Effect of vegetation on slope stability

5. 1 Introduction

Incorporating the vegetation effect in slope stability has been used for many years in geotechnical engineering. The vegetation effect on slope stability usually ignored in conventional slope analysis and it is considered as a minor effects. Although the vegetation effect on slopes qualitatively appreciated after the pioneer quantitative research. The vegetation cover is recognized in urban environment and it is generally utilized along transportation corridors such as highways and railway, river channels, canals, mine waste slopes and artificially made sloping ground.

There are some remedial techniques for soil stabilizations in civil engineering practice such as geosynthetic reinforcement or soil nailing are often used at slopes at great expense, but now many parts of the world considered sustainable alternative methods such as using the vegetation cover or soil bioengineering in civil engineering applications. This method reduces the cost and local labour force and it is environmental friendly method.

The vegetation cover, the roots draw out moisture from soil slopes through evapo-transpitation leads to shrinking and swelling in soil. After prolonged wet and dry period, it is possible to foam cracks at dry period due to reduction of moisture content from vegetation covers.

5. 2 Influence of vegetation

The vegetation effect influence on soil slopes, generally classified into two types, they are mechanical and hydrological effects. The hydrological effect is responsible for soil moisture content, increasing the evapo-transpiration and resulting increasing the soil matric suction. Water is removed from the soil region in several ways, either evaporation from the ground surface or by evapo transpiration from vegetation cover. The process produces upward flux of the water out of the soil. The mechanical effects from the vegetation root responsible for physical interaction with soil structure

5. 2. 1 Hydrological effects

The influence of vegetation cover in soil moisture content in different ways. The rain water evaporates back to atmosphere ultimately reduce the amount of water infiltrate into the soil slope. The vegetation roots extract moisture from the soil and this effects leads to reducing the soil moisture content. The reduction in moisture content in soil, it will help to increase the matrix in unsaturated soil or decrease the pore water pressure condition in saturated soil. Both of this action ultimately improves the soil stability. The vegetation's moisture reduction ability is well recognized. The root reinforcement is most important factor, it is generally considered in vegetation effects on slope analysis, thought the recent studies shows the importance of hydrological effects on slopes by Simon& Collision (2002). They studied the pore water pressure and matric suction in soil over for one cycle of wet and dry cycle under different vegetation covers. This result shows the significant effects of vegetation hydrological effects are soil structure.

5. 2. 2 Mechanical effects

The vegetation's root matrix system with high tensile strength can increase the soil confining stress. The soil's root reinforcement is described with root's tensile test and adhesional properties. The additional shear strength of soil is given by the plant root bound together with the soil mass by providing additional apparent cohesion of the soil.

The slope contain large trees need to consider the weight of the tree. The additional surcharge to the slope may give from larger trees. This surcharge increases the confining stress and down slope force. The surcharge from larger trees could be beneficial or adverse condition depending of the location on soil slope. If the trees located slope toe, the slope stability will be improved due to additional vertical load. On the other hand, if the trees located at upper surface of the slope, hence overall stability reduced due to vertical down slope force

Furthermore, the wind loading to larger trees increasing the driving force acting on the slope. In the wind load is sufficiently large it may create the destabilizing moment on the soil slope from larger trees. Larger trees roots penetrate deeper strata and act as stabilizing piles. The effects of surcharge, wind loading and anchoring usually considered only larger trees.

5. 3 Vegetation effects on soil slope numerical study

In this parametric study, the effect of vegetation on the stability of slope has been investigated using the SLOPE/W software tool. In this study only consider the parameter root cohesion known as apparent root cohesion (CR). This coefficient incorporated with Mohr-Coulomb equation.

5. 3. 1 Model geometry

20 m

10 m

20 m

10 m

20 m

Figure 5. 1 Slope geometry

ï 🚺 §ï€ ï€½ï€ 20 kN/m3

c = 15 kPa

ï 🚺 ¦ï€½ï€ 20°In this parametric study 10 m height 2: 1 homogenous slope (26. 57°) is used to investigate the vegetation effect on stability analysis, as shown in Figure 5. 1. The soil properties are as follows:

5. 3. 2 Vegetation covers arrangement for the numerical model

Case

Slope geometry

Description

01

No vegetation cover

02

1 m height vegetation cover-entire ground surface

cohesion 1 kPa to 5 kPa

03

2 m height vegetation cover-entire ground surface

cohesion 1 kPa to 5 kPa

04

3 m height vegetation cover-entire ground surface

cohesion 1 kPa to 5 kPa

05

vegetation cover only at the slope surface

06

vegetation cover only at the slope surface and upper surface

Figure 5. 2 Vegetation covers arrangement for the numerical model

5. 3. 3 The root cohesion values from previous researchers

Source

Vegetation, soil type and location

Root cohesion c’ v (kN/m2)

Grass and Shrubs

Wuâ€¡ (1984)

Sphagnum moss (Sphagnum cymbifolium), Alaska, USA

3. 5 – 7. 0

Barker in Hewlett

Boulder clay fill (dam embankment) under grass in concrete block reinforced

3. 0 – 5. 0

et al. â€ (1987)

cellular spillways, Jackhouse Reservoir, UK

Buchanan & Savigny * (1990)

Understorey vegetation (Alnus, Tsuga, Carex, Polystichum), glacial till soils, Washington, USA

1. 6 – 2. 1

Gray § (1995)

Reed fiber (Phragmites communis) in uniform sands, laboratory

40. 7

Tobias â€ (1995)

Alopecurus geniculatus, forage meadow, Zurich, Switzerland

9. 0

Tobiasâ€ (1995)

Agrostis stolonifera, forage meadow, Zurich, Switzerland

4. 8 – 5. 2

Tobiasâ€ (1995)

Mixed pioneer grasses (Festuca pratensis, Festuca rubra, Poa pratensis), alpine, Reschenpass, Switzerland

13. 4

Tobiasâ€ (1995)

Poa pratensis (monoculture), Switzerland

7. 5

Tobiasâ€ (1995)

Mixed grasses (Lolium multiflorum, Agrostis stolonifera, Poa annua), forage meadow, Zurich, Switzerland

-0. 6 – 2. 9

Cazzuffi et al. § (2006)

Elygrass (Elytrigia elongata), Eragrass (Eragrostis curvala), Pangrass (Panicum virgatum), Vetiver (Vetiveria zizanioides), clayey-sandy soil of Plio-Pleistocene age, Altomonto, S. Italy

10. 0, 2. 0, 4. 0, 15. 0

Norrisâ€ (2005b)

Mixed grasses on London Clay embankment, M25, England

~10. 0

van Beek et al. â€

Natural understory vegetation (Ulex parviflorus, Crataegus monogyna,

0. 5 – 6. 3

(2005)

Brachypodium var.) on hill slopes, Almudaina, Spain

van Beek et al. â€ (2005)

Vetiveria zizanoides, terraced hill slope, Almudaina, Spain

7. 5

Deciduous and Coniferous trees

Endo & Tsuruta â€ (1969) O'Loughlin & Ziemer â€ (1982) Riestenberg & Sovonick-Dunford * (1983) Schmidt et al. â€¡ (2001) Swanston* (1970) O'Loughlin* (1974)

Ziemer & Swanston â€¡§ (1977)

Burroughs & Thomas* (1977) Wu et al. â€¡ (1979)

Ziemer â€ (1981) Waldron & Dakessian*(1981) Gray & Megahanâ€¡ (1981) O'Loughlin et al. â€ (1982)

Waldron et al. â€ (1983)

Wu â€¡ (1984)

Abe & Iwamoto â€ (1986)

Buchanan & Savigny * (1990) Gray § (1995)

Schmidt et al. â€¡ (2001)

van Beak et al. â€ (2005)

Silt loam soils under alder (Alnus), nursery, Japan

Beech (Fagus sp.), forest-soil, New Zealand

Bouldery, silty clay colluvium under sugar maple (Acer saccharum) forest, Ohio, USA

Industrial deciduous forest, colluvial soil (sandy loam), Oregon, USA

Mountain till soils under hemlock (Tsuga mertensiana) and spruce (Picea sitchensis), Alaska, USA

Mountain till soils under conifers (Pseudotsuga menziesii), British Columbia, Canada

Sitka spruce (Picea sitchensis) – western hemlock (Tsuga heterophylla), Alaska, USA

Mountain and hill soils under coastal Douglas-fir and Rocky Mountain Douglas-fir (Pseudotsuga menziesii), West Oregon and Idaho, USA

Mountain till soils under cedar (Thuja plicata), hemlock (Tsuga mertensiana) and spruce (Picea sitchensis), Alaska, USA

Lodgepole pine (Pinus contorta), coastal sands, California, USA

Yellow pine (Pinus ponderosa) seedlings grown in small containers of clay loam.

Sandy loam soils under Ponderosa pine (Pinus ponderosa), Douglas-fir (Pseudotsuga menziesii) and Engelmann spruce (Picea engelmannii), Idaho, USA

Shallow stony loam till soils under mixed evergreen forests, New Zealand

Yellow pine (Pinus ponderosa) (54 months), laboratory

Hemlock (Tsuga sp.), Sitka spruce (Picea sitchensis) and yellow cedar (Thuja occidentalis), Alaska, USA

Cryptomeria japonica (sugi) on loamy sand (Kanto loam), Ibaraki Prefecture, Japan

Hemlock (Tsuga sp.), Douglas fir (Pseudotsuga), cedar (Thuja), glacial till soils, Washington, USA

Pinus contorta on coastal sand

Natural coniferous forest, colluvial soil (sandy loam), Oregon

Pinus halepensis, hill slopes, Almudaina, Spain

2. 0 – 12. 0

6. 6

5. 7

6. 8 – 23. 2

3. 4 – 4. 4

1. 0 – 3. 0

3. 5 – 6. 0

3. 0 – 17. 5

5. 9

3. 0 – 21. 0

5. 0

~ 10. 3

3. 3

3. 7 – 6. 4

5. 6 – 12. 6

1. 0 – 5. 0

2. 5 – 3. 0

2. 3

25. 6 – 94. 3

-0. 4 – 18. 2

* Back analysis and root density information. â€ In situ direct shear tests. â€ ¡ Root density information and vertical root model equations. & Laboratory shear tests.

Table 5. 1 Values of Cv for grasses, shrubs and trees as determined by field, laboratory tests, and mathematical models

In this parametric study apparent root cohesion (CR) was varied over the following range:

1 â‰¤ CR â‰¤ 5 kPa ; CR âˆˆ {1 kPa, 2 kPa, 3 kPa , 4 kPa , 5 kPa }

Three vegetation root depth zones (hR) were used namely:

hR âˆˆ {1 m, 2 m, 3 m}

A

C

BThe soil slope assumed as homogeneous slope. The case 1 soil slope (no vegetation cover on it) compared with the soil slope with vegetation cover on it.

Figure 5. 3 Slope failure plane through slope region

5. 3. 4 Vegetation layer entire surface

The case 2 condition applied the vegetation cover entire surface, the vegetation depth (hR) were 1 m and root cohesion were 1 kPa to 5 kPa. The same root cohesion applied to the case 3 and case 4 conditions.

C (kPa)

CR (kPa)

hR (kPa)

FOS

Case 1

15

0

0

1. 568

Case 2

15

1

1

1. 571

15

2

1

1. 575

15

3

1

1. 579

15

4

1

1. 582

15

5

1

1. 586

Case 3

15

1

2

1. 575

15

2

2

1. 583

15

3

2

1. 591

15

4

2

1. 599

15

5

2

1. 605

Case 4

15

1

3

1. 580

15

2

3

1. 593

15

3

3

1. 605

15

4

3

1. 618

15

5

3

1. 630

Table 5. 2 Slope Analysis results for Case 1, Case 2, Case 3 and Case 4.

Vegetation cover plays a significant role in slope stability analysis. The root cohesion experiments from various researchers over the past three decades results are shown in Table 5. 1. In this research only consider the grass and shrubs root reinforcement. The apparent root cohesion range is 1 kPa to 5 kPa. If we consider the bigger trees in slopes need to consider its weight for slope stability calculations. The Table 5. 2 shows the factor of safety analysis results for different root cohesion for different depths.

Figure 5. 4 Different root cohesion (CR) values for factor of safety for different root depths

The analysis carried out with the software tool SLOPE/W. The graph shows the influence of vegetation cover i. e. root cohesion (CR) and its root depth (hR). The soil slope without any vegetation cover (CR = 0 kPa), the factor of safety is 1. 570. This result shows the vegetation cover applied entire surface. The factor of safety linearly increase when increase with the root cohesion and root depth. The root cohesion and root depth has linear relationship with slope's factor of safety.

5. 3. 4 Vegetation layer only at slope surface and upper surface

C (kPa)

CR (kPa)

hR (kPa)

FOS

FOS

Case 6

Case 5

15

1

1

1. 571

1. 569

15

2

1

1. 575

1. 572

15

3

1

1. 579

1. 574

15

4

1

1. 582

1. 576

15

5

1

1. 586

1. 578

15

1

2

1. 575

1. 572

15

2

2

1. 583

1. 577

15

3

2

1. 591

1. 581

15

4

2

1. 598

1. 586

15

5

2

1. 605

1. 591

Table 5. 3 Slope Analysis results for Case 6 and case 5

The vegetation layer only considered at slope surface and upper surface, analysis carried out with SLOPE/W tool. The case 6 analysis results same as the case 2 and case 3. The results not affect with toe vegetation (section C at Figure 5. 3) because failure plane only at section A and B section at Figure 5. 3. So only influence with slope vegetation layer and upper surface vegetation layer in this slope analysis.

The vegetation layer only at slope surface analysis results (case 6) compared with vegetation only at slope condition (case 5) shows lesser factor of safety values. The slope's upper surface vegetation has considerable influence in slope stability.

5. 3. 4 Vegetation layer only at toe

C (kPa)

CR (kPa)

hR (kPa)

FOS

Vegetation layer only at toe

15

1

1

1. 568

15

2

1

1. 568

15

3

1

1. 568

15

4

1

1. 568

15

5

1

1. 568

15

1

2

1. 568

15

2

2

1. 568

15

3

2

1. 568

15

4

2

1. 568

15

5

2

1. 568

Table 5. 4 Slope Analysis results for Vegetation layer only at toe

The SLOPE/W analysis shows (Table 5. 5) for vegetation at toe Figure 5. 1 section C. All the results for different depths and different root cohesion values are the same. The failure plane of this analysis only at section A & B. So there is no influence with the toe vegetation. If the failure plane goes to section only toe vegetation influence in slope stabilization.

5. 3. 5 Slope failure plane through toe

C

B

A

Figure 5. 5 Slope failure plane through toe

CR (kPa)

Vegetation at toe

hR (kPa)

FOS

1

1

1. 619

2

1

1. 624

3

1

1. 628

4

1

1. 632

5

1

1. 636

1

2

1. 621

2

2

1. 626

3

2

1. 632

4

2

1. 637

5

2

1. 642

Table 5. 5 Slope Analysis results for failure plane through toe region, Vegetation layer only at toe

This slope analysis failure surface was set through slope toe using entry and exit method. The Figure 5. 5 shows clearly the failure plane, the failure region cover the entire region (A, B & C). The vegetation layer applied at toe region for this analysis. The FOS increase with the increasing root cohesion and root depth, but there is no changes observed from the previous analysis, which is the failure plane only at section B & C Figure 5. 1. So the vegetation layer influent with the slope failure surface.