A Study on the Allowable Safety Factor of Cut-Slopes for Nuclear Facilities

Kim Myung Soo *, Eric Yee
KEPCO International Nuclear Graduate School (KINGS), 658-91 Haemaji-ro, Seosaeng-myeon, Ulju-gun, 689-882 Republic of Korea
*Corresponding author: kms092@hanmail.net

1. Introduction

During the construction of a nuclear facility, in the case of the adjacent soil and rock slope, a safety factor is required to ensure the stability of the slope is maintained. This safety factor can be further subdivided into two; normal and earthquake factors, a factor of 1.5 is applied for normal conditions and a factor of 1.2 is applied for seismic conditions.

This safety factor takes into consideration the effect of ground water and rainfall conditions. However, no criteria for the case of cut-slope in nuclear facilities and its response to seismic conditions is clearly defined, this can cause uncertainty in design.

Therefore, this paper investigates the allowable safety factor for cut-slopes in nuclear facilities, reviews conditions of both local and international cut-slope models and finally suggests an alternative method of analysis.

2. Allowable safety factor of Local and International Cut-Slopes

The stability of cut-slope is determined by use of a safety factor. Theoretically, the safety factor is determined to be adequate at a value of 1.0 or more, to take into consideration uncertainties in actual cut-slope behavior, the concept of allowable safety factor has been applied to the design. Local and international agencies allowable safety factors are as follows.

2.1 Allowable safety factors of the local cut-slopes

Allowable safety factors for cut-slopes during dry season is set at ≥1.5 and range from 1.1 – 1.3 during the rainy season. For earthquake conditions a minimum factor of 1.1 is used given the same conditions as that of the rainy season. The cut-slope design criteria, mainly construction work slope design criteria (Ministry of Land, Transport and Maritime Affairs, 2011) has been applied in KOR and conditions have been relatively described in detail(Table 1)

Classification		Standard safety factor	Conditions
Long term	Dry season	FS>1.5	·No groundwater
	Rainy season	FS>1.2 or FS>1.3	· Rock: - To apply FS = 1.2 when it is analyzed from determining the underground water level up to half of the high · Soil and weathered rock: - To apply FS = 1.2 - when it is analyzed from determining the underground water level up -To apply FS = 1.3 when it is considered the penetration of rain
	Earth-quake	FS>1.1	·Groundwater level is applied in the same as during the rainy season
Short term		FS>1.1	· Less than one year · Groundwater conditions is the same as the rainy season

Table1. Cut slope safety factor (Ministry of Land, Transport and Maritime Affairs, 2011)

2.2 Allowable safety factors of the international cut-slopes

Table.2 shows cut-slope safety factors according to international classification which is done using load case and field stress conditions.

For example, Hong Kong (which has many cut slopes), the slope safety factor is 1.2 for a saturated ground surface and 1.2 ~ 1.4 when considering the rain rate (Geotechnical Engineering Office, 1997).

Classification	Minimum safety factor	Conditions
Case 1	FS>1.5	· the load is applied to long
Case 2	FS>2.0	· it is a foundation of the structure
Case 3	FS>1.25~1.30	· a temporary load acts
Case 4	FS>1.15~1.20	· the earthquake load is applied

Table 2. Cut slope criteria of US Navy engineer team.

2.3 Limitations of Local and International Cut-Slopes Allowable Safety Factor

Survey results of local cut-slope criteria covers a wider scope of conditions and provides a more detailed analysis when compared to other countries cut slope criteria.

When determining local cut standards for slope, the construction work slope design criteria (Ministry of Land, Transport and Maritime, 2011) has been proposed in detail as follows, conditions in the rainy season is generally divided into ① the method assumed level of underground water and ② the method of applying the groundwater level and pore pressure distribution considering the rainfall intensity.

The first method listed above does not adequately account for groundwater level it however provides a simple method and is usually applied for analysis. This analysis method is normally done by setting the underground water level -3.0m from ground surface or saturated condition during rainy season depending on the designer's opinion. However, there is a difference between the calculated and actual soil behavior. Most of the time slope failures are caused by the rise in the groundwater, shallow slope failures of the ground surface by wet soil is the primary failure source, it is therefore necessary to modify the method to reflect the actual behavior according to the rainfall infiltration.

Thought the analysis method considering the rainfall intensity is to consider rainfall intensity and duration, it is suitable to estimate the surface water runoff of wide area because there is no explicit mention of the design frequency and it considers only duration and rainfall intensity. In cases where the slope infiltration is by a short period of, it is more reasonable and safe to apply the actual rainfall record or the ground infiltration ratio (the possibility of maximum ground infiltration) (Land Housing Corporation, 2013).

3. Proposal of Detailed Design Criteria for Cut-Slope Allowable Safety Factor

Currently, there is no proposed design criteria for the detailed allowable safety factor of cut-slopes in the nuclear power plane facility, therefore an allowable safety factor of 1.5 for normal conditions and 1.2 for seismic design is currently used, however, this results in design analysis which differ from actual conditions. Due to the sensitive nature of nuclear facilities which require high levels of safety and security, it is necessary to develop more explicit design criteria. Therefore, in this paper, using case studies, we hope to propose design criteria which puts into consideration more detailed soil behavior in determining allowable safety factor for cut-slope in nuclear facilities.

First the allowable safety factor would be categorized based on seasonal effects (dry and rainy seasons) (Ministry of Land, Transport and Maritime Affairs, 2011), then the effect of long-term and short-term loading conditions provided by international standards will be considered. In determining the allowable safety factor during the rainy season, the stability analysis method based on rainfall infiltration method that can describe the actual behavior is proposed and in case of rainfall infiltration, surface infiltration rate method is suggested rather than rainfall intensity probability method. The rain duration is applied to the past three days or maximum rainfall records in a nearby area to take into consideration of the importance of the structure. Where there is no surface infiltration rate data, values given in Table. 3 can be applied.

Soil type	Basic infiltration rate (mm/hr)
sand	less than 30
sandy loam	20-30
loam	10-20
clay loam	5-10
clay	1-5

Table3. Basic infiltration rates for various soil types, field infiltration test (FAO and Water Development Division)

3. Conclusion

In this study, the issues of allowable safety factor design criteria for cut-slopes in nuclear facilities is derived through case analysis, a proposed construction work slope design criteria that provides relatively detailed conditions can be applied in case of the dry season and some unclear parts of slope design criteria be modified in case of the rainy season. Thus, it is expected that the new design criteria adequately ensures the stability of the cut-slope to reflect clear conditions for both the supervising and design engineers.

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