S15-1

DEVELOPMENT AND APPLICATION OF SUBSTRUCTURE NON SUPPORTING FORMWORK FOR TOP-DOWN CONSTRUCTION

Mee-Ra Jeong[1], Hong-Chul Rhim[2] , Doo-Hyun Kang[3] and Kwang-Jun Yoo[4]

[1] Graduate Research Assistant, Dept. of Architectural Engineering, Yonsei University, Seoul, Korea
[2] Professor, Dept. of Architectural Engineering, Yonsei University, Seoul, Korea
[3] President/P.E, HYUN Structural Engineering, Seoul, Korea
[4] Director, Research and Development Division, CM Partners Inc., Seoul, Korea
Correspond to *mummy0321@gmail.com*

ABSTRACT: Constructing substructures by using Top-Down or Downward method needs an efficient formwork system because of difficulties in supporting concrete slabs from the bottom while excavation is in process. Existing underground formwork systems can be classified by three types: graded ground supported type (Slab On Grade, Beam On Grade), suspension type (Non Supporting Top Down Method), and bracket supported type (Bracket Supported R/C Downward). Each method has its own advantages and limits. Application of a specific formwork system for a given construction site is determined by various conditions and affect construction time and cost. This paper presents a newly developed underground non-supporting formwork system, which combines the advantages of a suspension type and a bracket supported type while it overcomes limits of two types. The developed system has a moving formwork which is supported by suspension cables hanging from the bracket placed at the top of pre-installed substructure columns. Then, the moving formwork is repeatedly lowered down for the next floor below to support concrete slab during curing. The details of this bracket and cable supported system have been investigated for the improvement of easiness in construction.

Keywords: Top-Down, Downward, Formwork, Bracket Supported, Suspension

1. INTRODUCTION

As the typical method of building construction, it is usual to use an open-cut method with tie-back for the construction of building substructures. However, in crowded downtown areas as in Europe, Asia or some cities in U.S., there is a great possibility that the simplest tie back method cannot be applied [1], [2]. In those cases, top-down is an alternative substructure construction method avoiding tie backs and ensuring a rigid earth-retaining system for the installation of slabs in the substructures [3], [4]. The Top-down method also has the advantages of minimizing the impacts for surrounding buildings or residents with reduced dusts, vibrations, or noises [5]. In the future, for making full use of urban area, superstructures will have more number of stories in the form of high-rise buildings and substructures will go deeper for more subspace. As the significance of the subspace is growing, the necessity of Top-down method would be increased [6].

In the case of the open-cut method, entire construction processes for substructures are going upward. Once excavation is completed, foundation should be constructed first and then the columns are installed. Inversely, for Top-down method, columns for substructures should be installed together with construction of foundation before main excavation begins. Thereafter, as the slabs are placed while excavation is in progress, the difficulties come in supporting concrete slabs from the bottom. It is a special circumstance compared with open-cut method. There are three groups of existing formwork systems for Top-down method: ① Concrete on grade which is using stabilized ground as supporter of formwork is a general method for Top-down. ② Support Method with shores is similar to formwork method of open-cut [7], [8]. As the excavation cannot progress while concrete is being cured, it takes longer than the other system of formworks. Also, it has low workability by repetition of formwork setting for each level. ③ BRD (Bracket Supported Reinforced Concrete Downward Method) and NSTD (Non Supporting Top Down Method) are systemized formwork which are progressed by removing shores [9]. This paper proposes a system formwork for Top-down construction which eliminates shoring by hanging the formwork from the top of column using suspension.

The method presented in this paper, which is called Easy Down, is the similar to the above-ground system formwork like a flying form. Accordingly, it has advantages for construction of buildings with grids in plan. Though the time and the cost in pre-phase can be more demanding because of its requirement of preproduction of formwork, it shortens the time of

construction and improves workability and quality at the same time [10], [11], [12].

Easy Down combines two methods of BRD and NSTD, which are existing system formwork methods for top-down. BRD is a bracket supported type, NSTD is a suspended type, and Easy Down is a bracket supported and suspended type. It can maintain the advantages of BRD and NSTD while it overcomes limits of two methods. Following will show existing formwork methods for top-down construction, and present differences by comparison. Also, concept idea and details of Easy Down would be presented.

2. EXISTING FORMWORK METHODS FOR TOP-DOWN CONSTRUCTION

2.1 Concrete On Grade Method

This method uses grade for formwork by stabilizing the ground at desired elevation. There are two types in this method, SOG (Slab On Grade) which is applying for flat slab or flat plate, and BOG (Beam On Grade) which contains construction of beam or girder. This method has been used from early top-down construction because of its simple concept, but it is a labor intensive method.

After stabilizing the ground, and the forms are installed for slabs and beams. Then, reinforcing bars and concrete are placed. After curing, excavation and stabilization for next lower floor are processed. Above stated sequences are repeated (Fig. 1).

This method uses ground as a formwork supporter, so no other process is required in preparation phase. It is good to apply to buildings with various plans, because of its individual construction sequence for each floor. Also there is little needs for complicated procedures. However, uniformed formwork cannot be applied, so this form setting sequence for each level needs more time and labor than other methods. Moreover, the lower part excavation cannot be progressed while the concrete curing. It can be the main cause of delay which raises cost for construction. Dewatering system has to be considered in underground with high groundwater level. In addition, it can be only used for ground with normal condition, because ground with loose gravels has low supporting ability, and rock based ground can cause damage during excavation.

Fig. 1. Construction of Beam On Grade

2.2 Support Method with Shores

Support method with shores sets shores on the excavated ground, and it is similar to usual above ground support method. It can be applied in two types, which are regular downward sequence, and skipping one after the other floor sequence.

For regular sequence method, shored formworks set on the stabilized ground or the laid plain concrete. Therefore, this method needs deeper excavation than required depth. After reinforcing bars and concrete slab are set on the required depth, shores have to be maintained until the slab is fully cured (Fig. 2).

There are some advantages of this method compared to concrete on grade method. In this method, adjustment of formwork level, and finding or repairing of leaking part of formwork can be easier. However, still there is a necessity of waiting time for concrete curing. Shores cannot be removed so it is impossible to excavate under the concrete slab during curing. Also, there is a possibility of formwork deformation which is typical problem of above-ground shored formwork method.

Skipping sequence method is to improve the regular sequence of placing slabs one floor at a time. This method uses concrete on grade method together with support method. This method needs 2-story-depth excavation at once, and lower floor is constructed before upper floor by using concrete on grade method. During curing of lower floor's concrete slab, upper floor construction progresses by using support method.

This method can shorten the construction time by using two methods together. During the lower floor concrete slab curing, upper floor construction is progressing, so it can save the waiting time. This method maintains the difficulties of concrete on slab method and support method as well as advantages. Every slab has to be reconstructed each floor level, so it is advantageous for various planned building. However it can be cause delay because of labor intensive process. Also dewatering system and condition of ground has to be considered. For the construction of upper floors, shores should be maintained until complete curing.

Fig. 2. Construction of shoring method

2.3 Non-shored Formwork Methods

The main problem among the methods presented above is time for concrete slab curing and excavation cannot be progressed at the same time. That causes delay in the time of construction which raises the costs. To excavation be progressed during concrete slab curing, the formwork method has to have no shore and no grade. Shore removed formwork can be free in excavation without consideration of curing related timing. There are two types of non-shored formwork method, suspended formwork system and bracket supported formwork system.

Suspended Formwork Method, NSTD (Non Supporting Top Down Method)

Suspended formwork method is called NSTD, which means Non Supporting Top Down Method. This method is the kind of pre-produced system formwork, and it hangs the formwork by suspension so there is no need for shores. Formwork and concrete slab hang by uniformly distributed 12 ~ 16 suspensions per 1 span, and the suspensions are fixed at upper slab by rock bolts. Formwork lowering also is done via those suspensions.

For the construction of ground floor, deck formworks are fabricated on the stabilized ground. After reinforcing bars are placed, rock bolts are installed through the sleeves. Then concrete is placed and the soil under that concrete is excavated during curing. Formworks hang by the suspension and rock bolts in that time. When the excavation and concrete curing is over, deck formworks are lowered to the floor level below by using lifting devices. After that, the sequence is repeated (Fig. 3).

This method uses deck formworks repeatedly to each floor, so it has advantages for the consistent plan through the floors. The soil condition becomes a minor problem, because formworks are supported by not the ground but suspension. Also, suspension supporting makes it possible to parallel progress of concrete curing and excavation. Therefore, the construction time and the cost can be reduced by applying this method to appropriate case. However, there is a need for time and cost in the preparation-phase, for the formwork making. Uniformly distributed suspensions can cause the damage of upper floor slab, or disturb the working on the supported slab. Also, this method needs additional work of setting sleeves and rock bolts.

Fig. 3. Construction of Non-Supporting Top-Down

Bracket Supported Formwork* Method*, BRD (Bracket Supported Reinforced Concrete Downward Method)

Bracket supported formwork method is called BRD, which means Bracket Supported Reinforced Concrete Downward Method. This method is also pre-produced system formwork, so has some similarity with NSTD, but BRD has different supporting form and formwork material, metal deck. This method supports formwork by setting the brackets which are installed at the pre-founded column. 4 brackets per 1 span. Formwork is lowered by using the suspension like NSTD.

First, stop plates and brackets are installed at the each pre-founded column. Stop plate is a unit for the bracket level control and support. After formwork frame fabricated on the brackets, stop plates and brackets are fixed at designed level. Then metal deck is installed on the formwork frame, and concrete is placed. During curing, soil under the slab is excavated. When the excavation and concrete curing is over, stop plates and brackets are released and lowered to the next floor level. Bracket and formwork frames hang by the suspensions and the lifting devices lowers. After that, repetition progresses (Fig. 4).

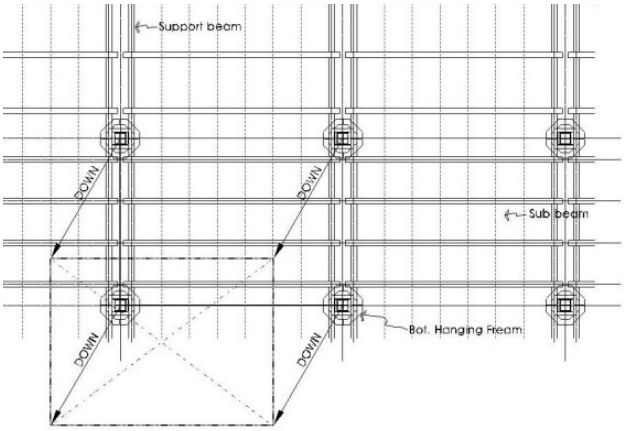
This method has the advantages of system formworks like NSTD. Those can make reduction of the time and the cost, but the loss in pre-phase has to be considered. After all, this method is appropriate to be applied to repetitive planned building. This method can be applied various types of soil. Bracket of this method can support the concrete slab reliably, and there is far less possibility of damaging the upper floor slab. However, brackets have to be released at each lowering sequence, and be fixed tightly as they support the load of slab.

Fig. 4. Construction of Bracket Supported R/C Downward

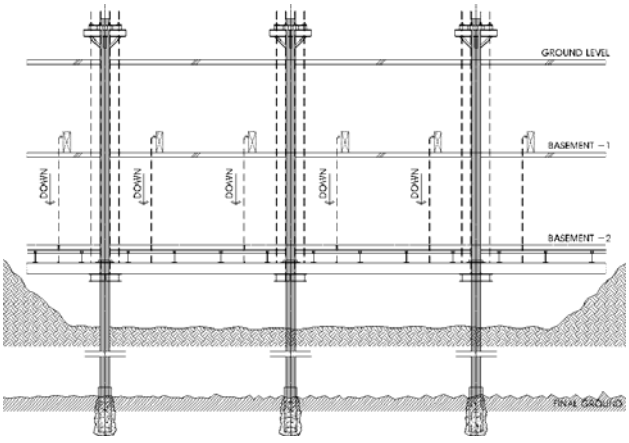
3. DEVELOPMENT OF EASY DOWN METHOD

3.1 Introduction to Easy Down Method

Easy Down method is a non-supporting formwork method for the top-down construction. It developed in the form of combination of suspended type, NSTD and the bracket supported type, BRD. In this method, formworks hang by the suspensions which are fixed at the bracket. Brackets are installed at the top of pre-founded column for whole substructure construction process, without moving. 1 span is supported by 8 suspensions, main steel bars, which are concentrated 2 per each corner. Lowering progresses by another 4 suspensions, sub steel bars, and lifting devices. (Fig. 5).



a) Plan View of columns and support beams



b) Section of Support System

Fig. 5. Schematic Diagram of Easy Down Method

Easy Down is a sort of system formwork, and needs pre-producing of formwork. This method has similar conditions of application with other non-shored formwork methods, NSTD, and BRD. Repetitive planned building through the floors is appropriate to application, when economical analysis has considered. This method has little limits about the conditions of soil, because of its non-shored system.

Easy Down is similar with NSTD in the form of suspension. By lessening the number of the suspensions and fixing the suspensions at the bracket not on the upper floor slab, this method can reduce the slab damages as well as the working spaces. Also, rock bolt setting process, which is necessary in NSTD, can be removed.

This method has similarity with BRD, using bracket as the main supporting unit. However, brackets in Easy Down are not moving, so the releasing and fixing process of BRD is not necessary. Therefore, Easy down is compromising method, which maintains advantages of two methods, while overcomes the limits of them.

3.2 Components Organization and Load Path

Easy Down formwork system consists of five main components, which are formwork, hanging unit, suspension, main bracket, and holding unit. These components are listed in order to load passage.

Load of the concrete slab (Fig. 6-1) passes to the formwork, the assembly of the sub beams and the support beams. Load is distributed to top placed formwork component, the sub beams (Fig. 6-2), and passes to the support beams (Fig. 6-3), which are perpendicular to sub beams. The Hanging unit (Fig. 6-4) is the component that conveys the load from the formwork, to suspension. 4 hanging units are placed under the formwork at each corner and two suspensions are attached per one hanging unit. Therefore 8 steel bars stand 1 span of concrete slab. The Steel bars (Fig. 6-5) are used as the suspension, and they passes the load to the holding units (Fig. 6-6). The holding unit is the component which is installed on the main bracket (Fig. 6-7). The load passed to main bracket is conveyed to the foundation via column (Fig. 6-8).

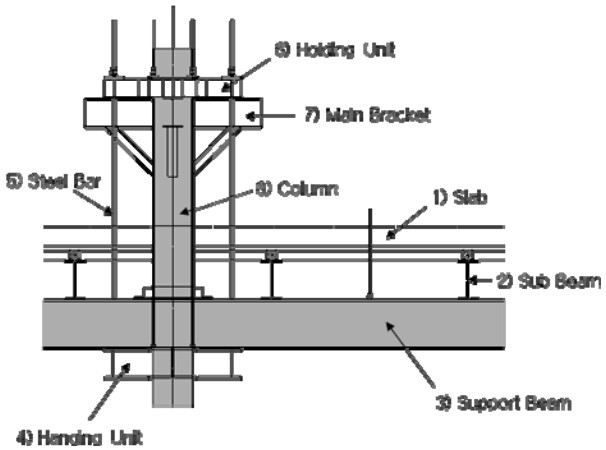
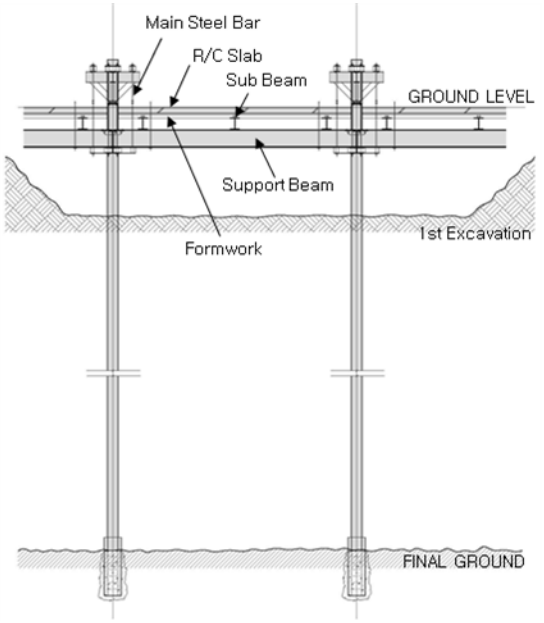


Fig. 6. Load path through connection with numbers indicating the sequence

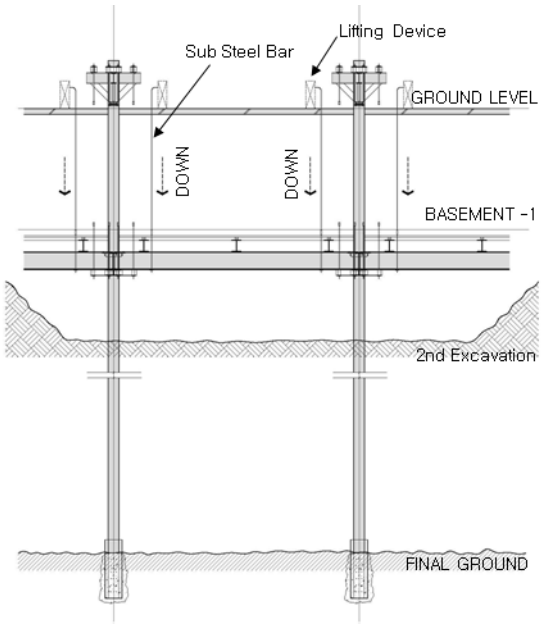
3.3 Sequence of Construction

The steps of construction operation using the Easy Down method are follows. The conceptual sequence of the operation is illustrated in Figs. 7(a-d).

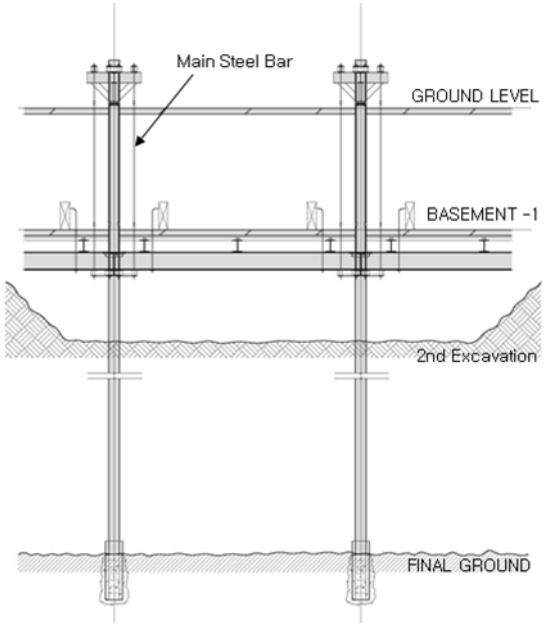
1) After soil retaining wall is constructed, ground is bored at the positions of designated columns. Foundation is constructed in the ground, and pre-founded column construction is finished.
2) Main brackets and holding units are installed at the top of pre-founded column, and hanging units hang by main steel bar.
3) After first excavation, the hanging units are fixed for ground floor slab. Support beams are placed on the hanging units, and sub beams are installed on the support beams. Then, formwork fabrication is finished by setting forms on them (Fig. 7-(a)).
4) The reinforcing bars are installed, and the ground floor concrete slab is placed. The sleeves for suspensions have to be installed on slab. While the concrete is curing, second excavation is progressed.
5) When the concrete slab is fully cured, lifting devices are set and connected with the sub steel bars. The fabricated formworks are lowered hanging by sub steel bar (Fig. 7-(b)).
6) After the formwork is set on first basement floor level, it connected with elongated main steel bar which hanging from holding units. Then the first basement floor is constructed (Fig. 7-(c)).
7) These steps are repeated down to the lowest basement floor (Fig. 7-(d)).



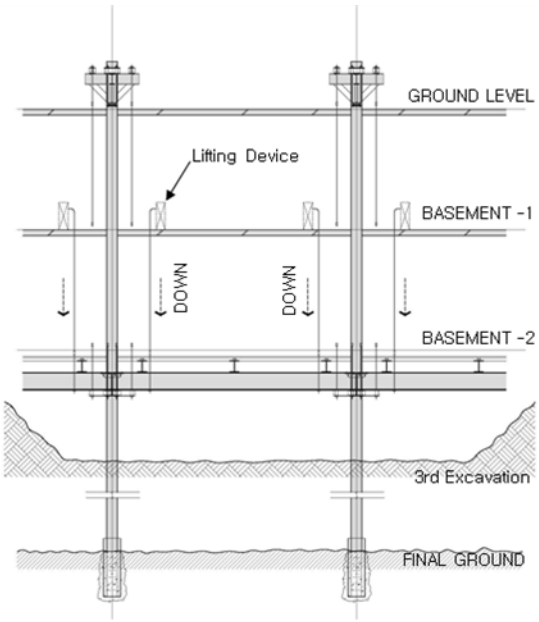
(d) Unit Setting and Construction of Ground Level



(d) Lowering by Sub Steel Bar and Lifting Deice



(d) Construction of First Basement



(d) Lowering to Second Basement

Fig. 7. Conceptual Diagram of Lowering Sequence

4. DISCUSSION and CONCLUSION

Easy Down is the non-supporting system formwork method for the top-down construction. Non-supporting formwork is the relatively newer method than the traditional methods as the slab on grade or shoring method. There are existing non-supporting methods which are similar to the Easy Down method: Suspended method, NSTD, and Bracket supported method, BRD. Easy down method take advantages of those two methods, while overcomes the limits of those. Followings are distinctive features of Easy Down method in comparison with NSTD and BRD.

1) Easy Down stands the loads from the suspensions by bracket not by the upper floor slab, so damages on slab can be reduced.
2) Easy Down has suspensions less than NSTD, so the lowering process can be simplified.
3) Suspensions of Easy Down are grouped together, so the working space is guaranteed.
4) Brackets of Easy Down don't need to move during the lowering step, so releasing and re-installation process is not needed.

In conclusion, the decision of using formwork systems for Top Down construction method has to be made considering various conditions, such as the condition of site, types of buildings. Therefore, the application of the Easy Down method presented in this paper gives an option to employ economical and easy-to-apply formwork system for substructure construction.

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