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Stability Analysis of Road-cut Slope (A Case Study of Jiling Landslide along the Galchi-Trishuli-Mailung-Syaprubeshi Rasuwagadi Road)

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Abstract

Infrastructure development is a prerequisite for the economic, social, and cultural transformation of a country. Traditionally, infrastructure development has only referred to construction work, but nowadays, infrastructure development is seen as a means to stimulate the economy and shall be sustainable. All three levels of government formed after the implementation of federalism in Nepal are working with a high priority on the construction of road infrastructure. The road construction is currently causing floods and landslides due to the failure to pay special attention to the construction of safe and reliable roads through the use of the latest technology according to scientific and engineering standards. The road asset management principle also deals with the use of a reliable and sustainable approach for the construction of the road. The conventional techniques that we are adopting for slope stabilization have not seemed economical and viable for the long run. Hence, this study searches the alternative approaches for slope stabilization. The study area lies in Jiling of Nuwakot district along the Galchi-Trishuli-Mailung-Syaprubeshi-Rasuwagadi. The Jiling Landslide area was found to be a vulnerable zone for slope instability. This study focuses on the stability analysis and probable remedial measures using ground anchors. To determine the physical and mechanical properties of soils field survey, investigation, and laboratory test was carried out. The factor of safety for the cut slope was determined for different anticipated conditions. The result shows that stability of the slope decreases with an increase in groundwater level, increase in unit weight, decrease in cohesion strength, and decrease in friction angle. The critical slope factor of safety increases to 1.52 from 0.809 after the application of ground anchors.

Keywords

Slope stability, Slope/W, Factor of Safety (FOS), Cohesion, Internal Friction Angle, Slope Stabilization

1. Introduction

Infrastructure development is a prerequisite for the economic, social, and cultural transformation of a country. Traditionally, infrastructure development has only referred to construction work, but nowadays, infrastructure development is seen as a means to stimulate the economy. All three levels of government formed after the implementation of federalism in Nepal are working with a high priority on the construction of road infrastructure. As Nepal Himalaya is one of the most tectonically and seismically active mountain chains in the world having complex geological and geotechnical conditions with frequent slope failure posed due to different natural and anthropogenic causes. Slope instability issues have consequent effects on the socio-economic development of the people and the region on a large scale. Geologically young fold mountains, especially those experiencing humid climates with seasonally intense rainfall, are among the steepest and unstable landscapes in the world. The problems encountered include steep and irregular topography, and difficult excavation and founding conditions due to the deeply weathered and transported nature of many of the soils. Intense and prolonged rainfall leads to locally high groundwater tables, saturated soils, and large quantities of surface runoff during the wet season[1] These problems are usually compounded by land sliding, erosion, river flooding, river incision, and periodic seismicity.

Nepal is a country where the road network has expanded rapidly since a couple of decades ago. In this regard, construction and maintenance of the roads in the hilly areas have been a challenge to all the tiers of government who focus on road construction and maintenance. The system of developing road infrastructure without following even the principles of general engineering has caused floods and landslides. The different authorities who are responsible for the road construction hesitate to pay special attention to the construction of safe and reliable roads through the use of the latest technology according to scientific and engineering standards. Due to which the country has to bear the huge loss of life and property. Road design, construction, and maintenance under Himalayan conditions require a different approach to that conventionally adopted for less severe flat or rolling terrains. The basic engineering principles remain the same but the design parameters and design priorities are quite different in a mountainous region like ours (TRL, 1997)[2]. The scenario also shows that the road construction and road maintenance cost is increased in areas where instability is a natural process and very common. In this context, we shall adopt a design that is appropriate to the terrain, with a good expectation that it will stand up to the forms and intensity of instability experienced in the region. Presently some of the roads have remained in place due to costly investments in construction and maintenance and some roads have suffered such instability that they have ruined the environment and have become impassable for long periods. Currently, the length of strategic roads in the country is 13,448 km. Out of this; 6,979 km is blacktopped, 2,277 km Gravel, and 4,192 km. Besides the strategic road, there is about 62 thousand km of provincial and local roads, out of which 3,981 km. blacktopped, 13,654 km. Gravel road, and 44,152 km. is earthen (NPC, 2020). In FY-2076/77, 44.9 percent of the total budget (about Rs. 688 million) has been allocated for development programs and in FY 2077/78, 35.4 percent of the total budget has been allocated[3][4]. A large part of the development budget is spent on road infrastructure. There is still no road access to one district headquarters and 28 administrative centers of local levels. Also, there is no fair-weather road connection to 263 local level administrative centers. There is still 4,000 km of roads that need to be expanded or upgraded and in some sections, new tracks need to be opened to blacktopped standard connecting the local level administrative center to the national or provincial road network[5]. Even though billions of rupees have been invested, we have not been able to get the return and service that should have been received from the road. There are some important issues in not getting the benefit according to the investment. One of the main reasons is the need to build roads in hilly areas using limited resources with conventional approaches and such roads are blocked due to landslides during the rainy season. It is not enough to simply apply conventional practices to construct the all-weather road in countries like Nepal. We need to make the road networks across the country usable at a minimum cost. The road asset management principle also deals with the use of a reliable and sustainable approach for the preservation of road assets. The conventional techniques that we are adopting do not seem economical and viable for the long run. Hence for optimizing the cost of road maintenance and construction new technology such as mechanical stabilization of slope should be introduced in our context. The objective of this study is to find the potential failure mechanism, slope stability analysis, determination of slope sensitivity towards different triggering factors, designing of the optimal slope with regards to safety reliability of the selected study area.

2. Study Area

The study area lies in Jiling of Nuwakot district along the Galchi-Trishuli-Mailung-Syaprubeshi-Rasuwagadi Landslide. The Jiling Landslide area is taken is vulnerable zone for the slope instability along that road section in about of total length of 470m. The first zone (Zone 1) of 200m is considered as the most critical zone, second zone (Zone 2) consists of 70m and third zone (Zone 3).T he maximum affected length of slope is 45m with average slope angle of 37 degree. The Slope Mass consists of 5-8m thick Colluviums deposit over rock bed and the site is covered by the thin vegetation. The threat seen on the study area is mass wasting and gully formation and damage of the road junction. There is instability of natural slope along the road section. To keep the road operational throughout the year and prevent road asset losses, further mass wasting is needed to be prevented, hence slope stability analysis is required and required to recommend probable solution measures.

Figure 1: Topographic map of landslide area with image

3. Literature Review

The shortest road alignment is not always necessarily being the easiest, quickest or cheapest option to construct or maintain the road. Topography, slope stability, flood hazard and erosion potential are likely to be the most significant controls on the choice of the most suitable alignment and design of cross-section in country like Nepal. Variations in geology and slope greatly influence road design and hence the cost of construction and these variations can occur over very short lengths of alignment in hilly region. Road geometry, earthworks, retaining structures and drainage measures must be designed in such a manner as to cause the least impact on the stability of the surrounding slopes and natural drainage systems. Excessive blasting, cutting, side tipping of spoil and concentrated or uncontrolled road drainage often lead to accelerated instability and erosion. Although many of these effects are often unavoidable to a certain extent, the design and the construction method adopted should aim to minimize them. Slope failures may involve two or more mechanisms, occurring either at different places on the slope, at different depths or at different times due to changes in ground conditions once initial failure has occurred. Furthermore, the engineering significance of a slope failure will vary according to whether it is a first-time or reactivated failure. First-time failures have an immediate effect on roads in their path but may not represent a continual maintenance problem because the failed mass may come to rest at an angle significantly lower than that from which it failed, and remain stable unless disturbed by toe erosion or seismic shaking. Reactivated slope failures on the other hand, and those that are expanding upslope due to progressive failure, are often the most problematic for road construction and maintenance.

3.1 Slope failure

Shallow soil falls, rock falls and rockslides, up to a depth of a few meters, tend to occur with intermediate or high frequency. Soil falls occur frequently from undercut river terrace banks and steep cuttings in soil, while rock falls are common on steep slopes formed in fractured rock, and especially from cut slopes during heavy rain[6]. Shallow rockslides usually occur as planar failures along adversely dipping bedding, foliation or joint surfaces, or as wedge failures along intersecting joint planes. Debris slides are shallow planar failures in granular soils. Despite being the most frequent hazards encountered, debris slides and shallow slope erosion usually have little more than a nuisance effect on mountain roads. Debris slides usually occur in the soil or weathered mantle in response to toe erosion, rapid saturation of granular soils or a release of negative pore pressures during heavy rain in more fine-grained materials. Slip surfaces often occur along the interface between the weathered mantle or colluvium and the underlying rock. Debris slides are frequently found in the heads of eroding gullies and are subsequently quickly incorporated into an expanding drainage system. Mudslides are shallow planar failures in fine-grained, cohesive materials such as weathered mudstones and shales. They are often triggered by undrained loading caused by failed material being deposited from above, or by toe erosion. Due to the predominance of granular non-cohesive soils on mountain slopes, mudslides tend to be infrequent. The term rotational slide describes the mechanism of circular failure in fine-grained, cohesive soils and argillaceous rocks. Shallow rotational failures are almost exclusively confined to the more clayey colluvial soils and weathered mudstones. Deep-seated rotational slides are comparatively rare due to the preponderance of structurally-controlled planar or wedge failure, although they can form important components of complex failures in highly fractured rock masses when a single discontinuity or wedge structure. Road construction can have significant effects on slope stability, drainage, erosion and sediment supply to drainage networks[7]. Studies from the Himalayas in Nepal and India indicate that cut slope failures after construction can generate an average of 500m3/km/yr of debris, and that up to 2,000m3/km/yr can be generated during single storms with 10-20 year recurrence intervals. Erosion rates in small catchments significantly affected by road construction can be at least 10 times those expected under natural conditions[2].

3.2 Limit Equilibrium and Finite Element Method of slope analyses

Limit equilibrium analyses are the most commonly used techniques in analysis of the slope stability. The popularity of limit equilibrium methods comes from their simplicity, ability to evaluate the sensitivity of stability to input parameters by using minimum input data. Despite its benefits, the limit-equilibrium approach has some prominent deficiencies, such as the technique ignores stress-strain behavior soils. As well, it makes arbitrary assumptions to provide statically determinate condition. Slope stability analysis using the finite element method is widely recognized in the literature for many years[8]. In slope stability analysis, the main advantage of finite element method than that of limit equilibrium methods is that no assumption is to be made about shape or location of the failure surface, slice side forces and their directions in FEM[8].

3.3 Slope Stability Analysis

Analysis of slopes in Nepal is commonly performed using Limit Equilibrium methods. The limit equilibrium methods of soil slope stability analysis used in geotechnical practice investigate the equilibrium of a soil mass tending to move down slope under the influence of gravity. A comparison is made between forces, moments, or stresses tending to cause instability of the mass, and those that resist instability. Two-dimensional (2-D) sections are analyzed and plane strain conditions are assumed. These methods assume that the shear strengths of the materials along the potential failure surface are governed by linear (Mohr-Coulomb) Limit equilibrium analyses assume the factor of safety is the same along the entire slip surface. A value of factor of safety greater than 1.0 indicates that the slope is stable with respect to sliding along the assumed particular slip surface. A value of factor of safety less than 1.0 indicates that the slope is unstable[9].

3.4 Ground anchors and anchored systems

A prestressed grouted ground anchor is a structural element installed in soil or rock that is used to transmit an applied tensile load into the ground. Permanent anchored systems are generally having a service life of 75 to 100 years; hence they can be cost efficient in long run and has low maintenance cost in future[10]. Ground anchors are often used in combination with walls, horizontal beams, or concrete blocks to stabilize slopes and landslides[10]. Horizontal beams or concrete blocks may be used to transfer the ground anchor loads to the ground at the slope surface[10] Grouted ground anchors, referenced simply as ground anchors, are installed in grout filled drill holes. Grouted ground anchors are also referred to as “tiebacks”. The basic components of a grouted ground anchor include the: (1) anchorage; (2) free stressing (unbounded) length; and (3) bond length. These and other components of a ground anchor are shown schematically in Figure 10. The anchorage is the combined system of anchor head, bearing plate, and trumpet that is capable of transmitting the prestressing force from the prestressing steel (bar or strand) to the ground surface or the supported structure. Anchorage components for a bar tendon and a strand tendon are shown in Figure 11 and Figure 12 respectively. The unbounded length is that portion of the prestressing steel that is free to elongate elastically and transfer the resisting force from the bond length to the structure. A bond breaker is a smooth plastic sleeve that is placed over the tendon in the unbounded length to prevent the prestressing steel from bonding to the surrounding grout. It enables the prestressing steel in the unbounded length to elongate without obstruction during testing and stressing and leaves the prestressing steel unbounded after lock-off. The tendon bond length is that length of the prestressing steel that is bonded to the grout and is capable of transmitting the applied tensile load into the ground. The anchor bond length should be located behind the critical failure surface. The anchor rod has advantages than other method due to its simplicity in construction, being fast and has minimum cost that other methods[11]. Conventionally methods of slices are used for the analysis of the slope, but when the anchors are installed they are treates as the point load, which may lead to abrupt changes in the normal stress strain distribution on the potential slip surface. Such abrupt change are not reasonable and doesnot reflect the actual field condition[11]. Lay out of the acnhors greatly influenced the factor of safety[12]. The increase of anchor length from top to its bottom can improve the FoS more effectively than the decrease of the anchor length[12]. Placing the anchors in the lower part of a slope effects the FoS greatly and to minimize the engineering costs, the anchors at the mid-lower part of slope should not be lengthened indefinitely, hence the anchors at the lower part of the slope should not be shortened arbitarily[12].

4. Research Methodology

The thesis works start with the desk study of the slope stability issues, challenges and probable remedial measures for minimizing it in context of Nepal. The document published by the different department of Government of Nepal was reviewed first before starting the actual work. Literature review was carried out to judge the probable remedial measure for the slope stability. The soil data, topographic survey data and drone survey image were collected from the Department of Road (DoR). The methodology include the preparation of the contour map of the entire slope to determine the geometry and assessing the soil characteristics over the slope by collecting fairly representative sample and determining the input soil parameter. The numerical analysis is carried out using limit equilibrium computer software. Various Excel based software's are used for the quick calculation, data formatting, listing, and manipulation. The result from the analysis is interrelated and interpreted and based on that a probable remedial measure was suggested.

Table 1: Slope stability analysis procedure[13]

S.N	Step
1	Data preparation
2	Data input
3	Material properties
4	Analysis
5	Design option
6	Back analysis
7	Sensitivity analysis

5. Result and Discussion

The available data shows that the most of the soil layers are found to be cohesion less (C) 3.0 KN/m. The angle of internal friction of the soil up to 4.5 m is found to be 29.04 degree and below is rock. The bulk unit weight of the soil is known to as 18.5 KN/m3. Natural Moisture Contents of the soil ranged from 27.53 to 28.44 percent. Similarly, Specific Gravity of soil is in the range of 2.51 to 2.55. The above shows that the soil falls in well graded or poorly graded gravelly sand and strength parameter gives the medium strength. Natural Moisture Contents of the soil ranged from 27.53 percent to 28.44 percent at the time of July. Direct Shear Test was conducted on disturbed representative samples. The most of the soil layers are found to be cohesion less with angle of internal friction of 29.04 and cohesion of 3.0 KN/m2. The strength parameter leads to give medium shear strength value and the soil is with medium denseness. From the field data the soil found to be a cohesionless and hence analyzed for the liquefaction susceptibility. Based on the factor of safety against liquefaction given by Seed and Idris (1971)[14], it is concluded that during the anticipated earth quake the in situ soil is not susceptible to liquefaction. The site is geologically located in middle mountain range and the rock materials are almost Sandstones.

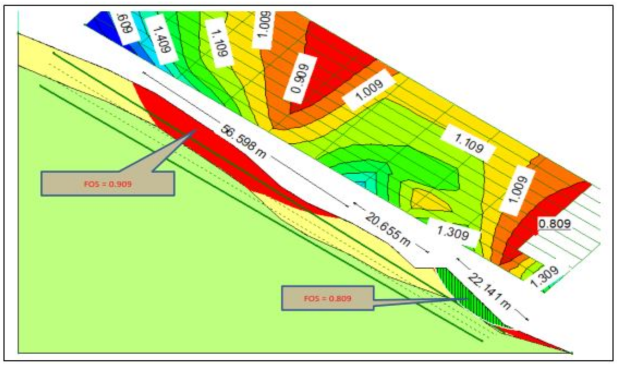

Figure 2: Numerical Modeling of the slope at chainage 0+280 (Slope/w)

5.1 Slope stability analysis

The GeO5 software and Slope/w software is used for the analysis. The slope stability analysis of the slope was performed on the cross-section from the topographic survey using limit equilibrium method. The actual cross-section was imported into the Slope/w software and based on that cross-section stability analysis was carried out. The factor of safety of the slope above the road found to be 0.909 and that of the slope below the road is found to be 0.809.Effect of soil Cohesion, water table, Internal Friction Angle, unit weight etc on the Factor of Safety is analyzed.

5.2 Slope Model Analysis

From the field investigation it was noticed that there was rock exposed in some part although it is not continue in all of the area. The most critical cross-section of the slope at chain age 0+280 is

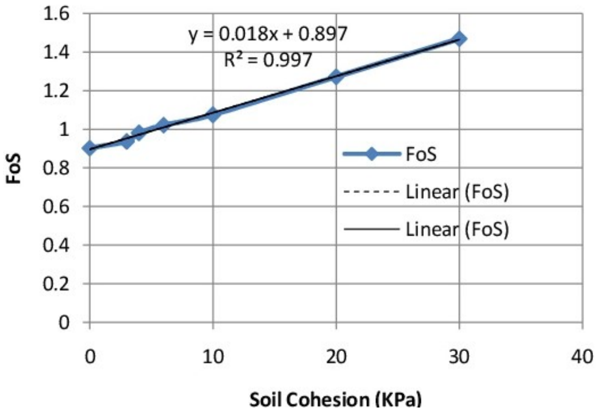

Figure 3: Effect of soil cohesion on factor of safety

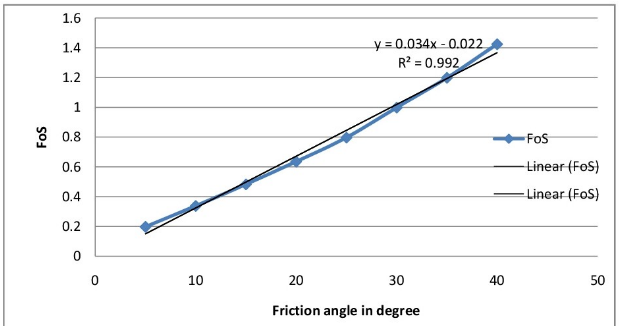

Figure 4: Effect of angle of internal friction on factor of safety

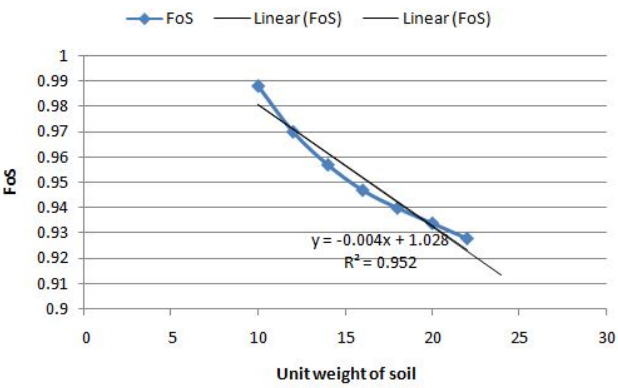

Figure 5: Effect of unit weight of soil on factor of safety

consider for the critical analysis of the slope and the slope stability measures will be design based on that slope. Slice force information required for the ground anchor design is taken from the Slope/w software and the ground anchor is design based on FHWA,1999[10] with following arrangement. After the application of ground anchor the factor of safety reaches to 1.52.

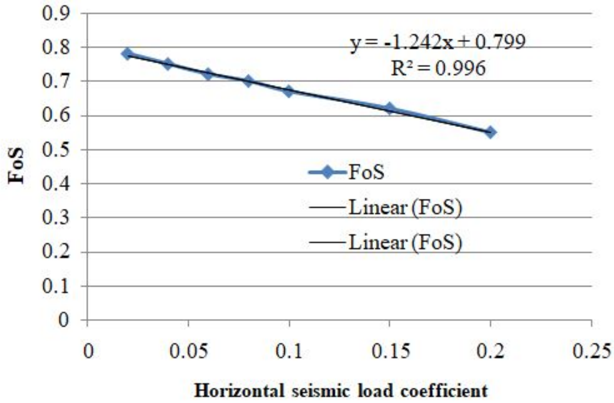

Figure 6: Effect of seismic load variation in FOS

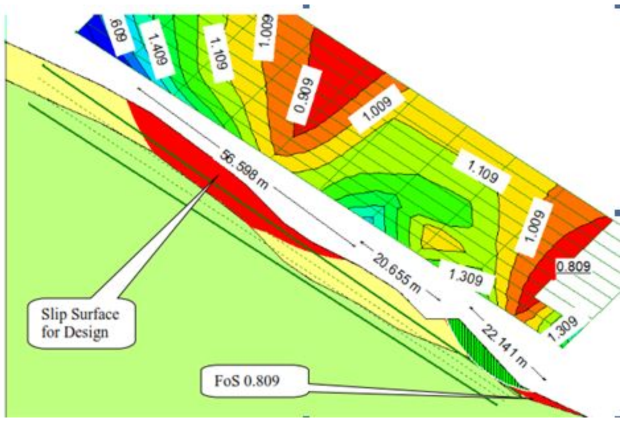

Figure 7: Contour of the FOS along the critical failure slope at chainage 0+280

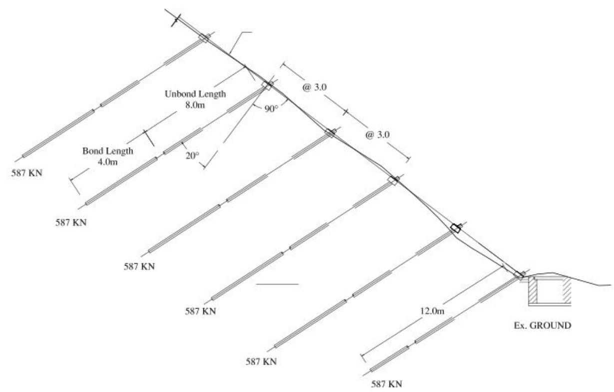

Figure 8: Arrangement of ground anchor

6. Conclusion

The slope sections are very high landslide susceptibility hence requires the preventive measures. From the results of numerical calculations, it is found that the different parameters studied have significant influence on the stability of cut slope, especially increase in ground water table highly reduce the factor of safety of slope. When selecting a cost-effective, sustainable treatment for road slope stabilization, both the short- and long-term costs need to be considered. Permanent anchored systems are generally having a service life of 75 to 100 years; hence they can be cost efficient in long run and has low maintenance cost in future[10]. In this case ground anchorage system is chosen for road slope stabilization treatment because it disturbs the least amount of soil, keeps topsoil on site, reuses on-site vegetation to strengthen the slope and will be cost effective in long run.

References

[1] Ranjan Kumar Dahal, Shuichi Hasegawa, Takuro Masuda, and Minoru Yamanaka. Roadside slope failures in nepal during torrential rainfall and their mitigation. 2006.

[2] Transport Research Laboratory (TRL). *Principels of Low Cost Road Engineering in Mountainous Regions, with Special Reference to the Nepal Himalaya*. TRL, 1997.

[3] Government of Nepal. *Budget Speech-2076*. GoN, Ministry of Finance, 2019.

[4] Government of Nepal. *Budget Speech-2077*. GoN, Ministry of Finance, 2020.

[5] Natioanl Planning Comission. *Fifteenth Plan (2076/77-2080/81)*. GoN, NPC, 2020.

[6] Deoja, B. et.al. Mountain risk engineering handbook. 1991.

[7] Robert Hack. Geophysics for slope stability. 2000.

[8] Liu.et.al. Slope stability analysis using the limit equilibrium method. 2014.

[9] JICA. *The Study on Disaster Risk Management for Narayangharh-Mugling Highway (Technical Guide)*. JICA, 2005.

[10] FHWA. *Ground Anchors and Anchored Systems*. Federal Highway Administration-FHWA, 1999.

[11] Zhang, Rui et.al. Stability analysis of anchored soil slope based on finite element limit equilibrium method. 2016.

[12] Dongliang He.et.al. Effect of anchor layouts on the safety factor and slip surface of slope. 2018.

[13] Department of Road. *Roadside geotechnical problems: A practical guide to their solution*. GoN, MoPIT, Department of Road (DoR), 2009.

[14] Steven L. Kramer. *Geotechnical Earthquake Engineering*. Pearson India Education Services Pvt. Ltd., 2007.