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CHARACTERISTICS OF SLOPE FAILURES IN MAKINOHARA, JAPAN

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ABSTRACT: Makinohara City, located in south-central Shizuoka Prefecture in Japan, is renowned for the production of high quality Japanese green tea. Approximately 25% of Makinohara City’s land is used as tea plantation fields and annually 5,800 tonnes of tea is produced. However, slopes in this region are occasionally subject to failures following construction activities. In this light, this paper investigates characteristics of slope failures in Makinohara region. Based on the author’s experience, a number of recommendations are also made for slope analysis and mitigation works.

Keywords: Makinohara Plateau, Tea Plantation Fields, Slaking, Slope Mitigation, Surface Protection

1. INTRODUCTION

Makinohara City, founded by the merger of Sagara Town and Haibara Town in 2005, is located in the south-central region of Shizuoka Prefecture in Japan. The city is known for production of Japanese green tea for a long period. Approximately 25% of Makinohara City’s land is used as tea plantation fields [1]. The Makinohara City Hall also has an unique department called Tea Promotion Section which specifically deals with tea related matters. Today Makinohara City produces 5,800 tonnes of tea, which is approximately 6% of Japan’s overall tea production.

In this region, a number of major transportation networks have been developed. These include Tomei Expressway, Japan National Routes 15 and 473, Tokaido Shinkansen (Japanese high speed train), Omaezaki Port, and Mt Fuji Shizuoka Airport which newly opened in 2009.

The author has noted that slopes in this region are occasionally subject to failures following construction activities. The author also identified that the landslide prone areas often impinge on the tea plantation fields [2]. The recent landslide which occurred in the tea plantation fields in Hamamatsu, Shizuoka is a good example illustrating the association between landslide prone areas and the tea plantation fields.

In this light, this paper investigates the characteristics of slope failures in the Makinohara region. Based on the author’s experience, a number of recommendations are made for slope analysis and mitigation measures.

2. GEOGRAPHY AND GEOLOGY

This region principally consists of the Makinohara Plateau with an elevation of less than 200m. A number of gullies are developed on this plateau. A narrow alluvial plain of the Katsuma River also lies in the middle of the Makinohara City.

According to relevant geological maps [4 and 5], the Makinohara Plateau comprises the Makinohara river terrace gravelly layers, which are in turn underlain by layers of various degrees of decomposed Neogene (Miocene) age Kakegawa Group and Sagara Group siltstones. The tolerance of these siltstones to the weathering is relatively low and their structure often includes advanced fragmentation and softening. The overlying soils are usually suitable for growing tea plants due to their weakly acidic characteristics.

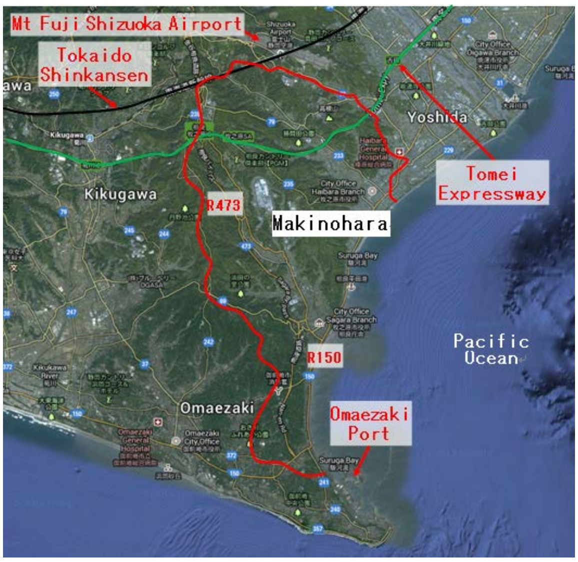


Fig.1 Google Map of Makinohara Region (after [3])

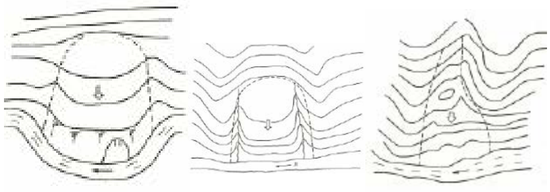
Photo 1 Typical Tea Plantation Fields in the Makinohara Region

3. TYPE OF FAILURES AND SLIP SURFACE IDENTIFICATION

In the Makinohara region, slope failures are often triggered by the earthwork excavations [6]. The author also observed a number of failures caused by earthworks during the road and pond constructions associated with the airport construction. There are also slope instabilities caused by the construction of embankments near the crest of past landslide sites.

According to the classification proposed by [7], slope failures in this region can be broadly classified into the following categories:

- Weathered rock type: the shape of slope failure is the convex hill type or the concave mono hill type. Scarps and a strip of depression zone are often observed near the slope crest. This type is typically triggered by the intensive rainfall events after the construction of medium to large size earthworks.
- Clayey soil type: the shape of slope failure is usually the concave poly hill type. This type consists of a number of shallow and small past failures. Gully features are developed and the terrain topography is generally disturbed. The groundwater table is usually high.



(a) (b) (c)

Fig.2 Shape of Slope Failures: (a) Convex Hill Type, (b) Concave Mono Hill Type and (c) Concave Poly Hill Type (after [7])

In many cases, determination of the slip surface based on borehole core observation or monitoring results (e.g, inclinometer or pipe strain gauge) may not be difficult in this region. This is because the core is often slickensided and monitoring results typically show clear movement at the location of the slip surface. The slip surface is also occasionally seen on the faces of excavations.

It is noted that when the slope movement is significant, boreholes and inclinometer casings may bend making the monitoring of the slip surface impossible. This is not unusual in this region due to the relatively fast movement of the slope. Based on the author's experience, this phenomenon could happen within a very short period (e.g., 2 to 3 weeks) if the strength of geomaterial is low. When this is anticipated, the pipe strain gauge needs to be used for the slip surface monitoring.

Photo 2 Slope Failure Triggered by Excavation

4. FACTOR OF SAFETY AND ANALYSIS

The following design Factor of Safeties (FOS) are usually used for the slope mitigation works in Japan:

- Temporary works: FOS ≧ 1.05
- Permanent works: FOS = 1.12 – 1.20, depending on the importance of assets to be mitigated or protected.

In Japan, the design of slope mitigation works is undertaken by back-calculating strength parameters for the slope, based on certain assumptions regarding groundwater levels and cohesion. However the choice of the highest groundwater level (HWL) as the groundwater level for the back-analysis is a relatively arbitrary choice, that may be affected by a limited duration of monitoring. In addition, there are always uncertainties in determination of the slip surface. The required force to achieve the design FOS could differ significantly even with a slight difference in the shape of the slip surface.

Moreover, the following factors need to be carefully considered during analyses and design of slopes in this region:

- Many clayey soil type slopes appear to be marginally stable, i.e., their FOS is close to 1.0. Landslides in this area could be reactivated even with relatively minor triggering events.
- The regional geology tends to dip to southeast direction. This structural geological setting as well as other adverse geological conditions (e.g., advanced weathering) often have significant influence on the stability.
- Strong slaking and erosion events often cause creep of slope and as a result overall FOS decreases with time possibly within a short time. The author encountered a number of instances of temporary remediated slopes being damaged prior to the start of permanent mitigation works.

Taking into account all of these factors as well as the low design FOS commonly adopted in Japan, the author considers that a slightly conservative approach is required particularly during temporary works in this region.

Photo 3 Damage to Temporary Slope Mitigation Works Prior to Permanent Works

5. SELECTION OF MITIGATION MEASURES

Fig. 3 shows the commonly used landslide mitigation measures in Japan. They consist of landslide control measures and landslide restraint measures [8].

Among those measures, earth removal, buttress fill, groundwater control and anchors which are commonly used in this region will be discussed in the following sections.

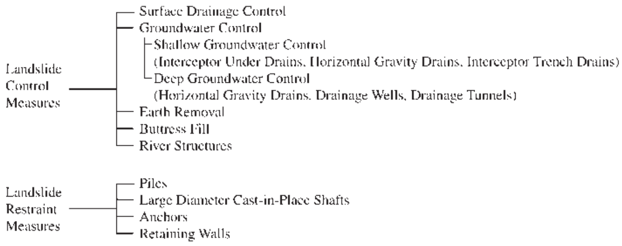


Fig.3 Landslide Mitigation Measures (after [9])

5.1 Earth Removal and Buttress Fill

Among various slope mitigation measures, cutting back the upper portion of the slope or buttress filling near the slope toe is usually the quickest and the most economical mitigation option. Groundwater can be also effectively lowered by earth removal.

Japan has one of the highest population densities in the world. Therefore slopes are often designed as steep as possible in order to minimise the disturbance to the surrounding areas. For instance, cut slopes in weathered siltstones are often designed at 1:1.0 (V:H) in this region. However the author observed a number of failures under the following adverse conditions:

- Long and intensive rainfall events. The average annual rainfall in this region is more than 2,200mm [1].
- Abundant seepage from the Makinohara gravelly layers. After daily rainfall events with more than 100mm, groundwater seepage typically lasts for a few days in tea plantation fields and a few weeks along cliffs [10].
- Adverse geological structural setting. The regional geology tends to dip to southeast, thus bedding is dipping out on slopes facing between the east to the south.

When earth removal or buttress fill is selected as a slope mitigation measure, the author considers that the following slightly conservative slope angles are appropriate in this region:

- Cut Slope = 1:1.5 (V:H) or flatter for moderately weathered or better siltstones
- Fill Slope = 1:2.0 (V:H) or flatter

It is also prudent to apply surface protection even to the temporary slopes in order to minimise exposure of the cut surface. It is evident that many cut slope failures in this region occur following the first heavy rainfall event after slope construction.

When buttress fill is adopted, it is important not to use failed materials as buttress fill materials since surface water tend to concentrate around these impermeable materials and causes further instability of the slope.

It is noted that earthworks which will be affecting existing tea plantation fields are often considered inappropriate by landholders and governmental administration bodies since tea farming is a very important source of income in this region. In such a case, more rigorous mitigation measures (e.g., anchors) need to be considered.

Photo 4 Erosion occurring on 1:1.0 (V:H) Temporary Cut Slope

5.2 Groundwater Control

The tea plants grow well in areas with yearly rainfall of more than 1,400 mm [11]. While rainfall is essential to the growth of tea plants, there are a number of sediment related disasters due to heavy rainfall events.
In particular in this region, the steady seepage flow is located around RL 170m to RL190m. Even if the groundwater level is low during the dry season, the rise of groundwater could be significant following long intensive rainfall events. The research conducted by [10] also revealed that the volume of seepage fluctuates significantly at higher RL. Therefore groundwater control is one of the key slope mitigation measures in this region.
According to manuals commonly used in Japan (e.g., [9], [12] and [13]), the planned groundwater level (PWL), which is the groundwater level taking into account effects of groundwater control measures, is often set lower than HWL, i.e. 3m (gravity drains) and 5m (drainage wells). While lowering groundwater to the PWL in gravelly layers is usually achievable, the response of groundwater in siltstones is often not fast enough to lower the groundwater due to their relatively low permeability. As a result, an increase of FOS by these groundwater control measures could be much less than 3% when they are installed in siltstones.
In order to maximise effects of these groundwater control measures, it is essential to carry out detailed investigations to identify the groundwater table relative to the slip surface. In addition, the groundwater logging test is useful to determine the groundwater flow so that drains can be installed at locations where the groundwater flow is fast (i.e., the permeability is high).
In cases where the site is located within or adjacent to the tea plantation fields, it is important not to drain groundwater completely so that they remain suitable as tea plantation fields.

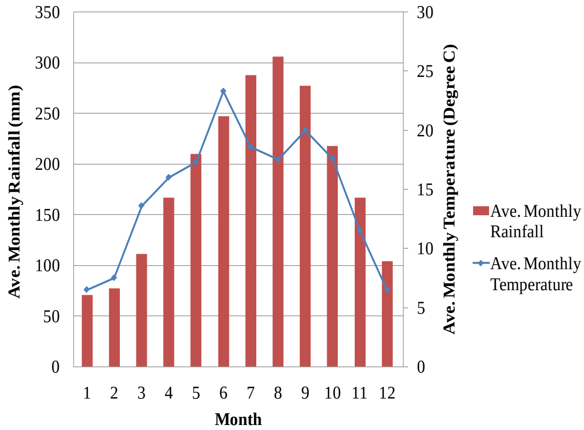


Fig.4 Rainfall and Temperature of Makinohara City (after [1])

Photo 5 Horizontal Gravity Drains Installed on Temporary Cut Slope

5.3 Anchors

Anchors are often required for both temporary and permanent works in Japan. In the Makinohara region, tensioned anchors are preferable to compression anchors for weathered siltstones because:

- The extent of anchor forces acting along the tendon is greater in the tension type than in the compression type for rocks consisting of fine particles (e.g., siltstone) [14].
- The compression type tends to create the stress concentration at the bottom of the anchor [15].

The design of anchors in this region is often based on the circumferential skin friction (τ) of 0.6 MN/m^2, which is the smallest τ value for weathered rocks in accordance with [16]. However many case studies revealed that the actual τ value could be potentially smaller than this value in this region. Therefore it is strongly desirable to confirm the τ value by anchor pullout tests.

Due to the potentially low τ values, additional anchors may be required in this region in order to achieve the design FOS. A larger anchor bearing plate is also often necessary due to the low bearing capacity. Meanwhile increasing the number of anchors and using a larger anchor bearing plate allows restraint to a wider area of the slope surface, resulting in a reduction of the risk of surface erosion. In addition to these measures, providing surface protection and appropriate drainage systems (e.g., shotcrete and gravity drains / weepholes) is also highly desirable.

In this region, installation of anchors is preferably undertaken in the dry season. The following steps are also recommended for anchor installation:

- Undertake excavation and anchor installation in stages from top down.
- Install anchors as soon as the slope is trimmed in order to minimise the unsupported period.
- Fabrication of the precast anchor bearing plate in a factory prior to anchor installation to minimize the lead time associated with acquisition of the anchor bearing plate.

After initial tensioning, anchor bearing plates occasionally settle in this region. Slopes also often show creep movement and the anchor lift off stress could be much lower than the design stress. Taking into account these facts, re-tensioning of anchors is often required and therefore an initial tensioning to approximately 80% or less of design anchor load is usually considered appropriate.

Photo 6 Pullout Test Revealed τ = 0.5 MN/m^2 for a Project in the Makinohara Region

Photo 7 Photograph of Anchor Bearing Plate Indicating Creep Movement of Slope

6. CONCLUSION

In this paper, characteristics of slope failures in the Makinohara region are described. Based on the author's experience in this region, various recommendations are made for slope mitigation works. From a series of studies, the following conclusions can be drawn:

- Slope failures are often triggered by earthworks excavations. These failures can be broadly classified into the weathered rock type and the clayey soil type.
- Due to various adverse conditions and the low design FOS commonly used in Japan, a slightly conservative approach (e.g., conservative slope angle) is required particularly during temporary works in this region.
- Protection of the slope surface and the control of groundwater and surface water are key to the mitigation of slope instability since siltstones show strong slaking phenomenon in this region.
- The τ value could be smaller than the commonly adopted design value in this region, and performing anchor pullout tests is highly desirable. Re-tensioning of anchors is also often required and therefore an initial tensioning to approximately 80% or less of design anchor load is usually considered appropriate.

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