Proposal of Ground Subsidence Risk Rating (GSR) Due to Excavation in Order to Prediction of Ground Subsidence

Myeong Hyeok. Ihm and Eugene. Jang
Daejeon University/Construction & Disaster Prevention Engineering, Daejeon, Republic of Korea
Email: mhihm61@hanmail.net , jiniixz@naver.com

***Abstract*— Throughout studying geotechnical field related to excavation work among dozens of influence factors related to the ground subsidence through case study and literature analysis. As a result Park et al. (2017) selected as 7 categories and 22 factors for the ground subsidence influence factors. The factors of the ground subsidence determined in the study were classified into 7 categories: Existence of the cavity, soil and rock, soil, rock, hydrogeology, external influence, and monitoring ground subsidence during construction. In case of existence of the cavity, influence factors are classified as depth of oveburden and thickness of overburden. In case of soil and rock, it is classified as depth of boundary and orientation of boundary(strike and dip). In case of soil, it is classified as type, shear strength, relative density, dry unit weight, water content by weight and liquid limit. In case of the rock, it is classified as rock types, distance from main fracture and RQD. In case of hydrogeology, it is classified to intensity of rainfall, depth and distance from main channel, coefficient of permeability and fluctuation of groundwater table. In case of external influence, it is classified to as depth of excavation and distance from the retaining wall, method to handle groundwater during excavation, existence of artificial facilities and loss of soil particles through the earth retaining wall. Finally, in case of monitoring ground subsidence during construction, measuring settlement during construction is important factor. The 22 most important factors affecting the ground subsidence are listed in order of importance. The most important order is groundwater level fluctuation, monitoring during excavation, kind of soil, type of rock, groundwater treatment during excavation, distance between main channel , soil depth and thickness, soil shear strength, RQD, liquid limit, relative density, permeability coefficient, distance between excavation depth and retaining wall, water content, distance from stream, existence of artificial facilities, rainfall intensity, soil gravity loss, orientation and depth of soil and rock interface, and dry unit weight of soil. In the preparation of the GSR sheet, a total of 22 influence factors were grouped into seven influential factor groups, and the top five influential factor groups corresponding to 94% of the seven influential factor groups were selected as the five essential factors. The score of each item was calculated by the number of citations in the GSR sheet.**

***Index Terms*—Ground subsidence, prediction of ground subsidence, excavation, influence factors**

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I. INTRODUCTION

In the field of excavation work, there are frequent occurrences of ground subsidence due to internal and external factors. This is a major social issue because it causes not only economic losses but also human casualties. In order to cope with these accidents, the National Geotechnical Research Project has been carried out. As part of this project, research is underway on the prediction of geotechnical subsidence between excavation works from 2016 to 2018. The purpose of this study was to develop the technology to predict and evaluate the subsidence of the ground during the excavation work. It is important to have sufficient field data related to the subsidence in the study. However, it is a reality that the reliability of the data measured in the actual field is very low and it is difficult to obtain the data of the site where the actual large amount of settlement, collapse and destruction occurred. Park et al (2017) conducted various papers and literature surveys in order to derive the factors affecting the subsidence of the ground. The factors influencing the ground subsidence were derived and listed in order of importance. In this paper, we describe the influential factors and propose a rating method of influential factors for predicting ground subsidence.

II. FACTORS OF GSR

A. *Existence of Cavity*

When there is a cavity in the ground, overburden load is a major influence factor. A cavity is an empty space existing under the surface, including not only naturally occurring cavities due to reduction, dissolution and discharge of fluid in the ground but also artificial cavities such as tunnels. 10cm × 10cm × 10cm for soil and 1m × 1m × 1m for rock ground. There is a risk of collapse of the ground if the overburden load is applied to the ground with cavities. The overburden load is applied by the weight of the overburden at the upper part of any point. If the overburden load is larger than the shear strength of the soil foundation, or when it is larger than the fracture strength of the rock foundation, the ground collapse may occur. Therefore, when there is a cavity in the ground, the risk of ground subsidence can be evaluated by

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considering the overburden depth and thickness and considering the overburden load.

B. Characteristic of Soil

The ground can be roughly divided into soil and rock ground. In the case of the soil, the engineering properties differ depending on the heterogeneity and the type of soil. Therefore, it is important to classify the types of soils in the field and to understand the shear strength, degree of compaction, dry weight, water content, and liquid limit that affect the strength of the soil.

C. Characteristic of Rock

In case of rock ground, it is composed of continuous rock, so it has higher strength than that of soil. However, if the solubility of the constituent rocks is high or if there are discontinuities such as joints and fault zones, there is a high possibility that the ground subsidence occurs. Therefore, the investigation of the type of rock constituting the rock, the distance between the main fracture and the fracture density should be carried out in the field.

D. Boundary of Soil and Rock

When the excavation is carried out, the soil layer due to weathering is present on the upper part, and the boundary surface where the bedrock with the bedrock is in contact is common. The boundary between soil and rock is likely to become an activity surface because it differs in various characteristics such as permeability and continuity. In case of excavation section, there is a possibility of settlement or collapse due to correlation with boundary orientation. Therefore, the orientation (stike, dip) of the interface between the soil layer and the rock layer plays an appropriate role as an influential factor. As the depth increases, the load applied to the boundary becomes larger, so that the depth at which the boundary exists can also be an appropriate influence factor.

E. Hydrogeology

Groundwater is a major factor in ground subsidence, such as the rearrangement and extraction of soil particles in soil and the dissolution of rock in rock-mass ground. Therefore, it is appropriate to use it to evaluate the risk of ground subsidence through groundwater flow, inflow and outflow, rainfall intensity, distance to river, permeability coefficient, and groundwater level fluctuation.

F. External Influences

There are some factors affecting the soil depression during excavation as well as excavation method and other methods. During the excavation, the distance between excavation depth and retaining wall, groundwater treatment method during excavation, existence of artificial structure around excavation surface, and loss of soil particles through earth retaining wall can affect ground subsidence.

III. RATING FOR FACTORS OF GSR

A. Existence of Cavity

1) Depth of Overburden

Because the depth of the cavity decreases the risk of subsidence, the higher the depth, the higher the score. In the case of large-scale excavation work, it is not common to excavate to a deeper depth than 30m, so it is classified into six grades of 60 ~ 55, 55 ~ 50, 50 ~ 45, 45 ~ 40, 40 ~ 35 and 35 ~ 50m.

2) Thickness of Overburden

Since the thickness of the overburden and the overburden load are proportional from the surface to the cavity, the risk of ground subsidence risk increases. Therefore, the higher the thickness of the overburden, the lower the score. The thickness of the overburden was divided into six grades of 0 ~ 5, 5 ~ 10, 10 ~ 15, 15 ~ 20, 20 ~ 25, 25 ~ 30m.

B. Characteristic of Soil

1) Type of Soil

Fine grained particles, such as clay and silt, are sensitive to groundwater changes, and organic soils in addition to clay and silt can also have a significant impact on subsidence. In the case of settlement, it is known to occur mainly in soft clay ground (Seong and Shin, 2008; Tan and Li, 2011; Finno et al., 2002). The sudden occurrence of soil depression or destruction occurs as homogeneous loose sand, which is sensitive to erosion, flows out along with changes in groundwater level and flow. If the existing classification system is used, the engineering characteristics of the soil can be grasped roughly and applied to the estimation of the ground subsidence risk. The grades of soil were divided into five classes: uneven granular soils, even granular soils, even fine sand, loose cohesive soils and organic soils.

2) Shear Strength

TABLE I. UNDRAINED SHEAR STRENGTH AND CLAY CONDITION

Undrained shear strength (KN/m^2)	*Condition*
< 20	Very soft
20 ~ 40	Soft
40 ~ 75	A little stiff
75 ~ 150	Stiff
150 ~ 300	Very Stiff
> 300	Hard

Soil with high shear strength is prevent immediate ground subsidence when underground soil are leaked or cavities are formed in the ground due to groundwater descent(Hu et al, 2003). Vallejo and Ferrer (2011) presented the soil condition according to the undrained shear strength (Table Ⅰ), and used it as the criterion for the shear strength.

3) Relative Density, Compaction

In the case of soil with low relative density or low degree of compaction, there is a large amount of voids, so that when the consolidation by the continuous load occurs, a large ground subsidence occurs. In addition, it has been found that shear strength increases with shear strength compared to loose soil, and Yoon and Ahn (2011) suggested the improvement of soil density through relative density and compaction. Table Ⅱ shows the relative density and state of N values (Gibbs and Holtz, 1957). In this study, we divided the class of relative density by using the commonly used N value.

TABLE II. RELATIVE DENSITY FOR N VALUES IN GRANULAR SOILS

N(SPT)	Relative density (%)	Friction andgle(Φ)	Condition
0~4	< 15	< 28°	Very loose
4~10	16 ~ 35	28° ~30°	Loose
10~30	36~65	30°~36°	Moderate
30~50	66~85	36°~41°	Dense
> 50	86~100	> 41°	Very dense

4) Dry Unit Weight

The higher the dry unit weight, the lower the likelihood of ground subsidence. In the case of collapsible soil such as loess, the dry unit weight of the soil and the possibility of soil collapse from the collapse test using a consolidation tester can be predicted. The dry unit weights were classified as < 10, 10-12, 12-14, and > 14 KN/m^2.

5) Water Content by Weight

Water content It is the ratio of water weight to the weight of the ground. The water content is especially important in the fine grained soil. In the case of clay, it changes into a solid, plastic, and liquid state depending on the water content. Depending on the state, the engineering characteristics including strength are significantly different. If the water content exceeds a certain level, the soil is lost due to the piping phenomenon and induces ground subsidence. The water contents were classified into five grades as> 55, 40 ~ 55, 25 ~ 40, 15 ~ 25, < 15%.

6) Liquid Limit

The liquid limit refers to the water content at the moment when the soil changes from a sintering state to a liquid state and is usually determined by performing an Atterberg test. When the water content of the ground exceeds the liquid limit, it becomes low hardness and the damage of the ground subsidence becomes large. Therefore, in the case of soil with low liquid limit, it is vulnerable to groundwater or rainfall environment, causing ground subsidence. In this study, the liquid limit was classified as <35%, 35 ~ 50, 50 ~ 90, 90% < 4 levels.

C. Characteristic of Rock

1) Type of Rock

In the case of rocks with high solubility, such as limestone and salt rocks, cavities are formed in the ground, which is the cause of direct subsidence, so you must pay special attention. Because muddy rocks have relatively low strength in relation to other rocks, the possibility of ground subsidence must be considered. If other rocks are bedrock, they are stable. Therefore, it was classified into eight grades in order of rock salt, gypsum, limestone, dolomite, mudstone, coaly shale, shale, and other rocks.

2) Distance to Main Fracture

Fracture refers to a discontinuity that develops in rocks such as joints and faults, and main fracture refers to the most prevalent fracture among rocks. In the main fracture, fracture can easily occur, and in this case ground subsidence occurs. The distances from the main fracture were divided into 6 classes of <1, 1 ~ 2, 2 ~ 5, 5 ~ 10, 10 ~ 50, < 50m.

3) RQD

The RQD is a value expressed as a percentage divided by the total length of the cores that are longer than 10 cm from the drilling core. The degree of development of the fracture must be applied as an influence factor in the rock layer. The RQD was divided into five grades: 0 ~ 20, 20 ~ 40, 40 ~ 60, 60 ~ 80, 80 ~ 100%.

D. Bodunary of Soil and Rock

1) Depth of Boundary

The depth of the boundary between the soil and the rock was classified as > 60, 60 ~ 50, 50 ~ 40, 40 ~ 30, 30 ~ 20, 20 ~ 10, < 10m.

2) Orientation of Boundary

The orientation of the boundary between the soil and the rock ground was classified into three grades according to the difference of the direction of the excavation slope from 0 to 30, 30 to 60, and 60 to 90 degrees.

E. Hydrogeology

1) Rainfall Intensity

There are many reports of ground subsidence after heavy rainfall. On the other hand, Singh (2007) argued that the material that was eroded in the weathered toe layer with rainwater moved to the fault plane with rainwater, and that the material moved to the fault plane lowered the shear strength of the ground and made the ground unstable. In addition, rainfall affects groundwater level fluctuation, so it is appropriate to apply it as a ground subsidence influence factor through precipitation per hour information. The rainfall intensity was classified as > 20, 15 ~ 20, 10 ~ 15, 5 ~ 10, < 5 ㎜/h.

2) Depth and Distance from Main Channel

The river affects groundwater level fluctuation through inflow and outflow of groundwater in rainy season and dry season. The effect generally reaches a depth of 12m. In addition, the flow velocity of the groundwater around the river is accelerated, so that there is a possibility that the ground subsidence and sinking occur. Therefore, there is a greater risk of ground subsidence due to groundwater around rivers than groundwater at a certain distance from rivers. The distances to the rivers were divided into four grades as <100, 100 ~ 200, 200 ~ 400, and > 400m.

3) Permeability Coefficient

The coefficient of permeability varies depending on what kind of soil the ground is composed of. Powers (1992) classified the soil based on the unified classification method and presented the coefficient of permeability in each soil. If the coefficient of permeability is high, the groundwater movement in the ground is rapid, and the variation of the groundwater level increases. In severe cases, the drainage of the soil may occur. Table Ⅲ shows the coefficient of permeability according to the type of soil as proposed by Powers (1992). In this study, we classified > 1, 1 ~ 0.3, 0.3 ~ 10-4, 10-4~10-8, < 10-8 cm/sec 5 grades by referring to the permeability coefficient study.

TABLE III. PERMEABILITY COEFFICIENT ACCORDING TO SOIL TYPES

Type of soil	K(cm/sec)
Poorly sorted gravel (GP)	≥ 1
Equationally graded gravel (GP)	0.2 ~ 1
Wellsorted gravel (GW)	0.05 ~ 0.3
Equationally graded soil (SP)	$5x10^{-3}$ ~ 0.2
Well sorted soil(SW)	10^{-3} x 0.1
Silty soil (SM)	10^{-3} ~ 5 x 10^{-3}
Clay soil (SC)	10^{-4} ~ 10^{-3}
Low plasticity silt (ML)	5 $x10^{-5}$ ~ 10^{-4}
Low plasticity clay(CL)	10-5 ~ 10^{-8}

4) Fluctuation of Groundwater Table

Factors influencing groundwater level fluctuations include industrial development, including natural rainfall, and artificial groundwater pumping due to continuous rural and urban development. Small granular soil such as clay and silt in the aquifer are the most representative of ground subsidence due to groundwater pumping. When the groundwater level falls due to groundwater pumping or other factors, the pore pressure between the particles decreases and the pore pressure decreases, so that the randomly arranged plate-like sediment particles are again compressed, rearranged and the porosity is reduced. Groundwater changes above 0.4 m are likely to cause ground subsidence and continual repetition may lead to ground subsidence (Thinh and Ludmila, 2015). Groundwater level fluctuations were classified into four grades as > 4, 2 ~ 4, 1 ~ 2, < 1m / d.

F. External Influences

1) Depth of excavation / Distance to retaining wall

The relationship between excavation depth and subsidence is known from studies by Wang and Xin (2015). The extent and settlement of ground subsidence depend on depth of excavation depends on the ground condition. However, the range of excavation effect is 1 ~ 2 times of excavation depth on sandy ground, 1 ~ 4 times of excavation depth on silty and clayey ground and 1 times of excavation depth on rock-mass. However, if the discontinuity is formed in the rock layer in a poor direction with the excavation work, the influence range may be increased to twice or more. In Korea, the range of excavation effect is generally set to about 1.5 to 2.5 times the excavation depth. In Korean geotechnical society (2007), it was suggested that the depth of excavation should be regarded as the distance from the surface to the upper part of the bedrock in domestic geologic conditions where the soil layer and the rock layer are distributed together. The distance between the excavation depth and the retaining wall was classified as 1H, 1H ~ 2H, 2H ~ 4H when the distance from the retaining wall is H.

2) Groundwater Treatment Method at Excavation

There is a drainage method in which the groundwater level is lowered to the excavation surface and an exponential method to prevent the groundwater from flowing into the excavation site by imperviously treating the excavation main surface and the back surface. In the case of the drainage method, the consolidation of the surrounding ground can be caused, and when the exponential method is applied, the boiling phenomenon may occur at the bottom of the excavation and the hydraulic pressure acts on the retaining wall (Park, 2015; Wang et al., 2009; Long, 2001; Yoo, 2001)

3) Presence or Absence of Artificial Facilities

In some cases, ground subsidence is caused by artifacts such as waterpipe and sewage, which are not natural factors. In particular, pipes and pipelines may be damaged due to aging, and in this case, the inflow of the gravel into the waterway or the outflow of water from the pipe may cause the ground subsidence by eroding the ground. When the sewer was buried in a shallow place, it was more likely to be damaged than when it was buried deep. When the sewer line was located below the groundwater, the ground was more likely to flow into the sewer line and be lost. Therefore, in order to avoid ground subsidence due to artificial structures, it is necessary to check the relationship with the groundwater level and not to damage the sewer pipe.

4) Loss of soil particles through retaining walls

Groundwater and soil may leak due to defects in the wall construction. In such cases, piping may occur at the bottom of the surrounding ground or under the excavation surface (Choi and Baek, 2016).

IV. GSR WEIGHTING

The impact factors do not have the same effect on the ground subsidence. There are significant influential factors and small influential factors (Table Ⅳ), depending on the type of soil characteristics, ground condition, and construction method. Therefore, by converting the statistical score according to the influence into the grade and setting each factor, it is possible to calculate the GSR grade according to the field ground, and to be able to predict the ground subsidence.

TABLE IV. WEIGHTING FOR INFLUENCE OF GSR FACTORS

Ground subsidence influence	*influence factor*
High	fluctuation of ground water table
	soil type
	rock type

Ground subsidence influence	*influence factor*
	groundwater treatment method at excavation
	overburden depth/orientation distance from main fracture
	shear strength liquidlimit relative density RQD coefficient of permeability depth of excavation/ distance retaining wall
	water content by weight
	depth and distance from main channel
	existence of artificial facilities
	intensity of rainfall loss of soil particles through retaining walls
	orientation of soil and rock boundary
Low	depth of soil and rock boundary
	dry unit weight

V. CONCLUSION

The factors of the ground subsidence determined in the study were classified into 7 categories: existence of the cavity, soil and rock, soil, rock, hydro, external influence, and monitoring ground subsidence during construction. The 22 most important factors affecting the ground subsidence are listed in order of importance. The most important order is groundwater level fluctuation, monitoring during excavation, kind of soil, type of rock, groundwater treatment during excavation, distance between main fracture , soil depth and thickness, soil shear strength, RQD, liquid limit, relative density, permeability coefficient, distance between excavation depth and retaining wall, water content, distance from stream, existence of artificial facilities, rainfall intensity, soil gravity loss, orientation and depth of soil and rock interface, and dry unit weight of soil. In the preparation of the GSR sheet, the score of each item was calculated by the number of citations in the GSR sheet.

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Myeong Hyeok Ihm was born in Daegu, Republic of Korea, and December, 21, 1961. He studied in the Kyungpook National University Daegu, Republic of Korea. And got Ph.D .(1993) structural geology. Daejeon University Professor, Dept. of Construction & Disaster Prevention Engineering

Eugene Jang was born in Ulsan, Republic of Korea, and January, 19, 1987. He studied in the Kyungpook National University Daegu, Republic of Korea. He got his Bachelor (2013) geology from Daejeon University master's degree in the Dept. of Construction & Disaster Prevention Engineering.