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Types and processes of slope movements along East–West Highway, Surai Khola area, Mid-Western Nepal Sub-Himalaya

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ABSTRACT

Many landslides and debris flows have occurred and destroyed the East–West Highway that extends along the valley slopes of the Siwalik Hills. Wedge slide, rock fall, slump, rock topple-rock slide, debris flow, slope failures and gully erosion were recorded in the Surai Khola area. The most of the slope movements distributed therein are active, reactivated and retrogressive. Differential weathering and gully erosion related to bedding planes of rocks are common phenomena, which contribute instability. The areas between Surai Naka and the Chor Khola suffer remarkable uplift, tilting and river incision, and thus indicate tectonically active zone. Tectonic activity, lithological assemblage, rock strength and weathering of the Siwalik Group have remarkable input on distribution, causes and activity of slope movements.

INTRODUCTION

In adddition to mountainous regions, hilly areas (Siwalik Hills) of Nepal experience landslides and debris flows (Sharma 1981; Tamrakar et al. 1999). Several slope movements can be observed on steep slopes of the Surai Khola in mid-Western Nepal (Fig. 1). Sandstone, mudstone and conglomerate form slopes, which dip steeply due to tectonics. Differential weathering of rocks is remarkable. Authors attempted to recognize various slope movements, causes and their processes based on field observation.

LITHOLOGY, STRUCTURE AND WEATHERING

From Surai Naka to Dhan Khola area (Fig. 2), Bankas Formation (BF), Chor Khola Formation (CKF) (Jungli Khola Member and Shivgarhi Member), Surai Khola Formation (SKF), Dobata Formation (DF) and Dhan Khola Formation (DKF) make up the Siwalik Group (Dhital et al. 1995) of age >13 to <1 Ma (Appel and Rösler 1994).

A north dipping monocline exists between the Rangsing Thrust (RT) and the Main Frontal Thrust (MFT) (Fig. 2), and dips at various angles; the highest tilt (80^{o}) is being measured around the Chor Khola area. Deformation into the existing tilt is probably explained by thrusting along the Quaternary faults (Kizaki 1994).

Three geomorphic surfaces with relative heights; 80–120 m, 30–60 m and 5–15 m, and unclassified surfaces were distinguished on the hillslopes. The

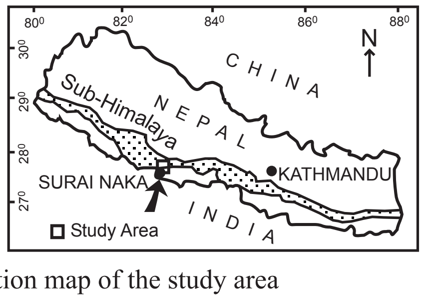

Fig. 1 Location map of the study area

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relative heights increase from upstream to downstream notably between Dobata and Surai Naka indicating incision yielding steep and unstable slopes.

Mudstones of Surai Naka–Chor Khola are clayey, but of the Surai Khola–Dhan Khola Bridges are sandy, and are extremely weak rocks (UCS: 0.01–1.00 MPa after Tamrakar 1999). Sandstones of Surai Naka–Jungli Khola area are fine- to medium-grained, but those of Chor Khola–Dobata are very coarse-grained. Sandstones have UCS of 35–117 MPa (Tamrakar et al. 1999a). The contrast in strength between sandstone and mudstone is remarkable.

Conglomerates are distributed between Dhan Khola and the Rangsing Khola. The lowermost (volcaniclastic clast–dominated) and the uppermost units (terrigenous clast–dominated) are matrix–supported and poorly consolidated, whereas those of the middle part (dolomite clast–dominated) are strongly indurated.

Bed thickness and style of interbedding

Thickness variation of stiff and weak rocks gives rise to various pattern of interbedding (Fig. 2). Mudstone bed-thickness, that is 5 m in the BF, CKF and SKF, becomes 30 m in the DF and the DKF. Sandstone beds have lower thickness (2–5 and 5–10 m) in the BF, CKF, DF and DKF than in the SKF (10–20 to 100 m). Conglomerates have thickness ranging from 5 to 120 m.

Stiff bed density (SBD) and stiff bed interval (SBI) were calculated per 100 m of intervals (Fig. 4). SBD is the total thickness of stiff beds per 100 meters. SBI is an average thickness of soft bed per 100 m. The lower SBI indicates increase in number of stiff beds. SBD is high (~ 75%) in SKF and the middle part of DKF. SBD is low (7 to 50%) in the DF and is intermediate in other formations. SBI is 1–7.6% in BF, CKF and SKF showing that stiff beds are frequently intercalated therein. SBI is relatively high in DF and DKF.

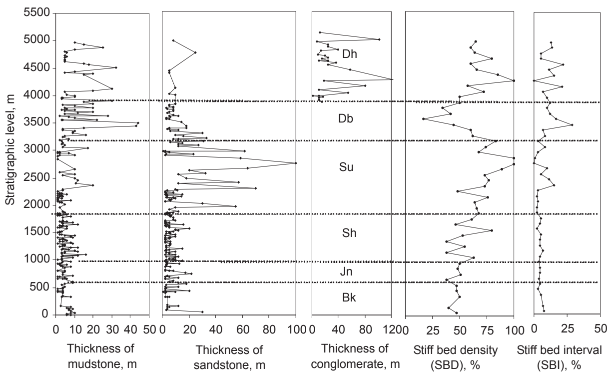

Fig. 2 Thickness of mudstone, sandstone and conglomerate, stiff bed density (SBD) and stiff bed interval (SBI) against stratigraphic level. Dotted lines represent boundaries of lithologic units (based on the litholog after Dhital et al. 1995)

Joints and weathering

Joints are distinctly developed in sandstones of BF and CKF, where they are closely spaced and widely opened compared to the widely spaced and less persistent ones of the SKF. Stiff conglomerates consist of fractures. Mudstones show shrinkage cracks. Jointing in the Siwalik sandstones is the potential cause for wedge slide, rock fall and rock topple-rock slide.

Weathering rate of the Siwalik rocks may be high as rocks are fragile, and this is even higher in mudstone compared to sandstone as slaking greatly affects mudstone. Exfoliation and spheroidal weathring pattern was observed in sandstones. Solution of cement in both sandstone and conglomerate helps to produce rock blocks and contributes rock falls. Differential rock weathering is one of the remarkable causes for slope movement in the Siwalik Hills.

SLOPE MOVEMENTS

Spatial distribution of slope movements which vary in their type and magnitude are shown in Fig. 3. Rock fall, wedge slide, slump, debris flow, slope failure and gully erosion have been recognized. Most of them distribute on natural slopes, but slope failure commonly occurs on excavated slopes.

Wedge Slide

Large–scale wedge slides occur at the right bank of the Surai Khola at 1 km from Surai Naka. They also occur in scarp slopes of the East–West Highway between the Jungli and the Kaila Kholas and transform into debris flow. Outcrops of Surai Naka are composed of highly jointed fine-grained sandstone, siltstone and variegated mudstone of BF. Beds dip 10^{o} due 258^{o} opposite to the slope-face direction ($80^{o}/45^{o}$). Three lines of intersections 60^{o}, 99^{o} and 108^{o}

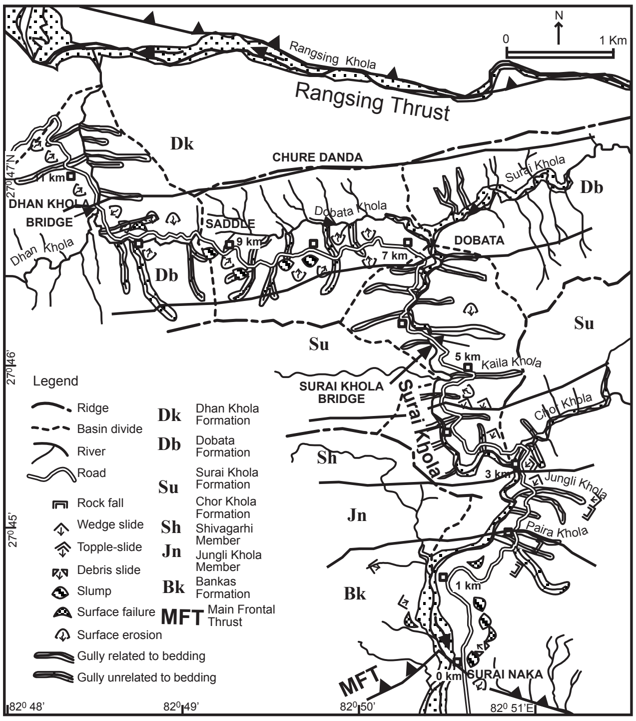

Fig. 3 An inventory map of slope movements along the Surai Khola and the East–West Highway, Mid-Western Nepal

according to the criteria of Norrish and Wyllie (1996), were potential. Therefore, wedge slide occurred due to presence of daylighting structural wedges.

Rock fall

Rock fall often occurs by collapsing of rock blocks due to removal of underlying support of soft beds. Such rock fall has a low magnitude of displacement (1 to 10 m), but has frequent impact on the highway. Collapse of rock blocks occurs widely in areas of BF, CKF and DKF due to gully erosion. In conglomerate and mudstone sequences of DKF, mechanism of collapse involves (1) gully erosion of mudstone, (2) dissolution of cements in conglomerate and enlargement of vugs, and (3) collapse of conglomerate blocks (Fig. 4).

Large–scale rock falls were recognized at 1.56 km and 2 km from Surai Naka (Fig. 3). In the former, a slope is composed of sandstone and mudstone with differential weathering and plunge 60^{o} N . Two major potential wedges (320^{o} to 334^{o}) were measured. The wedge that faced 174^{o} became potential when underlying mudstone bed was eroded. Therefore, this rock fall occurred by failure of wedges.

Slump

Slumps occurred at Surai Naka 0, 1 and 8.55 km along the East–West Highway. The former is a large-scale slump (about 100–150 m wide and 60 m high) containing weathered mudstone and fine-grained sandstone covered by the terrace gravel. These strata have undergone shearing due to the effect of the MFT. Multiple minor scarps were developed within the slump block showing retrogressive and multiple activity. The slump located at about 8.55 km was triggered by rainstorm in November 1998. It was a typical spoon shaped failure that occurred in coarse-grained sandstone.

Rock Topple–rock slide

At about 3 km from Surai Naka along the East–West Highway, near the Chor Khola, a topple-slide structure was recognized (Tamrakar et al. 1999b). The structure contains jointed sandstone and mudstone, showing a distinct stiffness contrast of the order of 10^3 (Tamrakar 1999). Steep slopes, steep dips of strata with stiffness-contrast, prominent joints and river incision against active uplift had contributed this landslide (Tamrakar et al. 1999b).

A very huge overturned structure is observed in the area between Dobata and Saddle along the East–West Highway. in this structure had overturned towards the south. It is yet to be identified whether the structure is of tectonic tilting or of gravitational phenomenon.

Debris flow

Some major debris flows are located at Surai Naka 3.5 and 1.56 km, in the Paira, Jungli, and the Kaila Kholas (Fig. 3). Older debris flow deposits were also recognized from gullies across the highway. Tributaries in the northern face of the Chure Danda carry abundant debris to the Rangsing Khola. Friable sandstone and loosely consolidated conglomerate are the chief source materials for debris flows.

Slope failure

Slope failure is the most common phenomenon along the East–West Highway (Fig. 6). It is a surficial and rapid down slope movement of mass of rock or debris induced by rainstorm. Surai Naka and the East–West Highway between Dobata and Dhan Khola area are vulnerable to slope failures as rocks therein

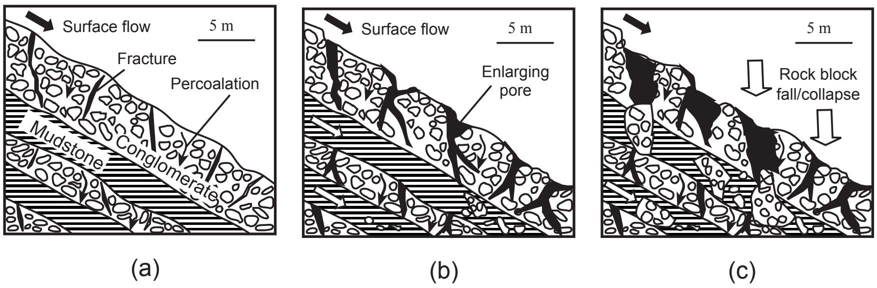

Fig. 4 Schematic diagram showing processes of rock fall: (a) Surficial flow and percolation of water, (b) Solution of cementing material, formation of vugs in conglomerate, and erosion of underlying soft rock (mudstone), and (c) Rock block fall by gravity, and collapse of beds due to removal of underlying support of mudstones

are sheared or weathered, thus contributing to low shear strength.

Gully erosion

Gullies often follow mass and structural discontinuities. Gullies related to bedding plane are distributed in Surai Naka–Kaila Khola and in Dobata –Dhan Khola Bridge (Fig. 3). The magnitude of gullies depends on thickness and plunge of beds, contrast in stiffness of strata, SBD and SBI.

Gullies unrelated to bedding plane are often >15 m deep and 40 m wide and contain huge debris. Such gullies are found on the valley slopes of the Chor Khola, upstream stretch of the Surai Khola, Dobata Khola and Dhan Khola, and slopes of the Chure Danda. Gullies are retrogressive, incising and widening.

CONCLUSIONS

Rock fall, wedge slide, slump, rock topple-rock slide, debris flow, slope failure and gully erosion occur in the Surai Khola area. Valley slopes with steep strata, tectonic tilting, river incision, discontinuities in rocks, differential weathering, stiffness contrast between rock types and style of interbedding (SBD and SBI) are major contributors for unstable phenomena. Although several factors influence simultaneously, the style of interbedding, joints and differential weathering play important roles on activities and magnitudes of various slope movements in the study area. Differential weathering and gully erosion often induce rock fall and rock block collapse.

Thrusting along the MFT, high degree of tilting of strata and river incision pose threat on stability of slopes between Surai Naka and the Chor Khola. Valley rebound, as caused by valley deepening made by river and relieving of lateral stress to the valley walls are important processes in contributing to increase shear stress after the removal of the lateral support. This phenomenon governs many large-scale and active slope movements in the southern region.

ACKNOWLEDGEMENTS

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