International Journal of Advanced Culture Technology Vol.6 No.4 255-261 (2018)
DOI https://doi.org /10.17703//IJACT2018.6.4.255

IJACT 18-4-32

Ground Subsidence Risk Ratings for Practitioners to predict Ground Collapse during Excavation (GSRp)

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Abstract

In the field of excavation, it is important to recognize and analyze the factors that cause the ground collapse in order to predict and cope with the ground subsidence. However, it is difficult for field engineers to predict ground collapse due to insufficient knowledge of ground subsidence influence factors. Although there are many cases and studies related to the ground subsidence, there is no manual to help practitioners. In this study, we present the criteria for describing and quantifying the influential factors to help the practitioners understand the existing ground collapse cases and classification of the ground subsidence factors revealed through the research. This study aims to improve the understanding of the factors affecting the ground collapse and to provide a GSRp for the ground subsidence risk assessment which can be applied quickly in the field.

Keywords: *Ground subsidence risk, Influence factors, Manual, Excavation, GSRp.*

1. Introduction

In the field of excavation work, there are frequent occurrences of ground collapse due to internal and external factors. This is not only an economic loss but also a loss of life, which is a major social issue. In order to predict and cope with the ground collapse before excavation, it is important to recognize and analyze the influencing factors that cause the ground subsidence. However, there is a lack of knowledge about the factors affecting the ground subsidence and there is no related manual for the actual construction worker. Therefore, Park et al. (2017) conducted a variety of papers and literature surveys in order to analyze the factors affecting the subsidence of the ground. The factors influencing the ground subsidence were derived and listed in order of importance. The purpose of this study is to provide a manual of **Ground Subsidence Risk Rating for pre-excavation (GSRp)** to improve the understanding of the designers and practitioners of these influencing factors and the applicability to the field. Since it takes much time and difficulty for the design and construction practitioner to apply detailed field application method for each influence factor, the manual is written for the convenience of the user. This is expected to result in higher efficiency of work.

2. Manual

The influence factors to be described in the manual are 18 factors in six category as shown in Table 1. The six category show geological engineering characteristics and each category has one to six influence factors. Each influence factor is graded on a quantitative basis for scoring. Each element is scored with a score of 100, and the higher the score, the lower the risk of subsidence. In the following, we explain the reasons for selecting

Manuscript Received: October 20, 2018 / Revised: October 30, 2018 / Accepted: November 5, 2018
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each category and the influence factors and the quantification criteria.

Table 1. Factors of ground subsidence risk due to geotechnical characteristics during pre-excavation.

Type	Influence factors
1. Existence of the cavity	Depth and Thickness of Cavity
2. Soil	Soil types, Shear strength, etc
3. Rock	Rock types Distance from main fracture RQD
4. Soil + Rock	Depth of boundary between soil & rock Orientation of boundary between soil & rock (Strike/Dip)
5. Hydrogeology	Rainfall intensity Depth and distance from main channel Coefficient of permeability Fluctuation of groundwater table
6. External Influence	Existence of artificial facilities

2.1 Existence of the 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 collapse can be evaluated by considering the overburden depth and thickness and considering the overburden load.

2.1.1 Depth of Cavity

Because the depth of the cavity decreases the risk of collapse, 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 ~ 30m.

2.1.2 Thickness of Cavity

Since the thickness of the cavity and the overburden load are proportional from the surface to the cavity, the risk of ground collapse increases. Therefore, the higher the thickness of the cavity, 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.

2.2 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.

2.2.1 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.

2.2.2 Shear Strength

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, and used it as the criterion for the shear strength.

2.2.3 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. In this study, we divided the class of relative density by using the commonly used N value.

2.2.4 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.

2.2.5 Water Content by Weight

Water content 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%.

2.2.6 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%.

2.3 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.

2.3.1 Type of Rocks

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 clay 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.

2.3.2 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.

2.3.3 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%.

2.4 Soil + Rock Ground

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 (strike/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.

2.4.1 Depth of Boundary between soil and rock

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.

2.4.2 Orientation of Boundary between soil and rock

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.

2.5 Hydrogeology

2.5.1 Rainfall Intensity

There are many reports of ground collapse 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.

2.5.2 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.

2.5.3 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 4 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.

2.5.4 Fluctuation of Groundwater

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.

2.6 Presence or Absence of Artificial Facilities

In some cases, ground subsidence is caused by artifacts such as water-pipe 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.

3. Future Research Directions

It is not easy to predict the collapse of ground because of various factors depending on the subsurface environment. Table 2 (Ihm, 2018) presents the influence factors and the criteria for quantifying each factor presented in this study. It is hoped that construction workers will be able to obtain necessary information on the site and apply it to the prediction of the ground subsidence risk. In addition, it is necessary to apply the weight differently according to the geotechnical characteristics and application site, it is expected that it will be developed as a simple and accurate estimation of the ground collapse prediction.

Table 2. Ground subsidence influence factors and rating criteria (Ihm, 2018).

Type	Influence factor	Rating score (0 1 2 3 4 5 6 7 8 9 10)								note (Unit)
Existence of the cavity	Depth of Overburden	30 ~ 35	40 ~ 35	45 ~ 40	50 ~ 45	55 ~ 50	60 ~ 55			m
	Thickness of overburden	30 ~ 25	25 ~ 20	15 ~ 20	10 ~ 15	5 ~ 10	0 ~ 5			m
Soil	Soil Type	uneven granular soil	even granular soil	even fine sand	loose cohesive mud	organic soil				
	Sherar strength	< 20	20 ~ 40	40 ~ 70	70 ~ 150	150 ~ 300	> 300			KN/㎡
	Relative density	0 ~ 4	4 ~ 10	10 ~ 30	30 ~ 50	> 50				N(SPT)
	Dry unit weight	< 10	10 ~ 12	12 ~ 14	> 14					KN/㎥
	Water content by weight	> 55	40 ~ 55	25 ~ 40	15 ~ 25	< 15				%
	Liquid limit	< 35	35 ~ 50	50 ~ 90	> 90					%
Rock	Rock Type	rock salt	gypsum	limestone	dolomite	mudstone	coaly shale	shale	other rock	
	Distance from main fracture	< 1	1 ~ 2	2 ~ 5	5 ~ 10	10 ~ 50	> 50			m
	RQD	0 ~ 20	20 ~ 40	40 ~ 60	60 ~ 80	80 ~ 100				%
Soil+Rock	Depth of boundary	60 ~ 50	50 ~ 40	40 ~ 30	30 ~ 20	20 ~ 10	< 10			m
	Orientation of boundary (Strike/Dip)	60~90	30~60	0~30						°
Hydro	Rainfall intensity	> 20	15~20	10~15	5~10	< 5				mm/h
	Depth and distance from main channel	< 100	100 ~ 200	200 ~ 400	> 400					m
	Permeability coefficient	> 1	1 ~ 0.3	0.3 ~ 10^{-4}	10^{-4} ~ 10^{-8}	10^{-8} >				cm/sec
	Fluctuation of groundwater table	> 4	2~4	1 ~ 2	< 1					m/d
External Ifluence	Existence of artificial facilities	pipelines and water								

4. Conclusion

The recent increase of ground collapse in Korea requires the development of technology for predicting the possibility of ground collapse. Eighteen parameters affecting the ground subsidence for pre-excavation are classified into 6 categories considering ground types, groundwater, and external factors. Eighteen parameters consists of a table which gives ground subsidence risk ratings for pre-excavation (GSRp). Certain scores are given to these parameters after they are divided into several classes considering the importance and the credibility of parameters and the engineering judgements of the authors. The suggested GSRp tables obtained from this study are expected to be used by engineers for the estimation of ground subsidence risk ratings for pre-excavation sites.

Acknowledgement

This research was supported by the Daejeon University Research Grants (2017), and Korea Agency for Infrastructure Technology Advancement under the Ministry of Land, Infrastructure and Transport of the Korean government (Project Number: 17SCIP-B108153-03).

References

[1] Finno, R. J., Bryson, S., & Michele, C. (2002). Performance of a stiff support system in soft clay (Journal of Geotechnical and Geoenvironmental Engineering). 128(8), 660-671.

[2] Gibbs, H. J., & Holtz, W. G. (1957). Research on determining the density of sands by spoon penetration testing (4th International Conference on Soil Mechanics and Foundation Engineering). London, Vol. 1, pp. 35-39.

[3] Hu, Z. F., Yue, Z. Q., Zhou, J., & Tham, L. G. (2003). Design and construction of a deep excavation in soft soils adjacent to the Shanghai metro tunnels (Canadian Geotechnical Journal). 40(5), 933-948.

[4] Ihm, M. H. (2018). Proposal of ground subsidence risk rating (GSR) due to excavation in order to prediction of ground subsidence, ICGCE 2018, Phuket, Thaland.

[5] Ihm, M. H. (2018). Proposal of Ground Subsidence Risk Rating (GSR) Predict to Sink-Hole and Ground Subsidence, Korean Geotechnical Society, 2018 Spring Conference, (in Korean with English Abstract).

[6] Park, J. Y., Jang, E., Kim, H. J., & Ihm, M. H. (2017). Classification of ground subsidence factors for prediction of ground subsidence risk (GSR) (The Journal of Engineering Geology). 27(2), 153-164. https://doi.org/10.9720/kseg.2017.2.153

[7] Powers, J. P. (1992). Construction dewatering, new methods and applications, 2nd ed. John Wiley and Sons, New York, 528p.

[8] Seong, J. H., & Shin C. K. (2008). Analysis of case study for ground subsidence (The Journal of Facility Safety). 31, 70-80.

[9] Singh, K. B. (2007). Pot-hole subsidence in son-Mahanadi master coal basin. (Engineering Geology). 89(1), 88-97.

[10] Tan, Y. & Li, M. (2011). Measured performance of a 26m deep top-down excavation in downtown Shanghai (Canadian Geotechnical Journal). 48(5), 704-719.

[11] Thinh, H. P., & Ludmila, A. (2015). Prediction maps of land subsidence caused by groundwater exploitation in Hanoi (Vietnam, Resource Efficient Technologies). 1, 80-89.

[12] Vallejo, L. I. G. & Ferrer, M. (2011). Geological engineering, CRC Press, Balkema Book, 678p.

[13] Yoon, M. S. & Ahn, D. W. (2011). Estimation of vaccum pressure and prediction of settlement at optimum stage of ground with individual vaccum pressure method (Journal of Land Housing and Urban Affairs). 2(2), 163-170. (in Korean with English Abstract).