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Stress Variation of Underground Building Structure during Top-Down Construction

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***Abstract*—**In the construction of a building, it is necessary to minimize construction period and secure enough work space for stacking of materials during the construction especially in city area. In this manner, various top-down construction methods have been developed and widely used in Korea. This paper investigates the stress variation of underground structure of a building constructed by using SPS (Strut as Permanent System) known as a top-down method in Korea through an analytical approach. Various types of earth pressure distribution related to ground condition were considered in the structural analysis of an example structure at each step of the excavation. From the analysis, the most high member force acting on beams was found when the ground type was medium sandy soil and a stress concentration was found in corner area.

***Keywords*—**Construction of building, top-down construction method, earth pressure distribution, member force, stress concentration.

I. Introduction

THE construction of underground structures for buildings and civil structures is necessarily accompanied by an excavation work, and a retaining structure is installed to keep the ground in equilibrium during the excavation.

In recent years, there has been an increasing number of building constructions using underground space due to a lack of available space in urban areas. In addition, cases of deep excavation conducted in close proximity to the site boundaries have increased in order to utilize the land efficiently. However, since existing buildings are close to the downtown area, work space is insufficient in most cases. In such cases, when the excavation starts, the stress condition of the ground is relaxed, and thus deformation occurs in the ground around the excavation work. Therefore, the retaining structure should have sufficient strength and stiffness so that it can withstand the earth pressure acting on the building structure when the excavation proceeds. In addition, the surrounding ground settlement caused by drainage, the deformation of structure and leakage of back soil that occur during construction or after completion of construction, which frequently results in damages to adjacent roads, structures or objects buried underground, and therefore it is necessary to conduct a comprehensive review at the design stage.

A strut method (resisting method by using temporary supports), which is common underground construction method, is highly likely to cause problems in terms of safety, such as cracks that occur in buildings due to the settlement of the surrounding ground and risks like a collapse of retaining structure during the earth excavation. In addition, it has disadvantages of visual instability and extended construction period [1]. On the other hand, a top-down construction method can not only reduce the construction period significantly in construction projects in downtown areas, but also proceed with the excavation process while securing the work space. As a result, the application of the top-down construction method has recently been further expanded in underground works in downtown areas [2], [3].

In the top-down construction method, the distribution of earth pressure in the surrounding ground affects the bearing capacity of the supporting member. Therefore, this study seeks to analytically investigate the structural characteristics depending on the distribution of earth pressure of the surrounding ground in the top-down construction method.

First, this study identifies the construction procedures of the top-down construction method. Next, it observes the changes in the distribution of the member forces by excavation stage according to the ground conditions of the example building. With the use of MIDAS program [4], a structural analysis is conducted to confirm the stress distribution on the earth pressure distribution applied in stages of excavation from the first basement to the third basement.

II. Construction Procedure

The construction method which has widely been used in Korea can be classified into three types according to the construction procedure as shown in Fig. 1. They are a top-down method to construct ground structures irrespective of underground construction period, an up-up method to construct ground structures after completion of foundation slabs and a down-up method to construct ground structures after completion of foundation slabs and underground structures. And as top-down method, there are SPS (Struts as a Permanent System) method [1] and NSTD (Non-Supporting Top-Down) method [5] and BRD (Bracket supported R/C Downward) method [6] according to the classification of form-work. The SPS method is to construct steel columns and beams for underground structures to utilize them as retaining braces during the excavation work, and to use them as the structures after completion of construction work. In the case of the NSTD AND BRD methods, form-work is hanged to upper beam and slab so that it is possible to construct bottom slab and beam without installation of a supporting post. Also the form can be

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moved down without dismantling in order to be used as the form for slab and beam construction of bottom floor. Fig.2 represents the construction flow of the top-down method widely used in Korea.

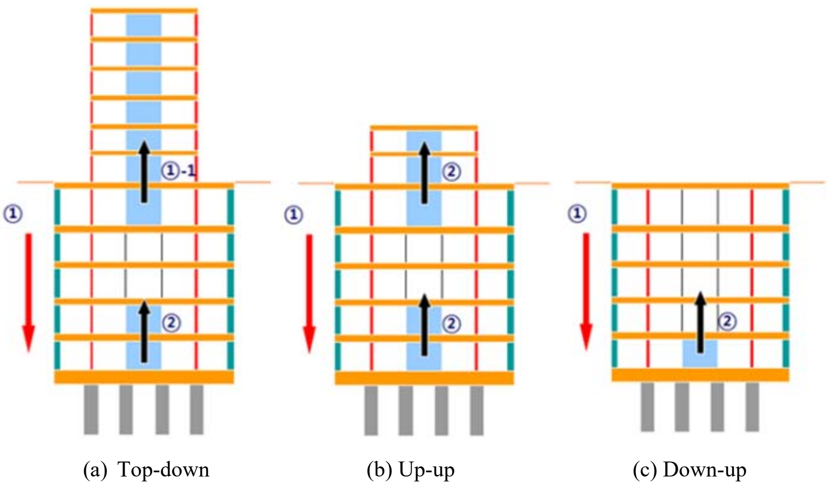


Fig. 1 Construction processes of Top-down method

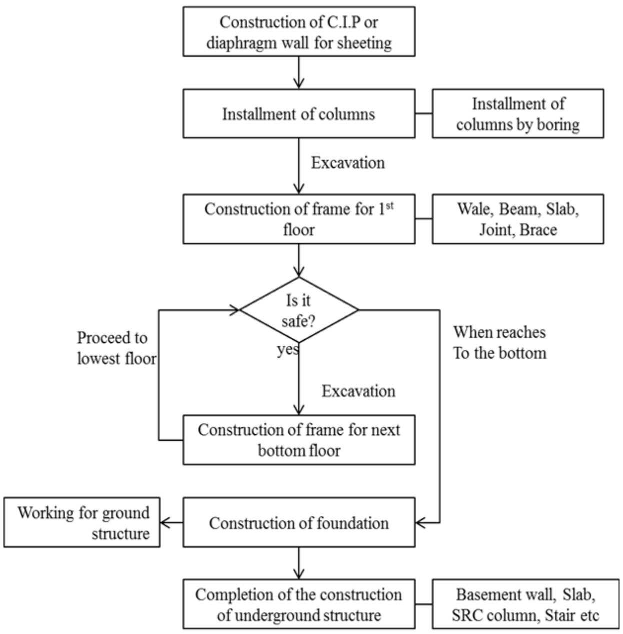


Fig. 2 Construction flow in top-down method

III. Structural Analysis of Frame during Top-Down Construction

A. Design of Example Building

The target building of this study is three stories beneath ground level and ten stories above ground, and the story height of the first basement is 3.4 m and that of the second and third basements is 3.2 m. Fig. 3 represents the typical basement floor plan. Modeling was performed using an analysis program based on the design as shown in Fig. 4, and then the framework was designed as shown in Fig. 4.

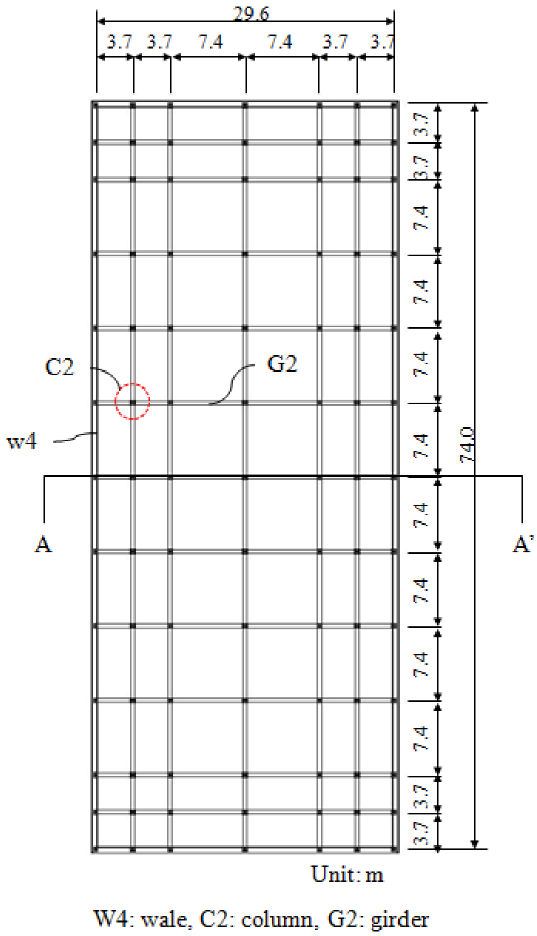


Fig. 3 Plan of the example building

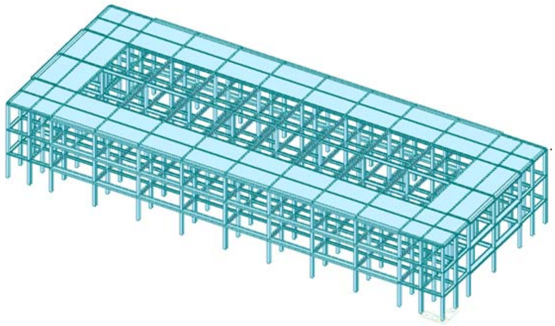


Fig. 4 Structural modeling of the example building

B. Ground Condition and Loads

With respect to the distribution of the earth pressure acting on the back of a retaining wall, the soil pressure was calculated by using the distribution proposed by Terzaghi and Peck [7]. The unit weights of soils are summarized in Table I. And then, through a simple analysis method, the reaction forces acting on wales were calculated using the equilibrium condition of force and the values were applied to each wale as an axial load. In addition, the construction load applied to the first floor slabs was 1.5 kN/m^2.

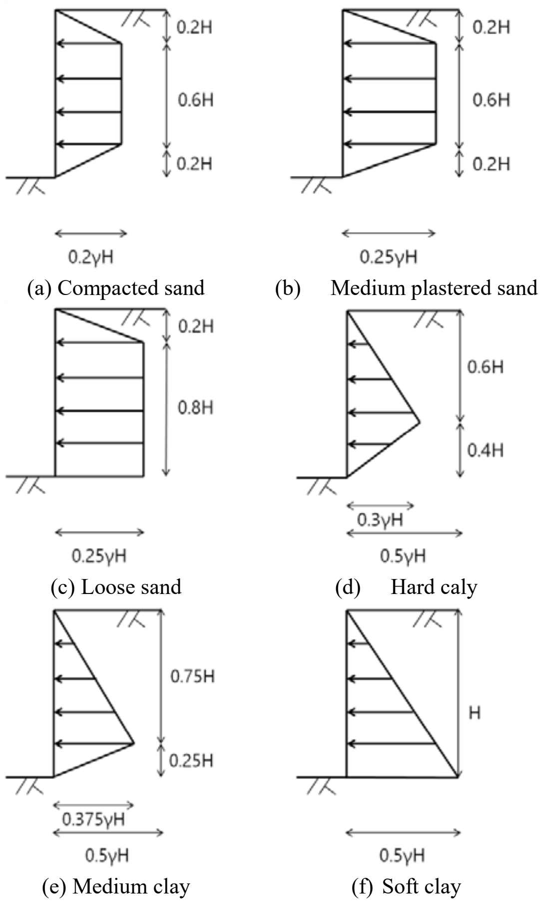


Fig. 6 Distribution of earth pressure corresponding to ground type

TABLE I
UNIT WEIGHT OF SOIL

Type	Unit weight (t/m^3)
Compacted sand (A)	2.0
Medium compacted sand (B)	1.9
Loose sand (C)	1.8
Hard clay (D)	1.8
Medium clay (E)	1.7
Soft clay (F)	1.7

C. Stress Distribution at Each Excavation Step

Table II shows the member forces of W4, C2 and G2 located in the first to third basements of the example building to which the earth pressure of the compacted sandy ground is applied at each excavation step.

The stress applied to W4 members in each basement by construction stage showed the lowest value when the excavation work was done for the first basement, and the largest value was shown when the excavation work was completed to the third basement level. This is because the earth pressure acting on the retaining wall according to the earth pressure distribution increases in proportion to the depth of the excavation. And it was confirmed that with respect to the same excavation depth, a further reduction in the moment and shear force of the W4 member at lower floors is due to a further decrease in the magnitude of the earth pressure towards the basement floors.

It was also confirmed that the G2 member that acts as a strut exhibits a high compressive force as the earth pressure transferred from the W4 member is applied as an axial load. The C2 member is subjected to the vertical loads such as self-weight and construction load, and the axial load of beam member (G2) and wale (W4) as a vertical member. It is found that for the G2 member, the axial load applied to the column increases towards the lower floors since the vertical loads, and loads received from the beam member and wale are delivered to the column of the lowest floor. The moment generated in the column was found to be largest when the ground was excavated to the third basement level, and the size became larger towards the basement.

D. Stress Distribution Corresponding to Ground Condition

The member forces acting on each member were confirmed with respect to various earth pressure distributions depending on the ground conditions. Especially for the W4 member, a horizontal member which is more affected by the earth pressure, which is a horizontal stress, than by vertical stresses such as self-weight and construction load, the maximum moment, shear force and axial load applied due to the earth pressure depending on each condition were confirmed. Fig. 7 shows the maximum member forces acting on W4 member with various ground conditions where the excavation towards the third basement level is completed.

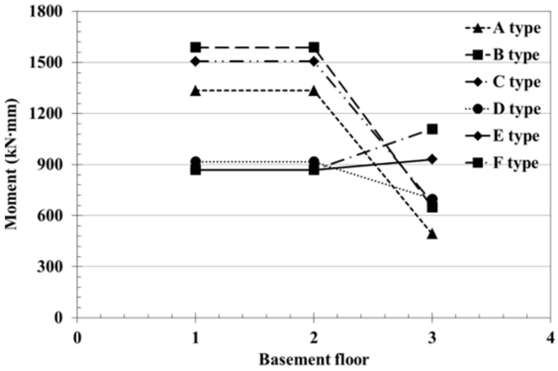
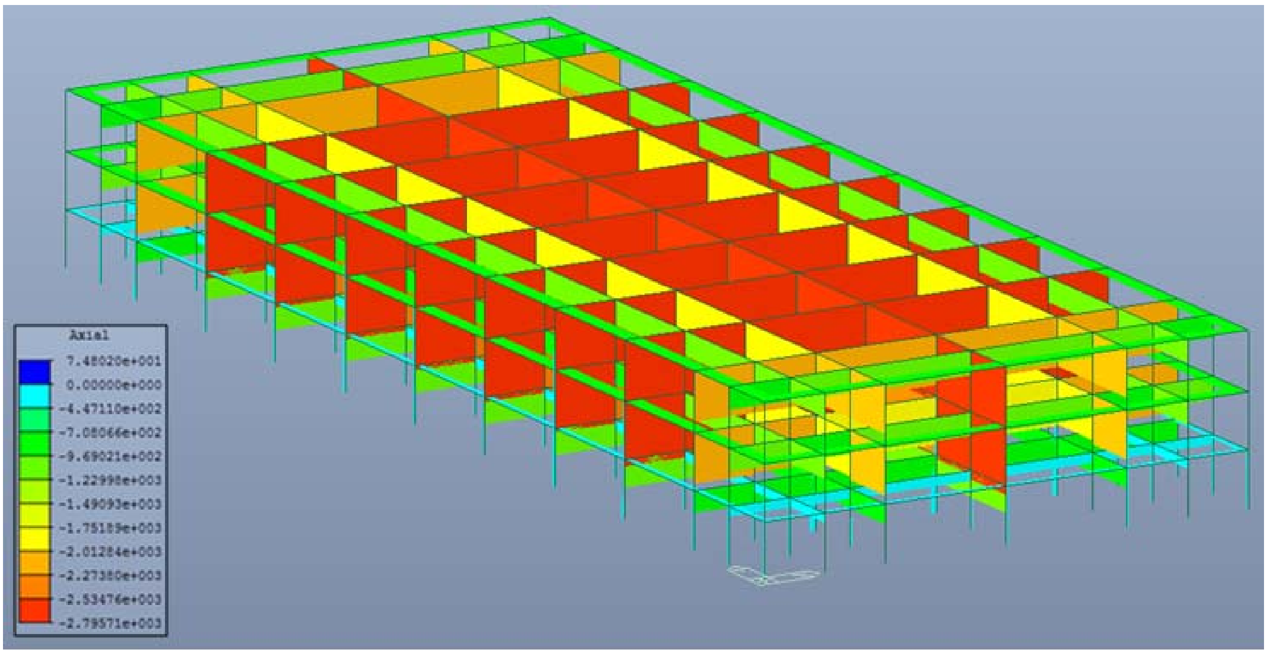


Fig. 7 Maximum moments acting on W4 with various ground conditions

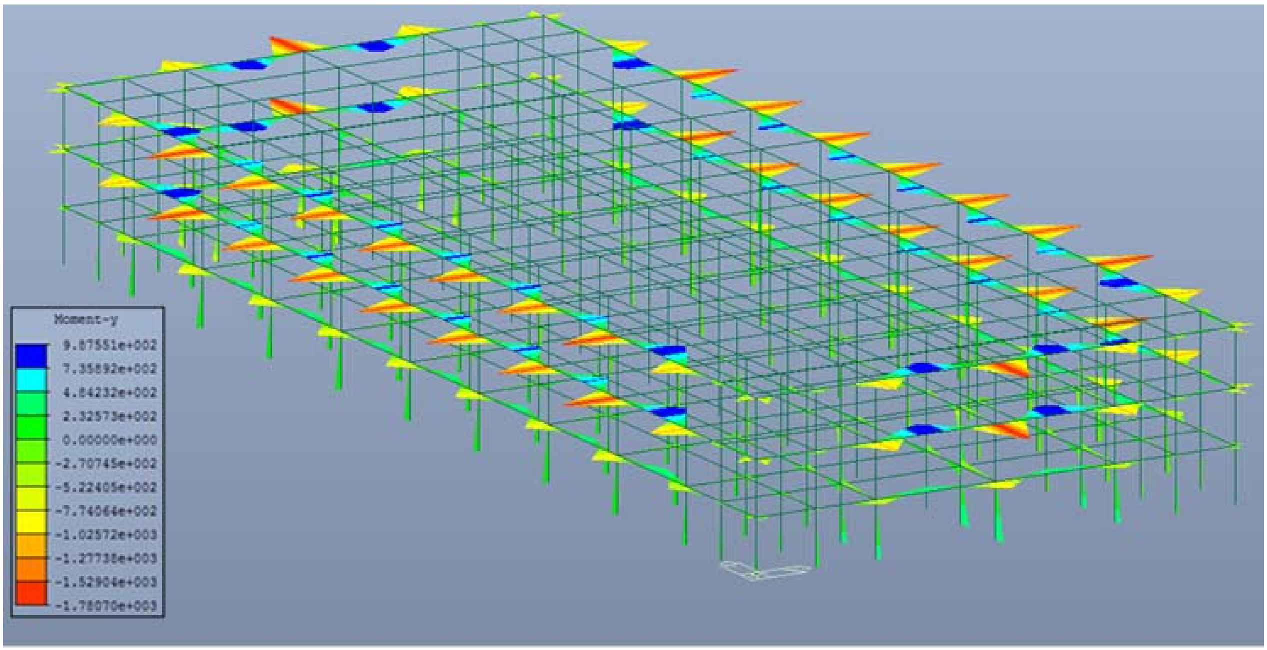
It was confirmed that the same maximum moment is applied to the W4 member located on the first and second floors in the all sandy soil condition and hard clay soil condition and the moment value decreases in the W4 member located at the third basement level. In the medium clay and soft clay soil grounds, the same member forces were observed on the first and second floors as in other ground conditions, and a higher value was found in the third basement unlike in other grounds. This suggests that the earth pressure in the medium clay and soft clay soil grounds is greater at the lower part than at the upper part. Fig. 8 shows the axial and shear forces acting on the members when the ground condition is loose sandy soil. In Table II, the values of forces acting on the member are represented; the ground condition is compacted sandy soil.

TABLE II
FORCES ACTING ON THE MEMBERS AT EACH EXCAVATION STEP IN COMPACTED SAND SOIL CONDITION

Member		Moment (kN·m)			Shear force (kN)			Axial force (kN)		
		After excavation of -1F	After excavation of -2F	After excavation of -3F	After excavation of -1F	After excavation of -2F	After excavation of -3F	After excavation of -1F	After excavation of -2F	After excavation of -3F
W4	-1F	149.9	599.6	1334.8	81.0	324.1	721.5	-42.8	-252.2	-593.8
	-2F	-	599.6	1334.8	-	324.1	721.5	-	-110.8	-340.1
	-3F	-	-	492.8	-	-	266.4	-	-	-124.0
C2	-1F	-36.2	31.3	89.2	-17.0	4.5	33.2	-155.0	-134.9	-107.8
	-2F	-	-171.3	177.0	-	-84.2	-87.8	-	-162.1	-125.9
	-3F	-	-	-226.5	-	-	-98.4	-	-	-175.1
G2	-1F	-7.5	-10.4	-13.4	-5.1	-6.3	-7.5	-127.1	-718.7	-1629.6
	-2F	-	-13.3	18.9	-	-7.5	-9.0	-	-368.8	-1110.6
	-3F	-	-	20.6	-	-	-9.3	-	-	-502.1



(a)Axial force



(b) Bending moment acting on wale

Fig. 8 Member forces after excavation of -3rd floor (loose sandy soil)

IV. SUMMARY

This study investigated the stresses of each member by construction stage on the various ground condition of the building with three stories below the ground to which the top-down construction method was applied, and analyzed the stresses acting on the main structural members by applying the earth pressure distribution depending on each ground.

Through a comparison of member forces according to each ground, it was confirmed that the ground that shows the greatest member force is the medium sandy ground. A comparison between the types of the earth pressure distributions may lead to a judgment that greater earth pressure is applied to the loose sandy ground than to the medium sandy ground. However, the analysis results confirmed that the largest member force is found in the medium sandy ground due to the unit weight of the soil.

The comparison of member forces according to each soil also revealed that the member force (moment and shear force) decreases towards the lower floors on the hard sandy ground, the medium sandy ground, the loose sandy ground and hardened clay ground, but the member force increases towards the lower floors on the medium clay ground and the soft clay ground.

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