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State-of-the-Practice in Design and Construction of Deep Basements in Jakarta | 雅加达深基坑地下室设计与建造的实践

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Abstract | 摘要

Jakarta is a large metropolis with a strong trend for vertical urbanism marked by the construction of numerous high-rise buildings with 5- to 7-level deep basements. Common construction methods for 3-level basements have been the conventional bottom-up with earth-retaining structure using temporary ground-anchor as lateral support. However, for deeper excavations, application of a ground anchor becomes risky. For this reason, a top-down method has gained popularity for deep basements due to its favorable inherent stiffness, applicability for excavations within densely-built areas, and time & cost-saving advantage, which are decisive factors in the successful completion of the project. Revitalization of central business districts, where older buildings are redeveloped into taller ones with deeper basements, further dictates the use of a top-down method. This paper discusses state-of-the-art practices in the design and construction of deep basements in Jakarta as related to local conditions and expertise, focusing on of the top-down method with case studies from actual projects.

Keywords: Deep Basement, Design & Construction and Top Down

雅加达是一座有着以建造众多有五到七层的深基坑地下室的高层建筑为特点的垂直城市化强大趋势的大都市。利用临时土锚做为横向支撑的带有挡土结构的传统的由下而上的方法通常被用来建造三层基坑地下室。但是，对于挖掘三层以上的基坑地下室来说，土锚的应用是有风险的。为此，由于其良好的固有刚度、在建筑稠密地区挖掘的适用性以及节约时间和成本的优势（这些对于项目的成功完成都是决定性的因素），由上而下的方法目前已经流行开来。重振中心商业区，将中心商业区里的老建筑重新开发成有更深的基坑地下室的高层建筑的任务更加决定了有必要使用由上而下的方法。本文讨论了与雅加达当地情况和专门知识相关的深基坑地下室的设计与建造的实践状况，并且通过实际工程案例分析重点讨论了由上而下的方法。

关键词：深基坑地下室、设计与建造、自上而下

Introduction

Jakarta is a metropolis with a strong trend for vertical urbanism marked by the construction of numerous high-rise buildings with deep basement structures within central business districts (CBDs). The recent emergence of 6- to 7-level-deep basement structures provides clear evidence of this phenomenon. It is worth-noting that the cost and time required to construct deep basement takes up a considerable portion of the cost and time involved in the entire construction. Therefore, success of a project will be governed by proper selection and application of deep basement construction methods.

The following discussion demonstrates that a top-down method can be safely and effectively employed for construction of deep basements within the densely built urban setting of Jakarta, saving significant amounts of construction cost and time. In order to develop appreciation on the effectiveness of the top-down method and its role in

引言

雅加达是一座有着以在中心商业区建造众多带有深基坑地下室结构的高层建筑为特点的垂直城市化的强大趋势的大都市。最近出现的六到七层的深基坑地下室结构清楚的证明了这一现象。值得注意的是，建造深基坑地下室所需的成本和时间在全部的施工过程所需的成本和时间中占相当大的一部分。因此，深基坑地下室建造方法的合理的选择和应用将决定项目的成功与否。

下文将证明由上而下的方法可以被安全的、有效的用在在雅加达的建筑稠密的城市环境中建造深基坑地下室，而且这一方法节省了大量的施工成本和时间。为了对由上而下的方法以及其在雅加达的垂直城市化的过程中的影响有所认识，有必要对若干有关联的方面加以了解。这些方面包括当地的地基土条件、对可用的由上而下的方法建造深基坑地下室方法、设计以及建造方面的描述。这些方面将在接下来的章节中加以讨论。另外，本文还提供了若

shaping dense vertical urbanism in Jakarta, some understanding on a number of relevant subjects is necessary. These subjects include local subsoil condition, description on available deep basement construction methods, design, and construction aspects of top-down method, which will be discussed in the following sections. Some project case studies will also be provided to complement the detailed discussion on top-down construction.

Subsoil Condition In Jakarta

Topographically, the South Jakarta region is on high ground at about El.+35.0 above MSL, sloping down to North Jakarta at the coastal area. During the past volcanic activities, lava flow predominated the upper soil layer in South Jakarta, which at present becomes residual soils with favorable mechanical properties, while the upper soil layer of North Jakarta area at the coastal area is predominated by very soft alluvial marine clays. Upper and lower lava formations consisting of hard cemented silty-sands can be found in deeper layers of the Jakarta area. However, some areas in central Jakarta have no bearing layer at all due to natural geological processes of the lava flow. In general, subsoil conditions in the North Jakarta region is more homogeneous compared to South Jakarta.

Deep Basement Trend and Construction Methods

The growing number of deep basements is mainly driven by local regulation requiring buildings to have sufficient parking space for the occupants. The public preference in Jakarta is to use private vehicles as a main mode of travelling. Local jurisdiction permits sub-grade construction to take up to 75% of lot area, making it ideal for basement areas to absorb most of the required parking spaces.

Common deep basements in Jakarta, ranging between three to four stories in depth, have been conventional constructed via bottom-up methods utilizing various reinforced concrete (RC) retaining walls with temporary ground anchors for stabilization of the excavation. This method is prevalent due to the simplicity of its design and construction, and is still popular for sites where ground anchors may be installed into adjacent periphery without any physical or legal restrictions. However, in recent times, as basement structures get deeper and project sites are located in increasingly dense city centers, anchoring is becoming less effective, less practical, or sometimes not even feasible to

干工程实例来对由上而下的建造方法的详细讨论加以补充。

雅加达的地基土条件

从地形上来说，雅加达南部地区在高于平均海平面35米以上的高地上，其向雅加达北部地区的沿海地区向下倾斜。在过去的火山运动过程中，熔岩流是雅加达南部地区的上部土层中的主导成分，其目前已成为有着良好力学性能的残积土。而在雅加达北部地区的沿海地区的上部土层中，非常柔软 / 柔软的冲积海相粘土是主导成分。雅加达地区的深部地层中有由硬质的粘合在一起的粉沙组成的上下熔岩地层。但是，由于熔岩流的自然地质作用，在雅加达中部地区的一些区域里没有任何承载层。一般来说，与雅加达南部地区相比，雅加达北部地区的地基土条件更加均匀。

深基坑地下室趋势和建造方法

在雅加达可以看到越来越多的带有深基坑地下室的建筑，而这些带有深基坑地下室的建筑的建造主要是由当地的一项规定所导致的：这一规定要求建筑物须有足够的停车位提供给其住户。雅加达的当地居民偏爱使用私家车做为主要的交通工具。当地的司法部门允许地基工程占有最多地块面积的 75%。这一规定使得利用基坑地下室的空间来提供所要求的停车位变得十分理想。

传统的使用多种钢筋混凝土挡土墙并利用临时土锚来稳固挖掘的由下而上的方法一直被用来在雅加达建造常见的三到四层深的深基坑地下室。这一方法之所以被普遍使用是由于其简易的设计和施工过程。由下而上的方法仍然被广泛的使用在土锚可以在不被物理条件或法律规定限制下被安装在临近的周边地区的工地上。但是， 最近，由于基坑地下室结构变得越来越深，并且工程地点都在稠密的市中心地带，锚固定的效果和可行性都降低了。有时锚固定根本就是不可行的。在一些有记录的案例中，使用这一方法导致了土壤的过度运动，从而造成了周边建筑的下沉。这一情况使得另一种方法在深基坑地下室的建造中流行起来。这种方法就是由上而下的方法。由上而下的方法之所以更加受到青睐是由于这一方法的适宜性、高效率及高安全性。至今，在雅加达，只有少数工程是用由上而下的方法来施工的。

由下而上的方法和由上而下的方法的主要区别在于相对于挖掘工作的基坑地下室楼层的建造时机。在由下而上的方法中，基坑地下室楼层是在挖掘工作完全结束后建造的。在由上而下的方法中，基坑地下室楼层的建造是与挖掘工作同时进行的。

由下而上的方法

使用由下而上的基坑地下室建造方法时，挡土结构的设置是在挖掘工作开始前进行的。永久性挡土结构（比如隔墙或咬合桩墙）以及临时性挡土结构（比如相邻钻孔灌注桩）都是经常被使用的挡土结构。当挡土结构将整个的工地全部围起来后，挖掘工作就可以分阶段的进行。随着挖掘工作进行到一定深度，充足的临时横向支撑将被沿着挡土结构按照中等间距安装。土锚是最常用的临时横向支撑，而临时钢支柱也可以做为代替土锚的一个选择。 当挖掘到开挖底面时，基坑地下室楼层通常从最底层开始向上建造，即从开挖底面向最高层进展。在向上进行建造的过程中，临时横向支撑会被按着基坑地下室楼层的建造顺序仔细地移除。

从施工层面上来看，挖掘工作和之后的基坑地下室建造工作可以很容易的、快速的、毫无阻碍的完成（图1）。但是，从法律层面上来看，需要取得在建筑红线外的区域安装土锚的许可。另外，松解土锚将会造成过度的土壤运动，并可能会因此损害周围建筑。

做为土锚的替代物，临时钢支柱可以被用来对挡土结构提供横向支撑。当使用临时钢支柱来提供横向支撑时，将不用再担心非法进入周边的他人土地的法律问题，因为钢支柱是安装在挖掘工地内的。但是，因为钢支柱需要大量的钢，所以使用钢支柱的成本通常非常的高。

通过使用至多四行临时土锚，挖掘深度达18米的基坑地下室结构已经被成功的在雅加达建造。

由上而下的方法

在由上而下的方法中，挡土结构的设置是和钻孔灌注桩及嵌入式柱的安装一起在挖掘工作开始前进行的。之后，基坑地下室楼层的建造是和挖掘工作同时进行的，并且在这一过程中由嵌入式柱向基坑地下室楼层提供临时的重力支撑。隔墙或咬合桩墙被选做挡土结构。随着挖掘工作进行到一定深度，在这一特定的深度以上的基坑地下室楼层被建造完成。基坑地下室楼层做为钢筋混凝土系统来给挡土结构提供横向支撑（图2）。这一过程一直持续到底层被建造完成，此时基坑地下室结构的建造也就完成了。

从施工方面来看，由上而下的方法比由下而上的方法要复杂得多。但是，由上而下的方法克服了许多由下而上的方法的局限性。由上而下的方法没有非法进入周边的他人土地的法律问题。因为高刚度的钢筋混凝土楼板被用来对挡土结构提供横向支撑，周边土壤的运动被降低到最小，从而将对周边建筑的潜在破坏的危害性降低到最小。

apply. There have been several recorded cases where the use of this system caused excessive movement of the soil, causing settlement of the surrounding buildings. This situation provides a way for another method, namely the top-down method, to gain popularity in the construction of deep basements. This method is preferred mainly due to the suitability, efficiency, and high level of safety it provides. To date, only a handful of projects have been constructed using the top-down method in Jakarta.

The main difference between the two methods is the time at which basement floors are constructed with respect to excavation work. With bottom-up, the basement floors are constructed after excavation work has been fully completed. With top-down, the basement floors are constructed parallel with excavation.

Bottom-up Method

In the bottom-up basement construction method, a retaining structure is placed prior to the commencement of excavation work. Permanent retaining structures, such as a diaphragm wall or secant piles wall, or temporary retaining structures like contiguous bored piles are commonly used. Once the retaining structure is completed, enclosing the entire site, excavation work can proceed in stages. As excavation work progresses to certain depths, a sufficient amount of temporary lateral support is installed at intermediate spacing along the retaining structure. The most commonly used type of temporary lateral support is ground anchors, while temporary steel struts may also be used as an alternative. Once the base of the excavation has been reached, construction of the basement floors is carried out conventionally starting from the bottom level. During the process of constructing upward, the temporary lateral supports are carefully removed following basement floor construction.

From a construction aspect, excavation and subsequent basement works can be done easily and quickly without any obstruction (Figure 1). However, from a legal aspect, permitting is required to install the ground anchors to areas outside the property line. In addition, relaxation of the anchors can cause excessive soil movement and may result in detrimental effects to surrounding buildings.

As an alternative to ground anchors, temporary steel struts can also be used to serve as lateral support to the retaining structure. With temporary steel struts, the legal issue of trespassing into adjacent properties is no longer a concern since the steel struts are installed inside the excavation site. However,

Figure 1. Typical construction site in Jakarta using bottom-up method with temporary ground anchors as lateral support (Source: DSP)
图1. 在雅加达典型的利用临时土锚做为横向支撑的由下而上的方法的施工工地（来源：大卫・苏坎塔结构工程事务所）

Figure 2. RC slabs serve as lateral supports during excavation using the top-down method in a 6-level basement construction (Source: DSP)
图2. 使用由上而下的方法建造一个6层基坑地下室的挖掘过程中将钢筋混凝土板用作横向支撑（来源：大卫・苏坎塔结构工程事务所）

this alternative can often be very costly, requiring large amount of steel tonnage.

In Jakarta, basement structures with 18-meter-deep excavations have been successfully constructed using up to 4 rows of temporary ground anchors.

Top-down Method

In the top-down method, the retaining structure is placed prior to excavation work along with installation of bored piles and plunge columns. The basement floors are then constructed parallel with excavation work with the plunge columns providing temporary gravity support to the basement floors. The retaining structure is typically either a diaphragm wall or secant piles wall. As excavation work progresses to certain depths, a basement floor above the particular depth is constructed. The basement floors serve as an RC strut system providing lateral support to the retaining structure (Figure 2). This

在雅加达，由上而下的方法已经被成功的用来在一个建筑稠密的中央商业区建造挖掘深度达21米的六层基坑地下室。这一基坑地下室结构可能是世界范围内在柔软的冲积粘土中所建造的最深的基坑地下室结构。另一个挖掘深度为25米的七层基坑地下室项目目前正在施工之中。完成之后，这一基坑地下室将是该地区最深的基坑地下室。以上项目将在实际项目案例分析中加以详细讨论。

由上而下的方法的施工层面

从众多的施工考量上来看，由上而下的方法比传统的由下而上的方法要复杂得多。下面将对此展开讨论：

嵌入式柱

如前文所述，由上而下的施工过程需要使用嵌入式柱。在雅加达，最常用的嵌入式柱是嵌入式钢柱（工字形或管形）或复合

process continues until the base floor level is constructed thereby completing the basement structure.

From a construction aspect, the top-down method is generally much more complex in comparison to a bottom-up method. However, this method overcomes many limitations of its counterpart bottom-up method. The top-down method does not encounter the legal issue of trespassing into adjacent properties. With the stiff RC floor slab used to laterally brace the retaining structure, it will cause very minimal movement of the surrounding soil, thereby minimizing risks of potentially damaging the surrounding buildings.

In Jakarta, the top-down method has been successfully applied to 6-story basement in a densely built CBD with excavation depth of 21 m. This is possibly one of the deepest basement constructions ever completed world-wide in soft alluvial clay soil. Another project with 7-story basement and excavation depth of 25 m is currently under construction and will be the deepest in the region once completed. Detailed discussions on these projects are provided in the project case studies.

Construction Aspects of Top-Down Method

There are a number of construction considerations that make the top-down method much more complex in comparison with the conventional bottom-up method, which are further elaborated as follows:

Plunge Columns

As described in the previous section, plunge columns are required in top-down construction. In Jakarta, the most commonly used type of plunge column is steel plunge column (H-shaped or tubular) or composite Concrete-Filled Tubes (CFT). The main purpose of the plunge column is to provide temporary gravity support to the RC basement floor slabs (Figure 3), which in turn provide lateral support to the retaining structure. Proper installation of the plunge columns is a determining factor to a successful top-down construction.

Plunge columns are installed prior to excavation work from surface level, plunged into a hole in the ground, until sufficiently embedded into the fresh concrete of the bored pile directly underneath it. The plunge column must be properly held in position until the setting of the bored pile concrete is able to fix the plunge column in place. It can be imagined that the challenge of handling such an object: placing it in its proper place with a high degree of geometrical precision in both vertical and horizontal direction, while at the same time racing against the setting time of the bored pile concrete. Contractors typically use mobile cranes to lift the plunge column and lower it in place. The process of lowering it solely relies on the self-weight of the plunge column acting against the resisting buoyant pressure from the fresh bored pile concrete.

Excavation Technique

The excavation process in top-down construction is challenging since it is conducted under basement floor slabs with plunge columns obstructing the work. Heavy equipment is typically used to dig up soil under the floor slab. Equipment needs to be operated with extra care in such way to avoid damage to the plunge columns. Soil is accumulated at designated spots to be further transported upward and away from the site. A decent-sized opening is provided in the floor slab, enough to accommodate the soil-transporting process

钢管混凝土柱。使用嵌入式柱的主要目的是对钢筋混凝土基坑地下室楼板提供临时的重力支撑（图3），从而对挡土结构提供横向支撑。嵌入式柱的合理安装是由上而下施工成功的决定性因素。

嵌入式柱是在挖掘工作开始前从地表进行安装的。嵌入式柱被插进地面上的一个洞，直到它充分的嵌入到洞的正下方的钻孔灌注桩的新浇混凝土中。嵌入式柱须要被完全的固定，直到钻孔灌注桩的混凝土凝固到足以将其固定为止。可以想见处理嵌入式柱的挑战性：需要在垂直和水平的方向上以高几何精度将嵌入式柱固定在其合理位置，与此同时，还需要与钻孔灌注桩的混凝土凝固过程竞速。承包商通常使用移动式起重机来升起嵌入式柱然后将其降低到其位置。嵌入式柱的降低过程仅仅依靠嵌入式的自重来抵抗来自钻孔灌注桩的新浇混凝土的浮力。

Figure 3. Plunge column used to support basement floor slab during construction (Source: DSP)
图3：在施工过程中使用嵌入式柱来支撑基坑地下室楼板（来源：大卫・苏坎塔结构工程事务所）

Figure 4. The soil removal process requires opening in slab (Source: DSP)
图4. 土壤移除过程中需要在楼板上开孔（来源：大卫・苏坎塔结构工程事务所）

(Figure 4). Various methodologies can be used to accomplish this, involving the use of temporary ramps and platforms, gantry cranes, or long arm excavators. Another key step in excavation work is to remove the soil out of the site, which is done by strategic management of dump trucks in and out of the site. Due to unpredictable and non-conducive traffic conditions in Jakarta, especially in the CBD, the speed of removing excavated soil out of the site dictates the rate of excavation work.

Construction of RC Basement Floor Slab

The key to proper construction of RC floor lies in the type of formworks being used. In Jakarta, the most commonly used type of formwork system is either slab-on-grade formwork or timber or metal formwork utilizing metal props.

Slab-on-grade formwork relies on the soil bearing capacity to provide support for the wet concrete. Therefore, proper soil compaction is required if this system is used. Construction of the RC slab may be relatively simple with this system; however, the subsequent excavation work needed underneath the slab can be a bit problematic. The issue lies in the risk of formwork falling off the slab soffit during excavation. It is also common to find plywood formwork affixed to the slab soffit, necessitating additional scraping work (Figure 5).

Timber or metal formwork relies on intermediate metal props for temporary vertical support. This system is more

挖掘技术

由上而下的施工过程中的挖掘过程具有挑战性，因为这一过程是在基坑地下室楼板下进行的，其受到嵌入式柱的阻碍。重型设备一般被用来在楼板下挖土。操作设备需要特别仔细以避免破坏嵌入式柱。土壤被累积在指定地点，之后将累积的土壤向上传送并从工地现场移除。在楼板上开出合宜尺寸的洞，其大小足以传送土壤（图4）。多种方法可以被用来完成这一任务。这些方法涉及使用临时坡道和平台、龙门起重机或长臂挖掘机。挖掘工作的另一关键步骤是将土壤移出工地现场。这一步骤通过有策略的对自卸卡车进出工地现场的安排控制来实现。由于雅加达不可预测的、不利的交通状况（特别是在中心商业区的交通状况），移除挖掘出来的土壤的速度决定了挖掘工作的速度。

钢筋混凝土基坑地下室楼板的建造

钢筋混凝土层的合理施工的关键在于所使用的模板类型。在雅加达，最常用的模板系统类型是地面水泥板模板或木材或使用金属支架的金属模板。

地面水泥板模板依靠土壤的承载力来对未干的混凝土提供支撑。因此，地面水泥板模板系统需要合理地将土壤压实。当使用地面水泥板模板系统时，钢筋混凝土板的建造可能会相对简单；但是，之后在钢筋混凝土板下继续挖掘可能会有些困难。这一问题的产生是由于挖掘过程中的模板有从板底掉落的危险性。将胶合板模板粘在板底上的情况也很常见，但这就需要额外的抹平工作（图5）。

Figure 5. Challenging excavation work underneath slab constructed using slab-on-grade formwork (Source: DSP)
图5. 具有挑战性的在用地面水泥板模板建造的楼板下的挖土工程（来源：大卫・苏坎塔结构工程事务所）

systemized and eliminates excavation problems encountered in slab-on-grade formwork (Figure 6 and 7). Excellent soil compaction is critically required with this system since the construction load is concentrated at vertical props and may result in non-uniform settlement of the soil supporting the formwork. This settlement will cause undesirable initial deflection of the floor slab.

For both slab-on-grade and timber or metal formwork, excavation speed and staging is dictated by concrete hardening-time and consequently the amount of time required before formworks can be removed. Excavation work cannot proceed until the formwork is ready for removal. Premature removal of formwork may result in structural failures or excessive long-term deflection of the floor slab. Therefore, determining the right time for formwork removal is very important for this type of system.

Another type of formwork that can also be used for floor construction is the flying form system. This system consists of slab formwork assembly that can be reused on multiple levels of a building. This is done by lowering the assembly from one level to the next, without requiring dismantling work. Up to now, this system is rarely used in Jakarta although it has great potential to increase construction speed. Height-adjustable metal props, similar to ones used in metal formwork system, are commonly used to support the flying form system. Alternatively, the formwork decks may also be attached directly to the plunge columns, thereby omitting use for vertical props. By logic, the omission of vertical props should effectively overcome the shortcomings of the other types of system. Excavation work can proceed efficiently without having to remove the formwork since no intermediate metal props are present, increasing speed of excavation. The issue of poor slab performance due to premature removal of the formwork is also no longer relevant.

Another important factor to consider in RC slab construction is the effect of construction zoning in combination with formwork removal scheduling with respect to the continuity of the slab at supports. When the slab is constructed in multiple pour zones, mapping of the zones needs to be arranged such that the actual slab support condition, and consequently internal force distribution in the slab, is consistent with design assumptions. Therefore, proper coordination between the design and construction process is necessary.

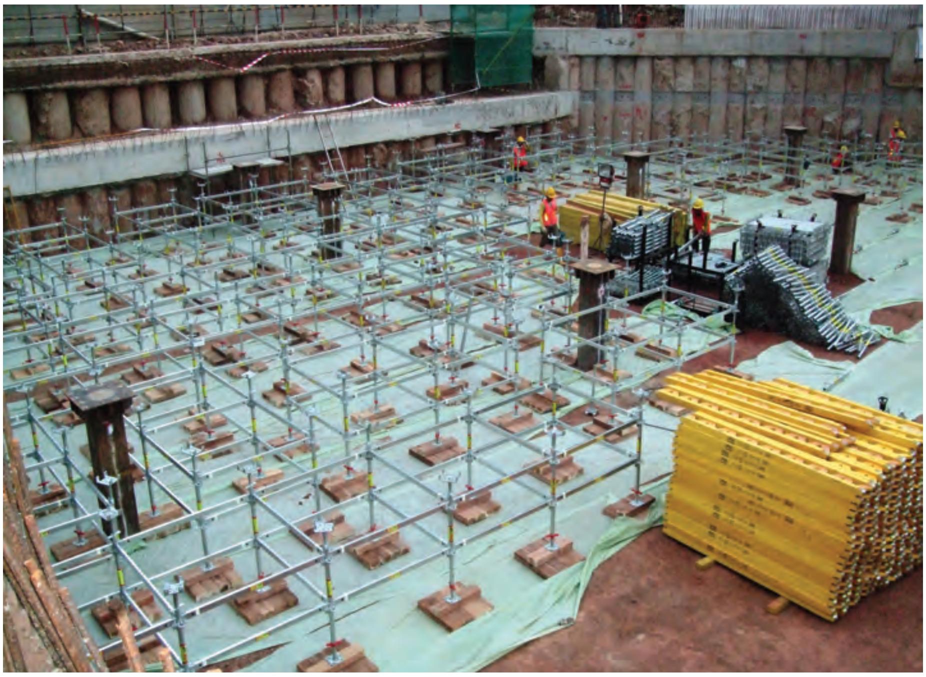

Figure 6. Metal formwork installation for construction of basement floor slab (Source: DSP)
图6. 安装金属模板来建造基坑地下室楼板（来源：大卫・苏坎塔结构工程事务所）

Figure 7. Completed basement floor slab in a top-down construction (Source: DSP)
图7. 一个由上而下施工的建筑建成的基坑地下室楼板（来源：大卫・苏坎塔结构工程事务所）

木材或金属模板依靠中间阶段的金属支架来提供临时的垂直支撑。这一系统更加系统化并且消除了在地面水泥板模板系统中遇到的挖掘问题（图6、7）。木材或金属模板系统要求极佳的土壤压实，因为施工荷载集中在垂直的支架上并且可能导致支撑模版的土壤的不均匀下沉。土壤下沉将会导致不良的楼板初始挠曲。

对于地面水泥板模板和木材或金属模板来说，挖掘速度和阶段安排是由混凝土硬化时间和因此决定的模板移除所需时间决定的。挖掘工作是不能在模板可以移除之前进行的。过早的移除模板可能会导致结构破坏或过度的楼板长期挠曲。因此，确定正确的模板移除时间对于这一类的系统来说是非常重要的。

飞模系统是另一种可以被用在楼层建造的模板。这一系统是由可被重复使用在一个建筑物的多个楼层中的楼板模板组合组成的。这是通过将模板组合从一层降低到下一层而实现的，并且这一过程不需要将模板拆卸。尽管这一系统有很大的加快施工速度的潜力，但时至今日，其很少在雅加达使用。类似于用在金属模板系统中的金属支架，可调节高度的金属支架经常被用来支撑飞模系统。或者，模板桥面可以直接固定在嵌入式柱上，从而省却了使用垂直支架。按照逻辑，省却垂直支架应当有效的克服系统其它种类的缺点。因为不存在中间阶段的金属支架，挖掘工作可以有效地进展下去而不需要移除模版，从而提升了挖掘速度。由于过早移除模版而产生的不良的楼板性能的问题也就不再存在了。

另一个需要在钢筋混凝土楼板建造过程中考虑的重要因素是与楼板在支撑处的连贯性相关的施工分区和模板移除时间安排的

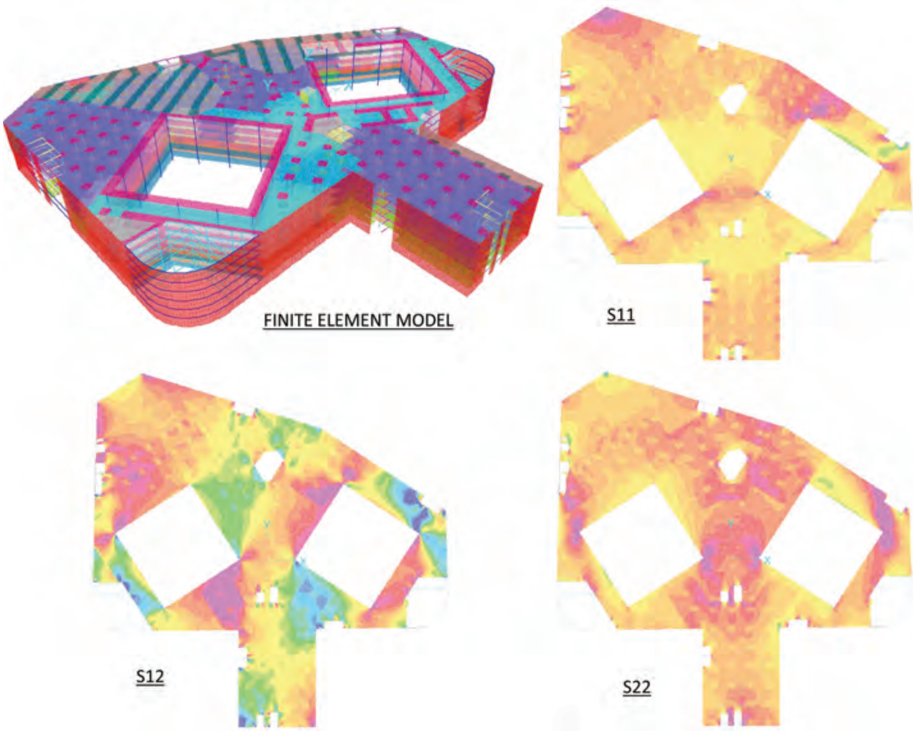

Figure 8. Finite Element Model results showing normal and shear stress contours in the floor slab (Source: DSP)
图8. 有限元模型结果显示楼板中的正应力和剪切应力等值线（来源：大卫・苏坎塔结构工程事务所）

Design Aspects of Top-Down Method

There are also additional design items to be addressed when conducting top-down construction, which are discussed as follows:

Plunge Column

Plunge columns have to be designed considering all the loads that will be present during the top down construction period. During early stages of excavation, the column is subjected to an uncommon condition of stability bracing along its entire height, relying on the stiffness of the soil to provide lateral bracing. As the floor slab construction progresses down into the base level, the bracing-role is gradually taken over by the slab. This staged-condition, with different loading states accompanied by changing stability bracing condition, needs to be accounted for in the design of the plunge column.

RC Floor Slab

As previously explained, in top-down construction the RC floor slab acts as the lateral support for the retaining structure. Therefore, the RC floor slab needs to be designed to resist the lateral earth pressure transferred from the wall. A complete in-plane load path needs to be clearly established, and diaphragm action within the slab needs to be thoroughly assessed to ensure stability of the basement structure. For complex plan geometry, finite element computer modeling is commonly used to analyze the floor slab. Design is performed based on analysis results from the computer model (Figure 8).

As mentioned in the construction aspect of RC floor slabs, consistency between design assumptions and actual construction condition is critical for RC slabs, particularly when construction is carried out in several zones.

Retaining Structure

Design of retaining structure in top-down construction is generally similar to that in conventional bottom-up construction. The retaining structure is designed to resist all internal forces that may develop during the construction process. In obtaining the internal forces, the stiffness of lateral support provided by the slab needs to be accounted for. It is also very important to incorporate construction-staging effect into the design of the retaining structure as this will have pronounced implications to the design.

Project Case Studies

Plaza Indonesia Extension

The Plaza Indonesia Extension (PIE) project comprises two towers with 48 and 42 stories, respectively, and a 7-story podium block resting on a 5-level basement. Each basement level has a very large floor plate with approximate area of 12,500 sq.m. The basement structure of PIE consists of a D-wall with RC flat slab system. The project is located very close to the Japanese Embassy and the existing Grand Hyatt Hotel, which has a 3-level basement structure resting on a soil-supported mat. Therefore, the 17 m-deep excavation needed to be accomplished

综合效应。当楼板在多个浇灌区进行建造时，浇灌区的布置应该使得实际的楼板支撑条件和因此而产生的在楼板里的内力分布与设计假设相一致。因此，需要合理的协调设计和施工过程。

由上而下的方法的设计层面

在进行由上而下的施工时，还需要处理一些其他的设计内容。这些内容将在下文中讨论：

嵌入式柱

在设计嵌入式柱时，需要考虑在由上而下的施工期间存在的全部荷载。在挖掘初期，嵌入式柱受到一个不常见的沿着其整个高度加固的稳定性条件的影响，其依靠土壤的硬度来提供横向加固。当楼板施工进行到底层时，楼板逐渐的接替了这一加固作用。这一有着伴随着变化的稳定加固条件的不同承载状态的分阶段条件需要在设计嵌入式柱时加以考量。

钢筋混凝土楼板

如前所述，在由上而下的施工过程中，钢筋混凝土楼板做为挡土结构的横向支撑。因此，钢筋混凝土楼板需要设计成可以抵抗来自于墙的横向土压力。需要清楚地建立全部的面内负载路径以及充分地估算楼板内的隔板作用来确保基坑地下室结构的稳定性。对复杂的平面几何，有限元计算机模型通常被用来分析楼板。根据计算机模型的分析结果来进行设计（图8）。

正如前面对钢筋混凝土楼板的施工层面的论述，设计假设和实际施工条件的一致性对于钢筋混凝土楼板是至关重要的，尤其是当施工在几个区域内进行时。

挡土结构

一般来说，在由上而下的施工过程中使用的挡土结构的设计类似于在传统的由下而上的施工过程中使用的挡土结构的设计。挡土结构被设计成可以抵抗在施工过程中可能产生的全部的内力。为了获得内力，需要考虑由楼板提供的横向支撑的刚度。将施工阶段效应包含在挡土结构的设计中也是非常重要的，因为其对设计会有着显著的影响。

工程项目案例分析

印度尼西亚广场扩建

印度尼西亚扩建项目包括一个48层的塔、一个42层的塔和一个有着5层基坑地下室的7层墩座大楼。每一基坑地下室楼层都有很大的大约12,500平方米的楼面板。印度尼西亚广场扩建项目的基坑地下室结构由带有钢筋混凝土平板系统的隔墙组成。扩建项目距离日本大使馆和已有的带有3层基

without causing considerable soil movement that would likely have a detrimental effect on the neighboring buildings. Temporary ground anchors are not an option due to lack of space and their lack of capability in limiting soil movement. In addition, the presence of a high groundwater table located 1.5 m below the surface and a tight construction schedule increases complexity for the project. Top-down construction was considered as the most suitable solution for the project.

In order to further save overall construction time, the top-down construction was extended to an up-down construction, where construction of the towers above grade level can proceed in parallel with construction of the basement. For this project, the application of up-down construction was able to save up to 11 months of construction time compared to conventional bottom-up methods (Figure 9 & 10).

In the project, installation of the plunge columns exceeded the verticality tolerance considered in design. For deep basements with long plunge columns, this will result in eccentric application of floor load and compromised axial load-bearing capacity of the plunge column. The initial up-down construction was designed to reach 15 floors above grade. However, due to the plunge column verticality issue, the upward construction progressing parallel with basement construction had to be limited to 10 floors above grade.

World Trade Center 3

World Trade Center 3 (WTC3) is a 44-story office tower building with 5-level basement with approximately 9,000 sq.m basement floor area, situated in the dense CBD (Figure 11). Retaining system for the 16 m-deep excavation is secant pile wall and the basement floor system is RC flat slab. The chosen method of construction for the 16-m deep excavation is the top-down technique.

In this project, innovation on the plunge column was first introduced by using CFT where the concrete infill is precast prior to plunging of the column. This improvement was found to aid the installation process since increased self-weight of the plunge column effectively counters the resisting hydrostatic uplift force of the wet concrete.

To prepare solid support for the slab formwork, compaction of soil was carried out using heavy compacting equipment. However, the compaction process actually disturbed the plunge columns making them lean towards the compaction side. The effect to column

Figure 9. Construction progress of Plaza Indonesia Extension using up-down method (Source: DSP)
图9. 使用逆作法进行的印度尼西亚广场扩建项目的施工进程（来源：大卫・苏坎塔结构工程事务所）


Figure 10. Plaza Indonesia Extension construction photos showing excavation work progressing parallel with tower construction above grade level (Source: DSP)
图10. 印度尼西亚广场扩建项目照片显示挖掘工作与地面线以上的塔楼部分的施工同步进行（来源：大卫・苏坎塔结构工程事务所）


Figure 11. Aerial site photo of WTC3 project during top-down construction (Source: DSP)
图11. 航拍由上而下施工中的世界贸易中心3号楼工地照片（来源：大卫・苏坎塔结构工程事务所）

坑地下室结构的凯悦大酒店很近。凯悦大酒店的基坑地下室结构建于土壤支撑的支柱地板上。因此，17米深的挖掘工作需要在不造成大量土壤运动的情况下完成，因为大量的的土壤运动很有可能会损害周边建筑。由于空间的不足和其缺乏限制土壤运动的能力，临时性土锚不能够被采用。另外，地表1.5米下的高地下水位以及紧张的施工日程更加提升了项目的难度。由上而下的施工方法被认为是最适合这一项目的方法。

为了进一步节省整体施工时间，由上而下的施工被扩展成逆作法施工。如此，对在地面线以上的塔的施工可以与基坑地下室的施工同时进展。对于这一项目，与传统的由下而上的方法相比，逆作法施工的应用节省了最多11个月的施工时间（图9、10）。

在这一项目过程中，嵌入式柱的安装超过了设计中考虑的垂直度超差。对带有长嵌入式柱的深基坑地下室来说，这将会导致楼面载荷的偏心施加以及损害嵌入式柱的

Figure 12. Aerial site photo of Sequis Tower during top-down construction (Source: DSP)
图12. 航拍由上而下施工中的塞奎斯项目照片（来源：大卫·苏坎塔结构工程事务所）

capacity was small but enough to prompt improvement of compaction method.

Sequis Tower

The Sequis Tower project consists of a 39-story-tall tower on a 6-level basement with 8,200 sq.m basement floor plate. The retaining system for the 21 m-deep excavation is a D-wall, and the basement floor system is RC flat slab. Located in the densely built CBD, the project site lies in very close proximity to surrounding buildings (Figure 12). The initial basement design for the building was bottom-up using temporary steel strutting as lateral support for the retaining system. However, this resulted in excessive cost arising from the amount of steel strut members required. In addition, due to the limited capacity of local steel production, the speed of fabrication would not be able to keep up with the required speed of basement construction. Since the initial design was not viable from a cost and time aspect, reengineering was necessary, developed based on the top-down concept. The deep basement construction using top-down method has been successfully completed saving significant amounts of construction cost and time, providing a great example of the effectiveness and efficiency of the top-down method for deep basement projects located in densely built regions.

Indonesia-1

The Indonesia-1 project is a 170,000 sq.m development encompassing two 63-story and 54-story towers both on a 7-level basement with 16,000 sq.m floor plate area, currently under construction. Both towers will have a RC core wall with outrigger and steel frame floor system. When completed, with excavation depth of 25 m, Indonesia-1 will have the deepest basement construction in Indonesia. The project site is one block away from the

轴向承载能力。最初的逆作法施工被设计成可以到达地面线以上的15层。但是，由于嵌入式柱的垂直度的问题，只有地面线以上的10层的向上施工过程可以与基坑地下室地下室施工过程同时进行。

世界贸易中心3号楼

世界贸易中心3号楼是一个坐落在建筑稠密的中心商业区的（图11）有5层基坑地下室的44层的办公大楼，其基坑地下室的楼层面积大约为9,000 平方米。咬合桩墙被用作16米深的挖掘工作的挡土系统。钢筋混凝土平板被用作基坑地下室楼层系统。由上而下的施工技术被用来完成16米深的挖掘工作。

在这一项目中，对嵌入式柱的首要创新是钢管混凝土管的使用，混凝土填充物的预制在嵌入式柱插入前完成。这一改进被发现可以辅助安装过程，因为增加的嵌入式柱的自重有效地抵消了未干混凝土的静水浮抗力。

为了准备对楼板模板的稳固支撑，重型压实设备被用来将土壤压实。但是，压实过程事实上干扰了嵌入式柱，使得嵌入式柱向压实侧倾斜。对柱效能的影响虽然很小，但足以让施工者对压实方法加以改进。

塞奎斯塔

塞奎斯塔项目由一个带有6层基坑地下室的39层的高塔组成，其基坑地下室楼面板的面积大约为8,200平方米。隔墙被用作21米深的挖掘工作的挡土系统。钢筋混凝土平板被用作基坑地下室楼层系统。项目工地在建筑稠密的中心商业区，距离周围的建筑非常近（图12）。该建筑最初的基坑地下室施工设计是由下而上的，利用临时钢支柱做为挡土系统的横向支持。但是，这一设计导致了由钢支柱构件引起的过度成本。另外，由于当地有限的钢生产能力，钢支柱的制造将不能够跟上所需的基坑地下室建造速度。因为最初的设计从成本和时间方面来看是不可行的，所以需要重新设计。新的设计是基于由上向下的概念。利用由上而下的方法已经成功的建造了深基坑地下室，节省了大量的施工成本和时间，并提供了一个很好的展示由上而下的方法用在建筑稠密地区的项目上的有效性和高效率的例子。

印度尼西亚1号

印度尼西亚1号项目是一个总面积为170,000平方米的开发项目，包括一个63层的塔和一个54层的塔。这两个塔有一个楼面板面积为16,000 平方米的7层基坑地下室。印度尼西亚1号项目目前正在施工中。两个塔都将有带有悬臂梁和钢框架楼层系统的钢筋混凝土心墙。完工后，印度尼西亚1号项目的挖掘深度将达到25米并将拥有印度尼西亚最深的基坑地下室结构。此项目地点与印度尼西亚扩建项目地点被一个街区隔开，日本大使馆位于这两个项目的中间。印度尼西亚1号的基坑地下室也将会有直接通向目前正在施工中的正好在这一项目工地前穿过的雅加达地铁线的隧道。根据这一情况，需要使用由上而下的方法来建造基坑地下室。

在设计的时候了解到，在这一深度，设计横向土压力可能会极大。因此，对钢筋混凝土板的设计的要求变得极高。所以，楼板上的开孔需要有策略地缩小到最低以维持楼板的整体连续性。否则，抵抗巨大压力所需的楼板厚度将变得不合实际的大。

结语

在雅加达，由于当地法规以及民众对私家车的偏爱，深基坑地下室对高层建筑开发来说是不可或缺的特征。对于地面线以上多于30层的建筑来说，有3到7层的深基坑地下室结构是很常见的。在建筑稠密的地区，比如说中心商业区，由上而下的深基坑地下室建造方法是传统的由下而上的方法更高效、更安全的替代选择。本文所展示的项目实例显示出了由上而下的方法的有效性。应该通过不断地学习和进行中的项目的试验过程来认识、评估和进一步了解由上而下施工的设计和施工层面的复杂度。随着对中心商业区重振的需要的不对增加，完善在雅加达使用的由上而下的施工技术对促进当地稠密的垂直城市化至关重要。

Plaza Indonesia Extension with the Japanese embassy situated in between the two. The basement of this building will also have direct tunnel connections to the presently under-construction Jakarta subway line, running right in front of the project site. This condition prompts the need for a top-down approach for construction of the basement.

During design, it was learned that at such depth, the design lateral earth pressure can be extremely large, producing very high demand for the RC slab design. Therefore, openings in the slab need to be strategically minimized to maintain overall continuity within the slab. Otherwise, the slab thickness required to resist the immense stresses will become impractically substantial.

Concluding Remarks

In Jakarta, due to applicable local regulations and social preference for private vehicles, deep basements are an inseparable attribute to tall building development. It is common for buildings with more than 30 floors to have between 3- to 7-level deep basement structures. In densely built areas, such as the CBD, the top-down method is the more efficient and safer alternative to the conventional bottom-up method for deep basement construction. The effectiveness of the top-down method is evident from successful project case studies presented in this paper. The complexities of design and construction aspects in top-down construction need to be recognized, assessed, and further understood through continual learning and experimental processes in ongoing projects. With increasing need for revitalization of the CBD, perfecting the art of top-down construction in Jakarta is essential in facilitating dense vertical urbanism in the region.

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