Challenges in Road Construction and Timber Harvesting in Japan

Hideo Sakai

Abstract

Japan Islands fundamentally consisted of the accretionary wedges. The stratum of accretionary wedges inclined, and it made dip slope and opposite slope. Granite magma intruded among accretionary wedges, and later granite itself became decomposed soil. Much annual precipitation of nearly 2000 mm, caused by monsoons, attacks forest roads, so innovative technologies for road construction are required. From ancient days, numerous circular slips and deep-seated landslides occurred. For the inclined stratum at Shimanto belt composed of sedimentary rocks, deep excavation for preparing structural road foundation was invented. After deep excavation until the depth that ensured the road width, about 30 cm thick blocks of compacted subsoil were piled up. It is difficult to make high cutting slope on smooth soil area, and the retaining wall with log structure is effective both for cutting and fill slopes at spur roads. Underground water that comes out through crushing zones is often troublesome. When crashing zone and dip slope overlap, the valley head is unstable causing landslide. This makes this area inadequate for road construction. Some forest road retaining technologies have been introduced recently in Japan. When crossing the crushing zone by simple structures, cage or L-shaped steel retaining wall is effective because the weight of stones and rocks in the structure presses down the road foundation with high water permeability. It is important to adopt the most appropriate road construction method in accordance with the soil, geology and terrain conditions to provide sustainable forestry.

Keywords: accretionary wedge, crashing zone, dip slope, reinforced soil wall, rolled grade drainage

1. Introduction

Planted forests have been increased since 1950s in Japan, and they have reached 10 million ha, which is equivalent to a quarter of the land area. About half of these forests are more than fifty years old, and they can be harvested any time by final cutting. However, timber demand in Japan is decreasing year by year to 70 million cubic meters, while domestic timber supply is only 30% in spite of the potential of 100% based on the statistics of the annual growth increment (Japanese Forestry Agency 2015). There are so many reasons for this unbalance of supply and demand, and these are primarily the low market price of timber and difficult terrain. From the view point of forest engineering, enhancement and upgrading of road network are still necessary for solving the problem. Simultaneously, new forestry mechanization must be established both for timber and fuel biomass production. These infrastructure developments can strengthen the management of logging contractors and create employment of forestry workers in mountainous areas.

In this review article, challenges in road construction related to timber harvesting are introduced and discussed from technological and economic point of view for future applications.

2. Geological background of road construction in Japan

Originally, Japan Islands were formed by accretionary wedges from ocean plate at the east end of the Asian continent until 65 million years ago (Taira 1990). At that time, Japan belonged to the Asian continent. Accretionary wedges were named after the stratum attached to the continent when the ocean plate sank under the continent plate. Japan Islands fundamentally consisted of the accretionary wedges. The stratum of accretionary wedges inclined, therefore, terrains were classified into either dip or opposite slope. A dip slope is a slope in the same direction of the inclined stratum, which generally makes filling difficult. The dip slope on a mountain side is generally gentle having long and smooth river systems (Suzuki 2000), but landslides and collapse of the cutting slope frequently occur, so that roads on a dip slope require higher maintenance costs. A dip slope is often covered with thick colluvial soil, and such accumulated soil is prone to slide after a heavy rain. On the contrary, a road planned on the opposite slope, with short and parallel waterfalls (Suzuki 2000), is winding in short sections and may take much time to construct, but is stable once constructed.

Then, the western part of Japan, the eastern part except Hokkaido Island, and the western and eastern parts of Hokkaido left the Asian continent until 65 million years ago, and combined and formed Japan Islands and Hokkaido Island as they are today.

In these processes of ancient times, debris flow of deposit under sea and on the ground shaved accretionary wedges, and granite magma intruded among accretionary wedges in the interior. It brought heat denaturation, and later granite itself became decomposed soil. Volcanic ash also covered thickly all over the Japan Islands.

In the western part from Kyushu Island to Kanto district, and in the southern seashore that is newer, there are geological belts named Shinmato belt, Chichibu belt, Sambagawa belt, Ryouke belt, which suffered heat denaturation by granite magma, granite mountains, Sangun belt, and Hida belt where heat denaturation still occurs (Saito 1992). Among Sambagawa and Ryouke belts, median tectonic line lies from Kyushu Island to Kanto district. Geology of the eastern part of Honshu Island is very complicated because it was under the sea for a long time and because there were a lot of volcanoes, which erupted a large quantity of volcanic ash.

In addition to the above complicated geological history, much annual precipitation of nearly 2000 mm, caused by monsoons, attacks forests and forest roads, so high and innovative technologies are required for road construction (Yuasa and Sakai 2012), while growing trees and providing rice cultivation with water from mountainous forest area.

3. Road construction in Shimanto belt

Shimanto belt is the latest belt and shows typical features of accretionary wedges. The slopes faced to north or Japan Sea are generally dip slope, and the ones faced to south or Pacific Ocean is opposite slope (Fig. 1). Numerous circular slips and deep-seated landslides occurred from ancient days especially on the slopes faced to north. It is still risky to construct roads on the dip slope. Therefore, downhill yarding by skyline system is indispensable. The possible skyline systems are conventional yarding systems, eg. Endless Tyler system (Samset 1985). Recently, a domestic interlocked three drums tower yarder, which could operate both downhill and uphill, was developed (Fig. 2).

For the inclined stratum in Shimanto belt, composed of sedimentary rocks, deep excavation for preparing structural foundation of the road was developed (Fig. 3). After deep excavation that ensured the depth required for the road width, about 30 cm thick blocks of compacted subsoil were piled up. This method is suitable for gravelly soil, which is the main soil

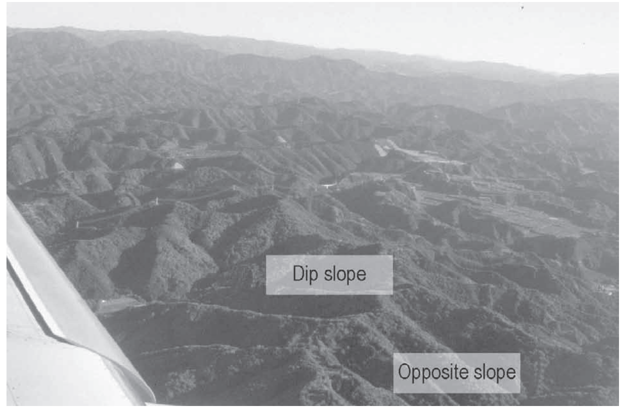

Fig. 1 Shimanto belt showing dip slope and opposite slope

Fig. 2 Interlocked three drums tower yarder which can operate both downhill and uphill

Fig. 3 Road construction method by deep excavation for preparing structural foundation

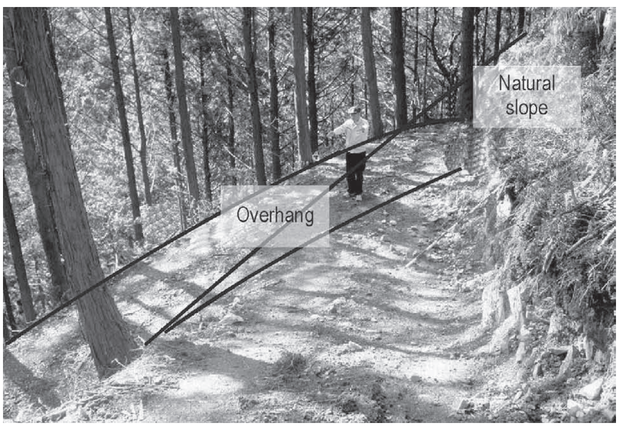

Fig. 4 Switch curve combining the function of both switch back and hair pin curve

type in Shimanto belt, while a small portion of clay serves as bondage. Surface soil of natural slope was kept during construction and used for the surface of the filling slope for providing early green surface because it contained buried seeds. Fig. 3 shows the section constructed eight years ago when the photo was taken. It is easy to understand why the boundary of the road surface and cutting slope was sharp. The surface of the filling slope was quickly green due to the surface soil.

New technology named switch curve was also developed combining the function of both switch back and hair pin curve at steep slopes (Fig. 4). Road bed was made overhang in front of the curve to secure the space of landing using the soil of cutting slope immediately after the curve turning. These innovative roads cannot be used for logging trucks, but are useful for small scale forestry with small forwarders (Fig. 5) and

Fig. 5 Small forwarder

light trucks, which are typical of the forestry and agriculture in Japan (see Fig. 8 below). They are called operation roads in Japan because of their function of forestry operation (Sakai 2004).

4. Retaining wall with log structure for Chichibu belt and decomposed granite area

Chichibu belt is the north neighbor of Shimanto belt. This belt collapsed from Sambagawa belt and deposited under the sea, so that the geologic stratum was not formed and the soil was smooth. Big land slide sometimes occurred by heavy precipitation, because smooth soil around rocks and stones fluidized by much rain, and once the collapse occurred, it continued from the bottom to the top of slopes like domino (Fig. 6).

Fig. 6 Large-scaled land slide like domino caused by heavy precipitation in Chichibu belt

Fig. 7 Retaining wall with log structure both at cutting and fill slopes in Chichibu belt

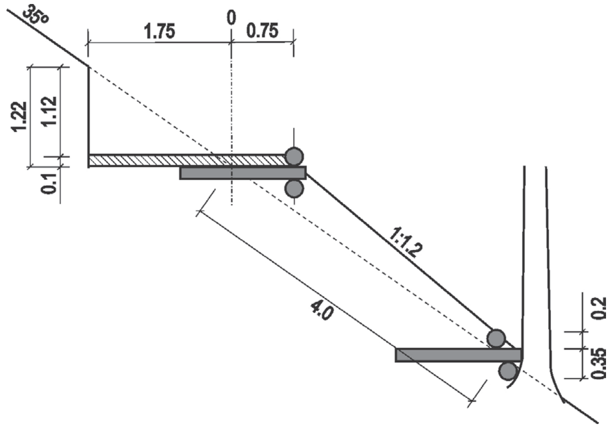

Fig. 9 Structure of retaining wall with log structure (Original: Oohashi 2001)

In such smooth soil area, it is difficult to make high cutting slope on steep slopes, and it is, therefore, necessary to make the retaining wall with log structure for providing operation roads (Figs. 7 and 8). It can be used for cutting slope and for stretching road width at filling by forming shoulder supported by the retaining wall of log structure at the bottom of fill slope (Fig. 9) (Oohashi 2001). This method was developed by Keizaburou Oohashi about sixty years ago in his forest located in decomposed granite area (Fig. 10). Fig. 10 shows the road section 50 years after the prescription of the retaining wall with log structure. Decomposed granite is sandy and it is difficult to make road bed only by earth work (Fig. 11).

Slope collapses of shallow depth have often occurred caused by recent torrential rain at decomposed granite area. Retaining wall with log structure is effective not only for decomposed granite but also for deposit of debris flow (Fig. 12), because its soil is mixed with soil and stones as is the case in Chichibu belt.

The logs used for making the retaining wall with log structure were first used for the frame with the aim of distributing the loads. However, these logs began to decay. It was reported that the Young's modulus of logs buried in the road would be zero within 30 years for sugi (*Cryptomeria japonica*) and 40 years for hinoki (*Chamaecyparis obtusa*) (Aizawa 2011). It is supposed that the internal and adhesive friction among logs and compacted soil makes the road bed stronger due to repeated traffic and soil and stones supplied during maintenance regardless of the decay of logs.

5. Black soil

A great deal of forest land in Japan is covered with volcanic ashes or black soil originating from volcanic

Fig. 8 Road constructed by retaining wall with log structure with narrow width of 2.5 m and a light truck

Fig. 10 Road by retaining wall with log structure at decomposed granite area

Fig. 11 Road construction with expanded mesh metal wall at decomposed granite area

Fig. 12 Retaining wall with log structure is effective for deposit of debris flow

soil. It is difficult to compact them, and they turn into mud after rain. The Shimonto method suitable for gravelly soil cannot be applied. Indeed, thick gravel is effective for volcanic black soil (Fig. 13) (Kishida and Abiko 1973), but it is not always easy to prepare the gravel.

Another method is to remove them, or to make reversal road from subsoil (Ryan et al. 2004) according to the thickness of the surface soil. However, the reversal road is not always strong enough for fully loaded trucks and crawler carriers. Logging companies sometimes cover the road with branches (Fig. 14).

On soft soils, it is recommended to separate the road bed and introduced gravel by geotextile (Keller and Sherar 2003). The use of an articulated forwarder with rubber crawler is also effective (Fig. 15), because it does not form ruts as there is no skid steering and due to large contact area and low ground pressure. It is also important for route location to find a stable natural bench on the slope in a volcanic area (Fig. 16).

Fig. 13 Good sample of thick gravel on volcanic black soil

6. Crashing zone

In addition to the soft soil and steep slopes, underground water that comes out through crushing zones is often troublesome. Crushing zones were made by frictions among bedrocks by frequent crustal movements and/or earthquakes since ancient days.

Fig. 14 A road covered with branches on volcanic black soil

Fig. 15 Articulated forwarder with rubber crawler

Fig. 16 Nick point, that is natural bench, is stable on the slope in a volcanic area

Crashing zones can often be found by irregular profile of the ridge line and an isolated high tree at the ridge (Fig. 17) (Oohashi 2012). Trees at the ridge are usually not tall, but trees at the ridge of the crushing zones are high because of sufficient water.

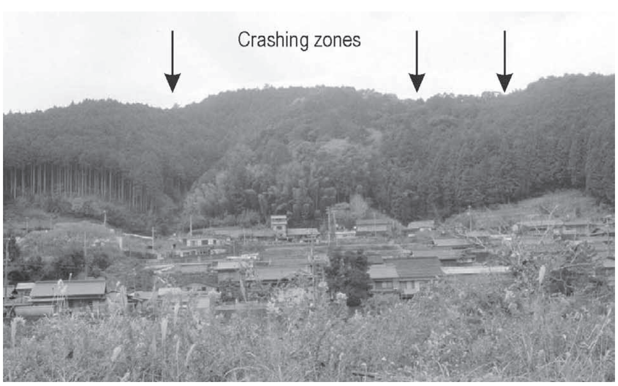

Fig. 17 Crashing zones can be found by irregular profile of the ridge line and a high tree at the ridge

Although crashing zones sometimes include water in the crashed rocks within the clay, which are also formed by numerous frictions, crashing zones are usually a way of water. Small-sized crushing zone is not so dangerous for road construction if the road crosses the zone at the right angle. However, it is costly to provide drainage using culverts or fords. If the route is parallel to a crashing zone, the road will be destroyed at many sections after heavy rain. Therefore, when crossing crushing zones with the planned route, it is important to take into consideration the drainage methods.

However, when the crashing zone and dip slope overlap, its valley head and the beginning of land slide are unstable, and it is not only impossible but also dangerous to construct roads on such terrain (Fig. 18). It was pointed out that the concave slope at the valley head was a dangerous area to construct roads (Oohashi, 2011; 2012). As shown in Fig. 18, the crack will

Fig. 18 Filling and constructing the retaining wall is impossible at the ridge when crashing zone and dip slope overlap

Fig. 19 Underwater is sometimes hidden under thick volcanic ash in such concaved slope and this can result in the collapse of the filling

Fig. 20 Old alluvial fan area where old rivers are covered by sediment and/or deposit of debris flow and drainage facilities are required

Fig. 21 A reinforced soil wall, TK wall, applied at the site where the height of the filling exceeded 2 m

be caused at the road side of the filling by intensive compaction because of unstable natural slope and its weathered gravel soil. The maintenance is difficult, and in the worst case, the road will collapse by penetrated rain water flow in the future. It is also difficult to construct the retaining wall or reinforced soil wall because the basement is unstable.

Another dangerous case is when the crashing zone is hidden under thick volcanic ash. The filling will collapse due to underwater (Fig. 19). This is also applied to old alluvial fan area, where the rivers are covered by sediment and/or deposit of debris flow. When constructing roads in such areas along a contour line, fords and drainage facilities are required (Fig. 20).

7. Road retaining technologies

In addition to the main forest road, which has the function similar to the public road in a region in Japan, spur roads, constructed mainly for the purpose of forestry use, are required to be strong and to incur low maintenance costs. Road structures are fundamentally made only by earthwork, where retaining structures can only be used for unavoidable reasons such as terrain, geology, and soil. Reinforced soil wall can save the volume of earthwork on steep slopes because of nearly perpendicular slope gradient of the wall and narrow clearing width of roadway (Tatsuoka 2005). The height of the filling and cutting slopes can be lower by adjusting formation of the road. Some forest road retaining technologies have been introduced recently in Japan (Yoshida et al. 2016).

A reinforced soil wall made by using thinned logs and geotextile, the so-called TK wall, was developed (Takahashi et al. 2015a) (Fig. 21). TK wall structure is the combination of L-shaped outer frame and the wall by diagonal brace frame, using thinned logs. They were wound by polyethylene geotextiles. The geotextile in the filling makes the resistance force of shearing strong, and can be integrated into the soil resulting in the stabilization of road bed. The thinned logs in the soil will decay soon, but the durability of the structure will be maintained by its self-strength and a few tensile elongations of geotextile.

L-shaped steel retaining wall technology, the so-called L-shaped mesh wall, is easy to construct, and it is efficiently used for underground water drainage (Nippon Steel & Sumikin Metal Products Co., Ltd., 2011). The structure is composed of L-shaped stiffening steel mesh and horizontal steel mesh, which reinforce the tensile strength and prevent the deformation of the wall. It was not designed as reinforced soil wall, but the effect of the reinforced soil wall in stabilizing the bearing capacity of the filling was soon recognized (Takahashi et al. 2015b). When crossing a crushing zone by simple structures, L-shaped mesh wall or cage filled with stones is effective because the weight of stones and rocks in the structure presses down the road foundation with high water permeability (Fig. 22). The difference between the L-shaped mesh wall and the cage is that the latter is easily deformed when using soil on site whereas the former can be pressed by rolling without deformation.

It is necessary to use road width efficiently especially at the outside of curves by strengthening the filling. These technologies are effective and provide environmentally friendly landscape with the vegetation grown from seeds contained in the surface.

Fig. 22 Retaining wall whose surface was covered by vegetation, L-shaped steel retaining wall, set on three cages stacked on top of each other when crossing a crushing zone

Fig. 24 Excavator with bucket, which can be rotated, and a felling knife

8. Rolled grade

Drainage of road surface is important and indispensable. Rubber belt diversion is used in Japan. The belt diversion is also used on low-volume roads to divert water off the road surface in United States (Bloser et. al 2012). It consists of a piece of used conveyor belt bolted to treated lumber and buried in the road.

Rolled grade without belt diversion is also attempted in Japan. It is effective along contour line (Fig. 23), but dangerous on sloping road when going down because of unexpected slip under wet condition. It is always necessary to provide distributed drainage. Oohashi emphasized that the level of the road should be raised when crossing valleys, except streams with stable water, because water from the upper slope could be induced and distributed not to the valley but to the ridge, where it is usually dry (Oohashi 2011). On the contrary, when crossing the ridge, the level of the road should be lowered because surface water could be drained to the dry ridge. When crossing the valley, the level of the road should be raised in accordance with the topography and require minimum earthwork (Keler and Sherar 2003).

Fig. 23 Rolled grade whose sloping at lower sections is used for drainage

9. Construction machinery

At the construction site, excavators with bucket, which can be rotated, are used for soft soil. Some of them are equipped with a felling and bucking knife, and the operator can continue both felling trees on the route and doing earthwork without getting out of the cabin (Fig. 24).

10. Conclusions

It is important to locate a stout and stable road network in advance to provide sustainable forestry. Forest road is constructed on slopes, so that the inclination of slopes directly affects the road width requiring minimum earthwork, which is related to the vehicle sizes and operation systems. High road density may be effective for harvesting operations, but will increase the cost of road construction and maintenance, on the other hand. Therefore, appropriate harvesting systems should be selected from the view point of forest civil engineering. For example, in case of slopes of more than 35 degrees, cable logging and low density of stout forest road for trucks are available. Especially in Japan, tower yarders, which can operate both uphill and downhill, are needed because of the existing dip slopes. In case of flat land of less than 15 degrees, a combination of the main road for trucks and skidding roads for CTL systems are available. In case of gentle and steep slopes ranging between 15 and 35 degrees, both vehicle systems and cable systems are available, and the choice depends on geology, terrain, soil, and forest management system. The existing forest roads tend to suffer unexpected situations such as heavy rain and spring water, and sometimes they are exposed to erosion after being finalized. Therefore, road maintenance, especially related to drainage system and its cost, is important to keep these structures effective. By adopting the most appropriate road maintenance method in terms of the soil, geology and terrain conditions and using the road repeatedly for a long time, the investment effect will be maximum and the construction cost will be negligible during long use. The early design and formation are important especially for controlling curves and longitudinal grade and for avoiding the overlap of the crashing zone and dip slope.

In the nearest future, new technology such as geotextile and reinforced soil wall should be developed and introduced. These challenges of road construction must take into account CO_2 reduction.

11. References

Aizawa, H., Sakai, H., Ando, N., Soma, T., Sakurai, R., 2011: Aging degradation of wood structure of operation road. J. Jpn. For. Eng. Soc. 26(4): 215–220.

Bloser, S.M., Creamer, D., Dimas, S., Scheetz B., Ziegler, T., 2012: Environmentally Sensitive Road Maintenance Practices for Dirt and Gravel Roads. USDA Forest Service. 126 p. http://www.fs.fed.us/t-d/pubs/pdf/11771802.pdf (Referred 25/11/2016)

Japanese Forestry Agency, 2015: Annual Report on Forest and Forestry in Japan, Fiscal Year 2014. Japanese Forestry Agency, Tokyo. 206 p. (In Japanese).

Keller, G., Sherar, J., 2003: Low-Volume Roads Engineering. US Agency for International Development, 158 p.

Kishida, S., Abiko, Y., 1973: Road Engineering. Coronasha, Tokyo, 389 p. (In Japanese).

Nippon Steel & Sumikin Metal Products Co., Ltd, 2011: L-shaped Mesh Wall. Catalog No. L532. 4 p. (In Japanese).

Oohashi, K., 2001: All of Road Construction. Zenkoku-Ringyou-Kairyou-Fukyu-Kyokai, Tokyo. 159 p. (In Japanese).

Oohashi, K., 2011: Forestry Operation Road – Road Network Planning and Route Location. Zenkoku-Ringyou-Kairyou-Fukyu-Kyokai, Tokyo, 121 p. (In Japanese).

Oohashi, K., 2012: How to Observe Mountain and Forest. Zenkoku-Ringyou-Kairyou-Fukyu-Kyokai. Tokyo, 136 p. (In Japanese).

Ryan, T., Phillips, H., Ramsay, J., Dempsey, J., 2004: Forest Road Manual – Guidelines for the Design, Construction and Management of Forest Roads. COFORD. Dublin, 156 p.

Saito, Y., 1992: Understanding Early Life of Japan Islands. Iwanami Shoten. Tokyo, 153 p. (In Japanese).

Sakai, H., 2004: History and importance of »operation roads« in Japan. Науковий Вісник: 354–360.

Samset, I., 1985: Winch and Cable Systems. Martinus Nijhoff/ Dr W. Junk Publishers. Dordrecht, 539 p.

Suzuki, R., 2000: Introduction to Map Reading for Civil Engineers. Terrace Hills and Mountainous. Kokonshoin. Tokyo, 942 p. (In Japanese).

Taira, A., 1990: Birth of Japan Islands. Iwanami Shoten. Tokyo, 226 p. (In Japanese).

Takahashi, H., Minami, Y., Yoshida, M., Sakai, H., 2015a: Relationships between reinforced soli wall and bearing capacity of forest road and management. Chubu Shinrin Kenkyu 63: 99–102. (In Japanese).

Takahashi, H., Sakai, H., Usuda, H., Watada, T., Furukawa, K., 2015b: Constructing L-shaped steel retaining wall and its bearing capacity. J. Jpn. For. Eng. Soc. 30(2): 79–84. (In Japanese with English Summary).

Tatsuoka, F., supervision. 2005: All of New Reinforced Soil Wall. Sougou Doboku Kenkyusho, 414 p. (In Japanese).

Yoshida, M., Takahashi, H., Sakai, H., 2016: Analysis of alternative forest road retaining technologies on difficult slopes in Japan. Eur. J. Forest Eng. 2(2): 61–66.

Yuasa, I., Sakai, H., 2012: Rule of Practice for Road Construction. Zenkoku-Ringyou-Kairyou-Fukyu-Kyokai. Tokyo, 217 p. (In Japanese).

Received: November 30, 2016
Accepted: June 13, 2017

Authors' address:

Prof. Hideo Sakai, PhD.
e-mail: sakaih@fr.a.u-tokyo.ac.jp
The University of Tokyo
Graduate School of Agricultural and Life Sciences
Department of Forest Sciences
Bunkyo-ku Yayoi 1-1-1
113-8657 Tokyo
JAPAN