Structural control of landslide in the accretionary complexes of the Southwest Japan

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Abstract

Relationship between landslide mechanisms and geological structure in the accretionary complexes of the Southwest Japan was examined. The analyzed region includes southern Kyusyu, Shikoku, Kii Peninsula and Akaishi Mountains. This region is geologically composed of Sanbagawa metamorphic belt, Chichibu belt as a Jurassic accretionary complex and Shimanto belt as a Cretaceous to Neogene complex in the Pacific Ocean ward.

Gently dipping strata more than slope tend to cause landslides of dip slope slide. In Chichibu belt in Shikoku and Kii Peninsula, this type of landslides is often recognized. Some numbers of cases are found in the Shimanto belt in Kyushu, Kii Peninsula and the foot of Akaishi Mountains. Although steeply dipping strata more than slope are originally stable, combined fault or cleavage planes in accretionary complex play important role to the instability of slope. Wedge-shaped slides and slides along the daylight low-angled fault often occur in the Shimanto belt in Shikoku and Kii Peninsula. Gravitational buckling in nearly vertical strata is responsible for landslides of toppling or slide along the hinge plane. In Akaishi Mountains affected by collision of Izu-Ogasawara arc in 15Ma, both the Chihibu and Shimanto belts have almost vertical structure of strata. Therefore, gravitational deformation is frequently developed and landslides also occur in this region.

Deep-seated rapid landslides in non-metamorphic accretionary complexes including Chihibu and Shimanto belts are dominant induced by earthquake or heavy rainfall. While, in Sanbagawa belt as a metamorphic accretionary complex, deep-seated slow landslides are dominant. This is not structural but rock control, that is schists are more ductile than the non-metamorphic sedimentary rocks.

Keywords: structural control, outfacing dip slope, accretionary complex, Outer Zone of Southwest Japan

1. Introduction

Stratified rock mass like sedimentary rocks has mechanical anisotropy; it is strong to the normal direction to planar structure but weak to the parallel one. In case that the planar structures dip to the same direction of the slope, the structure is called the outfacing dip (cataclinal) structure. The outfacing dip structure tends to be unstable slope contrasting to the infacing dip structure that the planar structure is dipping to the opposite direction of the slope. Many landslides induced by earthquakes and heavy rainfalls have occurred in the outfacing dip slope. The landslide of outfacing dip slope is one of the typical landslides controlled by geological structures. Based on the relationship between dips of slope and strata Suzuki (2000) subdivides the outfacing dip into three types; daylighting dip, parallel dip, and hangnail dip (Fig. 1).

The Outer Zone of Southwest Japan is a landslide-prone area as well as the coastal area along the Sea of Japan (Fig. 2). In the latter, most of landslides are distributed in the Neogene volcano-sedimentary rocks, whereas in the former, landslides occur in the Mesozoic to Paleogene accretionary complexes. Although structurally

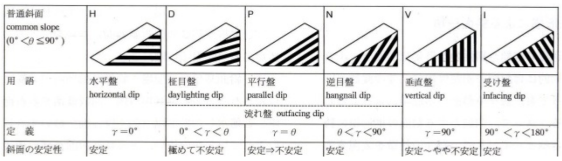

Fig.1 Relationship between attitude of strata and ground surface (Suzuki, 2000).

controlled landslides are recognized in both areas, rock strength, dimensions of landslide and movement characteristics are different. In this paper, we summarize the structural controlled landslides in the accretionary complexes and examine the mechanisms in detail and characteristics of regions.

2. Geology and geologic structure of the Outer Zone of Southwest Japan

The Outer Zone of Southwest Japan bounded on the north by the Median Tectonic Line (MTL) and on the east by the Itoigawa-Shizuoka Tectonic Line (ISTL) is the area of accretionary complexes formed by successive subduction of oceanic plate from the Jurassic to Neogene time. The ages of accretion are successively younging to the oceanward; The Sanbagawa metamorphic belt, the Jurassic Chichibu belt, and the Cretaceous Shimanto belt occur from north to south. The Shimanto belt is subdivided into the Cretaceous Northern Shimanto belt and the Paleogene to Neogene Southern Shimanto belt. The

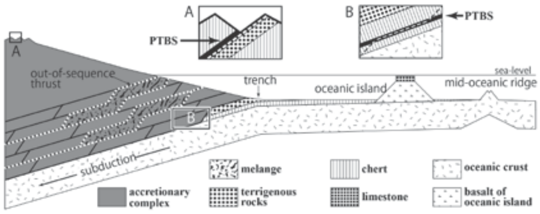

Fig.3 Schematic profile showing the formation process of accretionary complex (Kojima et al., 2015)

Sanbagawa metamorphic belt is mainly composed of crystalline schists (pelitic, psamitic, mafic and siliceous) associated with small amount of ultramafic rocks and weakly metamorphosed greenstones. The Chichibu belt consists of sandstone, mudstone, greenstones, limestone, chert, and melanges. The Shimanto belt is mainly composed of sandstone and mudstone with small amount of blocks of greenstones, chert, and limestone. Reflecting the subduction, these accretionary complexes have basically continental ward (north to west) dipping structures of strata and faults (Fig. 3). Therefore, north facing or west facing slopes tend to be outfacing and east facing or south facing slopes are infacing. However, exceptional structures are often developed by deformation like folding after the accretions.

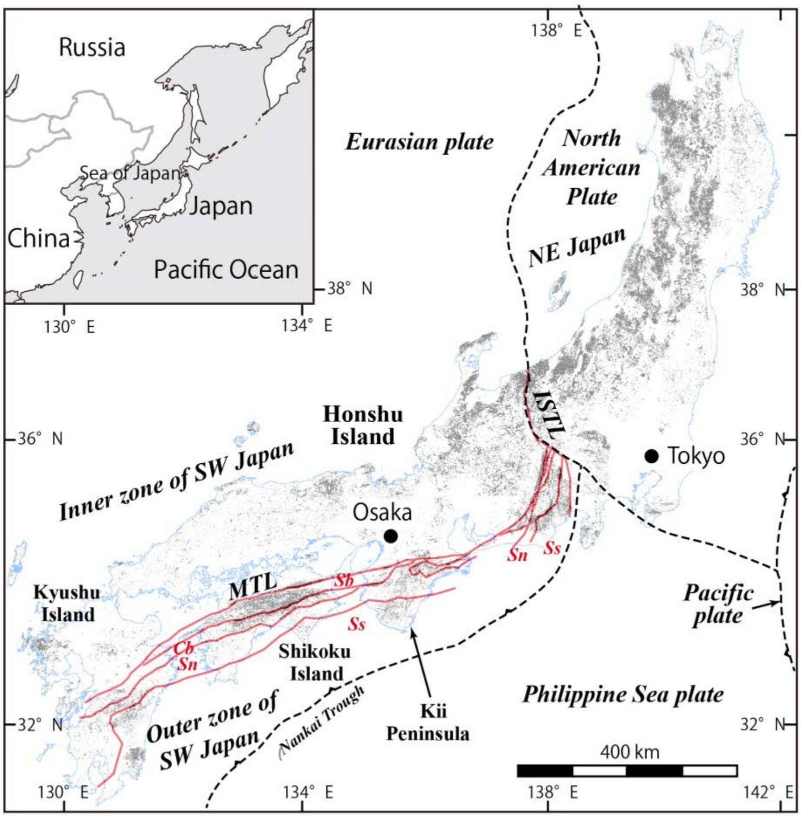

Fig.2 Index map also shown the tectonic setting (after GSJ, 2014) and landslide distribution (after Inokuchi et al. 2011).
MTL: Median Tectonic Line,
ISTL: Itoigawa Shizuoka Tectonic Line,
Sb; Sanbagawa metamorphic belt,
Ch: Chichibu belt,
Sn; Northern Shimanto belt,
Ss: Southern Shimanto belt.

3. Geologic structures and landslides in the Outer Zone of Southwest Japan

3.1 Kyusyu

In Kyusyu Island, inclination of strata tends to become gentle to the oceanward. Namely, The rocks of Sanbagawa and Chichibu belts dip vertically or steeply, Northern Shimanto belt dip moderately, and Southern Shimanto belt dip gently; moreover, the thrusts stacking the strata are more gentle.

Under such geological condition, heavy rain in 2012 brought five deep-seated rapid landslides of 0.3 to 3×10^6 m^3 on the slopes of the Mimikawa Valley composed of sedimentary rocks of the Northern Shimanto belt (Chigira, 2009). Among these, in the Matsuo-shinbashi landslide, although bedding planes of rock is hangnail dip, minor fault planes obliquely cutting the bedding is daylighting dip. Shimato landslide has the daylighting sliding plane originated from thrust.

3.2 Shikoku

In Shikoku Island, to the contrary in Kyusyu, strata of the Shimanto belt tend to dip steeply, whereas the Sanbagawa and Chichibu belts often show gently inclined bedding or schistosity. Fold structures with low-angle axial planes are also developed in the Sanbagawa belt. Distribution area of Sanbagawa crystalline schists has daylighting slopes in places, accordingly, it becomes to landslide-prone area. Also in the Chichibu belt, Sasaki and Yokoyama (2013) revealed that the Taninouchi landslide has the low angled daylighting structure (partly infacing) by detailed mapping. Although the Shimanto belt is low frequency area of landslide, large landslides occur occasionally because of the long term loosening of rock mass. The Kanagi landslide (8.5×10^6 m^3) probably induced by the 1707 Hoei earthquake collapsed in the toppled area of originally steeply inclined Southern Shimanto strata (Chigira, et al., 1998).

3.3 Kii Peninsula

Geologic structures similar to the Shikoku Island are developed in the Kii Peninsula. Namely, gently or moderately inclined schistosity and bedding planes are dominant in Sanbagawa and Chichibu belts. Figure 4 shows a stereo projection of schistosity in Sanbagwa belt and bedding plane in Chichibu belt along the Miyagawa River flowing in the eastern part of the Kii Peninsula (after Nagata et al., 2010). On the contrary, moderate to steep dip of beddings are prevailing in the Shimanto belt.

In the Chichibu belt, Kasugadani landslide induced by 2004 heavy rain which has the parallel dip structure (Nagata et al., 2010) and prehistoric landslide of Kasagi area inferred the collapse of daylighting dip structure (Kojima et al., 2015). In the Shimanto belt, many of the large rapid landslides caused by 2011 heavy rain were wedge type failure formed by combined fault fracture zone and hangnail dipping bedding plane (Chigira et al., 2013). Akatani landslide, which is one of the largest landslide induced by the 2011 rainfall, has parallel dipped main sliding plane and hangnail dipped bedding plane (Fig. 5; Yokoyama et al., 2013).

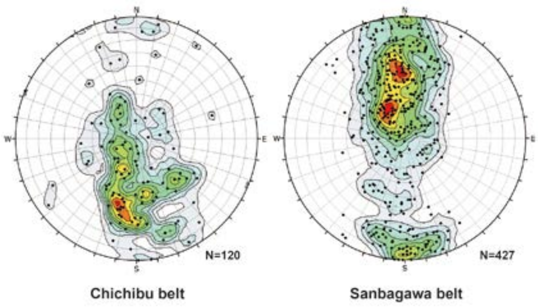

Fig.4 Stereo projection of bedding planes in the Chichibu belt and schistosity in the Sanbagawa belt along Miyagawa River, Kii Peninsula.
Moderate to gentle inclined mainly northward beddings are dominant in the Chichibu belt. In the Sanbagawa belt, dips of schistosity is gently inclined southward. According to mapping, The Chichibu belt has imbricated structure with open folding. On the contrary, in the Sanbagawa belt, tight recumbent foldings are recognized.

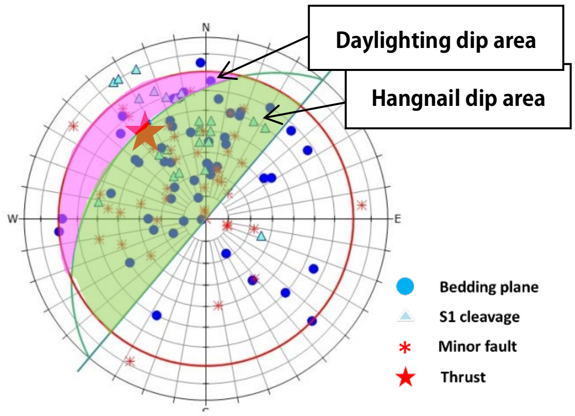

Fig.5 Stereo projection of dip vectors in the Akatani landslide (Yokoyama et al., 2013). The main slide plane is along the thrust plane. Bedding plane, cleavage plane, and minor fault planes are scattered. Green large circle shows the the slope angle. Red small circle indicate assuming friction angle (20 degrees).

3.4 Akaishi Mountains

Structural trend were bent into N-S direction by the collision of Izu-Ogasawara arc after 15Ma. Dips of the strata are generally steep in every geologic belt. According to such structural characteristics, slide-type landslides are few in main part of Akaishi Mountains. On the other hand, rapid landslides with precursory buckling or toppling (bending toward valleyside) of strata often occur. The Akakuzure landslide (Chigira and Kiho, 1994), which is not certain that it failed all at once, and the Oyakuzure landslide (1.2×10^8 m^3) are typical examples of this type of landslide. Rocks of both landslides are mainly composed of phyllitic argillaceous rocks of Shimanto belt.

4. Discussion

4.1 Relationship between geologic structures and inclination of ground surface

The daylighting dip slope has the gentler dip of planar structure than that of ground surface. Weak plane like shear zone and intercalated bed along the planar structure becomes daylight and tensile strength parallel to the planar structure is small. Thus the daylighting dip slope tends to be unstable. Many landslides of daylighting dip structure are recognized in the area of Sanbagawa schists.

The parallel dip slope is more stable than the daylighting dip slope. In case that the foot of slope is cut down, however, parallel dip slope also becomes unstable similar to the daylighting dip slope. As the Outer Zone of Southwest Japan has been rapidly uplifted in Quaternary time, the undercut slopes are common and unstable.

The hangnail dip slope is originally stable because the weak zone layer is not daylight. But, as shown above, many landslides are recognized even on the hangnail dip slopes. The instability is caused by daylighting gentle weak plane other than bedding plane (Fig. 6b) or wedge shaped slide combined with the other weak planes of outfacing dip (Fig. 6a). Low-angle cleavage or fault planes were generally formed during the development process of accretionary complexes (Fig. 3). Owing to that, there is no small extent of slopes accompanied by weak planes of daylighting or wedge shape forming.

In case of nearly vertical dip of planar structure, another type of slope movement may occur: buckling and valleyward bending. Weakened zone of rock mass is so deeper in the higher level because of weathering and stress release that the envelope of lower limit of gravitational deformation will make low-angle weak plane(Fig. 6c). The plane changes into sliding plane in the long term. Especially in steep slope, buckling and bending of strata begin much easily. Even in infacing dip slope, precursory gravitational deformation and landslide can form.

As indicated above, the structural control of landslides in accretionary complexes is not simple, but most of the factors are related to the generation and growth of the complex. In other words, weak planes such as cleavage and fault planes oblique to the bedding, fault planes formed during the stacking of accretionary wedge, fault planes accompanied by unequal subduction, and fault planes associated with the uplifting of accretionary complexes make the landsliding plane combined with bedding plane or schistosity plane.

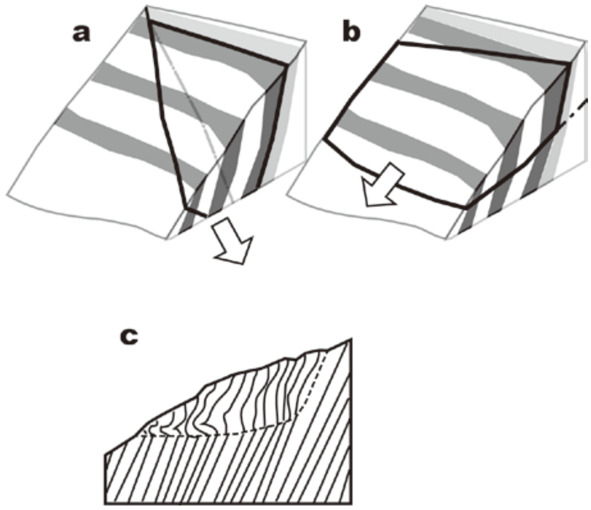

Fig.6 Schematic block diagrams and profile showing the landslide mechanism on hangnail dip slopes.
a: wedge shaped landslide slid along the intersection between bedding plane and weak plane like a fault fracture zone.
b: slide along the low-angle daylight weak plane.
c: formation of low-angle weak plane along the lower limit of gravitational deformation (buckling).

4.2 Structural control and rock control to landslides

Landslides are not only controlled structurally. Because cracky rock mass deforms more easily, landslides originated from buckling tend to occur in the area of steeply inclined schists or phyllite. Another type of landslides controlled by weathering are recognized in greenstones with poor stratification in the Mikabu belt, a part of the Sanbagawa belt. Both the lithology and structure give influence on the distribution density, dimensions and movement characteristics of landslides.

5. Concluding remarks

We summarize structural control of landslide in the Outer Zone of Southwest Japan from the viewpoint of relationship between the inclination of planar structure and ground surface. Though it is clear that the daylighting and parallel dip slopes are unstable as well, landslides often occur even in the hangnail dip slope which is originally stable. Other than the bedding and schistosity planes, weak planes formed during accretion play an important role to form landslides in the accretionary complexes.

Geologic structures in accretionary complex are furthermore complicated by the influence of post tectonic movement including gravitational deformation, and thus landslides are formed in the (apparent) horizontal or infacing dip slopes. The examination to geologic structure at landslide site is required in the future.

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