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Emerging Trend in Deep Basement Construction: Top-Down Technique

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***ABSTRACT*:** Infrastructural requirements in urban area make mandatory construction of basements which serve as space for car parking and housing utilities of various kinds. Demand for underground space has increased exponentially and this has triggered several levels of basement. Invariably, majority of such projects are planned on fast track basis wherein, technology of any form that can reduce the construction period is always a preferred choice. In this context, Top-Down construction has been increasingly used in urban areas, particularly for high rise buildings with basements so that the sub-structure and super-structure works can be executed concurrently. Top-down construction is replacing the traditional bottom-up construction technique owing to several advantages this new technique offers.

This paper presents details of Top-Down construction technology. Important component of this technique is the Diaphragm wall, which is a specialized slender retaining wall constructed from the ground. Construction intricacies and methodology of execution of such wall also form part of this paper. Two case summaries are reported on Top-down construction executed by principle authors' firm. One such site comprised multi-level car parking facility in a crowded area of Delhi, while other formed a part of underground metro station at Kolkata. The paper concludes with words of indispensability of such technology for early commissioning of the structures.

Keywords: *Top-Down Construction, Bottom-up Construction, Diaphragm wall, Barrette, Column, Pre-concreting and Post-concreting installation*

1. INTRODUCTION

Conventionally, buildings with underground basements are built by Bottom-up method where sub-structure and super-structure floors are constructed sequentially from the bottom of the sub-structure or lowest level of basement to the top of the super-structure. Though this conventional method is simple in both design and construction, it is not feasible for the gigantic projects with limited construction time and/or with space and other site constraints. Top-down construction method as the name implies, is a construction method which builds the permanent structure members of the basement along with the excavation from the top to the bottom. Top-down method is mainly used for two types of urban structures, namely tall buildings with deep basements and underground structures such as car parks, underpasses and metro stations. In this case the basement floors are constructed as the excavation progresses. The Top-down method has been used for deep excavation projects where tieback installation is not feasible and soil movements have to be minimized. This construction method which provides the significant saving of the overall construction time, is showing increasing adoption for major projects where time factor is of primary importance. The sequence construction begins with flexible retaining wall installation and then load-bearing elements that will carry the future super-structure.

The present paper presents this emerging technology in the construction industry, giving details of the procedure involved, and their advantages compared to its predecessor namely the Bottom-up method. Construction of Diaphragm wall which is a key element in this form of technology is given specific attention. Two case summaries of Top-down construction, where the principle authors' firm were involved, have been reported. Both of these projects derived inspiration from the imminent financial gains due to reduced project time and early commissioning of the services for which the infrastructural projects were intended for.

2. CONVENTIONAL APPROACH TO UNDERGROUND CONSTRUCTION – BOTTOM-UP CONSTRUCTION

In a conventional Bottom-up approach, after the construction of basement piles and diaphragm wall, the construction agency excavates the enclosed area to the desired depth and then proceeds for installation of strutting/ bracing system to support the basement walls as the excavation proceeds which is followed by construction of the basement. Depending on the depth of the excavation, structural design may require one or more different layers of struts to ensure sufficient resistance against earth and ground water pressure against the peripheral retaining walls.

After installation of strutting system is completed and ground is excavated to bottom level of foundation, the agency proceeds with construction of foundation mat, and proceeds upwards with the construction of series columns and slabs for various levels of basements. Thereafter, construction of superstructure of the building is initiated as per general practice.

Strutting system are used as a temporary support of the basement retaining walls, and are replaced by floor slabs which are also designed to provide permanent lateral support to these walls.

3. TOP-DOWN CONSTRUCTION

With increasing basement levels, excavation method have become more complicated, leading to Top-down techniques which allowed for simultaneous construction of the basement and superstructure erection. These techniques became popular in major international city centres during 1980s and 1990s. Developments in the underground techniques, particularly in London, earlier were largely based on a paper by Zinn [1] and indicated progressive refinements in the piling and diaphragm wall equipments.

3.1 Reported Works on Top-down Construction

The history of construction, design and developments of deep excavations is extensively covered by Puller [2]. This author reports developments across the globe and more specifically to the stringent requirements at London. Fenoux [3] describes the construction of a nine-storey basement for car parking in which the super structure was opened for use even before the completion of the sub-structure. In 1972, the House of Commons underground car park in London was built with peripheral diaphragm walls with temporary supports from floor slabs cast successively with continuing excavation. The basement reached a maximum depth of 18.50m with diaphragm wall 30m deep. Case history of a recent deep basement construction in London has been described by Marchand [4&5]. The basement is constructed by Top-down technique to a depth of 23.9m from ground level to the lowest formation level, and was built for car parking below an eight-storey office block superstructure. A successful application of this construction technique in a congested area of London in Knightsbridge for use by Harrods department stores have been described by Slade et al. [6], and control of ground movements and application of compensation grouting by Fernie [7] and Kenwright et al [8].

American practice of Top-down construction is described by Fletcher [9]. The excavation for a large four storey deep basement for the Milwaukee Centre, close to historic structures, demanded a cut-off and control of ground water, minimum soil movement and early completion. Bracing or a raker system was expected to be tedious and cost prohibitive, while a temporary freeze wall was thought to be unfeasible. Top-down method with deep diaphragm wall as a cut-off was adopted and proved successful. Puller [2] reports a case in Paris for 28m deep basement with anchored support in lieu of lateral support from the basement floor as excavation proceeded. Large barrette sections were constructed for super structure support. In Hong Kong, demand for deep basements is inevitable owing to high prices of land. Top-down construction is frequently adopted in spite of unfavourable soil conditions and stringent settlement criteria are a norm applied to basement peripheral subsoils. Construction of deep basement for the Dragon Centre in the heart of the Western Kowloon Peninsula has been reported by Lui and Yau [10]. The paper describes the structure, design and analyses and arrangements for the basement construction.

3.2. The Top-down Technique

Although Top-down is an overall system of multilevel basement construction, it is outlined here because of its efficiency with diaphragm walls (Santarelli and Ratay [11]). It involves the construction of successive basement levels from the ground down to the lowermost subbasement (Fig. 1). Construction begins with the installation of the perimeter diaphragm walls by the slurry trench method described in ***Section 4***. Interior column foundations,

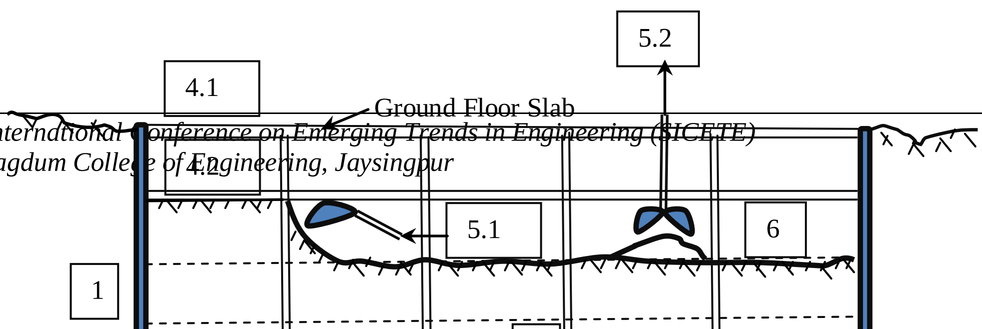


Figure 1: Sequences in the Top-Down construction technology (Santarelli and Ratay [11]) generally piles, are drilled in from the ground level to the bearing stratum using either conventional drilled shaft or slurry trench techniques. The shafts are concreted up to the lowermost basement level to form foundation piers or Barrettes. Cast-in-place concrete or structural steel columns are installed in the open shafts to rise from the foundation piers to the ground-floor level. The ground-floor slab is cast either on a mud mat over unexcavated soil or on a drop-down form system anchored to the columns. After the slab is cast and cured, its diaphragm action makes it a continuous lateral brace against the perimeter walls. The soil is excavated by an operation similar to low-headroom horizontal mining below the previously completed structural slab. Access openings have to be left in the overhead slab for vertical soil removal and for supply of equipment and materials. The next lower level basement slab is poured, becoming the subsequent lower level wall bracing, and the process is repeated down from level to level upwards. Thus each floor acts as both temporary and permanent bracing for the perimeter walls, eliminating the need for temporary bracing or tiebacks, as well as the need for separate retaining walls.

3.3 Structural Members Required for Top-down Construction

Design and construction principles for Top-down method primarily call for two major structural elements.

(i) Columns with sufficient capacity must be pre-founded in form of Bored Piles or Barrettes to sustain the construction load and to utilize as part of bracing system. Excavation for basement must be carried out with the support of permanent retaining wall so that basement floor slabs can be utilized as lateral bracing.

(ii) Diaphragm wall of 0.8m to 1.2m in thickness with sufficient embedment in firm soil layers is commonly used as a retaining wall, whereas prefabricated structural steel columns, also known as Stanchions, embedded in either large diameter deep-seated bored piles or barrettes are utilized as compression members. Fig. 2 illustrates the top-down construction method with utilization of columns and diaphragm wall.

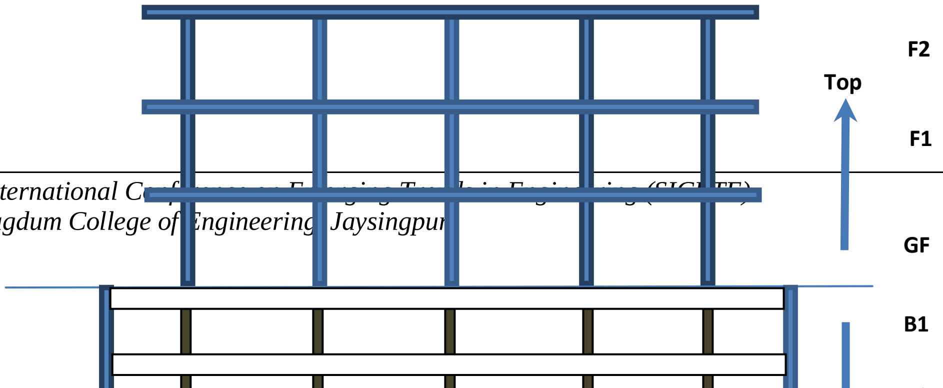


Figure 2: Top-Down construction with column and diaphragm wall

3.4 Column Installation Techniques

Column installation method is usually selected by the piling contractor who takes into consideration three main factors such as installation depth, size of column and size of bored or barrette piles. Though installation details may be different from one contractor to another, column installation can be categorized under two types, namely, Post-concreting or Plunging installation and Pre-concreting installation or placing column prior to concreting.

Historically, column installation technique has evolved since 1960s (Puller [2]). This operation required personnel to trim the pile, set pile caps or make in-situ bases for final column installation at final basement level.

(i) Post-concreting Installation or Plunging Method

In this method, column is installed immediately after completion of bored pile concreting process. General construction sequence involved in this method is demonstrated in Fig**.** 3. Guide frame or Jigs is used to install the column at the correct position.

On several occasions in the old past, installation of steel columns on the wet concrete were rejected because of the risk of inaccurate placing of columns. More recently in abroad, specialist firms have developed jigs to enable the steel plunge column to be placed very accurately both in verticality and position within the unlined box supported by bentonite slurry. The general accuracy of placing the plunged column into the wet concrete is of the same order as bored pile construction (1:75); but with the refined site controls, accuracy even upto 1: 200 to 1:400 could be maintained.

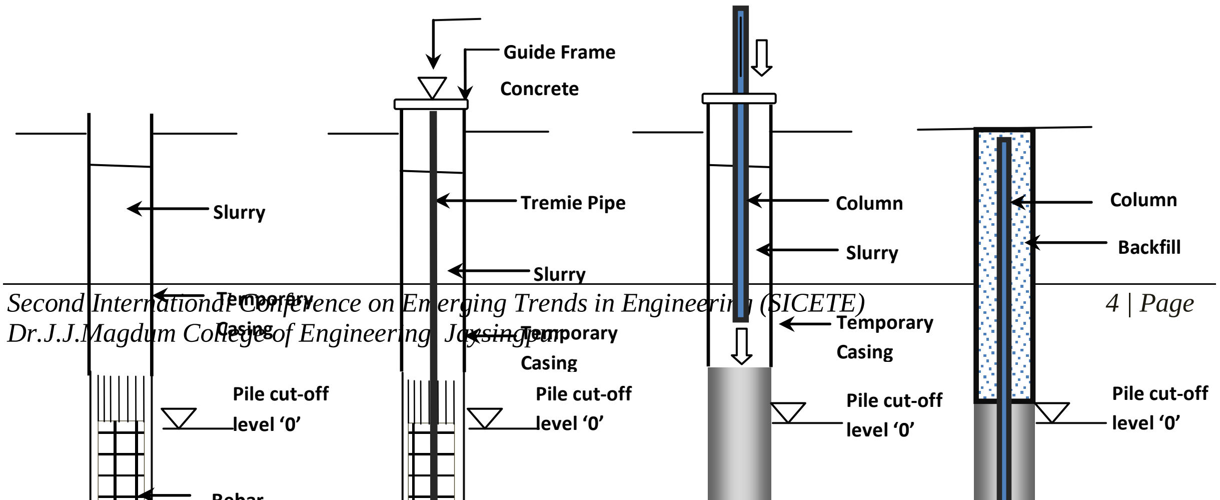


Figure 3: General construction sequence of post-concreting installation method

(ii) Pre-concreting method

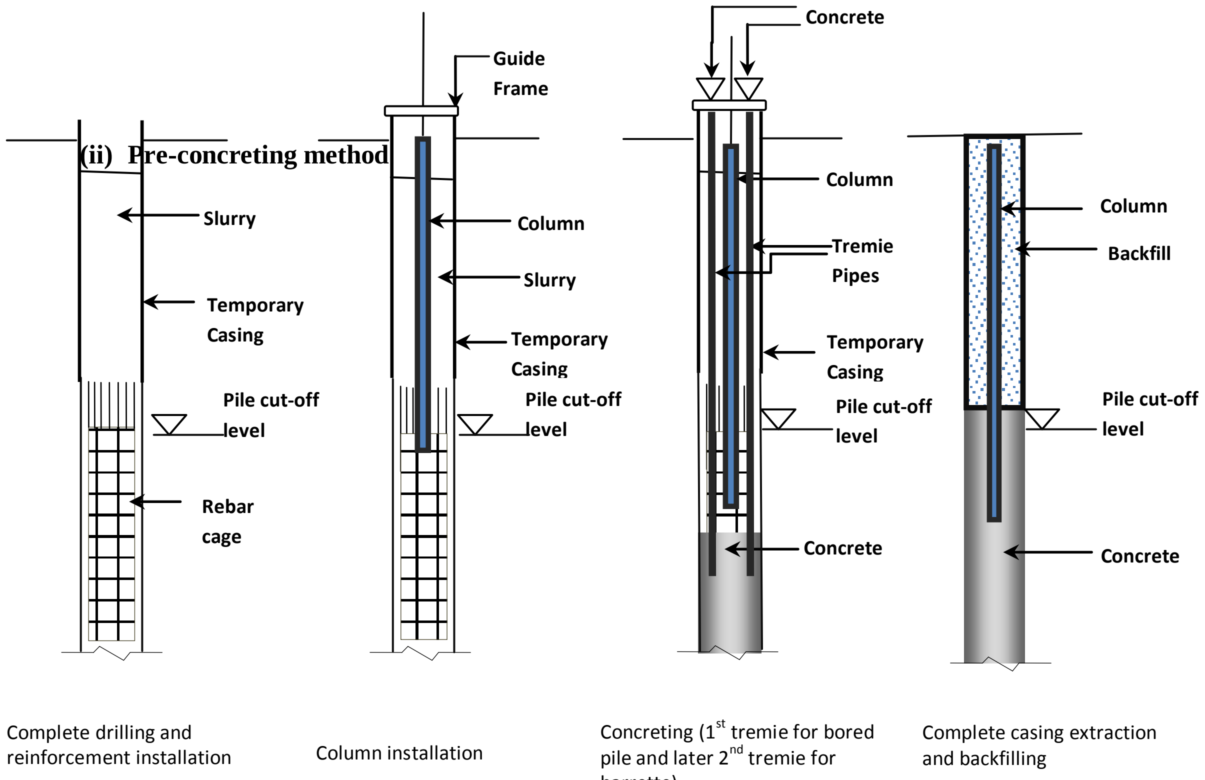


Figure 4: General construction sequence of pre-concreting installation method

In this method, column is installed immediately after completion of drilling and reinforcement lowering prior to concreting process. In some projects column is attached to the last section of reinforcement and installed.

3.5 Other Variations of Top-Down Construction

An extension of the top-down system is the **Up-down construction** of buildings, whereby erection of the superstructure begins as soon as the perimeter walls, the interior columns below the ground floor, and the ground-floor slab are completed. Thence the construction of the sub-basement floors and of the superstructure proceeds simultaneously, saving significant project construction time. Such scheme was used in a multi-level car parking scheme at Delhi, which is discussed later in this paper.

Large openings in floor slabs which are designed as lateral supports to the diaphragm walls together with the use of long dipper arm excavators enables to proceed below the top slab support for a considerable depths without intermediate floor support. This scheme enshrined in what is commonly known as **Semi-Top-down**

construction, uses only skeleton structure for the working platform and one intermediate floor was used for a 25m deep excavation for a station in Singapore MRT (Mitchell et al [12]).

Basements, which are part of large plan area, can benefit from the combination of both **Bottom-up and Top-down construction** technique. The core of such structure are built by Bottom- up method in a conventional frame supported excavation, while the floors around the core are constructed by Top-down method assisted by peripheral diaphragm / secant walls. This method was used for the basement of the Main tower in Frankfurt. A piped raft was used to support 198m high tower built bottom upwards while floors around the core and within the secant piles were constructed top down. This technique facilitated super structure core construction to advance parallel with the basement construction, which was advantageous to the overall programme.

3.6 Top-down Construction – Critical Remarks

Top-down construction does not require very large working space which is otherwise seen in Bottom-up construction method. Such construction technique enables simultaneous construction of high-rise superstructure and its sub-basement which means accelerated construction and substantial cost savings. An additional advantage of this technique is the ability of the system to minimize wall and soil movements, and consequently minimize or even prevent settlements of adjacent structures. Extensive and heavy temporary strutting system associated with Bottom-up construction is minimized in the Top-down technique, since the intermediate slabs offers the desired stiffness and lateral support to the retaining wall. More operational space is gained with advance construction of slabs. This fact, apart from being a convenient factor also adds to cost-saving in a project. Construction schedules can be compressed since, construction of substructures and high-rise superstructure can go along con-currently. Many construction problems associated with Bottom-up construction like continuous de-watering, slushy ground due to open working, problems associated with bad weather to name a few, are either eliminated or greatly minimized in Top-down construction.

On the other hand, higher unit costs, requirements of skilled supervision and labour force could be seen as disadvantages through skeptical eyes. Removal of soil from beneath the floor slabs in cramped conditions may prove tedious and costly compared to the conventional methods. Since the construction period of the basement is lengthened, the lateral displacement of retaining wall or ground settlement may possible increase due to the influence of creep if the soil layers are encountered. This, and other grey areas need careful considerations on site to site basis.

4. KEY ELEMENT IN TOP-DOWN CONSTRUCTION: THE DIAPHRAGM WALL

Diaphragm walling is in-situ technique of constructing a deep, vertical and flexible underground barrier. Such form of walls were patented and introduced by Icos [13] into Europe during late 1950s and early 1960s. Diaphragm wall had replaced other walling methods since it provided dual support both, at the construction stage and then during the basement life. It offered advantages compared to its predecessor in terms of cost savings, noise and vibration reduction, as a convenient facilitator to propping, strutting and anchoring; and better utilization of moment of resistance owing to its rectangular section. In India, first diaphragm wall was constructed sometime back in 1964 at Ranchi (Jharkhand).

Typical wall thickness varies between 600 to 1200mm. The wall is constructed panel by panel in full depth. Panel width varies from 2.5m to about 6m. Short widths of 2.5m are selected in less stable soils, under very high surcharge or for very deep walls. Different panel shapes other than the conventional straight section like T, L are possible to form and used for special purposes (for instance, T-shaped panels have been used for a shipyard project at Dahej, Gujarat, India). Traditionally, panel excavation is carried out using cable supported Grab. Hydraulic grabs with Kelly arrangement have recently been introduced in India on large Infrastructural projects. Details of construction methodology and design background vis-à-vis Indian scenario, have been described by Kumar [14] and Basarkar [15].

4.1 Advances in Diaphragm Wall Construction Technique

Since inception of diaphragm wall technique, efforts were put on to systematically refine the construction methodology, development and use of modern mechanical techniques (Wankhade et al [16]). The improvement in constructional aspects were aimed at meeting the qualitative requirements, whereas the inception of modern equipments was looked upon as means to achieve the quantitative requirements like improving performance and achieving progress. Enhancing the load capacity of sections, trenching, handling bigger and heavier reinforcement cages and concreting were important aspects wherein continuous advances took place.

The following paragraph summarizes the most recent technological evolution in diaphragm walling:

Use of kelly mounted hydraulic grabs: Earliest diaphragm walls were constructed by cable grab mounted on tripod on rails, which were replaced by rope grabs mounted on heavy crawler cranes. Kelly bar mounted hydraulic grabs were introduced in Europe during late 1970s and in India during mid 1990s. These grabs are capable of excavating wall widths between 500 to 1500mm with telescopic Kelly bars offering trenching to a depth of 30m.

Trenching in rocks: Earlier methods of trenching in rocks comprised use of drop chisel progressively along the panel under slurry, grab the muck and chisel again. Evidently, the progress was very slow, and noise and vibrations prohibited working in urban areas. Puller [2] reports advent of rail mounted reverse circulation rigs for excavation in rocks which was introduced in 1970s by Tone Boring Company in Japan, and which was followed by development of Hydrofraise by Soletanche. In mid 1980s, Bauer and Casagrande introduced similar equipments. Smaller versions of such machines known as *City Cutters* offered improved maneuverability, and facilitated trenching through rocks in urban condition. Guillaud and Hamelin [17] provide interesting review of the development of diaphragm walling equipments since 1990s till recent years.

Polymer Slurry: New generation polymer slurries are slowly replacing bentonite slurries since they are considered environmental friendly and eliminate disposal problems. Polymer slurries have molecular lattice structure and unlike bentonite slurry, act in trench support without forming a filter cake. These slurry system are known to reduce pumping efforts, prevent adherence to trench walls thus increasing the load carrying capacity, and in many cases do not require bore hole cleaning operations. Although they posses high initial cost, but with due caution, they can be used for several cycles.

Fibre reinforcement: Special post construction requirements such as convenience of forming hole across reinforced diaphragm wall panel has encouraged use of specially manufactured fiber reinforcement bars. Steel reinforcement bars are replaced by fiber bars and suitably positioned at location where opening is required. These bars are used to facilitate breaking of diaphragm wall panel and at the same time meeting the design stress requirements. Fiber reinforced diaphragm wall panels are specifically used during vertical shafts construction at Delhi Metro Stations 2005-2011, from where metro tubes were supposed to be launched. Circular portion of the tube for railway could be cut by Tunnel Boring Machine (TBM) and the tube operation can conveniently proceed.

Stop-ends: Stop-end in diaphragm wall construction are the fabricated and removable element provided at the end of each diaphragm wall panels. These are fabricated so as to maintain continuity of two adjacent panels in addition to allowing ease of removal. Traditional practice involved use of Circular Stop-end tubes, which had disadvantages of allowing passage of water through their joints. Again, Circular stop-ends are to be extracted 6 to 8 hrs after concreting of panel. A new trend had been in form of Peel off Stop-end which was introduced at Delhi Metro's ISBT Project during 1999. Peel off Stop-end was developed in-house by authors' firm, and had trapezoidal shape with a provision of a groove to accommodate a PVC / Rubber water Stopper. This innovative Stop-end had excellent water resisting capabilities which improved functional performance of Diaphragm Wall.

Verticality monitoring: Verticality of the trench needs continuous monitoring, so that in the intervening period corrective actions to restore verticality may be taken. In this context, Koden, a commercially available ultrasonic drilling monitoring device is frequently used to monitor verticality of trench in India and abroad.

The technological improvements stated in the preceding paragraphs, enable to guarantee tighter tolerances in the execution of the walls, and hence assist in ensuring higher quality of the finished product.

4.2 Trends in Trenching Equipments in India

Diaphragm walling works for BC-24 stretch of Delhi metro rail corridor (2005-2009) having thickness 800 mm and 1000 mm and depth varying from 10.0 to 24.0 m were carried out over total length of 2.0 km. Trenching for these walls was carried out using rope operated grabs of 6.5 to 8.0 MT capacity mounted on TFC 280 and Tata 955 cranes (later having capacity of 75 MT). More recently, Kelly mounted grabs are used since they offer better control over verticality and address to quality issues better that rope mounted grabs. Similar trend and practices are also adopted at the currently in progress metro rail works at Kolkata.

Trenching in rocky and bouldary sub-surface conditions have posed serious challenge. Heavy duty Hydraulic Trench cutter system overcomes such site rigorities. Hydromill trench cutter is an excavating machine that operates on the principles of reverse circulation. The torque output of the cutter wheels in combination with the weight of the cutter is sufficient to cut into any type of soil, and to crush cobbles, small boulders or rock. This machine has overcome several challenges which till now had been considered formidable. In India, this machine was used in Dhauliganga hydroelectric power plant for cut-off trenching during 2002 in midst of highly boulder sub-surface condition. This machine was also used at Chennai metro rail project, where trenching at certain stretches had to penetrate very hard rock with compressive strength exceeding 70MPa.

5. TOP-DOWN CONSTRUCTION: SUMMARIZED CASE STUDIES IN INDIA

With the inception of fresh technologies and real estate growth in India, fast track project requirements have become the key driver to use of Top-down technology. It is to be noted that the key element in the Top-down construction is diaphragm wall, which is economically suited in the regions of silty-sand, or clayey-silt soils which can be grabbed. This fact makes it note worthy that Top-down construction technique is more economical in northern and eastern India, where such soils are common. In the central and south India, presence of hard rocks pose impediment to use of such technology. First reported use of this Top-down technology was for construction of underground metro stations of Connaught place, ISBT etc during first phase of Delhi Metro rail project on 2002-03. The same technique is now used for metro works at Kolkata and to some extent at Chennai. There are very few reported cases of commercial buildings at Delhi with deep basements where this technique is used. Though this technique is still in its infancy stage in India, two of the case summaries have been presented to demonstrate its growing demand.

5.1 Case Summary 1: Automatic Multi-Level Cark Parking Facility at Delhi

This project site is located at a crowded circle at Delhi, and was intended to alleviate car parking problems along its narrow arterial roads, and relieve the congested streets and markets from heavy traffic problems. The out to out construction diameter of the circular parking structure was 64.5m (Fig. 5a), and working conditions were challenging due to extremely limited space, problems of transporting reinforcement and concrete trucks. The car parking structure comprised seven levels of basement slabs constructed using partial Bottom-up and Top-down technique. Pre-excavation works comprised external peripheral diaphragm wall 800mm thick forming an enclosure, while barrettes 600mm thick and 3.5m/ 2.2m wide as internal vertical supports. Raft below the 7th level (Fig**.** 5b) was 1.75m thick and was designed for uplift and buoyant forces using 321 bored piles, 1200mm diameter and of length 22.1m.

5.1.1 Excavation and Slab Casting Sequence

Open excavation with excavators was undertaken up to 3.0m to 3.5m depth. After completion of excavation to (-)3.5m level, prop-less formwork for slab was erected with the help of sleeves, inserts provided in Diaphragm walls. Reinforcement & inserts were placed and slab was cast at (-)2.3M. This slab construction was undertaken in 4 to 6 segments. The slab thickness was 600mm and designed to take the loads of cranes, earth piles, DG, tippers etc and other construction equipment.

Once the slab was laid at (-)2.3m level, this was made as base for further excavation works which was carried out up to 9m to 9.5m depth. After excavation to 9.5m level, a 4th basement base slab was laid leaving the slab at 2nd level and 3rd level unattended. With the 4th level slab cast, subsequently formwork was erected for 3rd level slab and concreting done in segments. This was followed by casting of 2nd level slab. By the time work was being carried out for 3rd and 2nd slabs, excavation up to 6th basement upto (-)18.0m was undertaken by deploying excavators, cranes, hoists and buckets etc. Though the most of excavation were done by machines, some of the excavations around diaphragm walls were undertaken manually. This was followed by casting of 6th level basement slab. 6th slab was then used as a support for construction of 5th slab level, and parallely, further

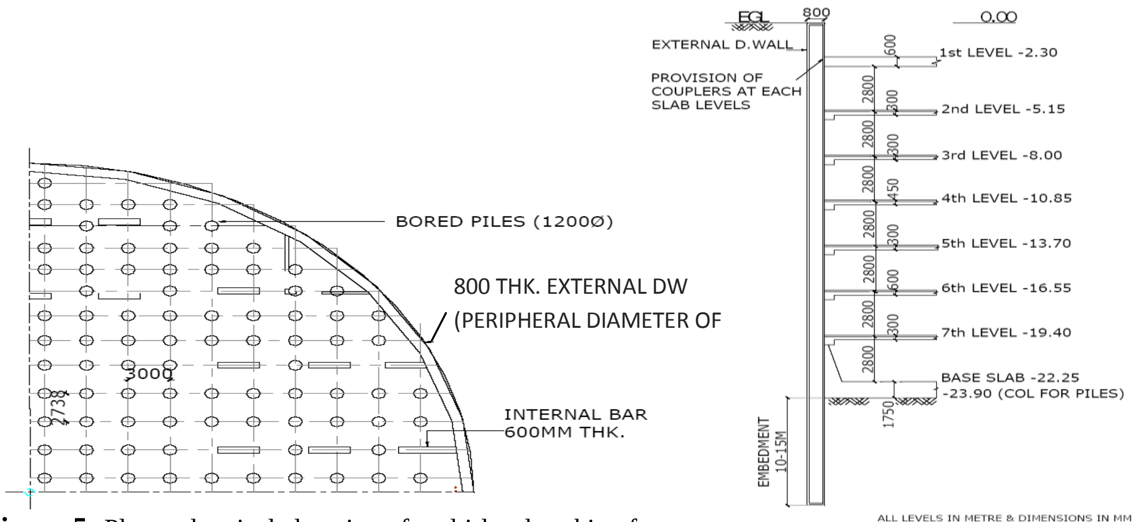


Figure 5: Plan and typical elevation of multi-level parking facility

excavation was carried out till the raft level was reached. After the final dressing and breaking of pile heads, raft slab was cast followed by excavations in localized areas like lift and sump pits. Raft preparation and casting was undertaken to go hand in hand with casting of 7^{th} level slab.

In all the excavation works, the excavated earth used to be loaded instantly on to tippers, and at times earth used to be stacked at (-) 2.3m slab and transported during night to designated site. Approximate excavated material used to vary from 500 to $900m^3$ per day.

5.1.2 Construction of Central Part by Bottom-up Method

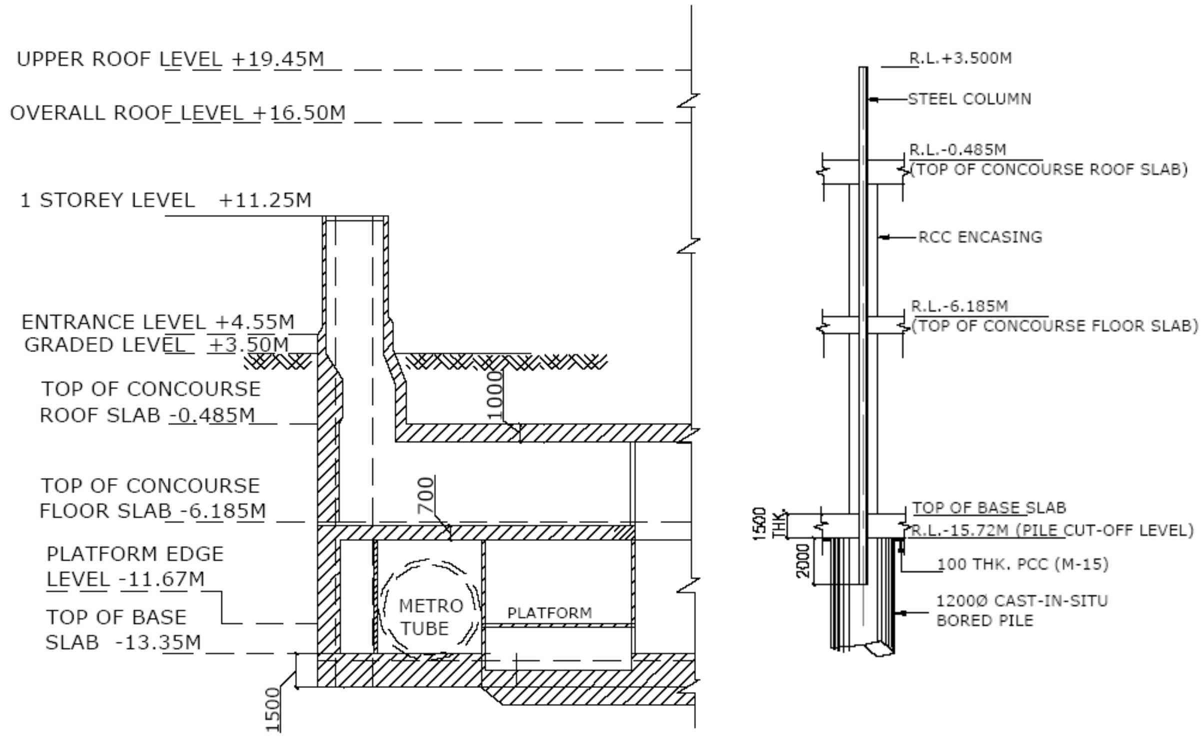
Bottom-up works were initiated for the central portion of parking area after construction of raft slab. Columns and lift walls were raised to each level of floor and respective floors were cast. Similar sequence was repeated till the construction opening at -2.3M level slab is covered.

5.1.3 Construction of Super Structure

After construction of bottom raft, all heavy equipments used for excavations were removed from the basements and construction activities for super structure were initiated. This was an instant were basement and superstructure construction activities were witnessed simultaneously. The sequence of superstructure was a normal column casting followed by beam-slab casting. Below the GL, once the central opening at (-) 2.3m level was covered, columns and lift walls were raised up to ground floor and remaining portion of ground level slab was completed.

5.2 Case Summary 2: Construction of Metro Stations

Underground Metro stations at Delhi and Kolkata are constructed based on very similar Top-down technique to keep abreast with the activities of tubings, rail track and other related activities so that such mass rapid transport (MRT) facilities are handed over for public use at earliest. Typical metro station levels for a Kolkata metro station basement can be seen in Fig**.** 6a. Base slab bottom level is (-) 15.72m, and is 1.5m thick. Also clear from the figure is presence of concourse roof and floor slabs at (-) 0.485 and (-) 6.185m. Sequential Top-down construction is adopted wherein, excavation from the grade level (+3.5m) is initiated after construction of peripheral diaphragm wall (1000mm thick with 10 to 15m embedment depending on location) and piles with deep cut-off (**Section** 5.2.1).



(a) Key elevations and typical section

(b) Typical section of structural column

Figure 6: Metro station elevation and structural column details

This excavation is followed by casting of concourse roof slab (1000mm thick), and with further excavations the concourse floor (700mm thick) and the base slab were cast. Other intermediate slabs and walls were constructed in a normal way after completion of base slabs, drawing support from the constructed slabs.

5.2.1 Construction of Piles and Structural Columns

Construction of bored piles 1200mm diameter was undertaken from ground before initiation of excavation. These piles had a deep cut-off depth of 15.72m, with structural length further 10 to 15m below. The pile construction was carried out by wet process with bore stabilized by bentonite slurry. After the concrete reached about 1.5m above the cut-off level, structural column is inserted under its own weight, with verticality and centre maintained through a guide frame. At times additional static pressure is applied on this column through hydraulic rigs to ensure its 2.0m embedment into structural concrete (Fig**.** 6b).

5.2.2 Construction of Concourse and Base Slabs

Excavation commenced from grade level and with its progress, the exposed diaphragm wall was manually cleaned and its cast-in couplers located. In case of missing or disoriented couplers, holed were drilled and starter bars were fixed using chemical grouts. After reaching the slab soffit level, additional 50 to 70mm excavation was undertaken to accommodate Blinding concrete, which aimed at providing a leveled surface for slab concreting. This layer was topped by 3mm plywood sheet over which rebar cage fabrication was initiated which included bar chair couplers and shear connectors. At the access openings, rebar couplers were left for future lapping. Formworks for slabs comprised plywood boards which were externally supported by bracings and strutted all along their length by props and waler system. Concreting of M40 grade was undertaken as per normal process with curing process carried out monitored by thermal gradient within the slab.

6. CONCLUDING REMARKS

This paper attempted to disseminate the practices and applications of Top-down construction technology for deep basement construction. It is evident that Top-down construction is well suited for most situations of urban construction environment. However, it demands constructional, planning and managerial skills; rigorous quality adherence and a thorough understanding of construction sequences for inclusion in the design and analyses. The benefits far overweigh likely inhibitions associated, and with proper planning, the cost and project time savings are enormous. This form of construction has picked up in India and is finding increasing applications for the construction of metro station buildings, malls and commercial complexes with deep basements. Examples and case studies of such technology has demonstrated that there are arrays of equipments and techniques that can assist even in the most severe sub-surface conditions; and India will soon see the light of the day when such technology becomes mandatory and indispensible for early commissioning of the structures.

7. Acknowledgement

The authors acknowledge with gratitude the encouragement and support from each of their organizations for carrying out creative and innovative practices. This paper owes immensely to the technology absorption of researches keeping abreast with fast track infrastructural projects, and the authors pay tribute to the stalwarts in the field Top-down technology and diaphragm wall construction. Sincere appreciation to the Clients, Consultants and other concerned agencies of the project, for vital information - their frequent interactions and discussions have lead to a definite refined implementation of this technique.

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