Rapid Recovery of Demolished Young-Dong Highway 205.4km Due to Heavy Rain

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ABSTRACT

Yong-dong highway that has an important role to connect between the west end and the east resort areas of South Korea was demolished at 205.4km from the west end due to an unexpected heavy rain whose intensity is 62.4mm/h on July 15th, 2006. Foundations of concrete retaining walls contact on Walljeong stream that has a steep bed slope and small water volume except a rainy season were scoured, and the concrete retaining walls were overturned. The water came into the embankment, and the westbound lanes of the highway were destroyed. The highway was blocked to traffic just before a big holiday season, and Korea Expressway Corporation (KEC), an agency of South Korea government, changed the flow line away from the embankment to protect it from scour, and dropped a lot of huge rocks whose diameters are over 1m to recover the demolished embankment. KEC finished the recovery works only for two days and reopen the highway. To prevent the highway from the pavement deformation and the future scour, grouting under pavement and rock-socketed concrete retaining wall with earth anchors without a foot were made for four months after the rapid recovery.

INTRODUCTION

Heavy rainfalls whose intensities are over 30mm/h or 100mm/d frequently come in Korean Peninsula in which mountains are 70% because of global warming and give severe damages to highway structures, which are designed by a highway design specification and have been stable. Nowadays many engineers agree to upgrade design specification to prevent damages of highways from a heavy rain. Fig. 1 shows a tendency that rainfall has been increasing since 1960s. The east areas of South Korea have a heavy rain whose intensity is 62.4mm/h and 244mm/d on July 15th, 2006, and Young-dong highway that has an important role to connect between the west end and the east resort areas of South Korea experienced debris flow at 12 locations and was demolished at 205.4km from the west end. Walljeong stream is contact on retaining walls of Young-dong highway at that location. The bed slope of the stream is steep, and the flow amount is a little except a rainy season, which is in July and August. Rapidly increased water scoured foundations of concrete retaining walls, and retaining walls were overturned. The water came into the embankment, and the westbound lanes of the highway were destroyed over 114m long. During a vacation season, July and August, Young-dong highway has a lot of traffic volume, about 55,000 vehicles/day/lane, because the east resort area of South Korea is the most attractive place in summer. Korea Expressway Corporation (KEC), an agency of South Korea government, that has an obligation to maintain the highway had to recover rapidly the destroyed location for travelers to go to the resort area. KEC recovered the highway only for two days with unbelievable efforts and reopened the eastbound lanes. However rapid recovery with rocks made many voids in the embankment, and these voids became a cause of pavement deformation and cracks. This accident gave us good instructions in designing, recovering and maintaining highways to cope with an unexpected heavy rainfall.

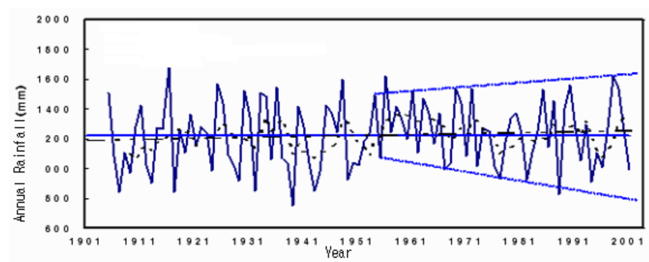


Fig. 1. Annual Rainfall trends in South Korea (TTA 2003)

GEOMETRY OF YONG-DONG HIGHWAY AT 205.4KM

The destroyed location of Yong-dong highway that goes through many mountains is the westbound two lanes near 205.4km from the west end. Fig. 2 shows the westbound lane is contact on Walljeong stream, whose bed slope is 4.26% and drainage area is 130.75km^2. The steep bed slope of the stream makes a rapid flow in a heavy rainfall in spite of S-shape stream channel, and it makes S-shape's head sharpened. Fig. 3 shows a horizontal and vertical geometry. If the highway moved toward the mountain to escape a contact of the stream, excavation of the mountain would be higher and it would have more possibilities for rocks to fall. High mountains and deep valleys gave us a difficulty to choose highway geometry. Fig. 4 shows cross section drawings at 205.4k before the accident. The westbound lane of the highway has concrete retaining walls and the eastbound lane is contact on mountains without excavating mountains, which have a steep slope and are very high. Most of this area is consist of granite, and lots of small rocks that are made from small wedge and toppling failure fall frequently.

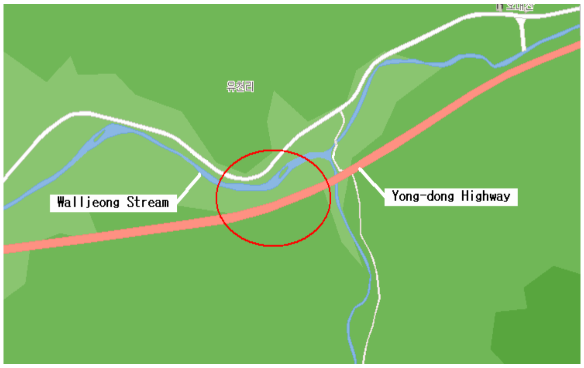


Fig.2 Geometry at 205.4k of Yong-dong highway

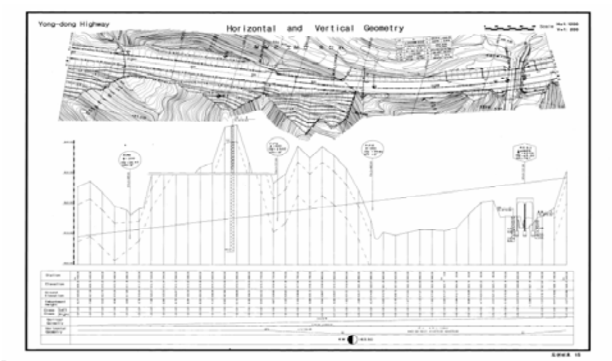


Fig.3 horizontal and vertical geometry at 205.4k of Yong-dong highway

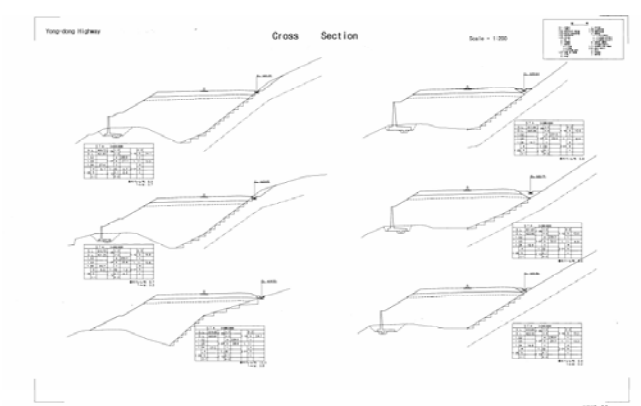


Fig.4 Cross section at 205.4km of Yong-dong highway

CAUSE AND DAMAGED AMOUNT

Walljeong stream has a small water volume except the rainy season, but heavy rainfall in the rainy season scoured the ground below concrete retaining walls, and retaining walls were overturned. A lot of water smeared into the embankment, and the two westbound lanes at 205.4km from west end of Yong-Dong highway contact on the stream were demolished. A sharpened S-shape flow line was detrimental to stability of the embankment. Length and maximum height of overturned concrete retaining walls were 114m long and 8m high, respectively. The lost soil amount of the embankment was about 19,000m^3, and length of broken asphalt concrete pavement was 72m. Pic.1 shows the overturned concrete retaining walls, the broken asphalt concrete pavement, and guardrails. Pic.2 shows S-shape line of water, which flows turbulently and some equipment try to recover the destroyed highway just after the accident.

Pic.1 Destroyed embankment

Pic.2 S-shape flow line

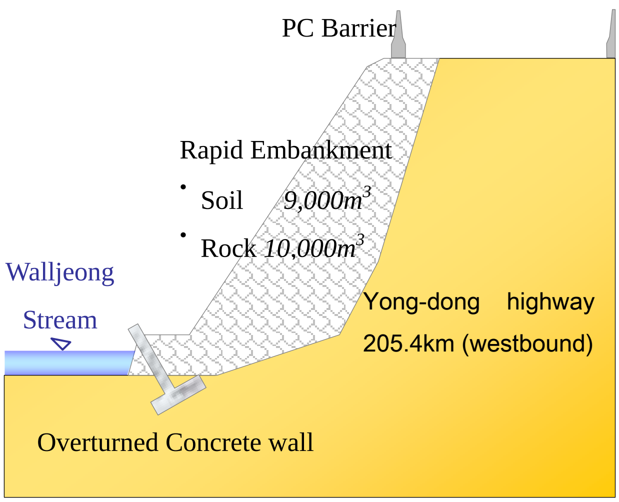
RAPID RECOVERY

In Korea about a half of rainfall a year comes for the rainy season. KEC has an obligation to recover the highway rapidly to provide a convenient travel to South Korean people. To get rid of possibility for fast flowing water to scour the embankment, we changed the flow line by removing the deposit area of the other side, and dropped big rocks whose diameters are over 1m to compensate the lost embankment without compaction. Pic.3 shows the scene dropping rock.

Pic.3. Dropping rocks

To prevent the further overturning of the concrete retaining walls a lot of rocks were deposited in front of them. Fig.5 shows a schematic drawing of the rapid recovery. Some soil was put below a subbase of an asphalt concrete pavement.

Fig.5 Schematic drawing of rapidly constructed embankment



We checked stability of the rapidly constructed embankment with Modified Bishop Method by SLOP/W 3.0. Table 1 shows values of unit weight, friction angle and cohesion to check stability of the embankment. A minimum safety factor was 1.4, and it satisfies a minimum value, 1.3, of South Korea slope design specification (KISTEC, 2006)

Table 1. Properties of soil and rock to check stability of the embankment. (Jeon, 2006)

	Unit Weight (t/m^3)	Friction angle (degree)	Cohesion (t/m^2)
Soil	1.8	30	1.5
Rock	2.3	41	0

We also could check the stability of the rapidly constructed embankment by driving heavy vehicles on it. After making the embankment, a big vinyl mat was covered on it to prevent the embankment from washing out as Pic.4. Asphalt concrete pavement was made on the recovered area just after rain stopped. It took only two days to recover the demolished embankment and additional two days to pave the damaged highway with asphalt concrete.

Pic.4 Vinyl mat was covered on the embankment

PERMANENT REMEDY

The rapidly constructed embankment that was consisted of big rocks had a lot of voids, and it could make upper soil fall down through them. The subbase below asphalt concrete pavement had resistance because of arching effects in a short period, but in the long run it could not resist the pavement and traffic load. To prevent pavement from losing subbase material through a lot of voids, we decided to make a wall with compaction grouting system (CGS), which has a role to prevent cement grout milk from leaking out though the voids and is grouting method with cement paste, and then grout the whole area recovered by rocks. The grouting was done at many points with low pressure to escape the disturbance from the high pressure. The foundation of the concrete wall was installed from 1m below sound rock to get rid of any possibility to be scoured considering 100-year flood. In South Korea L-type concrete retaining wall is common, but concrete wall and earth anchor were chosen in this case. The reason is that if the base of L-type retaining wall is constructed, a large excavation will be made and it will hurt the embankment. To escape the disturbance of the highway and deformation of the pavement, temporary retaining wall and earth anchors were installed before constructing the concrete retaining wall. A size of H-pile for the temporary wall is 250x250x9x14 mm, and it was driven at every two meters. Every earth anchor is installed at 20 degrees from horizontal line in one to six layers and length of anchors is from 12m to 24m including 6m bonded length. Design tensile forces of anchors are 5.1 ~ 24.0 ton. They are calculated in every cross section by EXCAV/W, which is for a temporary retaining wall design and back analysis program. During constructing the temporary wall some tilting gages were installed on H-piles, and the deformation of H-piles was monitored. We could check stability of the temporary retaining wall during construction through reviewing the measured data from them. Pic.5 shows the temporary retaining wall under construction. Pic.6 shows the concrete wall whose thickness is 1m was made in the front of the temporary wall and the anchor was extended. Fig.6 shows a schematic drawing of permanent recovery works. It took about four months, from August 14th, 2006 through December 16th, 2006, to complete permanent recovery works. Several cracks were found in the pavement of westbound and eastbound lanes due to deformation of the rapidly repaired embankment before grouting it with cement milk. Cracks of the eastbound lanes mean that deformation of rapidly recovered embankment was transmitted. The depths of cracks were very deep, and it indicated the cause of cracks was deformation of the embankment. Pic.7 shows cracks in the westbound pavement, and Pic.8 Shows cracks in the eastbound pavement. Table 2 shows the recovery work schedule.

Pic.5 Temporary retaining wall

Pic.6 Concrete retaining wall and earth anchor

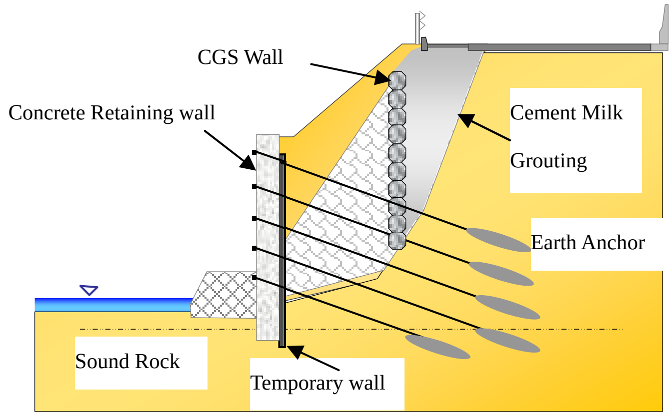


Fig.6 Schematic drawing of permanent recovery works

Pic.7 Cracks of the westbound lane pavement

Pic.8 Cracks of the eastbound lane pavement

Table2. Recovery work schedule in 2006

Date and time	Description
July15th, PM 1:00	Highway was destroyed and traffic was blocked in both directions.

July16th, AM 9:00	Equipment came to the damaged site.
July17th, PM 1:30	Two eastbound lanes were open.
July17th, PM 7:00	Destroyed embankment was recovered by a lot of big rock.
July20th, AM 7:00	Two westbound lanes were open.
Aug.14th	Beginning permanent recovery works.
Aug.22nd ~ Oct.31st	Temporary retaining wall was constructed.
Oct.24th	Cracks in the pavement were found.
Oct.27th	Grouting the cracks
Oct.28th ~ Dec.17th	Concrete retaining wall was constructed.
Nov.11th ~ Dec.9th	Grouting the embankment to prevent deformation due to big voids.
Dec.9th ~ 16th	Repaved the deformed area and installed guardrails.

CONCLUSION

Nowadays, unexpected heavy rainfall comes frequently, and excavated slopes and embankments that have been stable for a long time collapse due to the force of flowing water. Overturned retaining wall foundations of Young-Dong highway were designed in the consideration of under 100-year flood. The collapse of Young-Dong highway means that the conventional design concept needs to be revised to cope with heavy rain. According to South Korea specification revised in 2005, retaining wall foundations should be designed to withstand scour during floods between 50 and 200-year flood. Concrete retaining wall foundations at 205.4km were designed to withstand scour during floods equal to 100-year flood. A maximum diameter of a highway construction specification is 30cm, but dropping huge rock whose diameter is over 1m to repair the damaged embankment rapidly, was a very good method if we resolve the problem that the subbase materials fall down though voids. When a wall was made to prevent losing the cement milk and the embankment at many points with low pressure is grouted, losing bearing resistance of the subbase because of big voids could be prevented. The pavement condition had to be monitored because rapidly constructed embankment is easy to deform, and if some cracks were discovered but slopes of the embankment and retaining walls had no deformation, only pavement might be repaired without any reinforcement of the embankment. Asphalt concrete pavement is more suitable than cement concrete pavement in the rapid recovery because the curing period is short.

High excavations, retaining walls contact on streams, and high embankment are essential in mountainous area to construct highways satisfying geometry regulations. In the case that a highway is contact on streams and rivers, designers have to consider an unexpected heavy rainfall and the rainfall intensity graph has to be updated based on nowadays rainfall intensity.

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