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Paris Haussmann Building Underpinning. A case study.

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Abstract

Haussmann buildings architecture spread throughout the city of Paris. Nevertheless, those buildings are nowadays submitted to heavy operations of use change, conservation and rehabilitation, justified by several reasons, among others are building aging and the increasing demand for hotel rooms in Paris. In this paper, concrete pouring, an underpinning construction technique applied to a Haussmann building complex to create an additional basement floor is described. This description is the result of a construction survey realized during a heavy rehabilitation operation which takes place between 2015 and 2017 in a Haussmann complex located at La Madeleine. This work aims at providing contributions for a better understanding of concrete pouring technique, complementary an evaluation of the risks associated with this technique is done. The knowledge from this work could be very useful for the study of underpinning numerical modeling techniques or issues related to sustainable rehabilitation and strengthening, aiming to preserve this important building heritage or similar ones existing in other countries.

Keywords: Traditional construction; Haussmann buildings; strengthening; rehabilitation; underpinning.

1. Introduction

A huge quantity of rehabilitation and strengthening works are being realized actually in Paris Haussmann buildings. Those buildings are now centenarians since built or rebuilt around the 19th century, thus, they are very deteriorated and several pathologies affect their main structure behavior. Besides, the codes regarding structural and fire safety, thermal and sound insulation, have changed since those buildings were built, an upgrade is necessary to meet the new standards. Additionally, there is a huge demand for hotel rooms in the city of Paris due to a growing tourism activity, which justifies building use change and the creation of additional basement floors. Beyond that, environmental issues related to energy consumption to cooling and heating make those buildings obsolete. Finally, being Haussmann buildings representative of Paris architecture [1, 2], a traditional construction technique used during the 19th, it is vital to preserve and protect this legacy, demolition couldn´t be a solution All the reasons present previously justify the urgent need to realize rehabilitation and strengthening works. This scenario related to traditional building heritage state of conservation is not unique but can be found in several European countries, [3, 4]. In this paper, concrete pouring, an underpinning construction technique, applied in the scope of a

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Haussmann building complex rehabilitation, is described. The description is based on a construction survey realized during the rehabilitation works undertaken on this complex between 2015 and 2017. The complex is located at *La Madeleine* near the *Saint Marie Madeleine Church*. Fig.1 shows a front view of the existing facade.

Figure 1. The Haussmann building complex

This paper is original because it results from a site construction survey realized during the rehabilitation working stage, by the first author, which was simultaneously the underpinning project designer, [5]. Proper investigations were realized in the superstructure and on the foundations and several photographies accompanied it. The several steps of this underpinning technique are reported and an evaluation of the risks associated with it are presented.

We strongly believe this paper will allow to better understand the actual application of this underpinning construction technique, allowing further studies related to numerical modeling, heritage rehabilitation and strengthening and also sustainability issues. The organization of the paper is the following: firstly, the Haussmann complex is structurally and materially defined, subsequently, concrete pouring underpinning technique is introduced, thirdly a detailed step description of the concrete pouring application is done, fourthly an assessment of associated risks is presented and finally, some conclusions are indicated.

2. The Haussmann building complex

The building complex is constituted by two Haussmann buildings, built between 1830 and 1841. Malhesherbe building on the left and Madeleine building on the right in Fig. 1. Malhesherbe building as a gross floor area of 365 m^2 and 7 stories and Madeleine building as a gross floor area of 416 m^2 and 6 stories. The ground floor of the two buildings has a commercial use and the basement is used as a storage and also to the technical equipment. The other floors are used for office purposes and housing. Site observations allowed to conclude that the structure is highly composite, the main Haussmann facades are made of dressed stone, excepted the two upper floors which are made with a timber frame solution. The facades located in the backside are made with a timber frame or steel frame solution. Fig. 2-a) shows Madeleine buildings facades viewed from Place Madeleine, this is a typical Haussmann façade and Fig. 2-b) shows an elevation through Malesherbe building.

The interior walls are made with bricks or a timber structure filled with limestone, [5]. The floors are made with a timber joist or a metallic joist, [6]. The basement walls located in the building complex perimeter are limestone rubble masonry, while the interior walls can be made with limestone rubble masonry or clay bricks. Foundation investigations revealed that the foundations of the existing walls are essentially realized extending downward the walls from 15 cm to 1 meter below the ground. Sometimes a concrete or limestone masonry strip footing or a limestone footing is placed beneath the walls, in those cases, the footing has a height varying from 3 cm to 40 cm and the width extending beyond the wall surface varies from 4 cm to 13 cm.

a) Madeleine front façade b) Malesherbe Elevation

Figure 2. Building complex architectural drawings

3. Concrete pouring underpinning technique

3.1 The technique

To increase the depth of existing foundations, when adding one or two basement floors, one of the most commonly used technique for underpinning the existing foundations is concrete pouring, [7, 8]. This technique consists in excavating the soil under the existing foundation and pouring concrete to construct a new wall and its foundation at the desired lower level, [9, 10]. This technique is recommended if, simultaneously the digging depth is low, the dug soil is cohesive, there is no water level and the bearing resistance of the soil under the new foundation soil is sufficiently strong to bear the new loads, which are obviously greater than the existing loads.

Nevertheless, the excavation operation must be done regarding three main conditions. First, the length of the foundation underpinned is limited by the foundation strength to span over the excavated length but also by the pit shoring system resistance, for this reason, the wall beneath the existing foundation must be realized excavating and concrete pouring sections with a maximum fixed length. In second, since the main load from the existing foundation being underpinned will span onto the foundation existing on either side of the excavation, excavated pits should be reasonably spaced to avoid compromising the soil bearing capacity. Third, for stability purposes, each completed and concreted underpin section must be supported horizontally either by horizontal propping or by backfilling the excavation until the projected structure is able to prevent horizontal displacements or overturning, slabs can achieve this purpose. The existing gravity loads are also important for the stability of the concrete panel since it balances the overturning moment created on the new wall, due to the earth pressure and eventual load diffusion resulting from existing adjoining walls and their foundations.

Each section is excavated, usually by hand, to the required depth, through a box-shaped pit whose dimensions are those of the new concrete footing located at the bottom of the excavated pit. The box-shaped pit is supported by props and shoring along the entire perimeter and heigh to avoid the soil collapse. Afterward, the reinforcement is fixed and the concrete pouring task is realized from the pit bottom to the top, first the footing and then the wall section, resulting in a concrete panel located within 50-75 mm of the underside of the existing foundation. In this gap, a dry pack, a mix of sharp sand and cement, is injected, minimizing settlements and allowing to transfer the gravity load applied in the existing foundation to the new concrete wall and its foundation.

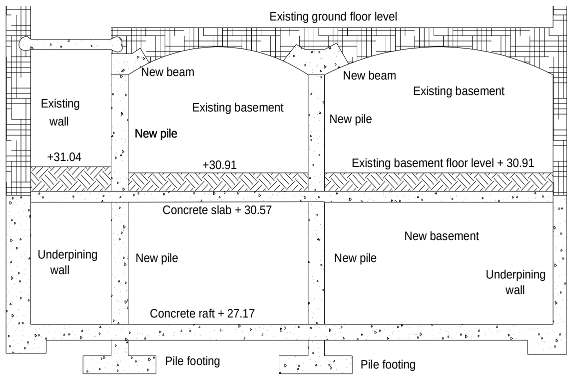
After one concrete panel is sufficiently cured and dry packed, another section can be started, so by repeating this process for all the sections, a continuous concrete wall, composed of contiguous panels of concrete, is built.

This technique is frequently used, nowadays, in Paris Haussmann buildings rehabilitation and strengthening, to increase the head height of the existing basement or to create one or two additional basements levels in a top-down construction methodology. The concrete pouring technique has the advantage of low labor cost, it is technically simple and theoretically allows the continued use of the building during construction without involving the necessity to evacuate the property.

3.2 The building complex underpinning application

In this building complex, the existing basement head height is to be increased 50 cm and one additional basement floor is to be built, besides, the change in the use and the regulation upgrade to Eurocode 1, [11], brought greater foundation loads. For those reasons the original foundation is no longer suitable and strong enough, thereby making it necessary to extend the foundation down to a lower level. Fig. 3-a) shows the existing basement and Fig. 3-b) illustrates the existing basement and the new one below.

a) Existing basement



b) Designed new basement

Figure 3. New basement

Fig. 3-b) illustrates the new peripherical walls and slabs to be constructed. The total increasing depth of the foundations is approximately equal to 4.16 m, which is an acceptable depth to apply this underpinning technique. The upper face of the raft footing level is 27.17, the new concrete footings level is approximately 24.90 for interior walls and piles, while along the perimeter the walls footing underside level is 26.60. Besides, the new foundation soil has good mechanical characteristics, at ELS, soil bearing capacity is 300 KPa at 28.60, 480 kPa at 26.40, and 600 kPa at 25.40, [12], beneath the existing foundations, allowing to construct underpinned wall sections with a maximum spacing equal to 2.0 meters, Fig. 4, corresponding to a spacing between peripherical footings varying from 0.52 to 1.50 meters, Fig. 5.

The underpin operation can be described through seven construction steps: in step 1, excavation and concrete pouring of sequential pits were realized, Fig. 4, in the complete perimeter of the building complex and in some points located in the interior. In each pit section, a rectangular concrete footing approximately 2.50 x 2.30 x 0.50 m^3 and a concrete panel approximately 0.80 x 2.00 m^2 were poured, in the interior underpinned pits the square concrete footing was 2.50 x 2.50 x 0.70 m^3.

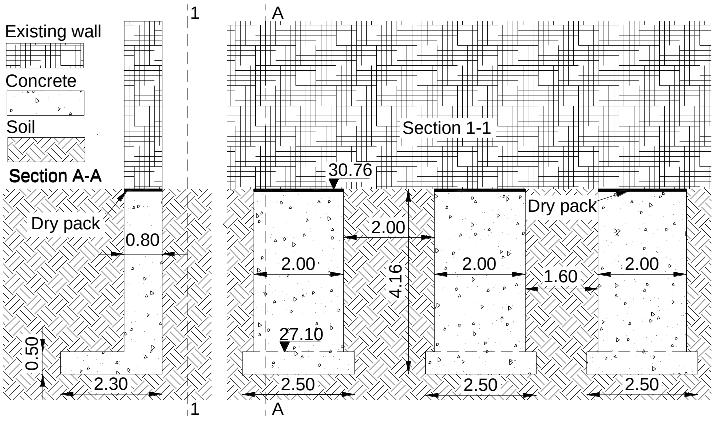
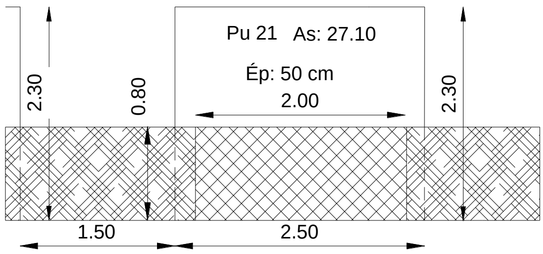


Figure 4. Underpinned pits pouring

Fig. 5-a) shows one of the excavated pits and the corresponding limestone rubble foundation, and Fig. 5-b) represent the design dimensions, 2.50 x 2.30 m^2 and the thickness, 50 cm, of the concrete footing relative to pit 21 with the underside at the level, 26.60. The concrete panel is 2.00 x 0.80 m^2, where the existing wall thickness is 80 cm.

a) Excavated pit



b) Fit foundation dimensions

Figure 5. Excavated pit

Each pit was excavated downward by 1.5 meter lift, while a timber shoring system was continuously constructed inside the pits and along with the perimeter and heigh. Furthermore, during the pit excavation, temporary vertical props or supports were placed under the spanning walls to keep any loose of existing limestone rubble masonry.

The pit width was limited to 2.50 m, because if bigger, the shoring system has to be made with steel sheet piling and because the rubble foundations and limestone walls are not well suited to bridging over large underpinning pits, laking from continuity. When the foundation depth was reached, corresponding to the underside of the concrete footing, reinforcement was fixed in the footing and in the panel beneath the existing foundation. The entire structure was then filled with poured concrete mass, from down to top. Trought timber shuttering, the wall concrete was held in place, while it was placed.

As new pits are excavated, previously poured pits are backfilled with the excavated soil to prevent underpins instability. The excavation and construction of the wall sections were carried out in a sequential pattern such that a maximum degree of support is offered to the existing foundation at all times. For that, the distance between simultaneous pits was kept higher than 7 meters, in order to keep within allowable values the pressure on the underlying soil. Fig. 6 shows the excavation pit planning for Malhesherbe and Madeleine buildings.

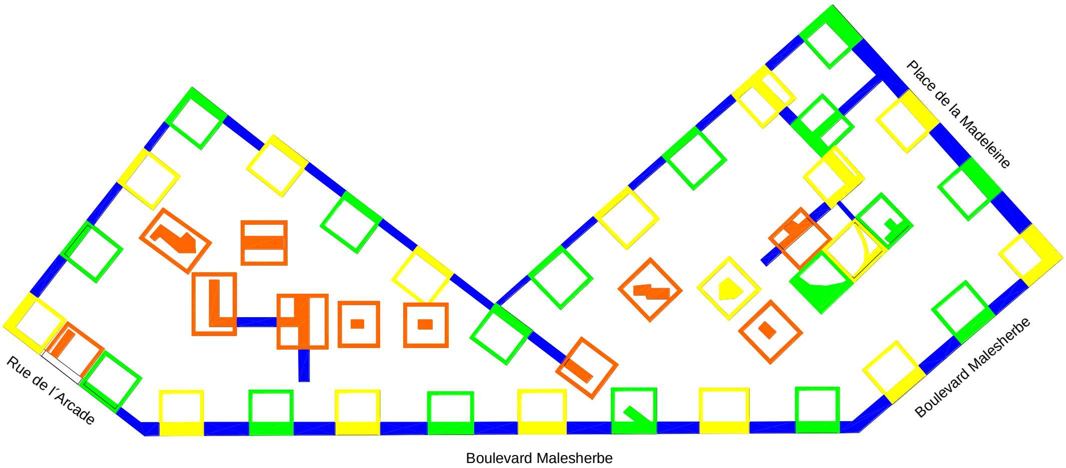


Figure 6. Excavation pit planning

Each color in Fig. 6, yellow, green, represents the pits that can be excavated simultaneously because they are spaced about 7 meters. First, the green pits were excavated and concrete poured and then yellow. The sections in blue, between the previously constructed underpin, were poured in step 3, those sections do not have a concrete footing and are directly supported on the concrete raft. The orange pits were kept to the last. At the end of step 1, all the pits should have been backfilled.

In step 2, a 2.65 m height excavation near the walls was realized with a mechanical shovel, Fig. 7. This operation will allow, in step 3, to pour concrete between the concreted wall sections (blue and yellow). At this step, it was very important that the concreted sections and their foundations have acquired the necessary resistance to carry the loads, since, the simultaneous removal of soil might lead to an increase in the vertical pressure exerted on the existing underlying soil, sometimes beyond allowable values. Furthermore, the depth was minimized, in order to avoid the collapse of the existing soil.

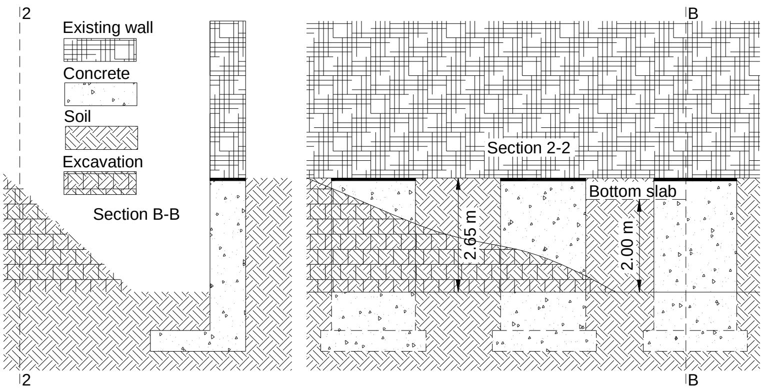
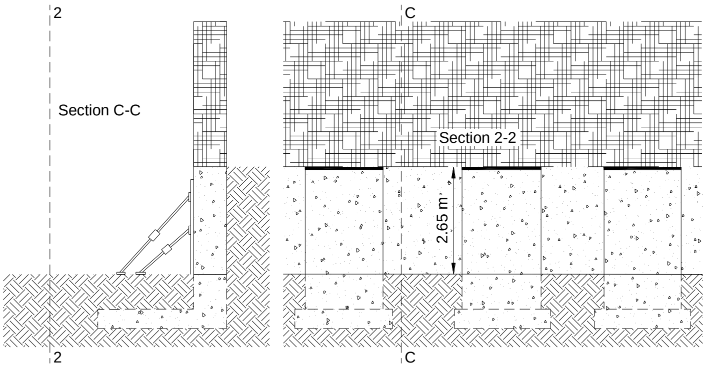


Figure 7. Mechanical shovel excavation

In step 3, the remaining wall sections (in blue in Fig.6), between pits, were poured downwards 2.65 m, reinforcement was fixed and a concrete pump was used for pouring concrete, a shoring system to fix the formwork during the curing was used, Fig. 8.

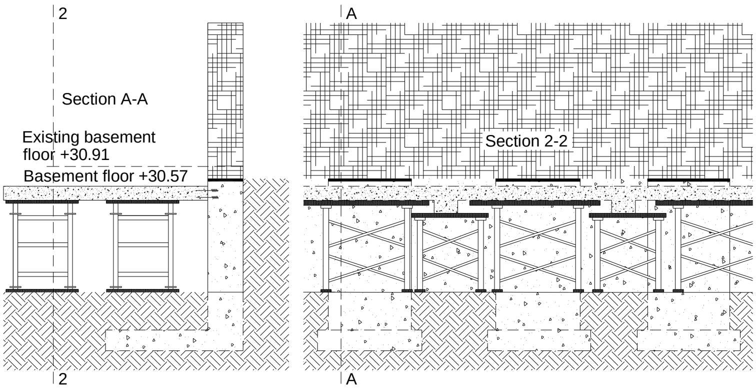
In step 4, since a top-down construction methodology was used, adjustable steel props and shoring towers for the slab were put in place, then the slab reinforcement was fixed and finally, concrete pouring was executed, Fig. 9. The slab was linked to the concrete walls throughout anchored steel bars sealed with an epoxy anchoring resin, [13].



a) Wall section pouring

b) Wall section reinforcement

Figure 8. Wall sections concrete pouring, step 3



a) Slab concrete pouring

b) Slab shoring tower

Figure 9. floor basement pouring

In step 5, the excavation was continued to reach the bottom of the foundation, approximately 1.44 meters below, Fig. 10.

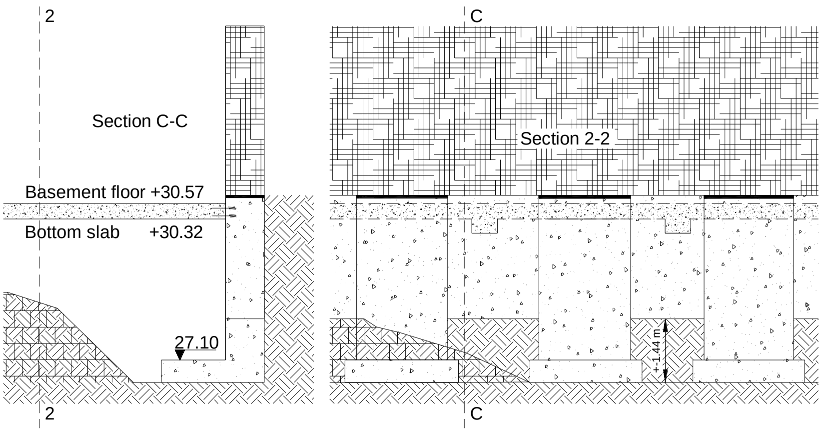


Figure 10. Continued excavation

After that, in step 6, reinforcement fixing and concrete pouring of the concrete walls panels were continued to reach the foundation level, Fig. 11. Timber shuttering was used to hold the wall concrete in place while poured.

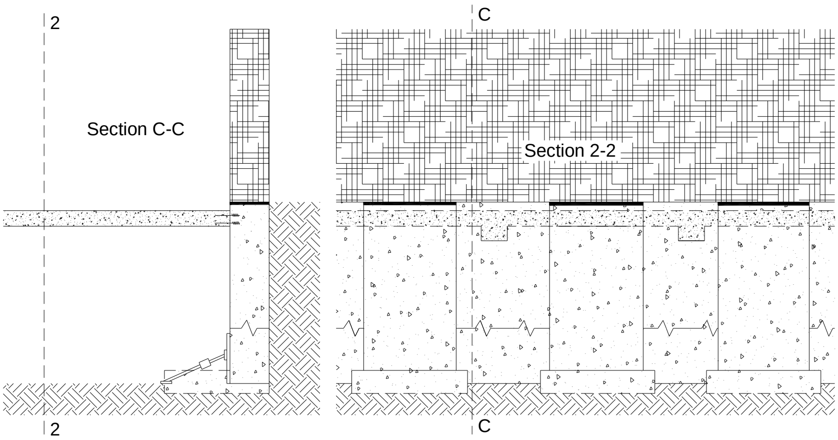


Figure 11. Wall sections concrete pouring

Finally, in step 7, a slab concrete was cast over all the ground area. The concrete raft with a thickness equal to 45 cm was poured, Fig. 12, and an appropriate waterproofing system was installed to protect the new basement from water penetration. As shown in Fig. 12, the raft foundation, together with the slab of the first basement level act as a bracing system to the new wall structure preventing horizontal or rotation displacements.

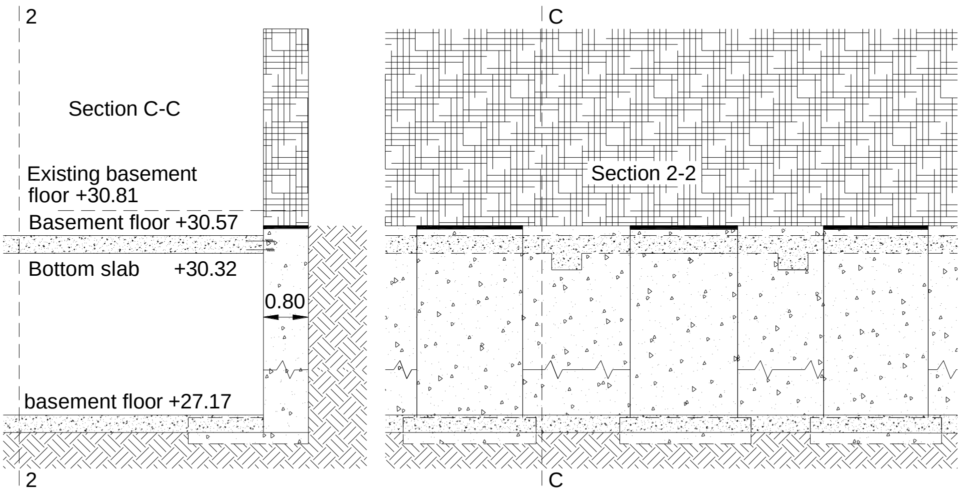


Figure 12. Basement concrete raft pouring

Moreover, some pits were also realized under the columns, Fig. 7 (in orange color), in that case, a shoring system was necessary to transfer the loads from the piles during the excavation stage.

4. Risk assessment

Concrete pouring technique is a heavy underpinning operation since it involves digging under the existing foundations, beyond that, this operation is realized in a confined place. Therefore, considerable risks are associated with it. For this reason, simultaneously with the underpinning works, a survey was realized in order to define the fundamental control measures associated with each underpinning step. In Table 1, the fundamental control measures are indicated for each risk.

As shown in Table 1, it is important to prevent falls, enable air renewal and provide hearing protection, among others. Besides the mechanical equipment should be equipped with particle filters to avoid air pollution. The one site risk assessment was successful since no major accident occurred during the underpinning operation.

Table 1: Risk assessment

Step	Risk	Control measure
Step 1	Falls into the excavated pit	Edge pit protection
Step 2, 5	Accidents with the mechanic shovel	Pedestrian zone creation
Step 2, 5	Poor ventilation, oxygen deficiency and air pollution	Ventilators for air renewal and mechanical equipment equipped with a particle filter
Step 2, 5	Noise	Hearing protection
Step 2, 5	Visibility	Reflective vests
Step 3, 4, 6, 7	Heavy procurement	Electric chain hoist to move the material up and down
Step 3, 4, 6, 7	Concrete projection	Personal protective equipment, safety, glasses and protective gloves
Step 3	Falls from pouring work platform	Soil flatness
Step 4	Fall from the slab pouring deck shoring tower	Guardrails

5. Conclusions

The planning, design, construction of underground spaces plays a very important role in global sustainable development. The demand for underpinning has increased steadily in the last years as renewals and refurbishment of old buildings have gained popularity, mainly in the European oldest cities and presently in Paris. This type of work requires skilled labor, not only constructors but also in the designing and planning stage. There is not a universal solution applicable to all cases, underpinning solutions are depending on many factors as the mechanical properties of the support soil stratum, the total depth to be attained and the restrictions imposed during this operation since realized in confined places, among others.

The underpinning operation described allowed to create a new basement level in a top-down construction methodology. This underpinning technique, adequate for shallow depth foundations is largely used actually in Haussmann building rehabilitation. A precise planning has to be drawn since a large quantity of hard work and multiple steps are needed. At the design stage, it is important to safely assess the width and spacing of the pits as it depends on how far the existing foundation can be unaffected because the soil removal affects the overall pressure on the nearby soil. The concrete footing volume is also dependent on the width pit and spacing. In design calculations, several scenarios should be therefore considered, as the existing boundary conditions applied to the concrete pit sections before and after slab and raft pouring.

It has been also shown that underpinning tasks envolve large risks that must be controlled by specific measures, as edge pit protection, ventilators installation, hear protection and deck shoring tower guardrails. The approach to mitigate risks was realized during the underpinning works and was successful, but preferably it should be done during the design stage.

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