unless absolutely necessary for structural design purposes. Horizontal bars have to be spliced at each pit joint and make digging of the filler pits more difficult. Reinforcing of underpinning piers entails considerable additional expense as the splices are difficult and the bars are hard to install, requiring ironworkers to be on the job. If reinforcing is necessary it is possible to form and pour a thin reinforced wall in the open in front of the underpinning; fortunately, the 36" wide pit does not usually require reinforcing.

If either intermittent or continuous underpinning does not have adequate bearing capacity it is often advantageous to bell out the bottom of the pits in the last three or four feet of the pit to provide extra pit area and therefore obtain additional carrying capacity. Unless the ground is hard and cohesive, the bell is difficult and requires highly skilled labor. It should not be attempted in wet running ground. Belling is often done when the pits are deep in order to increase the capacity of a pier that is expensive and time consuming to install.

If groundwater is within a few feet of the bottom of the pit it is possible to sheet the wet layer with tight vertical boards driven with a sledge or sheeting hammer inside the pit during final excavation. An example was the underpinning of a theater in Denver where it was necessary to seal off the bottom with vertical sheeting because of a water-bearing stratum over the rock (see Fig. 22.11). When the

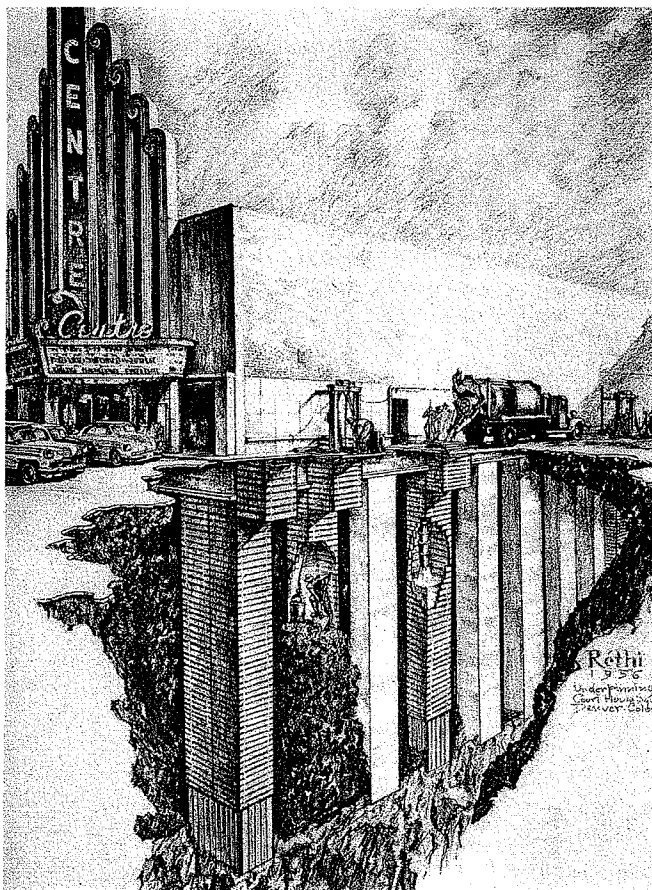


Fig. 22.11 Intermittent 65'-deep horizontally sheeted concrete pits to rock. Vertical bottom sheeting used to seal off water-bearing stratum over rock.

water level is more than 4 or 5 feet deep, other underpinning methods are advisable as several tiers of sheeting may have to be used and boiling in the pit may occur, which will lose ground. The pit method is basically for dry ground and unless a proper dewatering method is used should not be attempted in wet ground. It also is difficult to work in a pit where well points have been installed to lower the water level.

Large column footings can be underpinned in multiple pits installed one pit at a time. The size of the individual pits may vary according to the size of the footing but usually not more than 20% of the footing support should be underpinned at one time without shoring the columns. This can be accomplished as the design loads of buildings are often conservative, since the live loads are not actually there. The largest concentrations of load is in the center of the column enabling underpinning piers to be dug at the corners. In framed structures there is a tendency for column loads of the upper stories to arch to the adjacent columns so that the full theoretical load may not be on the footing being underpinned, making it desirable not to work on adjacent column footings at the same time. Once underpinning is started on a column it should be continued to completion without interruption other than normal night and weekend stoppages.

Concrete underpinning, in addition to supporting a structure, can function as a retaining wall holding back the earth behind it. If the difference in elevation between the existing floor and new subgrade is less than 7 or 8 feet, the earth pressure on a three-foot-thick underpinning wall can be ignored. When this depth is greater, the earth pressure behind the underpinning could be sufficient to displace the underpinning laterally, making it necessary to provide horizontal or diagonal support similar to that used for sheeting of earth cuts. This bracing is very important as the underpinning cannot carry horizontal loads. Lateral movement of the underpinning will cause serious cracking of the building and a failure of the bracing can cause a collapse of the structure underpinned.

If piling is to be driven after concrete pit underpinning is installed and a deep excavation made adjacent to the building, it is prudent to install jacking notches in the concrete underpinning in order to be able to install jacks and maintain the building if the underpinning pits settle due to consolidation of the ground caused by pile driving. These jacking notches are inexpensive to install during the concreting of the pits and are invaluable if settlement of the underpinning occurs.

22.4 PILE UNDERPINNING

The limitation of pit underpinning is the problem of excavating a small pit through water-bearing ground, particularly through fine-grained or silty material. To overcome this difficulty compressed air caissons were used in the early part of the twentieth century but they were expensive and caused loss of ground and settled the structures underpinned. Section steel piles were developed in 1912 for underpinning buildings where there were water problems with indifferent results, as the building underpinning settled even though the piles were jacked to overloads of 50 percent above their design load.

Lazarus White and Edmund A. Prentis overcame this problem during the construction of the William Street subway in New York City by the invention of the Pretest pile which was patented in 1917 (Prentis and White, 1950). This technique eliminated the rebound of the pile when the