Case Study on the Field Characteristics of Road Embankment Slope Failure in the Mountainous Regions of Korea

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Abstract

The continuous occurrence of embankment slope failure caused by torrential rains during the rainy season has affected the mountainous regions in Korea every year. Numerous lives were lost and extensive properties were damaged in slope related calamities and enormous budget was required to restore the damaged roads and infrastructure. The need to establish an embankment management system was realized and investigation of failure prone embankment slopes recommended by the national road administration office along the national road in the mountainous regions were performed. The field characteristics of embankment failure determined in the field investigation was presented and the efficient methods to mitigate these hazards and disaster were recommended.

Key words : Embankment slope, Embankment slope failure, Embankment Slope Management System(ESMS), Cut Slope Management System(CSMS)

요 지

국지적 집중호우로 인하여 절토사면 붕괴 및 산사태와 더불어 수많은 도로성토사면이 다수 붕괴되거나 유실되었다. 이로 인하여 막대한 인명 및 재산 피해가 발생되었으며, 이를 복원하기 위한 많은 수해 복구 예산이 소요되었다. 성토사면에 대한 관리 필요성이 제기되었으며, 본 연구에서는 국토관리사무소에서 요청한 성토사면 재해위험지구를 중심으로 현장조사를 시행하였다. 정밀 현장조사 결과의 분석을 통해 상토사면의 재해를 유발하는 현장 실태를 파악하고 위험성토사면에 대한 효율적인 대책방안을 제시하였다.

핵심용어 : 성토사면, 사면 붕괴, 성토사면유지관리시스템(ESMS), 절토사면유지관리시스템 (CSMS)

1. Introduction

The localized torrential rains and typhoons(Olga 1999, Gachi 2004 and Rusa 2006) has caused major cut slope failures and landslides together with the damage of road embankment slopes along the national road in the Kangwon Province. Slope collapse, landslide and rockfall related disasters has claimed 41 lives and 30 billion won worth of properties. Typhoon Rusa alone has damaged approximately 32 km of national road in the Kangwon Province. The restoration of the national road and other infrastructures took 1 year and required a national budget of 10 billion won. Due to this incident, the overall problem of the disaster prevention system was exposed and the need for the establishment of an embankment slope management system was realized.

It is a known fact that there is no scientific study on embankment slope not only in Korea but around the world so there is a need to perform advance research on embankment slopes that will serve as a foundation in the effective mitigation of embankment slopes.

In 2009, management of embankment slopes was included in the Cut Slope Management System(CSMS). Embankment Slope Management System otherwise(ESMS) was developed to manage embankment slopes located along national roads. Through the investigation of dangerous road embankment slopes recommended by the national road management offices, inventory investigation and field investigation method, embankment slope investigation priority, investment priority was established.

In this study, the field characteristics of embankment slope

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failure were determined through the analysis of field investigation results and case histories of previous embankment slope failures. Based on the results of the analysis efficient mitigation measures were recommended.

2. Objective and Methodology

2.1 Objective

This study was performed to determine the field characteristics of embankment slope failure and to propose the most effective mitigation methods for dangerous embankment slopes located along national roads:

- 1) determine the field characteristics of embankment slope failure through the field investigation of national roads which has failed or susceptible to failure.
- 2) proposed the most efficient mitigation method to prevent embankment slope failure.

2.2 Methodology

National road management offices where requested to recommend slope failure prone areas for field investigation in order to determine the cause of embankment slope failure along national roads in the mountain regions of Korea. 21 areas of the national road that were susceptible to failure(previous failure and signs of failure) were recommended and theses areas were divided in 40 portions for field investigation(Table 1). Field investigation of the embankment slopes were performed using the ESMS checklist.

ESMS checklist composed of two sheets, the first sheet or

the slope information sheet is use to record the slope information while the second sheet or the mapping sheet used is for the face mapping of the slope and for additional information not include in the slope information sheet. The slope information sheet is divided into 7 major categories namely : (a) investigator's information and embankment slope location, (b) topography, (c) road information, (d) pavement cracks, (e) embankment slope material, (f) embankment slope drainage structure, (g) embankment slope failure history, (g) risk factor and (h) mitigation method.

3. Signs of Embankment Slope Failure

During the field investigations several signs of embankment slope failure were observed. Among the signs of failure, the appearance of cracks on the pavement and road settlement were the most common and the most visible. In fact, most of the embankment slope recommended by the national road management office were selected due to the excessive cracks and settlement of road pavement. Signs of embankment slope failure can also be determined by observing the existing structures on the embankment slopes. The deterioration and damage of existing structures such like retaining walls, gabions, etc.

Trees growing on the slope are affected when the embankment soil moves. In most cases the trees has the tendency to

Fig. 1. Pavement cracks.

Fig. 2. Leaning of trees.

Table 1. Investigated failure prone embankment slopes

Management office	Embankment slopes	Failure prone portions	Signs of failure
Hongchon	4 (6 km)	10	pavement cracks, slope erosion and slope collapse
Kangnong	7 (14 km)	14	pavement cracks and settlement, retaining deterioration
Jeongson	3 (3 km)	7	continuous slope erosion
Gwangju	3 (1 km)	4	pavement cracks and settlement
Jeonju	1 (3 km)	2	pavement settlement
Namwon	1 (0.5 km)	1	pavement settlement and retaining wall cracks
Suncheon	1 (3 km)	1	slope collapse
Daegu	1 (0.5 km)	1	slope erosion
Total	21 (31 km)	40	

lean away from the slope. Generally, trees grow vertically but due to sudden movement or creep, the trunk has a tendency to twist or lean from the embankment slope was observed(Fig. 2).

4. Field Characteristics of Embankment Failure in the Mountainous Region

4.1 Topographic Condition

During the field investigation, it was determined that the presence of medium or large valleys affects slope embankments in mountainous regions. The depth and the size of the valley is directly proportional to the volume of rain water flowing to the embankment slope. Concave roads located adjacent to large valleys are prone to slope failure since rain water has the tendency to concentrate on this portion. The 2007 Gwangchiryoung Yanggu Embankment Slope Failure is an embankment slope failure which was caused by the topographic condition(Fig. 3).

During heavy rains and flood, the surface water and debris flowing down the has the tendency to block the transverse drains and culverts which causes the rapid increase in the drainage capacity and in some cases causes the damage of the embankment slope. Regular drainage maintenance is recommended during the rainy season to prevent this type of disaster(Fig. 4 and Fig. 5).

Fig. 3. Embankment slope failure (Hangyeryoeng, 2007).

Fig. 4. Reduced drainage capacity of culvert causing rainwater overflows.

Fig. 5. Embankment slope failure due to surface water from the valley (Hangyeryong, 2006).

4.2 Road Formation

The road formation found in embankment slope in the mountainous region and the road formation found in disaster prone areas are almost similar. Frequency of erosion or embankment slope failure on straight and convex shaped roads are low compared to embankment slopes on concave and “S” shaped roads. Embankment slopes that are located on the concave or “S” shape portion of the road are affected by the road surface water which has the tendency to drain down the slope causing weathering and scouring(Fig. 6).

Due to the road's structural characteristic, rain water coming from the cut slope flows onto the road and concentrates

Fig. 6. S shaped road prone to embankment slope failure.

Fig. 7. Slope failure due to the seepage of surface water (Hangyeryong, 2006)

Fig. 8. Slope failure due to the seepage of surface water (Hangyeryong, 2006).

on the downhill portion. If the embankment slope is located on the downhill portion, the continuous seepage surface water causes erosion and scouring thereby weakening the soil and later causes it to collapse. This type of embankment slope failure can be observed in the 2006 Hangyeryoung Embankment Slope Failure(Fig. 7 & Fig. 8). Surface water has the tendency to concentrate on the collapse portion causing large scale embankment slope failure.

4.3 Embankment Materials

Embankment are commonly composed of soil, rocks and boulders. These type of embankment slopes is generally classified as soil embankment slopes.

In the case of Japan embankment slopes in the mountainous regions are classified as low embankment (less than 5 m) and high embankment (more than 5 m). In the case of Korea, embankment are classified as low embankment (less than 5 m), medium embankment (5~10 m) and high embankment (more than 10 m). Generally, standard slopes are used for embankment slopes up to 10 m. But stability analysis must be performed for embankment slope higher than 10 m with unverified embankment material and steep embankment angles are specified in the National Road Construction Design Manual (2004) and Construction Work Slope Design Standard (2006). Refer to Table 2.

Since the standards presented in Table 2 and 3 are for construction of new embankment, it is not appropriate for existing embankment slopes. It can be seen in Fig. 9 that more that 85% high embankment slopes and are not in accordance with the embankment slope height standard. Additional research must be performed in order for an appropriate embankment slope maintenance standard to established.

The type embankment material used in the embankment slope in the mountainous region was also investigated. The type of embankment soil was classified into six categories namely: (a) weathered soil, (b) sandy soil, (c) gravel and soil, (d) silty soil and (e) clayey soil and (f) rock and boulder.

Table 2. Standard angle of embankment slope (National Road Construction Design Manual (2008))

Height	Standard Gradient	Remarks
0~6 m	1:1.5	1.0 m berm is constructed every 6 m
< 6 m	1:1.8	

*Values are adjusted depending on the soil property of embankment material

Table 3. Standard gradient of embankment slope (Construction Work Slope Design Standard (2006))

Material	Height (m)	Gradient for NPS	Gradient for WPS
Well graded sand, sandy gravel, rocks, boulders	0~5	1:1.5	1:1.5
	5~10	1:1.8	1:1.8~1:2.0
	> 10	Stability analysis required	Stability analysis required
Poorly graded sand, silty clay soil, clayey soil	0~5	1:1.8	1:1.8
	5~10	1:1.8~1:2.0	1:2.0
	> 10	Stability analysis required	Stability analysis required

*Applied if the foundation soil has sufficient bearing capacity

-NPS : no permanent structures above and below embankment slope like roads, railways, etc.

-WPS : with permanent structures above and below embankment slope like houses, buildings, etc.

Fig. 9. Height of embankment slope.

Fig. 10. Gradient of embankment slope.

ders. so rocks and boulders were included in the embankment material category. During the field investigation, the presence rocks and boulder at the base of the embankment slopes so it was included in the embankment slope material category.

Fig. 11. Embankment slope material.

Most embankment slopes in the mountainous region were constructed using rocks and boulders. Embankment slopes along national roads are not maintained after the design and construction. Most of the embankments are constructed using rocks and boulders from surrounding construction areas of roads and were used as embankment materials. It was determined during that field investigation that besides rocks and boulders, sandy soils is the most common embankment material used. Embankment slope constructed using clay soil and silty soil which is prone to embankment slope failure were relatively few as shown in Fig. 11.

4.4 Drainage Structure

Retaining wall, gabions and other structures are generally installed on the embankment slope while guardrails are installed on the road. Gutters are commonly installed on the road pavement above the embankment slope. The gutter is a relatively small structure considering the scale of the embankment slope but there are many cases where in the stability of the embankment slope is affected by the height and condition of the gutter.

The gutter prevents the surface water from seeping down the embankment slope. If there is no gutter or if the height of gutter is less than 10 cm then the surface water overflows onto the embankment slope weakening the soil causing embankment slope failure.

It was determined from the field investigation that height of gutter installed on the national roads in Korea is 11~20 cm(Fig. 12).

The condition of the gutter is poor or heavily degraded on portions of the road where surface water has the tendency to concentrate. Erosion and scouring of soil is generally

Fig. 12. Installed gutter height.

Fig. 13. Pavement settlement on portion with no gutter.

Fig. 14. Extension of crack from the construction joint to the pavement.

observed in this portion. The construction joint is the weakest point of the gutter. Plywood is usually inserted between the construction joint and it is not properly constructed cracks starts from this portion and extends up to the road pavement(Fig. 13~Fig. 14).

Caution must be taken when the gutter is damaged or when there are large cracks since the surface water flowing on the road has the tendency to concentrate on this portion thereby weakening the soil causing to fail.

4.4 Pavement Cracks

An indirect method to predict embankment slope failure is the appearance of cracks on the road pavement. Extreme caution must be performed when observing the pavement cracks may be related to the embankment slope failure or it may be due the pavement material or improper construction. But no matter what the cause of the pavement crack is, the continuous seepage of water into the cracks may later affect the stability of the slopes therefore the pavement cracks must be repaired immediately.

The pavement cracks were observed considering the signs of road settlement and location of cracks. The appearance of cracks on the cut slope side, centerline and embankment slope side were investigated. Appearance of cracks along the centerline and embankment slope side were observed on disaster prone sections of the road(Fig. 15~Fig. 17).

Fig. 15. Settlement and crack along the embankment slope side.

Fig. 16. Crack along the centerline.

Fig. 17. Location of pavement cracks.

5. Mitigation Methods

It was determined from the field investigation that most of the embankment slope failure were caused by the infiltration of rainwater into the soil matrix during heavy rains combined with other external factors such as topography, road formation, steep slope, and lack of proper drainage system. Since most of the embankment slopes in the mountainous region are composed of soil materials or combination of soil, rocks and boulders(soil embankment slopes) it is prone to soil erosion once excessive amount of water infiltrates into the soil layer.

The main types of embank slope failure observed in the field were pavement cracks, pavement settlement, slope ero-

sion and slope collapse. Since most of the embankment slope failures were due to the infiltration of surface water into the soil, the maintenance repair and construction of drainage system(road gutter, culverts, transverse drainage, etc.), sealing of cracks in the pavement and connection joints were recommended. For collapsed embankment slopes and portion with severe slope erosion, installation of gabion and inverted T-type retaining were recommend to stabilize the embankment.

5. Conclusions

Field investigation of disaster prone embankment slopes was performed to determine the causes of embankment slope failure. The results obtained are as follows:

- 1) Most of the embankment slopes in the mountainous region are classified as soil embankment slopes which are mainly composed of soil, rocks and boulders. This type of embankment is susceptible to erosion due to its material composition.
- 2) The main types of slope failure were pavement cracks, pavement settlement, slope erosion and slope collapse which were mainly caused by the infiltration of rain water into the soil matrix combined with other external factors such as topography, road formation, steep slope, and lack of proper drainage system.
- 3) Most of the road embankment slopes and existing facilities were not properly maintained. Most of the collapsed occurred on locations wherein the drainage system were clogged, damage or is not installed. The lack of sufficient drainage facility allows the surface water to drain down the embankment slope which initial causes erosion and scouring which later causes large scale embankment collapse.
- 4) The maintenance repair and construction of drainage system(road gutter, culverts, transverse drainage, etc.), sealing of cracks in the pavement and connection joints were recommended to prevent the infiltration of surface water into the embankment soil while installation of retaining wall(gabion and inverted T-type retaining was recommended to stabilize the collapse portion of the embankment slope.
- 5) It was also determined from the investigation that most of the road embankment slopes investigated were not in accordance with the existing standard for embankment slope in terms of embankment height and gradient. Therefore additional researches must be performed to establish a standard for existing embankment slopes.

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