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DEVELOPMENT OF CONCRETE FILLED TUBE AS A PILLAR PILE FOR TOP DOWN METHOD

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ABSTRACT: Top-down method is widely used for urban area construction for its advantages in reducing environmental problems such as dust and noise, and saving construction cost depending on given conditions of a construction site. Because the excavation and construction of super- and sub-structures of the building have to be proceeded simultaneously, a column has to be embedded prior to excavation. This column is called a pillar column or pre-founded column. Usually a wide flange section is used for these columns. To place the columns, usually the diameter of casing holes needs to be larger than the section of the wide flange itself in order to accommodate a couple of tremie pipes for pouring concrete. In this paper, a newly developed method of using circular pipe as an alternative to the existing wide flange section is discussed. The crucial part of the new method is to develop a connection between the circular column and concrete flat slabs. For shear force transfer from concrete slab to the concrete filled tube (CFT) column, shear jackets with studs and shear bands are proposed. The studs are welded on the jackets at shop and placed around the circular column on site. The shear bands are welded on the outer side of the CFT at shop and inserted into ground with the CFT. Test results and application of the method to a construction site are also provided in this paper.

Keywords: Top-down Method, Pillar Pile, Concrete Filled Tube, Connection

1. INTRODUCTION

Recently, for the purpose of reducing construction time and cost, concerns about underground structures are ever increasing [1]. Research efforts are focused on underground space development [2]. For substructure construction, both bottom-up and top-down methods can be used. In the bottom-up method, where foundation is constructed first and then the construction work is carried out from substructure to superstructure, temporary struts supporting retaining wall are required. On the other hand, in top-down method, where slab is placed first on the ground level and construction work is carried out from the ground level to substructure, slabs support the retaining walls [3]. In top-down method, prior to excavation, the ground floor slab is prefabricated. Because of the prefabrication of ground floor slabs, building process has less weather influenced and has less complaint from noise and vibrations. Therefore, top-down method can be more useful for constructions in urban cities.

The key element in top-down construction method is that the column has to be embedded prior to excavation [4]. Loads generated during construction and transmitted from slabs are transmitted to pillar piles, which means a higher capacity of columns to sustain the total loads [5]. Wide flange sections or CFT columns are usually used as pillar piles. CFT columns have bending capacity higher than wide-flange sections [6]. Also, as concrete is confined within the tube, CFT columns have high compression capacity [7].

Vertical placement of the pillar pile is relatively difficult in the top-down construction compared to bottom-up construction. Also, when a pillar is inserted, consideration regarding a vertical direction is necessary. On the other hand, in the case of circular CFT, vertical coordination is relatively easy as an effectiveness space is same at all courses. Also, as consideration regarding a vertical direction is unnecessary, insertion construction of a pillar is easier in case of circular CFT pillars. After inserting pillar pile, concrete is poured into boring hole. At this time small-size tremie pipe shall be used at the methods that used wide flange section as room space is short. Because of the forms of wide flange section, a space divides into four sections, so that it is hard to expect dense concrete pouring. Also, compression resistance of circular CFT is large relatively in the same section sizes. Therefore, a CFT pillar pile is economically favorable.

In this paper, a newly developed method of using circular pipe as an alternative to the existing wide flange section is discussed. The crucial part of the new method is to develop a connection between the circular column and concrete flat slabs, which is for shear force transfer from concrete slab to the concrete filled tube (CFT) column. Finally, the circular CFT section and the wide flange section are compared from the perspectives of construction time and cost.

2. CONSTRUCTION OF PILLAR PILES WITH WIDE FLANGE SECTION

2.1 Construction of Pillar Piles

In top-down underground construction, after installation of the retaining wall, pillar pile is placed. First, a pillar pile is inserted in a hole, and concrete is poured in order to make a foundation. After concrete is cured deep inside the excavated hole, gravels are filled in the hole. Once the installation of pillar piles is over, excavation begins. While proceeding excavation, slab is installed if excavation depth reaches a position of floor board. Through the repetition of the above process, the construction completes once the lower most slab is installed.

Pillar pile shall take loads from its own superstructure, fixed loads, working loads, wind loads worked to lateral loads to ground structure into consideration like general columns. When a pillar pile is designed, an elastic shear effect of floor structure shall be taken into consideration when a vertical load to work on a column by burden area.

A floor get from the work load that included own load in Top-down construction an underground structure is constructed. A bending moment is occurred to floor structure because of these loads. By the way, the edge part moment neighboring, and occurring from both floor structure of a pillar pile is different each other because of difference of a column interval, condition of an edge part. Imbalance moment working on a pillar pile by differences of these edge part moments shall be taken into consideration. Also, additional stress to occur on a pillar pile by contraction of floor structure by dry contraction, creep contraction of elastic contraction shall be taken into consideration.

In Top-down construction, after pillar piles were installed, concrete is poured after coordinates of pillar piles are measured and adjusted in first floor levels. In this case, coordination of coordinates regarding a pillar pile causes additional bending moment by compulsory displacement. As this additional bending moment decrease allowable compression ability of a pillar pile, vertical management is necessary in construction. When coordination of a pillar pile is necessary, excavation and adjusting of column's surroundings have to be planned to minimize additional bending moment. A pillar pile shall take an influence by construction errors to occur on a characteristic constructed to an underground unlike general pillars into consideration.

2.2 Wide Flange Pillar Pile

In this chapter, construction order of wide flange pillar pile is described. The construction order of the pillar pile which used wide flange section appears in Fig. 1 to 5. First, position to boring is designated.

Fig. 1 Position Designation

After position designation, it is prepared that equipment to bore soil. Usually RCD equipment is used for boring in under construction using wide flange section. In RCD method, water or bentonite solution is used to protect the hole. Once casing is set up, and boring is started. Once boring is done, setting up of pillar pile is started. RCD equipment appears to Fig. 2

Fig. 2 Boring with RCD Equipment

Before wide flange section is inserted, pier rebar is inserted. Pier rebar is an element for the basis. After pier rebar and wide flange pillar pile are inserted, pillar pile is fixed. Fig. 3 shows that pillar pile is inserted and fixed.

Fig. 3 Pillar Pile Insertion

Once pillar pile is inserted, tremie pipes are set up. Two tremie pipes are set up beside the wide flange section. Therefore, size of a hole has to be large than sizes of wide flange section with tremie pipes. Fig. 4 shows that tremie pipe is installed in the hole.

Fig. 4 Tremie Pipe Installation

Once tremie pipes are set up, concrete is poured through the tremie pipes to make basis. Concrete is poured to basis position, and gravel is filled to remaining spaces. Once gravel is filled in the hole, pillar pile construction is finished. Fig 5 is showing the pouring of concrete.

Fig. 5 Pouring Concrete

Wide flange section has several problems in construction. Because space surrounding a wide flange pillar pile is short in diameter size of the pier which is suitable for a compression support is required, vertical adjustment of a pillar pile is difficult. And a space to install pier, shear studs and tremie pipes to pour concrete isn't enough, so that concrete of pier is difficult to being poured.

Specially, a space to be able to fill concrete is divided with 4 because of the forms of wide flange section. Therefore, what concrete is filled densely in each space is complicated. Therefore, reliability for pouring concrete is low, so that it is indicated to things with problems to pier support performance. Generally, a wide flange pillar pile is installed with large diameter boring size than diameter sizes at pier supporting ability in order to solve these issues. However, a way to widen hole size has a disadvantage increased construction cost and construction period. Fig. 6 shows a wide flange pillar pile having been exposed after excavation.

Fig. 6 Pillar Pile Having Been Exposed After Excavation

3. CIRCULAR CFT PILLAR PILE

3.1 Construction Order of Pillar Piles

In Top-down construction, Wide Flange section or circular CFT section is used for pillar pile. First, position to insert a pillar pile is designated like the method that used wide flange section at the method that used CFT section. It is bored with larger diameter than diameter of a necessary hole by installation of tremie pipes that used wide flange section. However, it is bored with relatively small-size diameter that used circular CFT section, because a tremie pipe is inserted in the steel pipe. Therefore, RCD method is mainly used that used wide flange section, but PRD method is mainly used that used circular CFT section, because it is bored relatively small-size diameter. Fig. 7 shows boring with PRD equipment.

Fig. 7 Boring with PRD Equipment

After boring, pier rebars and circular CFT section is inserted into the hole. First, circular pier rebar made with a form of nets is inserted into the hole. The circular CFT section is inserted by the followings. At this time, pier rebar and circular CFT section are connected with coupler which was made in advance. Therefore, connection is easier than the method that used wide flange section. Fig. 8 shows the steel pipe being inserted.

Fig. 8 Pillar Pile Insertion

Once circular CFT pillar pile is inserted, a tremie pipe is installed. Only one tremie pipe is installed into the steel pipe unlike the method that used wide flange section. Because of that, the diameter of hole is small, and construction is more convenient. Fig. 9 shows that the tremie pipe is installed into the steel pipe.

Fig. 9 Installation of Tremie Pipe

Once the tremie pipe is installed, concrete is poured through the tremie pipe to make a basis like the method that used wide flange section. Fig. 10 shows the pouring of concrete.

Fig. 10 Pouring Concrete

Once pouring concrete is finished, and gravel is filled, excavation begins. Shear studs are welded on a pillar pile in advance at the method that used wide flange section. So proceeding excavation, shear studs are damaged. On the other hand, stud plates that shear studs are welded are produced particularly at the method that used circular CFT section. Stud plates are installed after excavation was progressed. Therefore shear studs aren't damaged during excavation. Fig. 11 shows the circular CFT pillar pile exposed after excavation.

Fig. 11 Pillar Pile Exposed After Excavation

3.2 The Advantage of Circular CFT Pillar Piles

Use of wide flange section is disadvantageous in top-down constructions. It was the issue that was derived as wide flange section that compression resistance efficiency was low with the diagonal line size. Furthermore it has not spare space in the hole. Therefore pillar pile section should be circular so that a space has equal spare space surrounding the pillar pile to all courses. Also, wide flange section is different in geometrical moment of inertial regarding each axis, so strong and weak axes exist. The section is disadvantageous to structural ability with weak axis in pillar piles getting from compression force. Also, materials could not be used efficiently. Compared with a wide flange section, as a circular CFT section has no weak axis, slenderness ratio is small and same rigidity to all courses. In arrangement of material, steel material is arranged outer side uniformly, and concrete poured in the inside of the CFT section. Concrete that is poured in the inside of the CFT increase stiffness. At the same time, confinement effect of the steel pipe increase stiffness more highly.

By these advantages in using circular CFT section, as diameter size of steel pipe and cross section are small, it is economic. Also, as a tremie pipe that is used for pouring concrete is inserted into the steel pipe, work of pouring concrete is more convenient. Furthermore, as rebar and concrete are filled in the steel pipe, circular CFT pillar pile could support high compression force

4. COMPARISON WF-SECTION WITH CIRCULAR CFT SECTION

Comparison between wide flange section and circular CFT section and analysis are performed in order to apply construction site. For comparison, wide flange section and circular CFT section are prepared that effective length 6 m, and could support about 5,500 kN compression force. $H-428\times407\times20\times17$ (SM 490) is used to wide flange section, and $\varnothing 457.2\times12$ (SM 490), 28 MPa concrete, and 8-D25 (SD 400) rebar are used to circular CFT section.

4.1 Workability Comparison

Each pillar pile is installed into PRD boring hole of which diameter is 0.8m. Effective space of inner boring hole is 105m at flange (72mm at x-direction, 76mm at y-direction). If construction control level is assumed to h/300, allowable vertical adjustment error is 100mm when underground is excavated by 30m. Therefore, in case of worst situation, vertical adjustment should be constructed precisely within 5mm error.

On the other hand, an effective space is equally 171mm at all courses in case of circular CFT pillar piles. Therefore, vertical adjustment is relatively easy after insertion of pillar piles compared with wide flange section. Also, insertion construction of a pillar is easier in case of circular CFT pillars as consideration regarding axis-direction is unnecessary. Fig. 12 and 13 are figures of each pillar pile inserted into the hole.

Fig. 12 Wide flange section as a pillar pile

Fig. 13 Circular CFT section as a pillar pile

In top-down construction, after boring, pillar piles are inserted, and concrete is poured through the tremie pipe in order to make a basis. Spare space surrounding a pillar pile is short at the method that used wide flange section with large diagonal line size, so that tremie pipes of small-size diameter are used. Also, a space is divided to four spaces because of section form, so that concrete is hard to be poured densely. However, in case of circular CFT method, using the inner space of steel pipe, tremie pipe of large-size diameter could be inserted, and pouring concrete is relatively easy.

Also, in installation of pier rebar, additional device is necessary to fix pillar pile with pier rebar at the method that used wide flange section. On the other hand, coupler is installed in advance to connect pillar pile and pier rebar at the method using circular CFT section, so that connection of pillar pile and pier rebar is more convenient.

4.2 Cost Comparison

Cross section of wide flange pillar pile is 360.7cm^2, and cross section of circular CFT pillar pile is 167.8cm^2. Even if rebar inner a pillar pile is considered, cross section of circular CFT is about 58% of wide flange section. Also, concrete used inside of the steel pipe is not additional material, because concrete that is used to compound column in process of the construction is used previously. Therefore, construction cost of a CFT pillar pile for a top-down construction is the about 60% of that of wide flange section. Also, in order to support higher compression force, cross section of steel should be increased at the method that used wide flange section. On the other hand, circular CFT section could support higher compression force with same cross section of steel through the control of quantity of rebar.

Besides, the longer effective buckling length of wide flange section is the bigger width of decreased allowable compression force. On the other side, width of decreased allowable compression force of circular CFT section is relatively small. Moreover, in order to compare efficiency of each pillar pile, structural ability of CFT pillar piles is about 3/2 level of wide flange pillar piles. Like this, the method of using circular CFT section is more economic compared with wide flange section. Table 1 shows the ability of circular CFT section with bases to wide flange section.

Table 1 Comparison Between Wide Flange Section and Circular CFT Section

Classification	Wide Flange Section	Circular CFT Section
Quantity of Steel	100 %	58 %
Construction Cost	100 %	About 60 %
Allowable Compression Force	Low	High
Structural Ability	100 %	About 150 %

5. CONCLUSION

In this paper, a wide flange section is compared to a circular CFT section which is used for pillar piles for top-down construction. As a result, the circular CFT section is proven to have a good workability and it is possible to use PRD method to drill 0.8 m diameter hole instead of RCD driven 1.5 m diameter hole. In the case of using PRD equipment, construction time is reduced about 1/6 compared to RCD equipment. Lastly, construction cost of circular CFT section is about 65% of that of wide flange section. Even though circular CFT has advantages, connection to slab needs to be considered. For the development of such connections, the details of construction sequence are described in this paper.

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