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Analysis of Alternative Forest Road Retaining Technologies on Difficult Slopes in Japan*

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Abstract

In Japan, soft and sandy soils and steep slopes were native problems and usually caused difficulties in forest road construction. In addition, there were many crushing zones in mountainous forested area, and underground water often sprung out from stones and rocks in these crushing zones. This underground water often caused road degradation and should be drained. Some forest road retaining technologies had been introduced recently for stabling spur roads. One is L-shaped steel retaining wall technology called L-shaped mesh wall. It is easy to construct and underground water can be drained easily. The other is reinforced soil wall using thinned logs and geotextile called TK wall. In this study, the bearing capacity and usage of these technologies were analyzed based on the points of terrain, bearing capacity, and future possibility. L-shaped mesh wall was effective when applied to cross the short section of crushing zone. TK wall was easy to construct on steep slopes with narrow clearing width for roadway by its perpendicular filling slope, and provided environmental friendly landscape with recovered vegetation from the seed contained at surface as well as using thinned woods. Both technologies made easier to construct spur roads on slopes with soft soils but it was clarified that they needed appropriate drainage systems and their regular maintenance for economical use.

Keywords: Forest road retaining, L-shaped steel retaining wall, Reinforced soil wall, Steep slope

1. Introduction

Forest road construction has been a big issue for Japanese forestry. The soft and sandy soils which covers Japanese land dominantly is troublesome especially on steep slopes. In the rocky area, underground water comes out through crushing zones which has been made by the ground plate movements and often be the causes of road degradation.

Apart from main forest road which has the function as a public road in a region, spur roads constructed mainly for the purpose of forestry use are required to be cheaper and stout. Such spur roads in Japan must be constructed with low cost by harmonizing terrain, and also be endurable for the repetition of traffics (Japanese Forestry Agency, 2010). Therefore, road structures are fundamentally made by only earthworks, and retaining structures can be used only for unavoidable reasons such as terrain, geology, and soil.

Some forest road retaining technologies has been introduced recently. Two retaining technologies are commonly available in actual forestry field. One was L-shaped steel retaining wall technology, whose product name is L-shaped mesh wall. It is easy to construct and underground water can be drained easily (Nippon Steel and Sumikin Metal Products Co., Ltd., 2011). The other was reinforced soil wall using thinned logs and geotextile, whose product name is TK wall. This study aims to discuss these technologies from the points of terrain, bearing capacity, future possibility, and the way of effective introducing to low volume road.

Reinforced soil wall by laying structural reinforcement in the filling can compensate tension resistance force and shearing resistance force which lacks when constructing only by earthwork. It realizes the force balance like retaining wall against soil pressure which works on the wall standing nearly vertical (Osaka National Government Building, 2005). In the conventional forest road construction, volume of earth work increases as steepening slopes. Reinforced soil wall can save the volume of earth work on steep slopes because it enables narrow clearing width for

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roadway (Tatsuoka, 2005), which will reduce land collapse caused by road construction. As slope gradient of reinforced soil is nearly perpendicular, the height of filling and cutting slopes can be lower by adjusting formation of the road. Reinforced soil wall also will reduce the construction cost by utilizing soil and rocks obtained at sites.

Retaining wall is also constructed nearly vertical, and can reduce earthwork by overhanging on valley side and by lowering the height of cutting, which enables to construct narrow clearing width for road making. When crossing the crushing zone by simple structures, quilt basket or retaining wall is effective because the weight of stones and rocks in the structure presses down the road foundation with high water permeability. These advantages can realize stable forest road construction (Figure 1).

Especially in Japan, trees in planted forest are getting matured and it is predicted that forestry vehicles will become larger and larger. Therefore, it is necessary to utilize road width efficiently especially at the outside of curves in front of valley by strengthening filled bank (Figure 2). These technologies are effective and furthermore provide environmental friendly landscape with recovered vegetation from the seed contained at surface.

Figure 1. Retaining wall (L-shaped steel retaining wall) crossing crushing zone

Figure 2. Retaining wall (L-shaped steel retaining wall) utilizing road width efficiently

2. Material and Methods

2.1. L-shaped steel retaining wall

A L-shaped steel retaining wall technology, whose product name is L-shaped mesh wall was developed by Nippon Steel and Sumikin Metal Products Co., Ltd. in 2010 (Figure 1) (Takahashi et al., 2015b). It is easy to construct and underground water can be drained easily (Nippon Steel and Sumikin Metal Products Co., Ltd., 2011). The structure is composed of L-shaped stiffening steel mesh and horizontal steel mesh which reinforced tensile strength and to prevent deformation of wall (Figure 3). It was not designed as reinforced soil wall, but it realized the effect of reinforced soil wall by increasing bearing capacity of filling.

The weight of filled soil secures its stability as the cage filled with stone. The difference between the L-shaped mesh wall and the cage is, however, the latter deforms easily when using soil on site whereas the former can be pressed rolling without deformation. The former one is also easy to recover the vegetation on the surface by greening sheets which contained seeds. The permeability of the L-shaped mesh wall was investigated, and confirmed the high permeability. When the height of wall was high, it could save cutting volume by combining with cart frame (Nippon Steel and Sumikin Metal Products Co., Ltd., 2011).

The weight of 2 m2 elements of the L-shaped mesh wall is 21.9 kg, and the 5.1 kg of horizontal mesh, so that it is easily constructed by only manual power using soil on site (Nippon Steel and Sumikin Metal Products Co., Ltd., 2011). Labor productivity per 10 m construction was said to be 0.05 men as a manager, 0.7 men for assembling, and 0.4 men for back-filling. The productivity of machines was 1.1 hours for backhoe operation with bucket volume 0.28 m^3, and 0.09 days for ramming (Nippon Steel and Sumikin Metal Products Co., Ltd., 2011). The L-shaped mesh wall had been introduced in 36 forest roads at all over Japan till June 2012 from hearing investigation.

Figure 3. Structure of L-shaped mesh wall

2.2. Reinforced soil wall

A reinforced soil wall using thinned logs and geotextile (Figure 4) was also investigated (Takahashi et al., 2015a). Its product name is TK wall which developed by KIC Co., Ltd, Maedakosen Co., Ltd., and Ishikawaken-mokusakupaneru-kyogikai in 2003 (Ishikawa Prefecture Federation of Forest Owners' Associations, 2011). The structure of TK wall is the combination of L-shaped outer frame and the wall by diagonal brace frame which utilizes thinned logs. Polyethylene geotextiles winded them as shown in Figure 4. The geotextile in the filling makes the resist force of shearing strong, and will be integrated into the soil resulting in stabilization of road bed. The thinned logs in the soil will be rotten soon, but the durability of structure will be maintained by its self-strength and a few tensile elongation of geotextile. The first merit of this system is to lead the increase of effective utilization of thinned logs.

Figure 4. TK wall before use

2.3. Bearing capacity measurement and analysis

The bearing capacity of the road surface was investigated to confirm the strength of these new technologies using simple measuring instrument, CASPOL made by Marui Co. Ltd. (Osaka National Government Building, 2005). It has the specific cone with the weight of 4.5 kgf and measures the shock acceleration when releasing the cone from the height of 45 cm. The measured value is the CBR (California Bearing Ratio) value. Measured points were mountain side ruts, valley side ruts, center of both ruts, and shoulders on the cross section (Takahashi et al., 2014). Since measured roads included brand-new sections which had not been in service previously, the position of both ruts was set at 100 cm from the road center assuming the medium class logging trucks with the distance between tires in 200 cm.

In the experimental road, the number of samples was designed to be nearly same among straight sections, and beginning, center, and end of curves. At each point, CBR values were measured at three to five times by CASPOL, and the average value of them was used to analyze. According to the result of analysis of variance (ANOVA) in Takahashi et al. (2014), totally more than 80 sample points were collected at both of the investigation sites and to secure the power of ANOVA.

The relationships of CBR with each point on the cross section (mountain side ruts, valley side ruts, the center of both ruts, and shoulders), the presence of retaining technologies (L-shaped mesh wall and TK wall) were analyzed by Tukey-Kramer test and Student's t-test or Welch's test, respectively. In the analysis of L-shaped mesh wall, the effect of different contractors to the CBR was also analyzed by Student's t-test or Welch's test according to the presence of the wall.

2.4. Investigated sites

2.4.1. L-shaped mesh wall

The L-shaped mesh wall was investigated in a section of 1,853 m of the forest road constructed in 2012 at Seki city, Gifu Prefecture. The road was used for thinning extraction and patrols after thinning. Road width was 4.4 m unpaved, and soil type was sandy gravel. There were existed welling of water at 11 points and some of them were applied with culverts. The L-shaped mesh walls were prescribed at 6 points which were considered crossing crushing zone (Figure 5). The crushing zones had both usual and temporal water flows. Total prescribed length was 83.0 m. The purpose of introducing L-shaped mesh wall was to secure stability of road bed by the weight of structure and to drain water by the high permeability (Figure 1). The contractor X constructed the beginning part of 1,040 m including four L-shaped mesh walls, and the contractor Y did the next 800 m including two L-shaped mesh walls.

Figure 5. An example of crushing zone and welling water where L-shaped mesh wall was prescribe

2.4.2. TK wall

The TK wall was investigated at a forest road located at Kaga city, Ishikawa Prefecture (Figure 6). It was constructed from 2010 to 2012 and the length was 557.4 m including the section of TK wall in 192.2 m. Pavement was gravel mingled with soil. The section constructed in 2010 was already in service but the sections constructed in 2011 and 2012 were not used previously. The road width was 5.3 m and surface soil type was gravelly soil. The TK wall was applied where the height of filling exceeded 2 m.

Figure 6. Investigated section where TK wall with vegetation on the surface was prescribed

3. Results and Discussion

3.1. L-shaped mesh wall (L-shaped steel retaining wall)

Between two contractors X and Y, the average mountain slope was 38.3 and 39.4 degrees where the L-shaped mesh walls prescribed, and 30.4 and 34.4 degrees where L-shaped mesh walls not prescribed, respectively. The sections of the L-shaped mesh wall were steeper. Although they were applied when crossing crushing zones, they were also introduced at the steep sections to keep filling minimum effectively.

In the sections of L-shaped mesh wall, the CBR values of the contractor X on mountain side ruts and valley side ruts were about 15 to 25 %, and those of the contractor Y were 15 to 20 %. The CBR values of both mountain side and valley side ruts were the highest, and those of center of both ruts followed, and the median of those of shoulders was lower at 15 % and 8 % for the contractors X and Y, respectively.

In the sections of non L-shaped mesh wall, the CBR values for contractor X were 25 - 35 % at mountain side and valley side ruts, and those of contractor Y were 15 to 25 %. Contractor X usually realized higher values because they were beginners of road construction and seemed to intend to pay attention. Those of shoulders were 13 to 14 %, which were lower than those of road inside. As the compaction was emphasized on the carriage way, the CBR values of shoulders were lower.

The CBR values except shoulders which showed lower values were shown in Figure 7. In the section of contractor X, the CBR values without L-shaped mesh were significantly higher than those with L-shaped mesh. On the other hand, there were no significant differences in the section of contractor Y, and the CBR values without L-shaped mesh were similar as those with L-shaped mesh in the section of contractor X. The depth of L-shaped mesh was 1 m and the height was 1 m, so that the area directly affected on the bearing ratio was 1 m from the filling surface (Figure 3). Thus, the CBR values with L-shaped mesh were not necessarily to be high, because filling slope and road bed were stable by the L-shaped mesh wall and the minimum bearing force was secured.

Contractor X took the charge of the steep section located on a concave slope at the valley head where land slide would occur. Indeed, the L-shaped mesh walls were prescribed at the both ends of this section, but it was not prescribed at the middle of the section, where two cracks were found at the shoulder of filling. As soil was mainly poor cohesive sandy gravel, it seemed difficult to achieve sufficient compaction. It was pointed out that the concave slope at the valley head was dangerous area to construct roads (Oohashi, 2011; 2012). The crack might be partly caused by rain water flow, and the maintenance was difficult and the road would collapse in the future in the worst case.

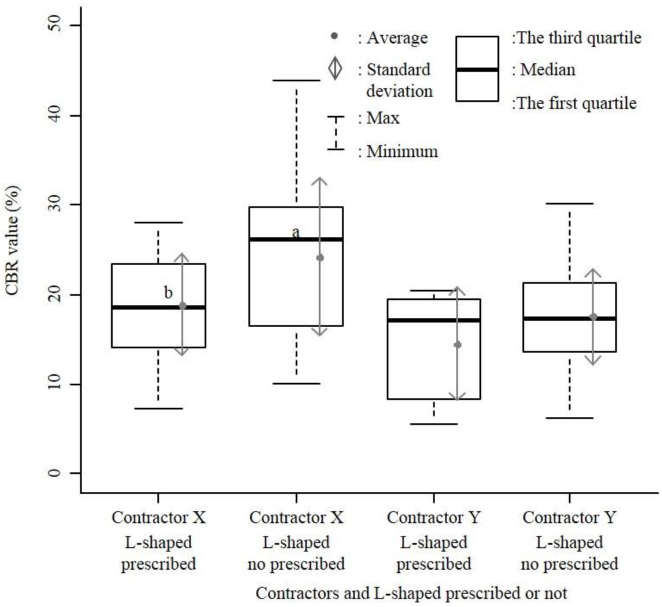

Figure 7. Relationships of CBR values between contractors where prescribed L-shaped mesh wall and not prescribed (Takahashi *et al*., 2015b) (Note: There is 5 % significant difference between "a" and "b")

It is difficult to construct L-shaped steel retaining wall, reinforced soil wall, and even concrete retaining wall if the base is thus unstable. Therefore, soil, geology, and terrain should be noted carefully prior to route location, and furthermore drainage is also the most important.

3.2. TK wall (Reinforced soil wall)

The average slope of the TK wall was 38.2 and 35.0 degrees prescribed or not, respectively, and differed significantly. Thus, the TK wall was applied to the steeper slopes which would bring much volume of filling.

In case of both TK wall prescribed and not, there existed significantly different CBR values between the group of mountain side and valley side ruts and center of both ruts, and shoulders (Figures 8 and 9). The CBR values of carriage way surface were even and higher than those of shoulders. The relationships between TK wall prescribed or not and the CBR values except shoulders were shown in Figure 10, and there was no significant difference. This meant that roads were constructed to realize enough bearing capacity in all sections.

Road surface erosion occurred at the investigated site regardless of the TK wall existed or not. The CBR values tended to be smaller by the road surface erosion at mountain and valley sides ruts (Figure 11), and there was a significant difference between with and without erosion. This reason was considered that the compacted surface was run off by the erosion and that water penetrated into road bed and weakened the bondage force among soils. Once a rut formed, water was concentrated, and the eroded weak part was easily damaged by erosion force.

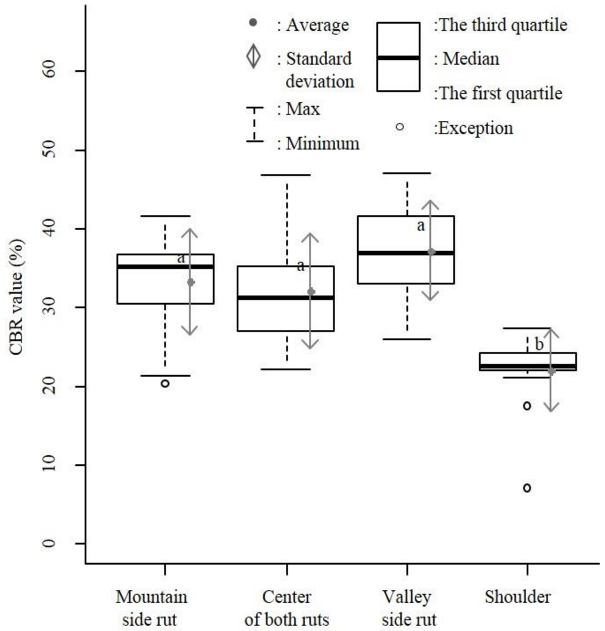

Figure 8. Relationships between positions on the road and CBR values where prescribed TK wall (Takahashi et al., 2015a) (Note: There is 5 % significant difference between "a" and "b")

Even in the section with TK wall, it was recognized that the drainage facilities to prevent surface erosion and early restore were fundamentally important.

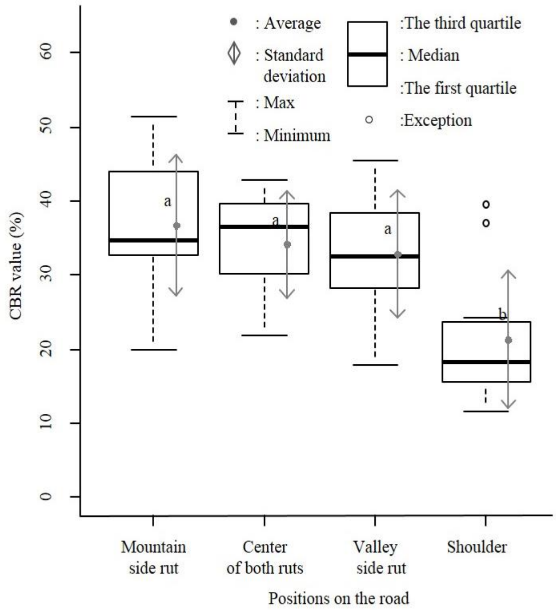

Figure 9. Relationships between positions on the road and CBR values where did not prescribed TK wall (Takahashi *et al*., 2015a) (Note: There is 5 % significant difference between "a" and "b")

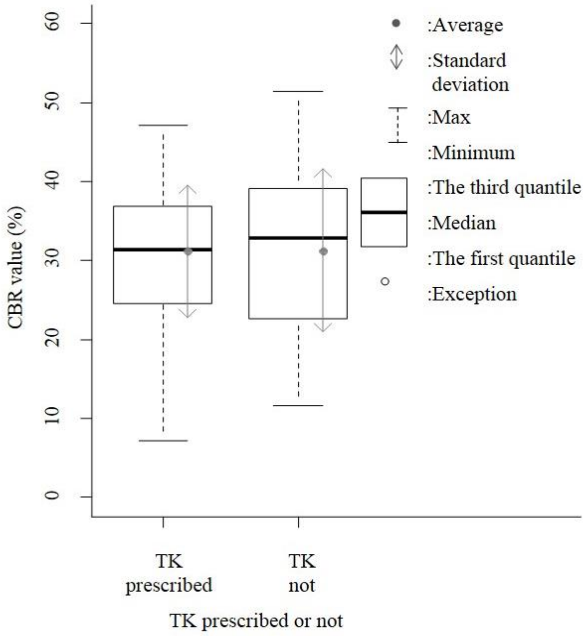

Figure 10. Relationships of CBR values between TK wall prescribed and not (Takahashi *et al*., 2015a).

4. Conclusions

From the results, the L-shaped mesh wall had stable bearing capacity and permeability, and it was effective with its weight to cross small sized crushing zone which sometimes caused land slide. Reinforced soil wall could also save earth work on steep slopes and increase flexibility of route location. It is, however, necessary for securing sustainable bearing capacity to locate enough drainage facilities.

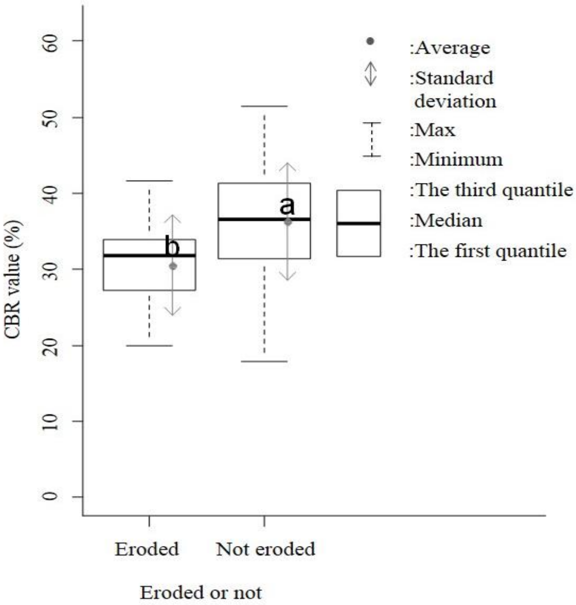

Figure 11. Relationships of CBR values between eroded and not eroded (Takahashi *et al*., 2015a) (Note: There is 5 % significant difference between “a” and “b”)

Actual forest roads tended to suffer unexpected situations such as heavy rain and spring water, and sometimes erosion after finalized. Therefore, road maintenance especially on drainage systems was important to keep these structures effective. By using forest road repeatedly for long time, the construction cost will be negligible as well as by adopting the most appropriate roading method according to soil, geology and terrain conditions.

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** In Japanese and titles were tentative translation by the authors.*
*** In Japanese with English summary.*