LANDSLIDE RISK MANAGEMENT AND OHIO DATABASE

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Dissertation

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ABSTRACT

Landslides or slope/embankment failures along highways present potential safety and operational hazards. Road closures or detours due to the landslides impact the regional economy when services and commercial goods cannot be distributed to their destinations and the extra fuel and maintenance costs for additional mileages due to road detours. With the limited resources to the Ohio Department of Transportation (ODOT), it becomes imperative that a decision-making tool is developed to effectively manage the landslide hazards impacting highways in Ohio. The objective of this research study is to develop a landslide risk management system. An innovative web-enabled database, built upon GIS platform is developed for real-time managing of landslide spatial and temporal data. A landslide hazard rating system has been developed to provide a means to numerically score and rate the relative hazard or risk level of each site. The associated statistical and cluster analysis results of 37 Ohio landslide sites collected as a pilot database validates the effectiveness of the rating system.

An alternative method to assist decision-making is also developed for managing the risks of potential highway slope failures. Usually, decision to manage risk on the failed highway project depends on many parameters. Some of them are based expert opinion and difficult to quantify and standardize. Relying only on expert experience may result in bias and irrational decision. In this dissertation, a method to deal with expert opinion was proposed. The linguistic fuzzy technique is used to transform the expert judgment into numerical values. The application of multi-criteria decision function standardizes the qualitative and quantitative parameters; therefore, the parameters (criteria) having different units can be combined. The importance of each risk parameter is determined using the factor analysis technique. It essentially involves the use of the best linear combination of the parameters to account for variance in data. The information of 37 landslide sites in Ohio is also used to illustrate the application of the developed method. It is shown that the multi-criteria decision making approach, in conjunction with factor analysis techniques can promote rationale decision-making for managing the risk of potentials roadway slope failures.

DEDICATION

Dedicated to my parents

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This dissertation cannot be accomplished without help and encouragement by these people. First of all, I would like to express my appreciation to my advisor, Professor Robert Liang, for his guidance, vision, inspiration, motivation and generous support. I have learned a lot from him, not only in engineering disciplines but also a person of a great merit. What I have learned from him is a life-time experience that I can use for the rest of my life.

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CHAPTER I

INTRODUCTION

1.1 Statement of the Problem

Landslides or embankment/slope failures may take place on highways due to a variety of reasons. For example, the natural slope or man-made embankment may deteriorate overtime due to causes such as improper compaction of fill, use of improper materials that are prone to deterioration. Other causes, such as heavy rainfalls, overloading, and erosion at the toe of a slope may also trigger landslide of slope instability. The highway agencies need to develop a strategy to provide preventive maintenance to avoid on-set of large or catastrophic slope failures. Furthermore, with limited financial resources, the highway agencies are forced in a position to make rational decision on the priority of landslide (slope failure) maintenance and remediation activities. The decision-making and prioritizing the landslide/slope failure related construction/ design projects requires the development of a framework for gathering and integrating the relevant data as well as a ranking tool for the known landslide sites.

The failures of the highway embankments can exert an adverse impact on other highway structures, such as pavement and bridges. As a result of landslide or slope failure, pavement surface may become undulated, developing cracks and dips, which would cause loss of driving control leading to car accident, fatalities and property loss. Similarly, a bridge structure may become unstable due to the failure of the abutment slope or the nearby landslide. Road closure due to repairing the failed roadway slope requires the traveling vehicles to take detours, resulting in loss in time, additional fuel cost, and diminished commercial activities. Thus, preventing slope failure by timely maintenance or repairing/stabilizing a slope before on-set of a large-scale slope movement should be a goal of the office in charge of state highway system.

In the state of Ohio, the Department of Transportation (ODOT) is responsible for maintaining its highway system consisting of over 19,000 miles of roadways. Most of these roadways were built in the 1960s and 1970s. Aging embankments and deteriorating highway slopes have forced ODOT to spend a large amount of fund to repair the unstable slopes. The Office of Geotechnical Engineering (OGE) of ODOT is in charge of developing a comprehensive geological hazard management system (GHMS) to enable better management of data and activities related to planning, design, construction, and maintenance of both existing and new highway infrastructures.

Landslide is one of five geological hazards to be eventually included in GHMS. The five geological hazards include rockfalls, landslides, underground mines, karst, and shoreline erosion. The guiding requirements of the GHMS are established to encompass: (a) maintain a comprehensive inventory of geological hazards, (b) establish and enforce routine monitoring schedules, (c) create risk assessment matrix for each geological hazard type, (d) generate cost-benefit scenarios, (e) provide support to decision-making for routine prioritization, (f) provide support to construction during new development and remediation projects, (g) preserve historical hazard data, and (h) enable information exchange with diverse groups of users. This dissertation contains the results of research and development efforts toward the landslide geohazards.

1.2 Objectives of the Study

- Development of a user-friendly field form for site reconnaissance report: This form will be used to collect information pertinent to landslide sites to include attributes such as physical properties, material properties, historical data, etc. The information collected should be useful for subsequent assessment of landslide hazard as well as for future study. The collection of site information is done either using a portable PC or through a hand-held GPS unit.
- Development of a web enabled, GIS based landslide database: The development of such a database provides means for ODOT engineers or consultants to collect, sort, query, and manipulate landslide information. This also allows all parties (ODOT engineers and consultants) to have ready access to the landslide database.
- Development of a field validated landslide hazard rating system: The rating is based on numerical scores of both quantitative data and qualitative judgment to take into account the potential hazard of landslide on the safety of roadways, adjacent structures and properties. The validity of the developed numerical rating matrix is established through extensive statistical analysis of a pilot data set of 37 landslide sites in Ohio.
- Development of a user-friendly manual for landslide reconnaissance and risk assessment, and GIS and internet database management.
- Development of a risk management approach for failed highway slope remediation. The proposed methodology can simplify expert opinion that usually provides useful information in decision making. The development provides the mean for treatment of these parameters before they are combined. The importance

of each proposed risk parameter is also determined. The finding would reduce bias in selection of risk parameters. Therefore, highway agencies can be more rationale in decision-making in project selection. The proposed methodology would be expected to minimize loss of highway agency fund and promote more highway operational safety.

1.3 Organization of the Dissertation

- Chapter I provides the statement of the problem to be addressed in this study, together with the specific objectives and tasks to be accomplished. The organization of the dissertation is also outlined in this chapter.
- Chapter II provides a literature review of related research. The basic understanding of the classification of landslides and typical landslide types in a highway system is presented. A review of previous efforts in the development of landslide rating system and a landslide risk management approach by other agencies is summarized in this chapter as well.
- Chapter III presents the development of the user friendly field reconnaissance form for ODOT use. The flow chart showing the process of collecting landslide site information is presented.
- Chapter IV presents the development of the landslide hazard rating system for ODOT use. Six factors are adopted in the rating system. Statistical analyses of a pilot database set consisting of 37 landslide sites compiled in this study are performed to verify the reasonableness of the rating system.

- Chapter V presents the structure of the developed web-enabled, GIS based landslide database. Information pertinent to the building blocks of the system is provided in this chapter. The detailed instructions on how to navigate the website for different user groups are provided in the User's Manual.
- Chapter VI presents the development of multi-criteria decision making and factor analysis approach for highway slope management.
- Chapter VII provides a summary of the major research results. The recommendations for implementations and future research directions are also presented at the end of this chapter.

CHAPTER II

BACKGROUNDS AND LITERATURE REVIEWS

2.1 Overview

This chapter provides background and review of literature that relates to the development of the landslide hazard rating system for the purpose of prioritization of remediation for slope failures. The types of landslides and their corresponding features are discussed. The principles of landslide management and the early works on the hazard slope rating systems are discussed as well.

2.2 Landslide Mitigation Needs

The term landslide is understood as "the movement of a mass of rock, debris or earth down a slope". The slope failure can be triggered by a number of external stimuli, such as earthquake shaking, intense rainfall, storm waves, stream erosion, etc. These activities can cause a rapid increase in driving shear stress or decrease in resisting shear strength of slope-forming materials. The long-term factors, such as vegetation cover, drainage conditions, climate, weathering, human activities (e.g., construction), also play a major role in making the slope susceptible to failure. Landslides are of primary concern because they have caused a large number of casualties and huge economic losses throughout the world. Although continuous efforts are being made to mitigate the losses due to landslides, the trend of considerable economic losses due to the occurrence of severe landslide hazards is expected to continue. The reasons are mainly due to increased urbanization and development in landslide–prone areas as a consequence of population expansion, continued deforestation of landslide-prone areas, and increased regional precipitation caused by changing climatic patterns (Dai, et al. 2002).

Efforts are being made by public sector, private sector, local administrations with full involvement of Geoscientists, Engineers, Researchers in the development of the system that can be implemented for the reduction of losses caused by landslides. The United States Geological Survey (USGS) has taken the lead in developing the National Landslide Hazard Mitigation Strategy in response to the significant losses resulting from landslide hazards in the United States on behalf of the large multisector, multiagency stakeholder groups involved in landslide hazard mitigation.

The implementation of effective planning and management systems could reduce both social and economic losses from landslide (Dai, et al. 2002). In the state of California, losses due to landslides were reduced to around 90% by implementing approaches that included (i) restriction of development in landslide-prone areas, (ii) use of excavation, grading, landscaping, and construction codes, (iii) use of physical measures to prevent landslides, and (iv) development of warning systems. It is also important to figure out and prioritize landslide-prone areas based on severity, elements at risk, and loss that may occur. Based on this list of priority landslide areas, financial resources could be judiciously used to remedy these landslide-prone areas.

National Landslide Hazard Mitigation strategy developed by USGS in response to the rising costs resulting form landslide hazards in the United States includes developing new partnerships among government at all levels, academia, and the private sector and expanding landslide research, mapping, assessment, real-time monitoring, forecasting, information management and dissemination, mitigation tools, and emergency preparedness and advances. Such strategy uses new technological advances and utilizes incentives for the adoption of loss reduction measures nationwide.

2.3 Factor Stimulating Landslides

Landslides or slope failures are usually not the result of a single causal factor; therefore, proper understanding of all possible contributing factors is important. The effects of all stimulating factors with the changing time span to the stability of slopes can be understood by categorizing causes into slow changing and fast changing processes. The pertinent literature review generally emphasizes the importance of the fundamental knowledge of the factors that govern the slope stability transition from stable to unstable state.

2.3.1 Stability of Slopes

There are several factors that trigger downslope movement and oppose forces that tend to resist movement. Factor of safety for the stability of slopes can be obtained by comparing the downslope shear stress with the shear strength of the soil, along an assumed or known surface of rupture. Popescu (1994) has given an example of variation of factor of safety as a function of time for a given slope as shown in Figure 2.1 It explains the seasonal long-term and sudden short-term variation in the slope stability due to the several external and internal causal factors. The stability of slopes is divided into stable, marginally stable and actively unstable slopes. Slopes that have sufficiently high margin of stability to withstand all destabilizing forces are stable slopes. Slopes that fail at some time in response to the destabilizing forces attaining certain level of activity that is judged by probability distribution curves of the factor of safety are marginally stable slopes. In case where the destabilizing forces produce continuous movement are actively unstable slopes. Though the computed value of the factor of safety results in the clear distinction between stable and unstable slope; physically, slopes existing in any of the three states can be best visualized with the proper understanding of the above concept.

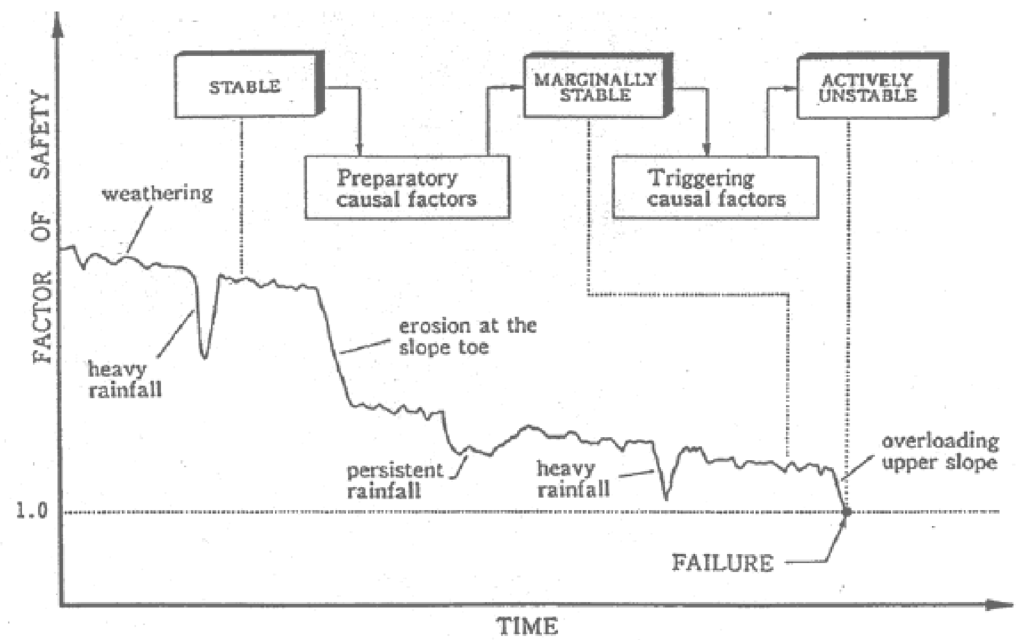


Figure 2.1 Changes of the factor of safety with time (Popescu, 1994)

2.3.2 Landslide Causal Factors

Various types of slope movements reflect a wide range of factors responsible for shifting a slope from stable state to unstable state. Correct recognition of conditions that made the slope unstable is of primary importance as it helps figuring out the most appropriate remediation option. The classification of a framework for understanding the various causal factors of landslides based on the three stability stages is described by Popescu (1994) and Dai, et al. (2002) into two groups as: Preparatory variables and Triggering variables. Preparatory variables are causal factors, which make the slope susceptible to failure without actually initiating it and thereby tending to place the slope in a marginally stable state. This may include geology, slope gradient and aspect, vegetation cover, soil geotechnical properties, drainage patterns and weathering. The triggering causal factors are those, which initiate the movement by shifting the slope from a marginally stable to an unstable state. These types of variables are very difficult to estimate as it may change in a very short time span.

Though slow changes due to preparatory causes considerably participate in the process of reduction of slope stability, the process that provokes greatest rate of change in short span of time should be focused as it involves sudden triggering mechanism that leads to the slope failure. A brief list of landslide causal factor is summarized in Table 2.1, which is arranged in four practical groups for easy understanding of the processes involved as well as for helping categorize the remediation alternatives.

Table 2.1 A brief list of landslide causal factors (Popescu, 1994)

1. GROUND CONDITIONS
(1) Plastic weak material (2) Sensitive material (3) Collapsible material (4) Weathered material (5) Sheared material (6) Jointed and fissured material (7) Adversely oriented mass discontinuities (including bedding, schistosity, cleavage) (8) Adversely oriented structural discontinuities (including faults, unconformities, flexural shears, sedimentary contacts) (9) Contrast in permeability and its effects on ground water contrast in stiffness (stiff, dense material over plastic material)
2. GEOMORPHOLOGOCAL PROCESSES
(1) Tectonic uplift (2) Volcanic uplift (3) Glacial rebound (4) Fluvial erosion of the slope toe (5) Wave erosion of the slope toe (6) Glacial erosion of the slope toe (7) Erosion of the lateral margins (8) Subterranean erosion (solution, piping) (9) Deposition loading of the slope or its crest (10) Vegetation removal (by erosion, forest fire, drought)
3. PHYSICAL PROCESSES
(1) Intense, short period rainfall (2) Rapid melt of deep snow (3) Prolonged high precipitation (4) Rapid drawdown following floods, high tides or breaching of natural dams (5) Earthquake (6) Volcanic eruption (7) Breaching of crater lakes (8) Thawing of permafrost (9) Freeze and thaw watering (10) Shrink and swell weathering of expansive soils
4. MAN-MADE PROCESSES
(1) Excavation of the slope or its toe (2) Loading of the slope or its crest (3) Drawdown (of reservoirs) (4) Irrigation (5) Defective maintenance of drainage systems (6) Water leakage from services (water supplies, sewers, stormwater drains) (7) Vegetation removal (deforestation) (8) Mining and quarrying (open pits or underground galleries) (9) Creation of dumps of very loose waste (10) Artificial vibration (including traffic, pile driving, heavy machinery)

2.4 Classification and Types of Landslides

Varnes (1978) developed the criteria for classification of landslides, based on the types of movements and types of materials involved. According to Varnes, a landslide can be classified using two words. The first word describes the material and the second word describes the type of movement, as shown in Table 2.2. The definition of the terms used in Table 2.2 is further explained in Table 2.3. The movements are divided into five categories: *falls, topples, slides, spreads, and flows*. The sixth type of movement originally proposed by Varnes (1978) has been substituted by a complex movement as a combination of the five types of movement. The five kinematically distinct landslide movements are described by Cruden and Varnes (1996) as shown in Figure 2.2.

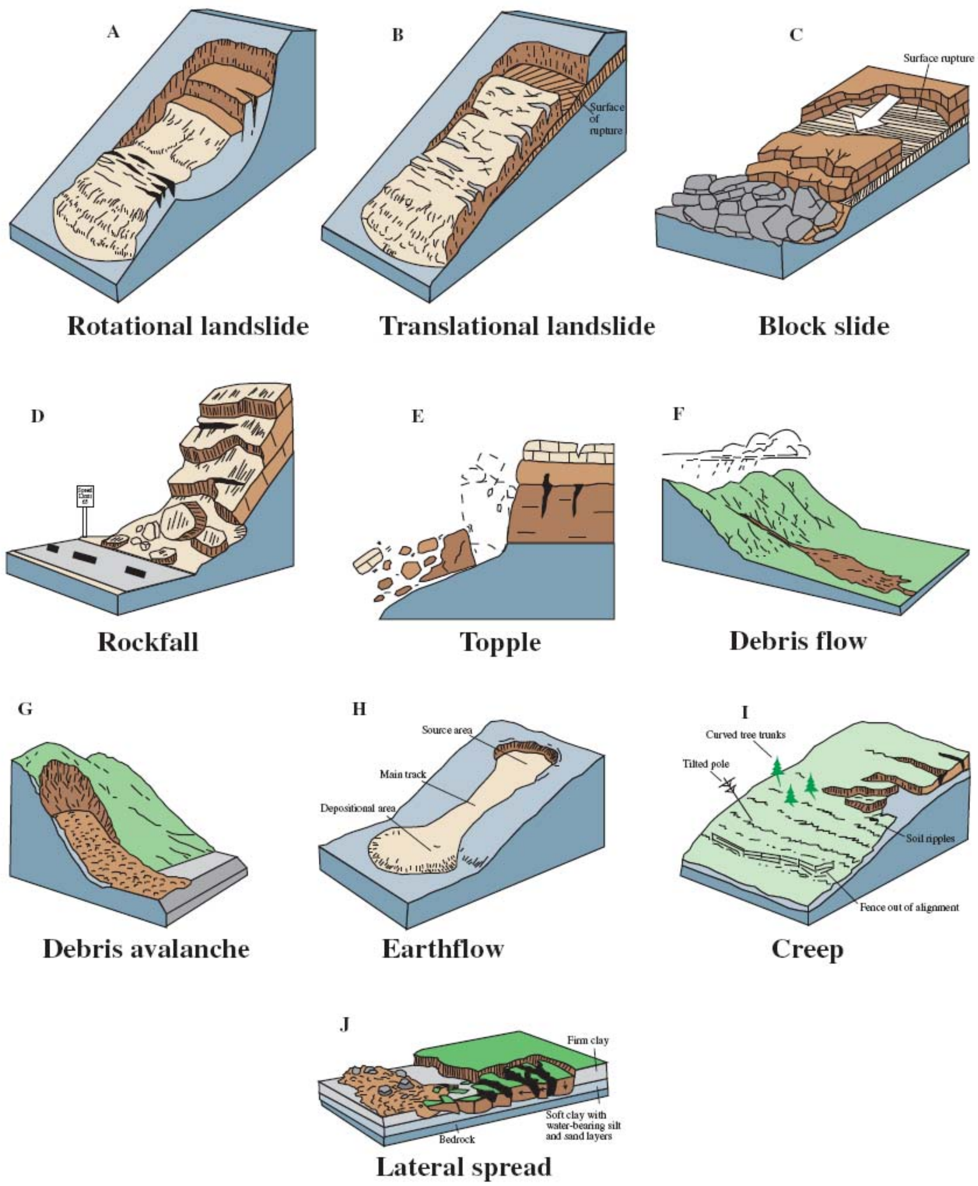


Figure 2.2 Types of landslides (USGS Fact Sheet 2004-3072)

Table 2.2 Abbreviated classification of slope movements (Cruden and Vernes, 1996)

Types of movements		Types of materials		
		Bedrock	Engineering slope	
			Predominantly coarse	Predominantly fine
Fall		Rock fall	Debris fall	Earth fall
Topples		Rock topple	Debris topple	Earth topple
Spread		Rock spread	Debris spread	Earth spread
Flow		Rock flow	Debris flow	Earth flow
Slides	Rotational slide	Rock slump	Debris slump	Earth slump
	Translation slide/ Wedge	Rock block slide	Debris block slide	Earth block slide
		Rock slide	Debris slide	Earth slide
Complex		Combination of two or more principal types of movement		

Table 2.3 Material types (Cruden and Varnes, 1996)

Material	Characteristics
Rock	A hard or firm mass that was intact and in its natural place before initiation of movement.
Soil	An aggregate of solid particles, generally of minerals and rock that either was transported or was formed by the weathering of rock in place.
Earth	Material with 80% or more of the particles is smaller than 2 mm, the upper limit of sand size particles.
Debris	Material contains a significant proportion of coarse material; 20% to 80% of the particles are larger than 2 mm and the remainders are larger than 2 mm.

2.4.1 Fall

A fall (Figure 2.2 D) is the detachment of soil or rock from a steep slope along a surface, on which little or no shear displacement takes place. The soil or rock material descends through the air by falling, bouncing, or rolling. Movement is very rapid to extremely rapid. Except when the displaced mass has been undercut, falling will be preceded by small sliding or toppling movements that separate the displacing material from the undisturbed mass. Undercutting typically occurs in cohesive soil or rocks at the toe of a cliff undergoing wave attack or in eroding riverbank.

2.4.2 Topple

A topple (Figure 2.2 E) is the forward rotation out of the slope of a mass of soil or rock about a point or axis below the center of gravity of the displaced mass. Toppling is sometimes driven by gravity exerted by the material upslope of the displaced mass, and sometimes by water or ice in cracks in the displaced mass, depending on geometry of the moving mass, the geometry of the surface of separation, and the orientation and extent of the kinematically active discontinuities. Topples range from extremely slow to extremely rapid, sometimes accelerating throughout the movement.

2.4.3 Slide

A slide is down slope movement of a soil or rock mass occurring dominantly on surfaces of rupture or on relatively thin zone of intense shear strain. Movement does not occur simultaneously over the whole of what eventually becomes the surface of rupture; the volume of displacing material enlarges from an area of local failure. Often the early sign of ground movement is cracks in the original ground surface along which the main scarp of slide forms. Varnes (1978) emphasized the distinction between rotational and translational slides as significant for stability analysis and control methods.

Rotational slides (Figure 2.2 A) move along the surface of rupture that is curved and concave. If the surface of rupture is circular or cycloidal in profile, kinematics dictates that the displaced mass must move along the surface with little internal deformation. The head of displaced material may move almost vertically downward, whereas the upper surface of the displaced material tilts backward toward the scarp. If the slide extends for a considerable distance along the slope perpendicular to the direction of motion, the surface of rupture may be roughly cylindrical. The axis of the cylindrical surface is parallel to the axis about which the slide rotates.

Translational slides (Figure 2.2 B) are the cases where the failure mass is displaced along a planar or undulating surface of rupture, sliding out and over the original ground surface. Translational slides are usually relatively shallower than rotational slides. Therefore, the ratio of depth to length of the translational slides is typically less than 0.1. The surfaces of rupture of translational slides are often broadly channel shaped in cross section. Whereas the rotation of a rotational slide tends to restore the displaced mass to equilibrium, translational slide may continue unchecked if the surface of separation is sufficiently inclined. As translational sliding continues, the displaced mass may break up, particularly if its velocity or water content increases. The disrupted mass may then flow, becoming a debris flow rather than a slide. Translational sliding often follows discontinuities such as fault, joints, or bedding surfaces, or the contact between rock and residual or transported soils. Translational slides on a single discontinuity in rock masses are called block slides (Figure 2.2 C). The moving mass of a block slide consists of a single unit or a few closely relate units that move downslope as a relatively coherent mass.

2.4.4 Spread

The term spread (Figure 2.2 J) was introduced by Terzaghi and Peck (1948) to describe sudden movements on water-bearing seam of sand or silt overlain by homogeneous clay or loaded by fills. *Spread* is defined as an extension of a cohesive soil or rock mass combined with a general subsidence of the fractured mass of cohesive material into softer underlying material. The surface of rupture is not a surface of intense shear. Spread may result from liquefaction or flow of softer material. Varnes (1978) distinguished spread typical of rock, which extended without forming identifiable surface of rupture, from movement in cohesive soils overlaying liquefied materials or material flowing plastically. The cohesive material may also subside, translate, rotate, disintegrate, or liquefy and flow. Clearly those movements are complex, but they are sufficiently common in certain materials and geological situation that the concept of spread is worth recognizing as a separate type of movement.

2.4.5 Flow

Flow is spatially continuous movement, in which surfaces of shear are short-lived, closely spaced and usually not preserved. The distribution of velocities in the displacing mass resembles that in viscous liquid. The lower boundary of the displaced mass may be a surface along which appreciable differential movement has taken place, or a thick zone of distributed shear. Thus, there is gradation from slides to flows depending on water content, mobility, and the evolution of the movement. Debris slides may become extremely rapid *debris flow* or *debris avalanches* as the displaced material loses cohesion, gains water, or encounters steep slopes (Figure 2.2 F and G).

Varnes (1978) used the term *earth flow* (Figure 2.2 H) and slow earth flow to describe “the somewhat drier and slower earth flows in plastic earth…common…wherever there is …clay or weathered clay-bearing rocks, moderate slopes, and adequate moisture.” *Creep* is the imperceptibly slow, steady, downward movement of slope-forming soil or rock. Movement is caused by shear stress sufficient to produce permanent deformation, but too small to produce shear failure. There are generally three types of creeps: (1) seasonal, where movement is within the depth of soil affected by seasonal changes in soil moisture and soil temperature; (2) continuous, where shear stress continuously exceeds the strength of the material; and (3) progressive, where slopes are reaching the point of failure as other types of mass movements. Creep is indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences, and small soil ripples or ridges (Figure. 2.2 I).

2.5 Landslide Prone Locations

The typical landslide prone areas and the typical sign of landslide movements are reported by FHWA (1988), as shown in Figures 2.3 and 2.4. The vulnerable locations of landslides are often related to the geometry of the slope, geologic conditions, and hydrogeology. This section provides typical areas that landslides are more prone to occur.

2.5.1 Under Cutting Rock Slope Where Bedding Planes Dip Toward the Roadway (Figure 2.3A)

When bedding planes of a geologic formation dip into the roadway undercut in such a way to produce an unsupported toe, slippage along weakened planes in the formation will occur.

2.5.2 Natural Occurring Spring (Figure 2.3B)

Sping located at the toe of embankment may soften the soil, causing it to lose strength and allowing the embankment to fail. If springs occur at the toe of a cut slope, on the uphill side of an embankment, the side-hill embankment may become saturated and fail.

2.5.3 Side-Hill Cut-and-Fill Sections (Figures 2.3C, 2.3D and 2.3E)

Side-hill cut and cut-and-fill sections are particularly prone to landslides. The toe of the cut slope on the uphill side is subject to erosion and loss of toe support (undercutting). The side-hill fill portion of a cut-and-fill section may be weakened by ground –water saturation. Also, if the interface between the original ground and the fill material is not constructed properly (benched), failure of the fill may occur along that plane.

2.5.4 Poorly Drained Location (Figure 2.3F)

Drainage is one of the most important factors involving landslides. Subsurface water may saturate and weaken the soil of embankment, foundation, and natural soils.

The result is often a landslide. Surface water, if not properly drained away from the earth structure, may saturate the soil or infiltrate rock structure, causing slope failure as well.

2.5.5 Vertical or Nearly Vertical Rock Faces Near Roadway (Figure 2.3G)

The locations shown in Figure 2.3G are always hazardous because of the proximity of the rock face to the roadway. Potential for rock debris is always present. Ditches are usually clogged, and debris often fall into the driving surface. Many rock falls are due to weathering, either from freezing and thawing or from differences in the rate of weathering between soft soil and rock layers and competent (strong) rock layer.

2.5.6 Very High Fill (Figure 2.3H)

When highway embankments or fills are over approximately 20 feet in height, the embankment will creep or slump under its own weight. This happens over a very long period of time (10 -20 years). Usually the sides of the embankment develop a noticeable bulge. The surface of the roadway may have a slight “dip”.

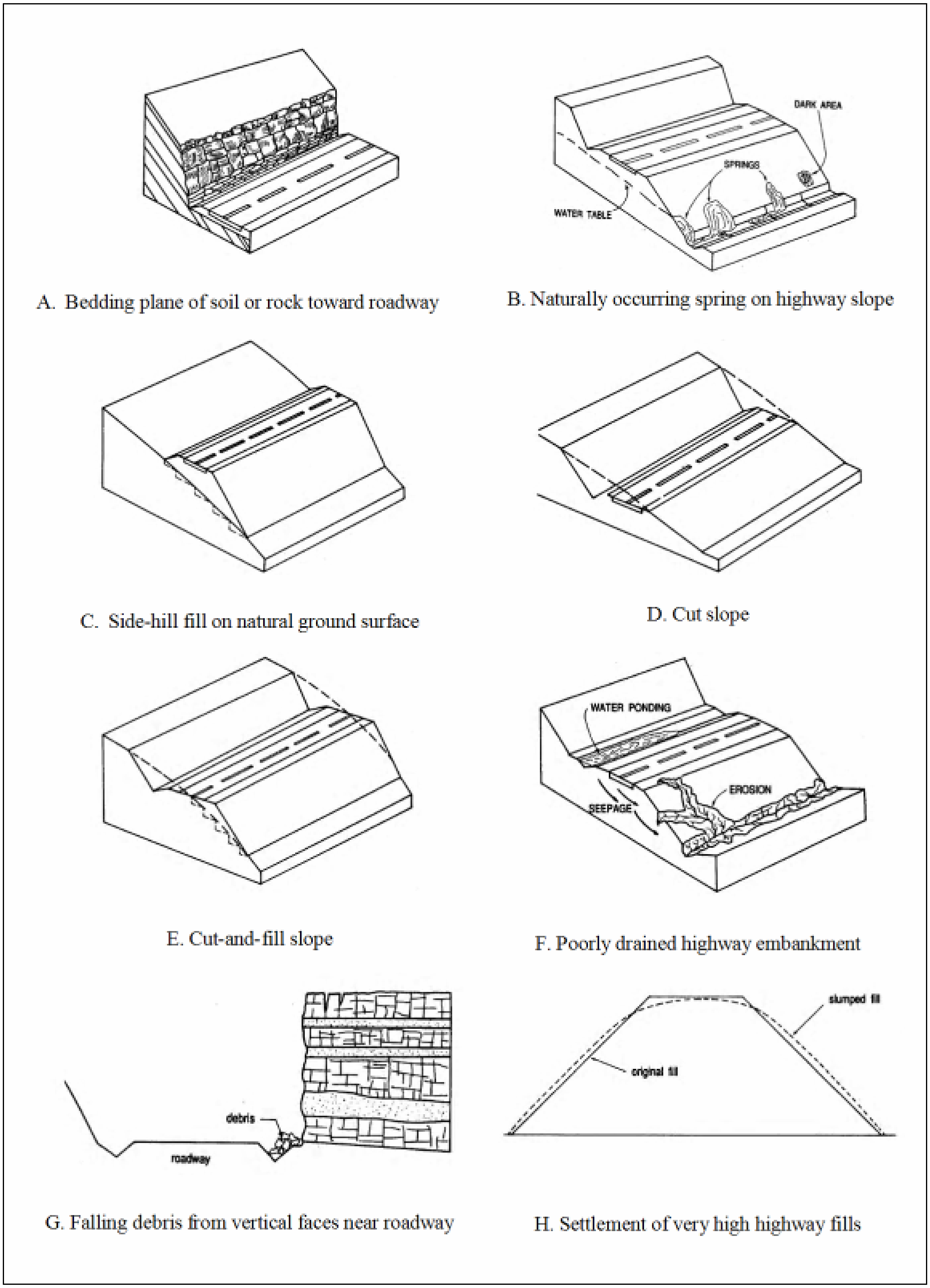


Figure 2.3 Vulnerability locations of landslides FHWA (1988)

2.6 Signs of Slope Movement

Many landslides do not occur without some advanced warning. Maintenance personnel should be trained to look for these signs. If a slide is discovered in the early stages, steps often may be taken to prevent further slope movement, thus preventing major failure and saving the cost of extensive repair.

2.6.1 Tension Cracks on Roadway or on Slope above the Roadway (Figure 2.4A)

Soil is very weak in tension and it only takes a small amount of movement at the top of a slope before the soil breaks and a crack forms. Tension cracks on the roadway indicate that movement has started. These cracks permit water to enter to soften materials along the failure plane as well as to add additional water pressure to the moving mass. Tension cracks above the roadway indicate that the natural slope or cut slope is in the early stage of movement.

2.6.2 Escarpments in or Above the Roadway (Figure 2.4B)

Escarpments indicate that the mass of soil or rock has already failed and moved. Some landslides will have more than one escarpment, as the soil mass often has a tendency to move in blocks.

2.6.3 Sunken Guardrail (Figure 2.4C)

Guardrails are installed to match the grade of the roadway. If there is an obvious dip in the guardrail, but none is observed in the roadway, this probably indicates that shallow movement is occurring within the embankment, involving only the shoulder but not the driving lanes. However, if there is an obvious dip on the roadway, this would indicate a major portion of the embankment is involved in the movement. Dips of the guardrail at bridge approaches indicate that the approach embankment and/or foundation have settled or the embankment is creeping.

2.6.4 Dips in Grade (Figure 2.4D)

For long and high embankments, dips in the grade usually involve all driving lanes. This type of movement may be associated with slumping or creeping of the embankment under its own weight. Dips in grade also may be associated with culverts located under large fills. In many cases, these dips may be attributed to settlement of the backfill around the culvert and are not related to slump or creep.

2.6.5 Debris on Roadway

Debris of soil or rock on the roadway may indicate an existence of unstable slope above the roadway. The presence of debris could be the forerunner of massive rockfall or slide. A continuing problem of debris on the roadway requires maintenance personnel to report to his/her supervisor.

2.6.6 Bulge Above, on, or below Roadway (Figure 2.4E)

Most slides in soil masses will have bulge at the toe of the slide where the sliding mass has accumulated and piled up. This bulge indicates considerable movement already has occurred and that movement will probably continue until complete failure occurs.

2.6.7 Poor Drainage (surface water)

Blocked Culverts: A blocked culvert does not permit water to flow properly, which in turn may cause water to pond next to the toe of embankments. This condition tends to facilitate saturation of the embankment toe, causing the soil to lose strength and hindering the ability of the soil at the toe to resist the weight of the soil on slope. Consequently, a landslide may result.

Broken Paved Ditches (Figure 2.3F): Paved ditches that are broken permit surface water to flow under the ditch. This may erode the embankment or permit surface water to saturate portions of the embankment.

Water Ponding above, below, on and in Median of Roadway: Ponding water is always an undesirable source of water. Water ponding above the roadway may cause a cut slope to become saturated and slide onto the roadway. Water ponding in a ditch or in a median may saturate the entire embankment or further saturate a weakened failure plane of the embankment. Water ponding at the toe of the embankment tends to weaken the toe and cause landslide.

Drainage Structure with Water Discharging onto Slope (Figure 2.4G): Pipes, culverts, ditches, or other drainage structures that permit water to flow onto an unprotected embankment or slope may be a major factor in causing landslides. Water from these structures may saturate soils or severely erode the slope.

2.6.8 Poor Drainage (Subsurface Water)

Spring on or at Toes of Slopes (Figure 2.4H): Springs indicate the presence of the ground-water table intercepting the ground surface. Spring may also indicate that water from a water-bearing rock formation has saturated a portion of embankment or cut slope. Area around springs is particularly vulnerable to landslides.

Light and Dark Areas on Slopes: Different colors may indicate distinct differences in the amount of water from one area of the slope to another. The area containing the greater amount of water is more vulnerable to landslides.

Vegetation (Figure 2.4I): The type or condition of vegetation growing on slopes may indicate the presence of subsurface water. Cattails or willow trees are plants indicative of subsurface water. Grassy areas on a slope that stay green on the dry season are sometimes an indication of subsurface water.

2.6.9 Erosion (Figure 2.4J)

Toe of Embankment Slopes: Surface water from paved ditches or other drainage structures may erode the toe of an embankment, removing supporting soil and causing a landslide.

Toe of Cut Slopes: Rapidly flowing water in drainage ditches often causes severe erosion at the toe of cut slopes. Also, poor practices in cleaning ditches may undercut the toe of the cut slopes or the embankments, which can cause landslides.

On Slopes or Embankments: Surface water from broken paved ditches or other drainage structures often is the source of the erosion. Poor maintenance practices are usually the cause of this type of erosion.

2.6.10 Change in Features (Figures 2.4K and 2.4L)

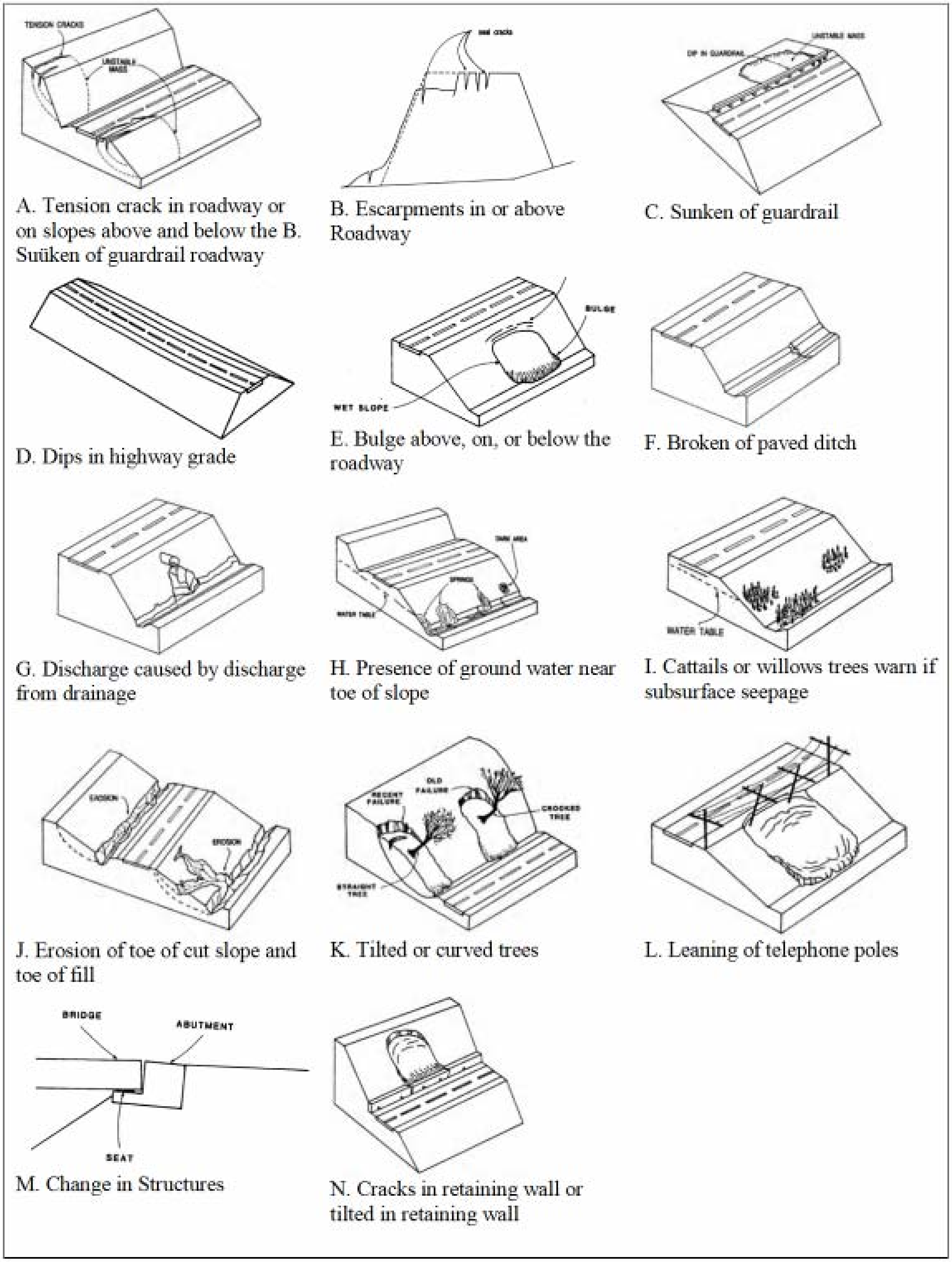
More subtle signs of earth movements may be trees that are tilted from vertical. Tilted trees at the toe of a slope that are now growing vertically indicate an old landslide that had moved years ago. However, the movement has stopped and the tree is now growing vertically again. A tree growing in a continuous gentle curve may indicate a very gradual and slow creeping movement. Telephone poles and fence that have sunken or tiled out of alignment are also good indicators of earth movement.

2.6.11 Changes in Structures

Bridge (Figure 2.4M): Bridge abutments that tilt in relation to the bridge beams or abutments that move toward the end of the bridge beams are indications that the approach embankment is moving or creeping toward the bridge. Settlement of bridge approach pavement slabs indicates that the approach embankment is settling or slumping.

Retaining Walls (Figure 2.4N): If the soil continues to move excessively, the wall tilts from the vertical position and, in the severe case, the retaining wall may overturn. Cracks in retaining wall may be evidence of soil movement behind the wall.

Building: Building located in the slide areas may provide evidence of earth movements. The most noticeable evidences are cracks in the foundations or in masonry walls. Buildings also may rise or fall in elevation, depending on their locations in the slide area.



A. Tension crack in roadway or on slopes above and below the B. Suüken of guardrail roadway

B. Escarpments in or above Roadway

C. Sunken of guardrail

D. Dips in highway grade

E. Bulge above, on, or below the roadway

F. Broken of paved ditch

G. Discharge caused by discharge from drainage

H. Presence of ground water near toe of slope

I. Cattails or willows trees warn if subsurface seepage

J. Erosion of toe of cut slope and toe of fill

K. Tilted or curved trees

L. Leaning of telephone poles

M. Change in Structures

N. Cracks in retaining wall or tilted in retaining wall

Figure 2.4 Signs of movements (FHWA 1988)

2.7 Concepts of Landslide Risk Management

Risk is an inherent element of all engineering systems, which cannot be predicted with certainty and cannot be totally eliminated. The hazards may result in adverse consequences such as injury, fatalities, economic losses and environmental damage. Risk management is a discipline needed for addressing the problem of slope failures. The performance of a slope is predominately controlled by uncertainty of soil properties, geologic setting, environmental conditions, etc. The assessment of performance of a slope not only relies on quantitative data, but also on empiricisms, judgment, and experiences.

Casagrande elucidated the process of recognizing and dealing with risks, which include two steps as follows: (i) The use of imperfect knowledge, which is guided by judgment and experience, to estimate the probable ranges for all pertinent quantities that enter into the solution of problem, (ii) The decision can be made on the basis of the appropriate margin of safety, or degree of risk, taking into consideration of economic factors and the magnitude of losses that would result from the failure.

Fell and Hartfort, (1997) suggested three basic structures of landslide risk management: (i) risk analysis, (ii) risk assessment, and (iii) risk management. The risk analysis can be practiced in many levels ranging from qualitative to quantitative evaluation (Aleotti and Chowdhury (1999) and Dai et al. (2002)). However, the ultimate aim of the risk analysis is to provide a judgment basis for measuring how safe a slope is. Risk assessment has the main objective of deciding whether to accept, or to treat the risk, or to set the priorities. The decision on acceptable risk involves the responsibility of the owner, client or regulator, based on risk comparison, treatment options, benefits, tradeoff, potential loss of lives and properties, etc. Risk management is the final stage of landslide risk management, at which the decision-maker decides whether to accept the risk or require the risk treatment. The risk treatment may include the following options (AGS, 2000): (i) accepting risk (ii) avoiding risk, (iii) reducing the likelihood, (iv) reducing consequences, (v) monitoring and warning system, (vi) transfering the risk, and (vii) postponing the decision.

2.8 Application of Database and GIS towards Landslide Risk Management

A database is an organized collection of records and can be called as a type of electronic filing system that enables efficient and quick retrieval of data. GIS is software that stores information about the world as a collection of themed layers that can be used together. These layers can contain features such as type of soil, land use, vegetation, population, etc. Effective integration of database and GIS can make possible for the geological hazard mitigation. The integration of database and GIS is possible because GIS software is developed considering several user-friendly features required for extraordinarily effective applications. Compilation of comprehensive landslide hazard information in electronic database aids the State Highway Departments in prevention and maintenance of landslide problems to a considerable extent.

Oregon DOT and Indiana DOT have generated an inventory database for the collection of landslide pertinent data linked to the GIS maps. These GIS maps can project the wide spread area with identification of landslide susceptible zones based on the organized, field collected data, on a sheet of paper with various scales which is easy to read and analyze.

Tennessee DOT has developed GIS application for the management of landslides along the Tennessee highways. This application includes the development of a statewide spatio-temporal landslide database and the production and visualization of landslide thematic maps accessible via the Internet. Essential information pertaining to a landslide included ‘attribute data’, such as type of slide, surfacial geology, remedial actions taken, and associated costs, and ‘temporal data’ such as dates of landslide activity and remedial actions, and ‘spatial data’ such as geographic location of the landslide, site special geological conditions and nearby related features. The GIS landslide inventory is then linked with the above-mentioned attribute, temporal and spatial data in a spatio-temporal database for cataloging, visualizing and managing landslides along the State Routes and Interstate Highways. Integration of spatio-temporal database with GIS is done using a custom script that is a small program used to customize projects and applications. GIS has served as the integrating platform for the entire landslide database management, query and analysis functions. GIS also provides links to the temporal database engine, digital photography, and other information. From the GIS interface, user may search for the landslide records using queries based on spatial, temporal, geotechnical or administrative types of information defined for landslides.

Kentucky Transportation Cabinet (KyTC) together with the University of Kentucky has also carried out similar type of work. The database developed by KyTC consists of rock slope, landslide and soil and rock engineering data and programmed procedures linked to the database are used to identify hazardous conditions and for risk management of landslides and rock slopes. One of the major components of database includes rockfall hazard rating system. All the components of the rockfall hazard rating system have been programmed into the Geotechnical Database using Graphical User Interface (GUI) screens. Total score is automatically tabulated after the user has entered data for all parameters. As the colored photographs of sites, such as landslide and rockfall sites, can provide valuable visual information, the feature of storing photographs is also enclosed in the database. Other visual images embedded in the database include county maps showing major highway routes of Kentucky. Since latitude and longitude of each site is obtained using GPS equipment, the locations and distributions of hazardous rock slope and landslides are displayed on roadways of the embedded maps. The developed programs can display multiple GIS layers such as roads, landslides, rockfall sites, geotechnical borings, streams, and boundaries.

As explained by Dikau, et al. (1996), the primary task to use databases and GIS in landslide research is to use temporal and spatial inventories of landslides and related information for the elaboration of landslide susceptibility and hazard models and for the analysis of landslide time series in relation to triggering factors. They gave a comprehensive explanation of temporal and spatial aspects for landslide prediction using GIS. It can help understand the landslide hazard model that expresses the probability and the extent of the occurrence within a specific period of time and within a given area of a potential landslide. Databases are used for effective storage and retrieval of time-related data, which are used for qualitative modeling of magnitude –frequency relationships and rainfall and landslide activity time series analyses.

Dikau, et al. (1996) stated that despite of high degree of uncertainty associated with spatial and temporal modeling, there are clear necessities to use computer tools in landslides research, especially with respect to the integration of high amounts of present and future data. This focuses on the utilization of efficient applications of computer tools like GIS and databases for the effective implementation of geological hazard mitigation strategy.

Westen (2000) emphasized that GIS is an essential tool in the data analysis and the subsequent hazard assessment. Making use of GIS techniques, three methodological approaches are differentiated: heuristic qualitative approach for small scale regional surveys, statistical quantitative approaches for medium scale surveys, and deterministic approach for detailed studies at large scale. Hazard zonation defined as the mapping area with an equal probability of occurrence of landslides within a specified period of time is carried out with the above mentioned three approaches.

2.9 Review of Existing Landslide Rating Systems

There are many agencies that have developed the landslide hazard rating system. However, each of them was developed to fit local or regional geological settings, traffic condition, population density, etc. Furthermore, the persons who developed the systems may have different experience and background knowledge in dealing with landslide issues.

Nevertheless, most landslide hazard rating systems were developed on the basis of assessing the impact of the landslides using selected criteria and weighting values. Most of applications were intended to provide the quantitative assessment of hazard potential to aid decision making. The high priority sites are those sites with urgency for mitigation. In the following sections, several existing landslide hazard rating system are reviewed.

2.9.1 Landslide Management in Hong Kong

Hong Kong developed a numerical rating system in 1988 for landslide. Slope failure problems in Hong Kong are severe because it has 60% of land steeper than 15 degree and about 40% greater than 30 degree. Hong Kong is also intense in urbanization. Thus, potential risk of loss of property, life and economy is relatively high due to a landslide. Hong Kong used three systems to classify slopes; including ranking system, squatter area, and classification of undeveloped land, which can be found in Tables A.1, A.2, A.3 and A.4 in Appendix A, respectively.

2.9.1.1 Ranking Systems For Cut and Fill Slopes

Hong Kong rates cut and fill slope, differently. The ranking system for cut slope was developed based on an assessment of failure consequence along with the assessment of its failure potential. The consequence score was to account for the risk to life in the event of the failure. The instability score was used to reflect the associated risk of landslide occurring. The sum of the consequence and instability score was used to account for both consequence and risk of failure.

The ranking system for fill slopes in Hong Kong takes two aspects of slopes into consideration: (i) the fill slopes with insufficient compaction and (ii) the fill slopes without enough protection system against infiltration of rainfall, groundwater, leakage of drainage pipe, etc. The score for ranking the fill slopes in Hong Kong is called “x” score.

The limitations of the cut slope ranking can be summarized as follows. In the high rank slopes, the consequence score may be high but the score of instability may be low. Furthermore, the system may not be suitable for other areas that urbanization is not as severe as in Hong Kong. The data used to calculate the score are subjective by its nature, which was further interpreted when assigning the weightings. Some slopes could be rated in either substantial higher or lower score than it should be. The system accounts for the proximity of a building to the slope and its use intended. However, the construction method of the building was not considered. It could be argued that a brick or timber structure would be more at risk than a reinforced concrete structure. Also, a building at the crest of a slope may be less prone to damage if it was supported on deep rather than shallow foundations.

2.9.1.2 Classification of Squatter Area

The classification of squatter area is for slopes in Hong Kong that are formed poorly. Especially, accessibility and subsequent works of these slopes are difficult without removing the structures at risk. The squatter areas in Hong Kong are usually occupied by the poor residents and usually have slopes steeper than 30 degrees. The criteria for classifying the terrain are given to allow the Hong Kong government to assign the priority and the development schemes.

2.9.1.3 Classification of Undeveloped Land

Hong Kong Government developed the program to classify its terrain. It is developed based on Geotechnical Land Use Maps (GLUM) at the scale of 1:20,000, which categorizes the terrain into four classes depending on slope angle, slope forming materials, hydrology and evidence of past instability. The assigned GLUM class indicates the general level of geotechnical limitations on the particular land unit for planning purposes. It is intended for technical and non-technical users.

2.9.2 Oregon Department of Transportation

Oregon Department of Transportation (Oregon DOT) developed a rockfall hazard rating system in early 1980's with financial aid from many state DOTs. More than 3,000 rockfall locations were inventoried. The system adopted six processes for slope management: (i) slope inventory, (ii) preliminary rating, (iii) detailed rating, (iv) preliminary design and cost estimate, (v) project identification and development, and (vi) annual review and update. Preliminary rating and detail rating are used during the rating process.

2.9.2.1 Preliminary Rating

The *preliminary rating* considers the following classification criteria.

- *A-Rating* is the risk range from moderate to high, where rock fall activity must be obvious.
- *B-Rating* characterizes the risk from low to moderate. Although rock fall from slope is possible, the frequency is low enough, or the roadside is large so that the rock fall is far from reaching the highway.
- *C-Rating* is used for rockfall that is unlikely to reach a roadway.

2.9.2.2 Detail Rating

The detail rating includes 12 different factors, such as slope height, ditch effectiveness, average vehicle risk, percent decision sight distance, roadway width, geologic characteristics, block size of quantity of rockfall per event, climate and presence of water in slope, and rockfall history. The exponential scoring system (3, 9, 27, and 81) was used. The total score of 12 factors represents the risk of a rockfall location. The exponential scoring system can rapidly distinguishes the more hazardous sites from others. Some factors adopt a set of continuum points in stead of only the discrete points listed above. This allows the users to more flexibility in evaluating the site condition.

Oregon DOT released the later version in 2001, for both landslides and rockfalls. The objectives of the new version is as follows: (i) develop a scoring system for rating landslides and rockfalls, (ii) develop a project selection process, (iii) develop database of landslides and rockfalls, and (iv) develop GIS database for managing unstable slope problem. The original version was merged in to the new version. The rating system of Oregon DOT also takes the historical information and benefit and cost ratio of a slope stabilization scheme into consideration. The new Oregon DOT slope rating system is summarized as follows.

- Determination of hazard scoring system is based on five categories: (i) Failure Hazard/ Speed of Failure, (ii) Roadway impact, (iii) Annual Maintenance Frequency, (iv) Average Daily Traffic, (v) Accident History.
- Hazard score modification factors are used to determine the final score. The modification factors consider the highway classification factor based on

importance of different highway classes, as well as the maintenance benefit-cost factor.

- Sorted final scores and a list of additional factors that may influence project selection, such as culvert impacts, environment impacts, repair cost, impact of adjacent structure.

The new Oregon DOT slope rating system uses both the exponential scoring system and the continuum points. This allows the rater a greater flexibility in evaluating the relative impacts of slope conditions. However, the new version is more subjective with some rating criteria relied on the experiences and judgment of the raters. In addition, the use of the hazard modification factor creates the path for the decision maker to make prioritized decision.

2.9.3 New York State Department of Transportation

New York State Department of Transportation (NYSDOT) developed a database for rock slope management in 1988, with more than 1,700 rockfall sites inventoried based on the following criteria: (i) Rockfall locations with rockfall histories, (ii) Posted rockfall zones, (iii)Apparently unstable rock masses, (iv) Overhanging rocks, (v) Highly fractured, jointed, or over-steep slopes, (vi) Areas of ice build up on slopes, (vi) Fallen rock in ditches, (vii) New cracks or gaps in the rock, (viii) Area with soil deltas at the toes of rock slope, and (ix) Rock slaps on slopes inclined toward the roadway.

NYSDOT improved its slope rating system in 1992. The new database and rock slope rating system were implemented with GIS. The unstable slopes in NYSDOT are prioritized using the Total Relative Risk (TRR), which is the product of Geologic Factor (GF), Section Factor (SF) and Human Exposure Factor (HEF).

Geologic Factor (GF) is the relative risk of rocks falling based on the slope specific geologic and physical characteristics. The GF includes Geology, Block Size, Rock friction, Water/Ice, Rockfall, and backslope above the cut. The value of GF is calculated by the sum of all factors mentioned above and divided by 10.

$$\text{GF} = \frac{\text{Geology} + \text{Block Size} + \text{Rock Friction} + \text{Water Ice} + \text{Rockfall} + \text{Backslope above cut}}{10} \quad (2.1)$$

Section Factor (SF) is the relative risk of fallen rocks that could reach the highway travel lanes. The SF is related to ditch and shoulder geometry and rock slope offset. The SF is calculated as fallows:

$$\text{SF} = (\text{DR} + \text{WR})/(\text{DA} + \text{WA}). \quad (2.2)$$

where DR stands for ditch depth in meters, WR is ditch width in meters, DA is actual ditch depth in meters, and WA is offset distance in meters for the toe of rock.

Human Exposure factor (HEF) is the relative risk of a traffic accident occurring, given that rock fall occurs and rock intrudes on the roadway. The HEF can be calculated as:

$$\text{HEF} = (\text{F}_\text{a} + \text{F}_\text{p})/3 \quad (2.3)$$

where F_a represents the sum of active case when a car hit a falling rock, F_p represents the passive case when a car hits a rock on the road. The formulas for calculate F_a and F_p are as follows:

$$\text{F}_\text{a} = \text{AADT} \times [(\text{L} + \text{SSD})/\text{V} \times 24000)] \quad (2.4)$$

$$F_p = \log_{10}(AADT) \times \log_{10}(L)[a/(SSD - a)] \quad (2.5)$$

where AADT represents average annual daily traffic (two-way for two-lane undivided highways, or one-way for divided highway, L is the length of rockfall zone in meter, SSD stands for stopping sight distance in meters, V is travel speed in Km/h, and "a" is (SSD-DSD) or zero when it is greater.

Risk reduction is defined as the benefit provided by a treatment that is applied to a rock slope. The Total Relative Risk (TRR) after remediation is called the residual risk (RR). The risk reduction can be calculated as follows:

$$\text{Risk Reduction} = \text{TRR-RR} \quad (2.6)$$

The NYSDOT can assign different remediation efforts, which the RR can be evaluated. The RR value can then be subtracted from TRR to determine Risk Reduction. This allows NYSDOT to evaluate cost-benefits and select the most effective remediation method for a given site.

2.9.4 Washington State Department of Transportation

The Washington State Department of Transportation (WSDOT) developed the unstable slope management system (USMS) in 1993, which can be used for both rockfalls and landslides. The strategies adopted for the failed slope management utilized both slope failure and economic assessment. The information used for failed slope assessment included the location of slope (based on state route mileposts), whether the slope in on left or right of centerline, type of instabilities, frequency of failure, and dollar range for estimated annual maintenance cost associated with mitigating the slope in stabilities.

The exponential scoring system was used, which the following discrete numerical points: 3, 9, 27, and 81. Eleven factors were used for failed slope risk assessment. The preliminary judgment isolates the unstable slopes that would have high future impact to highway facilities from others. These subjective categories include, category A (high potential), Category B (Moderate potential) and Category C (low potential). This specification allows the users to focus only on the slopes that have high potential impact to the highway.

The software of Microsoft Access was used to maintain the database, allowing for quick manipulation, sorting, grouping, and custom reporting the information. The WSDOT's system prioritized the remedial need by grouping the highway based on functional class, meaning that the interstate facilities and the principal arterials will be remediated first, followed by those of the lower volume road facilities. Within the same highway functional class, the slopes are ranked in descending numerical order, so that the highest-risk slope within that classes are considered first.

The cost consideration in the system is associated with traffic delay and annual maintenance cost factored over the life of 20 years. The cost associated with traffic delay is an estimate of how many days before the slope can be repaired. Life-cycle maintenance costs were determined on the basis of the estimated annual cost generated by maintenance personnel. This estimate is then multiplied by the 20 years program life. To determine benefit-cost ratio for each site, the traffic delay and maintenance cost are compared with the cost of mitigating the unstable slope site. The unstable slope must have a cost benefit ratio greater than one to be considered in the fund allocation for slope repair or stabilization.

2.9.5 Tennessee Department of Transportation

Tennessee Department of Transportation (TDOT) developed a management system for landslides along the Tennessee highways in 2000. The objectives can be summarized as follows: (i) development of a statewide spatiotemporal landslide database assessable to TDOT planners, engineers, and geologists. (ii) Production and visualization of landslide thematic maps assessable via internet. The system is implemented on GIS database, which allows the users to link attributes, temporal, and spatial data in a spatiotemporal database for cataloging, visualizing and managing landslides along the Tennessee highways. The spatiotemporal data includes attribute data, such as landslide types, age, scale, bed rock, geology, historical data, and maintenance data. All reports, letters, memos, design sketches, drawings, and contracts are also included.

The database of TDOT landslide inventory is designed using linear reference string, which is composed of a two-digit number representing the county, five-digit number representing the state route number, five-digit number representing the log mile along the state route, and one digit sequence number. This also includes Julian date, which is composed of a seven-digit string representing four-digit of year and three-digit of the day of the year. The Julian date is used as reference for each update of information, and for tracking of activities related to the project.

Landslide locations are modeled as event features in database and represented as points in GIS application. The spatial components are composed of three dimensional locations of landslide, (x, y, z) coordinates, which enables the referencing to the log mile with a one dimensional linear referencing model with automated segmentation procedure. This provides the measure of landslide location to the known reference monument along the Tennessee highway. Appendix A provides a summary of the Slope Rating Systems used by Hong Kong Government, Oregon DOT, New York DOT, and Washington DOT.

CHAPTER III

LANDSLIDE FIELD RECONNAISANCE FORM AND DATA COLLECTION PROCESS

3.1 Overview

The landslide reconnaissance form and the process of landslide data collection are described in this chapter. The purpose of developing a form is so that the landslide information is collected in a consistent and uniform manner. The form is developed based on the syntheses of ODOT in-house expertise and existing practices by other state agencies.

The landslide reconnaissance form is broken down into three parts for different ODOT personnel to fill in the information. The form can be filled out either by paper format or by the use of ArcPad® installed in a handheld GPS device or a laptop computer. The basic skills necessary for using ArcPad® to collect landslide information are provided in Chapter VI of the User's Manual. It is noted that the information of landslide collected through ArcPad® is called a shapefile. Once the landslide data collection is complete, the shapefile can be uploaded into the database though the webpage. Once the data is updated, the location of the landslide site is displayed as a dot on the GIS map on the webpage. The procedures necessary for managing the shapefiles and the webpages are described in Chapter V of the User's Manual.

3.2 Landslide Reconnaissance Form and Landslide Reconnaissance Process

The Landslide Field Reconnaissance Form is designed to consist of four parts: landslide observation report and landslide hazard forms: Parts A, B, and C. The complete form can be found in the User's Manual in Appendix B.

3.2.1 Landslide Observation Report

Reporting of a potential landslide site is initiated by filing out the Landslide Observation Report either by a highway maintenance/construction worker or a crew member from a County Office. The form can only be filled in using a paper format. The idea of the Landslide Observation Report is that the crew members, who may or may not have background knowledge in geology and geotechnical engineering, are often the first one to observe something had changed on the roadway. The user fills in the general site descriptions of a suspected landslide site, such as the approximated mileposts, locations of failures (above or below the road), types of movements (earth or rock), etc. Once the Landslide Observation Report is complete, the form should be submitted to the County/Transportation Manager (CM/TM) of the corresponding county.

3.2.2 Landslide Hazard Form Part A and Part B

Once CM/TM receives the Landslide Observation Report from the county workers, he/she makes a trip to the reported landslide site to verify the submitted information. If he/she determines that it is not landslide related, there is no follow up activity. The Landslide Observation Report is kept in the folder for the future reference. If he/she determines that it is a landslide. The Landslide Field Form, Part A should be filled in by the CM/TM. The CM/TM determines the significance of the landslide site using the *rated* and *non-rated* criteria provided in the document. If it is classified as *non-rated*, CM/TM would set up a schedule for revisit. If it is classified as *rated*, CM/TM continues to fill in the information in Part B, which requires a compilation of information of the landslide site history and traffic data, such as maintenance frequency and cost, traffic counts, speed limit, accident record, etc. The rough sketches of the landslide site should be drawn and site pictures should be taken. CM/TM submits the Part A and Part B landslide data to the landslide database via internet access and sends a notification to the District Geotechnical Engineer (DGE).

3.2.3 Landslide Hazard Form Part C

Once DGE receives the notification from CM/TM, he/she prepares a field team for a site visit to complete the Landslide Field Reconnaissance Form, Part C. DGE would verify the information previously collected by CM/TM in Part A and Part B. DGE would perform the site assessment using the landslide hazard rating matrix. The landslide assessment procedures are described in Chapter III of the User's Manual. Photos are taken and sketches are drawn for the site. DGE enters Part C information into the landslide database via internet access as well. The process of landslide data collection for ODOT is shown as a flow chart in Figure 3.1.

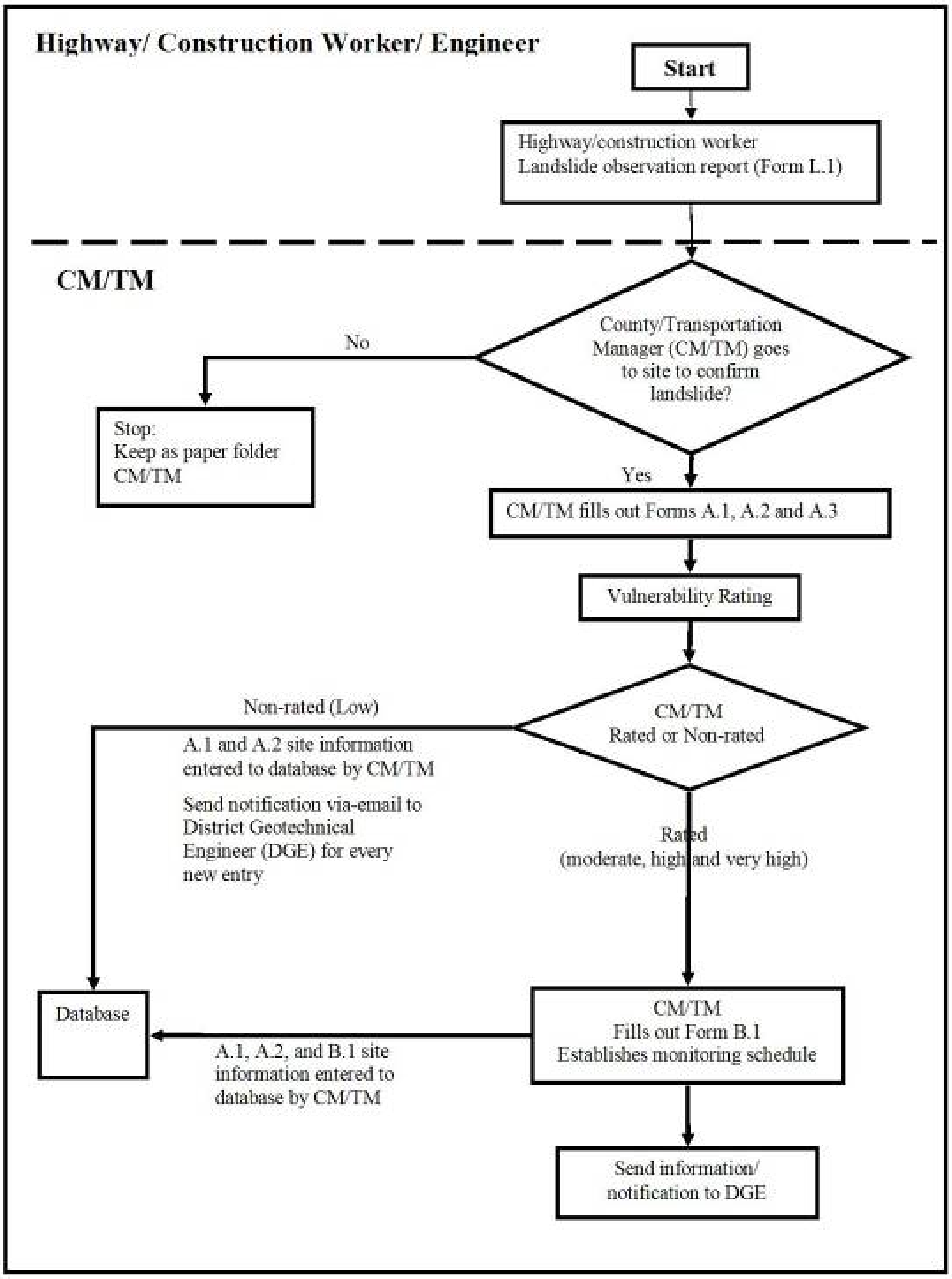


Figure 3.1 Landslide reconnaissance process

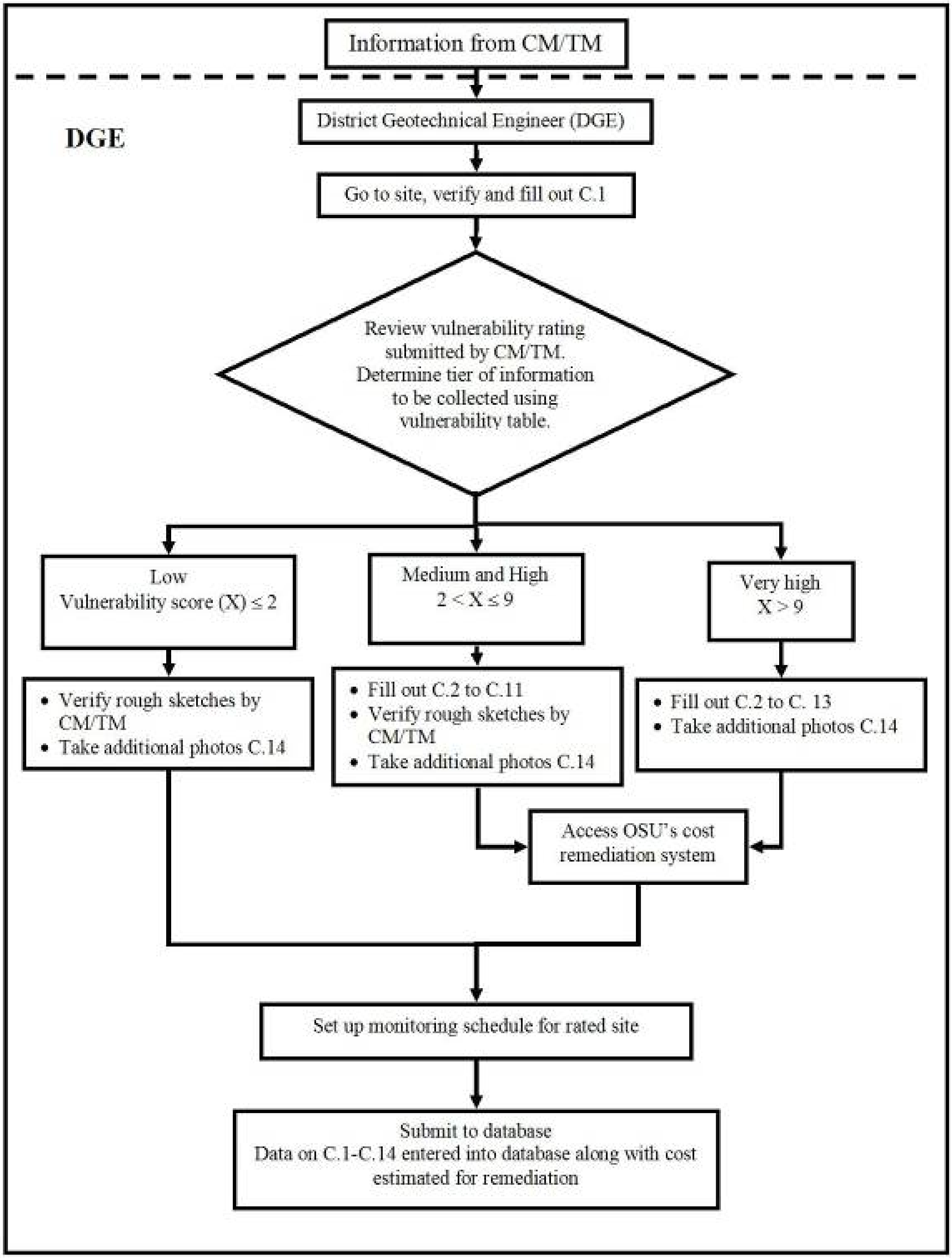


Figure 3.1 Landslide reconnaissance process (continued)

CHAPTER IV

DEVELOPMENT OF LANDSLIDE HAZARD RATING MATRIX

4.1 Overview

The development of a landslide hazard rating matrix for ODOT is presented in this chapter. Six risk factors reflecting potential impact of a landslide on the safety and operation of a roadway and adjacent highway structures are selected based on past experiences of senior ODOT engineers as well as the practices by other agencies. The potential hazard of a landslide site is represented using a composite numerical score of the proposed six risk factors. The effectiveness of the developed landslide hazard rating system is validated by a cluster analysis technique and a series of inferential statistical techniques applied to a pilot data set of 37 landslide sites in Ohio.

4.2 Locations of Thirty Seven Landslide Sites for the Study

Each ODOT district offices were asked to compile a list of all known and potential landslides adjacent highways within their districts. Based on the submitted list of landslide sites, ODOT engineers have selected 37 sites for a pilot study. The ODOT selection of these landslide sites was made to ensure that geological and hydrological conditions of landslides that exist throughout the State of Ohio are represented in the pilot study. The information of 37 landslide sites that are collected using the Landslide Reconnaissance Form has been uploaded into the landslide database. The summary of the locations and characteristics of 37 landslide sites are displayed in Figure 4.1 and Table 4.1, respectively.

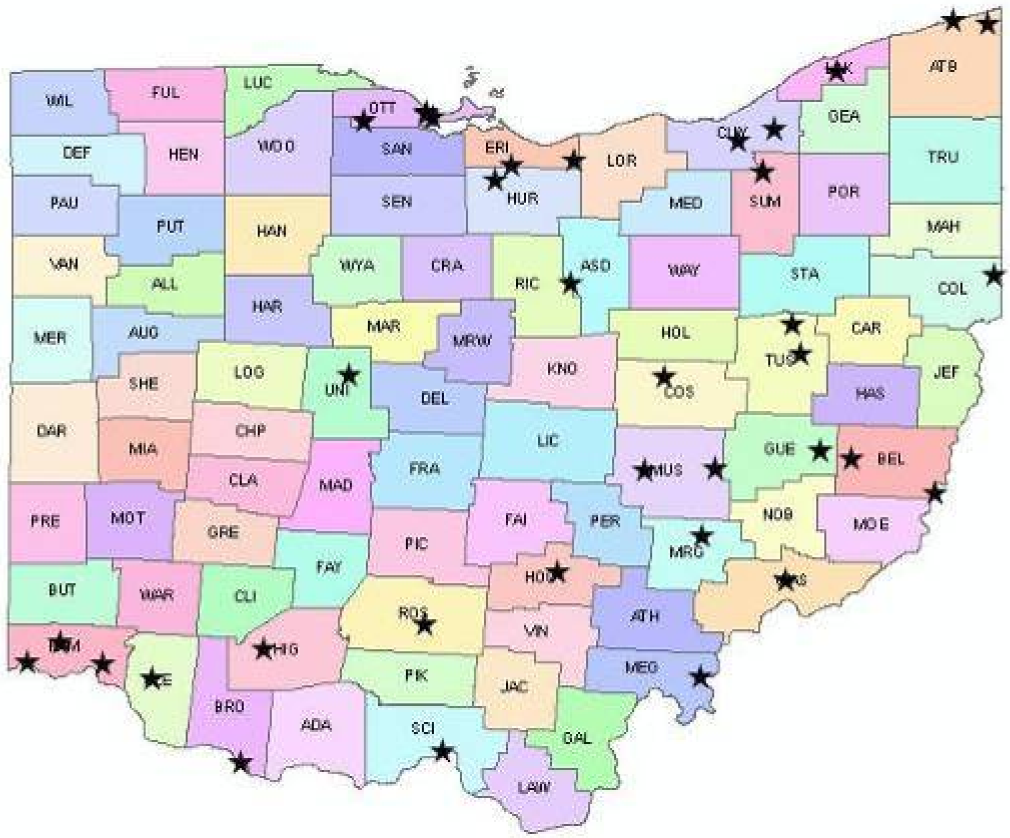


Figure 4.1 Locations of thirty seven landslide site

Table 4.1 Summary of characteristics of thirty seven landslide sites

Landslide No.	Slope type	Suspected type of landslide	Suspected cause of landslide		State of activity	Existing remediation
			Human	Nature		
1.	Fill	Rotational earth slide	Water leakage from pipes	Surface water level change	Active	-
2	Fill	Rotational earth slide	-	Degradation of construction material	Active	-
3	Natural	Rotational earth slide	-	Toe erosion	Mitigated	Retaining structure, internal slope reinforcement
4	Fill	Rotational earth slide	Construction related	Degradation of construction material	Mitigated	Slope geometry correction, retaining structure, erosion control
5	Cut and fill	Rotational slide	Construction related, loading	Toe erosion, surface water change/ rapid drawdown	Active	See comment
6	Fill	Debris flow	Utility lines' excavation	Toe erosion	Active	-
7	Cut and fill	Rotational earth slide	-	Toe erosion	Active	-
8	Natural	Unknown	-	Toe erosion	Active	-
9	Cut	Rotational slide	Excavation/ undercutting	Groundwater, toe erosion	Active	-
10	Natural	Rotational earth slide	-	Toe erosion, surface water level change / rapid drawdown	Active	
11	Fill	Rotational earth slide	Failure of drainage	Degradation of construction material	Active	-
12	Fill	Rotational earth slide	Failure of drainage	Degradation of material	Active	-
13	Cut	Rotational earth slide	Excavation and undercutting	Toe erosion, surface water level change/ rapid drawdown	Active	-
14	Fill	Rotational earth slide	Construction related	Degradation of construction material	Active	Geometry correction, drainage
15	Fill	Rotational earth slide	Construction related	Degradation of construction material	Active	-
16	Cut and fill	Translation earth slide	Construction related	Ground water, Degradation of construction material	Active	-
17	Fill	Rotational earth slide	Water leakage from pipes	Surface water level change/ rapid drawdown	Active	-
18	Fill	Rotational earth slide	Construction related	Degradation of construction material	Active	Slope geometry correction
19	Fill	Rotational earth slide	Construction related	Rainfall, groundwater, degradation of construction material	Active	-
20	Cut and fill	Translational earth slide	Construction related	Groundwater, toe erosion, surface level change/ rapid drawdown	Active	See comment
21	Cut	Rotational earth slide	Excavation/ undercutting	Groundwater	Active	Retaining structure
22	Cut and fill	Rotational earth slide	-	Toe erosion, rainfall, groundwater, surface water level change/ rapid drawdown	Active	-
23	Cut and fill	Rotational earth slide	-	Groundwater, toe erosion, surface water level change/ rapid drawdown	Active	Geometry correction
24	Cut	Translational rock slide	-	Groundwater	Active	-

Table 4.1 Summary of characteristics of thirty seven landslide sites (continued)

Landslide No.	Slope type	Suspected type of landslide	Suspected cause of landslide		State of activity	Existing remediation
			Human	Nature		
25	Cut and fill	Rotational Earth slide	Construction related	Groundwater, toe erosion, surface water change/ rapid drawdown	Active	-
26	Cut	Rotational earth slide	-	Groundwater	Active	-
27	Cut and fill	Translational earth slide	Construction related	Toe erosion, Degradation of construction material	Active	-
28	Cut and fill	Rotational earth slide	-	Groundwater, toe erosion	Active	-
29	Cut and fill	Translational earth slide	-	Toe erosion	Active	-
30	Cut and fill	Translational slide	-	Toe erosion	Active	Retaining structure (installation of I beam)
31	Cut and fill	Rotational earth slide	Failure of drainage	Toe erosion, surface water level change/ rapid drawdown	Active	Retaining structure, erosion control
32	Cut and fill	Translational earth slide	Construction related	Degradation of construction material	Active	Retaining structure
33	Fill	Rotational earth slide	Excavation /under cutting	Groundwater	Active	Slope geometry correction
34	Cut and fill	Translational earth slide	Construction related	Groundwater, toe erosion, degradation of material	Active	-
35	Fill	Rotational earth slide	Water leakage from pipe, construction related	Rainfall, degradation of construction material	Active	Sheet piles and drainage
36	Fill	Rotational earth slide	Construction related	Rainfall, toe erosion, degradation of construction material	Active	-
37	Natural	Rotational earth slide	-	Groundwater, toe erosion	Mitigated	Retaining structure (sheet piles)

4.3 OHIO DOT Landslide Hazard Rating System

Ohio DOT landslide hazard rating system is developed based on synthesis and modification of ODOT in-house expertise together with the existing systems developed by other agencies, such as Oregon DOT (Pierson ,1992 and ODOT, 2002), Washington DOT (Lowel and Morin, 2000), New York DOT (Hadjin, 2001), Utah DOT (Pack and Boie, 2002), Hong Kong Geotechnical Engineering Office (Koirala and Watkins, 1988), etc. Table 4.2 shows a comprehensive list of the landslide risk/hazard assessment systems found in the literature. As summarized in Table 4.3, a total of twenty three parameters have been used by agencies for hazard scoring purposes. The eventual adopted landslide hazard rating system for Ohio DOT is shown in Table 4.4. The selected risk factors include: (i) Movement location and impact on roadway, (ii) Hazard to traveling public, (iii) Decision sight distance, (iv) Average daily traffic, (v) Accident history, and (vi) Maintenance frequency and response.

The numerical scoring is based on an exponential scale system to heighten the severity of risk for each risk factor. The four numerical scores of 3, 9, 27, and 81 are assigned to four rating criteria for each risk factor. The final hazard score of a landslide site is a summation of the scores of six risk factors. A total score greater than 250 is considered as *high hazard* potential, while a score between 150 and 250 represents *moderate hazard*. The score less than 150 is considered as *low hazard*.

Table 4.2 Summary of existing landslide risk/hazard management system

Rating/Management System	References	Descriptions
Bulk Appraisal of Slopes in Hong Kong	Koirala and Watkins (1988)	Landslide risk classification system for urban development of Hong Kong
ODOT Rockfall Hazard Rating System (RHRS)	Pierson and Vickle (1993)	Systematic method of prioritizing rockfall sites requiring maintenance or repair
ODOT Landslide Rating System	ODOT (2001)	Enhancement of the RHRS to include all landslide as well as additional improvements to RHRS
WSDOT Unstable Slope Management System	Ho and Norton (1991)	System for ranking unstable slope sites that includes an "expert system" software program
NYSDOT Rock Slope Rating system (1988)	Hadjin (2002)	Hazard assessment for rock slope
NYSDOT Rock Slope Rating system (1992)	Hadjin (2002)	Modification of the previous system and Utilization of GIS based inventory.
UDOT Rockfall Hazard Inventory	Robert (2002)	Comparative study of NYSDOT and ODOT systems and application of GIS based inventory.
GIS Landslide Inventory Along Tennessee Highway	Rose et al (2000)	GIS application for the management of landslides along Tennessee roads
INDOT Landslide Remediation Using Unconventional Methods	Deschamps and Lange (1999)	GIS based inventory for unconventional slope remediation for Indiana

Table 4.3 Summary of parameters in various agencies' landslide numerical rating system

No	Parameters	Hong Kong (1988)	Oregon DOT (1992)	Oregon DOT (2001)	NYSDOT (1988)	NYSDOT (1992)	WSDOT (1993)	Ohio DOT (2006)
1	Slope Height	×	×		×	×		
2	Slope gradient	×						
3	Volume		×		×	×		
4	Average daily traffic		×	×	×	×	×	×
5	Population density							
6	Travel distance	×			×	×		×
7	Expected number of landslide fatalities for a given facility				×	×	×	
8	Decision sight distance		×		×	×	×	×
9	Risk to vehicle		×			×	×	×
10	Relative emergency							×
11	Detour time						×	
12	Expected damage					×	×	×
13	Annual maintenance cost			×			×	×
14	Failure frequency	×		×	×	×		×
15	Aspect							
16	Accident history			×			×	×
17	Benefit-cost ratio			×			×	×
18	Rate of movement							×
19	Known instability related to geology	×	×		×	×		
20	Occurrence of ground and water surface	×	×		×	×	×	
21	Impact to road structure and adjacent features	×		×			×	×
22	Vertical and horizontal of scarp of displacement			×			×	×
21	Traffic speed		×		×	×	×	×
22	Potential future impact	×				×	×	×
23	Highway classification			×			×	

Table 4.4 Ohio landslide hazard rating system

CATEGORY		RATING CRITERIA and SCORE			
		Points 3	Points 9	Points 27	Points 81
Movement location/ impact (select higher score)	Current and potential impact of landslide on roadway	On slope with a low potential to affect shoulder	On slope with a low potential to affect roadway	On shoulder, or on slope with a moderate potential to affect roadway	On roadway, or On slope with a high potential to affect roadway or structure
	Current and potential impact of landslide on area beyond right of way	On slope with a low potential to impact area beyond right of way (A)	On slope with moderate potential to impact area beyond right of way (B)	On slope with high potential to impact area beyond right of way (C)	On slope with high potential to impact structure beyond right of way (D)
Hazard to traveling public (Select higher score)	Rate of displacement in roadway if known	<1-inch/year	1 to 3-inches/year No single event ≥1-inch	3 to 6-inches/year No single event ≥3-inches	>6-inches/year Single event ≥3-inches
	Evidence of displacement in roadway	Visible crack or dip no vertical drop (E)	≤1-inch of displacement (F)	1 to 3-inches of displacement (G)	≥ 3-inches of displacement (H)
Maintenance (Select higher score)	Maintenance frequency	None to rare	Annually (one time/year)	Seasonal (1 to 3 times/ year)	Continuous throughout year (> 3 times/year)
	Maintenance response	No response (I)	Requires observation with periodic maintenance (J)	Requires routine maintenance response to preserve roadway (K)	Requires immediate response for safe travel or to protect adjacent structure (L)
ADT		<2000 (M)	2001-5000 (N)	5001-15000 (O)	>15001 (P)
%Decision Sight Distance (DSD)		≥ 90 (Q)	89 -50 (R)	49-35 (S)	< 34 (T)
Accident history		No accident (U)	Vehicle or property damage (V)	Injury (W)	Fatality (X)

4.4 Classification of Pilot Landslides Data by Cluster Analysis

Cluster analysis technique is a multivariate statistics technique, which can be applied to the landslide hazard rating system to achieve the following objectives: (i) classify landslides, (ii) simplify characteristics of landslides, and (iii) reveal similarities and differences among landslide data compiled. Cluster analysis has been used in diverse disciplines, such as biology, psychology, sociology, economics, engineering, and business to classify and characterize the interested objects. Holt (1996) demonstrated the use of a cluster analysis technique to select good contractor firms. Lakrod et al (2000) used the technique to study genetic variation of fungus. Recently, Woodard (2004) used the cluster analysis for rockfall assessment in Ohio.

Since the hazard rating system of Ohio DOT relies on risk factors that involve a wide variety of scales and units, it is therefore necessary to use a binary clustering technique. In the binary cluster analysis, a parameter can be characterized by using the so called two-way association or contingency table as shown in Table 4.5. If a parameter falls into a specified criterion, a numerical score of one is given. Otherwise, a numerical score of zero is specified (Everitt, 1993).

To determine the similarity between landslide sites, a contingency table is established in Table 4.6 for all 37 landslide sites compiled for this study. Using site no.1 and no. 2 as an example, the occurrence of various factors that are both present in sites no. 1 and no. 2 (i.e., 1 and 1) is 2 times. The occurrence of presence and absence of various risk factors in sites no.1 and no. 2 (i.e., 1 and 0) is 3 times. The occurrence of absence and presence of various risk factors in sites no.1 and no. 2 (i.e., 0 and 1) is 3 times. Finally, the occurrence of the absence and absence of various factors in sites no. 1

and no. 2 (i.e., 0 and 0) is 12 times. The parameters *a, b, c,* and *d* according to Table 4.5 are 2, 3, 3, and 12, respectively.

In order to determine the similarity between two landslide sites, a Euclidean distance calculation as shown in Equation 4.1 is used. Based on the coefficients found according to the contingency table, the similarity coefficient of site no. 1 and no. 2 can be calculated as $D_{ij} = \sqrt{3+3} = 2.45$. The similarity relationships of all 37 landslide sites are established in the fashion described in the above and are shown in Table 4.7 using a matrix form as in Equation 4.2.

Once the similarity relationships are determined, landslide classification can begin. The classification process uses simple rules as follows. Initially, each landslide site is in its own cluster. Subsequently, a new cluster is formed by combining the two most similar or two closest clusters together. The process is repeated and the number of clusters decreases by one in each step. Eventually, all landslide sites join into one large cluster (Hair et al, 1998).

Table 4.8 shows the combining process of the 37 landslide sites. As can be seen in the table, stages 1 to 7 are the very first step of the landslide sites being combined due to that their similarity coefficients are 0. At stage 1, the site no. 3 and 37 are grouped together as a cluster of two members. In the next step, this cluster joins the site no. 33 at the stage 25. The new similarity coefficient becomes $d_{(3,37),(33)} = (1/2)(d_{(3,33)} + d_{(37,33)}) =$ 2.0 at stage 25 in column 4. A new cluster is generated with members of site no. 3, 37, and 33. In the next step, this cluster joins another cluster at stage 32. It joins with site no. 2, 11, 36, 18, 26, 12, 14, and 4. The new similarity coefficient is calculated, which is equal to 2.379. The process is repeated until all sites are combined into one cluster. Based on the process illustrated in Table 4.8, a tree diagram or dendrogram is generated as shown in Figure 4.2, in which three groups of landslide hazards emerge. The numerical score of each landslide site based on the three hazard group classification are summarized in Table 4.9.

Table 4.5 Contingency table of binary variables of case i and j

i/j	1	0
1	a	B
0	c	D

$$D_{ij} = \sqrt{b + c} \tag{4.1}$$

$$\text{DMat} = \begin{bmatrix} D_{11} & D_{12} & . & D_{1n} \\ D_{21} & D_{22} & . & D_{2n} \\ . & . & . & . \\ D_{n1} & D_{n2} & . & D_{nn} \end{bmatrix} \tag{4.2}$$

Table 4.6 Binary data of 37 landslide sites

Site No.	Movement location and impact				Hazard to traveling public				Maintenance frequency/ response				ADT				Decision sight distance			
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	1	0
2	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0
3	1	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1
4	1	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0
5	0	0	1	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	1
6	0	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0
7	0	0	1	0	0	1	0	0	0	0	1	0	0	1	0	0	0	1	0	0
8	0	0	0	1	0	0	1	0	0	1	0	0	0	1	0	0	0	1	0	0
9	0	0	1	0	1	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0
10	0	0	0	1	1	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0
11	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0
12	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0
13	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0	1	0
14	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0
15	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0
16	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0
17	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	1	0	0
18	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1
19	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1
20	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	1
21	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0	1	0	0
22	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
23	0	0	0	1	0	1	0	0	0	0	1	0	0	1	0	0	0	0	1	0
24	0	0	0	1	0	1	0	0	0	1	0	0	0	0	1	0	1	0	0	0
25	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	1
26	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1
27	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	1
28	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	1	0	0	0
29	0	0	0	1	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	1
30	0	0	0	1	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	1
31	0	0	0	1	0	1	0	0	0	0	1	0	0	1	0	0	1	0	0	0
32	0	0	0	1	0	1	0	0	0	0	1	0	0	1	0	0	0	1	0	0
33	0	0	0	1	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1
34	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	1
35	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1	0
36	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0
37	1	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1

Table 4.7 Similarity relationships of 37 landslide sites.

i/j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	2.5	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	3.2	2.5	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	3.2	2.0	2.0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	2.5	3.2	2.8	3.2	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-
6	2.8	2.5	2.5	2.8	3.2	0.0	-	-	-	-	-	-	-	-	-	-	-	-
7	2.8	3.2	2.8	3.2	2.5	2.5	0.0	-	-	-	-	-	-	-	-	-	-	-
8	2.8	2.8	2.8	3.2	3.2	2.0	2.5	0.0	-	-	-	-	-	-	-	-	-	-
9	2.5	2.5	2.5	2.8	2.8	1.4	2.0	2.0	0.0	-	-	-	-	-	-	-	-	-
10	3.2	2.5	2.5	2.5	2.8	2.5	2.5	2.5	2.5	0.0	-	-	-	-	-	-	-	-
11	2.5	0.0	2.5	2.0	3.2	2.5	3.2	2.8	2.5	2.5	0.0	-	-	-	-	-	-	-
12	2.0	1.4	2.8	2.5	2.8	2.5	2.8	2.8	2.0	2.5	1.4	0.0	-	-	-	-	-	-
13	2.5	3.2	3.2	3.2	2.5	3.2	3.2	2.8	3.2	2.8	3.2	3.2	0.0	-	-	-	-	-
14	2.0	1.4	2.8	2.5	2.8	2.5	2.8	2.8	2.0	2.5	1.4	0.0	3.2	0.0	-	-	-	-
15	2.5	2.5	3.2	2.8	2.8	3.2	3.2	2.8	3.2	2.5	2.5	2.5	2.0	2.5	0.0	-	-	-
16	3.2	3.2	3.2	2.8	2.8	2.8	2.5	2.0	2.8	2.5	3.2	3.2	2.8	3.2	2.8	0.0	-	-
17	2.5	2.8	3.2	3.2	2.8	2.8	2.8	2.5	2.8	2.8	2.8	2.8	2.0	2.8	1.4	2.5	0.0	-
18	2.5	1.4	2.0	2.5	2.8	2.5	3.2	2.8	2.5	2.8	1.4	2.0	3.2	2.0	2.8	3.2	2.8	0.0
19	2.5	2.8	2.8	3.2	2.5	3.2	3.2	2.8	3.2	2.8	2.8	2.8	2.0	2.8	1.4	2.8	1.4	2.5
20	2.8	3.2	2.8	2.8	2.5	3.2	3.2	2.8	3.2	2.8	3.2	3.2	2.0	3.2	2.0	2.5	2.0	2.8
21	2.8	3.2	3.2	2.8	2.8	2.8	2.8	2.5	2.8	2.8	3.2	3.2	2.0	3.2	2.0	2.0	1.4	3.2
22	2.8	3.2	3.2	2.8	2.8	3.2	2.8	2.5	3.2	2.5	3.2	3.2	2.5	3.2	2.8	1.4	2.8	3.2
23	2.8	3.2	2.8	3.2	2.8	2.8	2.0	2.5	2.8	2.0	3.2	3.2	2.5	3.2	2.8	2.5	2.8	3.2
24	2.8	2.5	3.2	2.5	3.2	2.8	2.8	2.5	2.8	2.5	2.5	2.5	2.8	2.5	2.5	2.5	2.8	2.8
25	3.2	3.2	2.8	2.8	2.5	3.2	2.8	2.5	3.2	2.5	3.2	3.2	2.8	3.2	2.8	1.4	2.8	2.8
26	2.5	1.4	2.0	2.5	2.8	2.5	3.2	2.8	2.5	2.8	1.4	2.0	3.2	2.0	2.8	3.2	2.8	0.0
27	3.2	3.2	2.8	3.2	2.0	3.2	2.8	2.5	3.2	2.5	3.2	3.2	2.5	3.2	2.8	2.0	2.8	2.8
28	2.8	2.8	3.2	2.8	2.5	3.2	3.2	2.8	3.2	2.5	2.8	2.8	1.4	2.8	1.4	2.8	2.0	3.2
29	2.8	2.8	2.8	3.2	2.5	2.8	2.8	2.5	2.8	2.8	2.8	2.8	2.5	2.8	2.8	2.8	2.8	2.5
30	2.8	2.8	2.8	3.2	2.5	2.8	2.8	2.5	2.8	2.8	2.8	2.8	2.5	2.8	2.8	2.8	2.8	2.5
31	3.2	2.8	2.8	2.8	2.8	2.8	2.0	2.5	2.8	1.4	2.8	2.8	2.8	2.8	2.5	2.5	2.8	3.2
32	3.2	3.2	2.8	3.2	2.8	2.5	1.4	2.0	2.5	2.0	3.2	3.2	2.8	3.2	2.8	2.0	2.5	3.2
33	2.8	2.5	2.0	2.8	2.8	2.0	2.8	2.0	2.0	2.0	2.5	2.5	2.8	2.5	2.8	2.8	2.8	2.0
34	2.8	3.2	2.8	2.8	2.5	3.2	3.2	2.8	3.2	2.8	3.2	3.2	2.0	3.2	2.0	2.5	2.0	2.8
35	2.0	2.8	3.2	3.2	2.8	3.2	3.2	2.8	3.2	2.8	2.8	2.8	1.4	2.8	1.4	2.8	1.4	2.8
36	2.5	0.0	2.5	2.0	3.2	2.5	3.2	2.8	2.5	2.5	0.0	1.4	3.2	1.4	2.5	3.2	2.8	1.4
37	3.2	2.5	0.0	2.0	2.8	2.5	2.8	2.8	2.5	2.5	2.5	2.8	3.2	2.8	3.2	3.2	3.2	2.0

Table 4.6 (continued)

i/j	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	1.4	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	2.0	1.4	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	2.8	2.5	2.5	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	2.8	2.8	2.8	2.0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	2.8	2.5	2.5	2.5	2.5	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-
25	2.5	2.0	2.5	1.4	2.5	2.5	0.0	-	-	-	-	-	-	-	-	-	-	-	-
26	2.5	2.8	3.2	3.2	3.2	2.8	2.8	0.0	-	-	-	-	-	-	-	-	-	-	-
27	2.5	2.5	2.8	2.0	2.5	2.8	1.4	2.8	0.0	-	-	-	-	-	-	-	-	-	-
28	2.0	2.0	2.0	2.8	2.8	2.5	2.8	3.2	2.5	0.0	-	-	-	-	-	-	-	-	-
29	2.5	2.5	2.8	2.8	2.5	2.0	2.5	2.5	2.0	2.5	0.0	-	-	-	-	-	-	-	-
30	2.5	2.5	2.8	2.8	2.5	2.0	2.5	2.5	2.0	2.5	0.0	0.0	-	-	-	-	-	-	-
31	2.8	2.8	2.8	2.5	1.4	2.0	2.5	3.2	2.5	2.5	2.5	2.5	0.0	-	-	-	-	-	-
32	2.8	2.8	2.5	2.5	1.4	2.5	2.5	3.2	2.5	2.8	2.5	2.5	1.4	0.0	-	-	-	-	-
33	2.5	2.5	2.8	2.8	2.5	2.5	2.5	2.0	2.5	2.8	2.0	2.0	2.5	2.5	0.0	-	-	-	-
34	1.4	0.0	1.4	2.5	2.8	2.5	2.0	2.8	2.5	2.0	2.5	2.5	2.8	2.8	2.5	0.0	-	-	-
35	1.4	2.0	2.0	2.5	2.5	2.8	2.8	2.8	2.8	2.0	2.8	2.8	2.8	2.8	2.8	2.0	0.0	-	-
36	2.8	3.2	3.2	3.2	3.2	2.5	3.2	1.4	3.2	2.8	2.8	2.8	2.8	3.2	2.5	3.2	2.8	0.0	-
37	2.8	2.8	3.2	3.2	2.8	3.2	2.8	2.0	2.8	3.2	2.8	2.8	2.8	2.8	2.0	2.8	3.2	2.5	0.0

Table 4.8 Agglomerative Hierarchical Clustering Process

Stage	Cluster Combined		Coefficients	Next Stage
	Cluster 1	Cluster 2		
1	3	37	0.000	25
2	11	36	0.000	7
3	20	34	0.000	19
4	29	30	0.000	26
5	18	26	0.000	15
6	12	14	0.000	17
7	2	11,36	0.000	15
8	19	35	1.414	19
9	31	32	1.414	10
10	23	31, 32	1.414	22
11	15	28	1.414	21
12	25	27	1.414	18
13	16	22	1.414	18
14	17	21	1.414	20
15	2, 11, 36	18, 26	1.414	17
16	6	9	1.414	27
17	2, 11, 36,18, 26	12, 14	1.649	28
18	16, 22	25, 27	1.707	31
19	19, 35	20, 34	1.707	20
20	17, 21	19, 35, 20, 34	1.707	23
21	13	15, 28	1.707	23
22	7	23, 31, 32	1.805	24
23	13, 15, 28	17, 21, 19, 35, 20, 34	1.870	34
24	7, 23, 31, 32	10	1.966	31
25	3,37	33	2.000	29
26	24	29, 30	2.000	33
27	6, 9, 27	8	2.000	32
28	2, 11, 36, 18, 26, 12, 14	4	2.257	29
29	2, 11, 36, 18, 26, 12, 14, 4	3, 37, 33	2.379	32
30	1	5	2.449	34
31	7, 23, 31, 32, 10	16, 22, 25, 27	2.461	33
32	2, 11, 36, 18, 26, 12, 14, 4, 3, 37, 33	6, 9, 27, 8	2.529	36
33	7, 23, 31, 32, 10, 16, 22, 25, 27	24, 29, 30	2.540	35
34	1, 5	13, 15, 28, 17, 21, 19, 35, 20, 34	2.593	35
35	1, 5, 13, 15, 28, 17, 21, 19, 35, 20, 34	7, 23, 31, 32, 10, 25, 27, 16, 22, 24, 29, 30	2.718	36
36	1, 13, 15, 28, 17, 21, 19, 35, 20, 34, 7, 23, 31, 32, 10, 25, 27, 16, 22, 24, 29, 30	2, 11, 36, 18, 26, 12, 14, 4, 3, 37, 33, 6, 9, 27, 8	2.873	0

Table 4.9 Hazard Scores of Low, Medium and High Cluster

(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Low	2	3	3	9	81	3	99
	3	3	3	3	9	81	99
	4	3	3	3	27	3	39
	6	9	3	9	9	9	39
	8	81	27	9	9	9	135
	9	27	3	9	9	9	57
	11	3	3	9	81	3	99
	12	27	3	9	81	3	123
	14	27	3	9	81	3	123
	18	3	3	9	81	81	177
	26	3	3	9	81	81	177
	33	81	3	9	9	81	183
	36	3	3	9	81	3	99
	37	3	3	3	9	81	99
Medium	7	27	9	27	9	9	81
	10	81	3	27	9	3	123
	16	81	27	27	27	9	171
	22	81	27	27	27	27	189
	23	81	9	27	9	27	153
	24	81	9	9	27	3	129
	25	81	27	27	27	81	243
	27	81	27	27	3	81	219
	29	81	9	9	3	81	183
	30	81	9	9	3	81	183
	31	81	9	27	9	3	129
	32	81	9	27	9	9	135
High	1	27	81	9	81	27	225
	5	27	81	27	3	81	219
	13	81	81	81	3	27	273
	15	81	81	81	81	3	327
	17	81	81	81	81	9	333
	19	81	81	81	81	81	405
	20	81	81	81	27	81	351
	21	81	81	81	27	9	279
	28	81	81	81	3	3	249
	34	81	81	81	27	81	351
	35	81	81	81	81	27	351

Column heading designation:
(a): Cluster designation, (b): Site number, (c): Movement location/impact,
(d): Hazard to traveling public, (e): Maintenance response, (f): ADT,
(g): Decision sight distance, and (h): Total hazard score

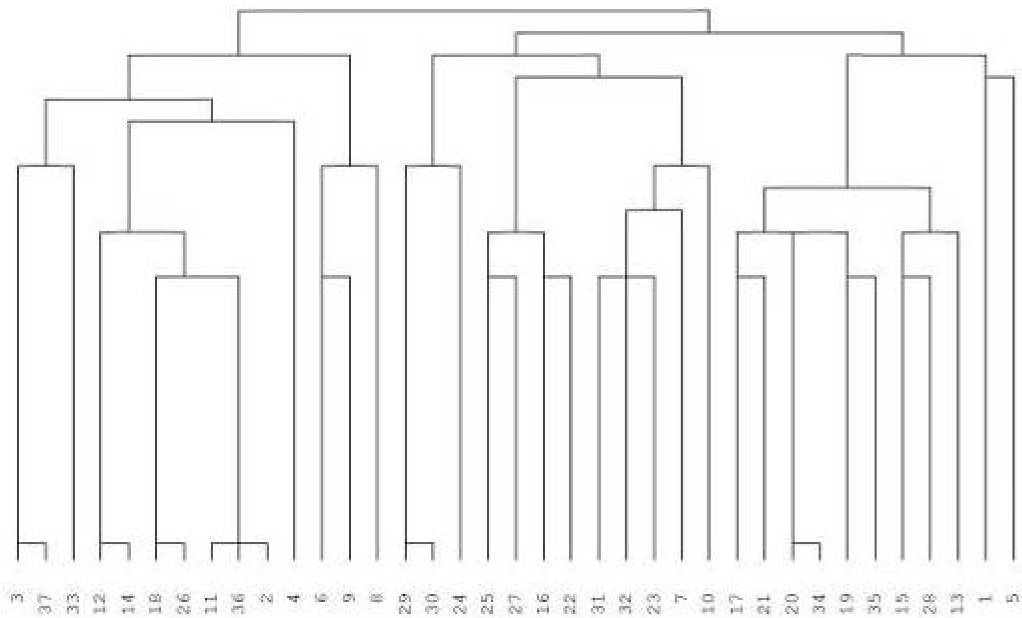


Figure 4.2 Tree diagram of 37 landslide sites

A sensitivity analysis of classification of landslides is also performed to verify that the analysis result is reliable. The methods found in literatures that can be used to determine of the similarity coefficients of interested entities are listed in Table 4.10. Landslides are classified according to the calculation steps provided previously. The results of landslide classifications according to different similarity calculation methods are summarized in column 3, 4, and 5 in Table 4.10, respectively. The results show that the similarity calculation methods give the same results of landslide classifications except Skodal and Sneath2 method, which classifies landslide no.1 as low hazard. However, this missed interpretation is minor and can be neglected. Therefore, it can be concluded that the proposed method to classify landslide risk is reliable.

Table 4.10 Sensitivity analysis of classification of landslides

Method	Equation	Cluster 1 (low)	Cluster 2 (medium)	Cluster 3 (high)
Dice	$\frac{2a}{2a+b+c}$	2, 3, 4, 6, 8, 9, 11, 12, 14, 18, 26, 33, 36, 37	7, 10, 16, 22, 23, 24, 25, 27, 29, 30, 31, 32	1, 5, 13, 15, 17, 19, 20, 21, 28, 34, 35
Euclidean Distance	$\sqrt{b+c}$	2, 3, 4, 6, 8, 9, 11, 12, 14, 18, 26, 33, 36, 37	7, 10, 16, 22, 23, 24, 25, 27, 29, 30, 31, 32	1, 5, 13, 15, 17, 19, 20, 21, 28, 34, 35
Hamann	$\frac{(a+d)-(b+c)}{a+b+c+d}$	2, 3, 4, 6, 8, 9, 11, 12, 14, 18, 26, 33, 36, 37	7, 10, 16, 22, 23, 24, 25, 27, 29, 30, 31, 32	1, 5, 13, 15, 17, 19, 20, 21, 28, 34, 35
Jaccard	$\frac{a}{a+b+c}$	2, 3, 4, 6, 8, 9, 11, 12, 14, 18, 26, 33, 36, 37	7, 10, 16, 22, 23, 24, 25, 27, 29, 30, 31, 32	1, 5, 13, 15, 17, 19, 20, 21, 28, 34, 35
Lance and Williams	$\frac{b+c}{2a+b+c}$	2, 3, 4, 6, 8, 9, 11, 12, 14, 18, 26, 33, 36, 37	7, 10, 16, 22, 23, 24, 25, 27, 29, 30, 31, 32	1, 5, 13, 15, 17, 19, 20, 21, 28, 34, 35
Pattern difference	$\frac{bc}{(a+b+c+d)^2}$	2, 3, 4, 6, 8, 9, 11, 12, 14, 18, 26, 33, 36, 37	7, 10, 16, 22, 23, 24, 25, 27, 29, 30, 31, 32	1, 5, 13, 15, 17, 19, 20, 21, 28, 34, 35
Simple Matching	$\frac{a+d}{a+b+c+d}$	2, 3, 4, 6, 8, 9, 11, 12, 14, 18, 26, 33, 36, 37	7, 10, 16, 22, 23, 24, 25, 27, 29, 30, 31, 32	1, 5, 13, 15, 17, 19, 20, 21, 28, 34, 35
Skodal and Sneath1	$\frac{2(a+d)}{2(a+d)+b+c}$	2, 3, 4, 6, 8, 9, 11, 12, 14, 18, 26, 33, 36, 37	7, 10, 16, 22, 23, 24, 25, 27, 29, 30, 31, 32	1, 5, 13, 15, 17, 19, 20, 21, 28, 34, 35
Skodal and Sneath2	$\frac{a}{a+2(b+c)}$	1, 2, 3, 4, 6, 8, 9, 11, 12, 14, 18, 26, 33, 36, 37,	7, 10, 16, 22, 23, 24, 25, 27, 29, 30, 31, 32	5, 13, 15, 17, 19, 20, 21, 28, 34, 35
Variance	$\frac{b+c}{4(a+b+c+d)}$	2, 3, 4, 6, 8, 9, 11, 12, 14, 18, 26, 33, 36, 37	7, 10, 16, 22, 23, 24, 25, 27, 29, 30, 31, 32	1, 5, 13, 15, 17, 19, 20, 21, 28, 34, 35

4.5 Statistical Validation

The inferential statistics techniques are used to evaluate the reasonableness of the developed landslide hazard rating matrix. The score distributions or histograms of the three hazard groups and all group combined are compared to the normal distribution curves in Figure 4.3. A good rating system ideally can give a normal distribution for the numerical scores of all landslide sites in each cluster as well as for all landslide sites in all clusters combined. The Kolmogorov-Smirnov test results shown in Figure 4.4 provide a comparison of the empirical (ECDF) and the theoretical cumulative distribution functions (TCDF) of hazard scores for each cluster. The null hypothesis is that the numerical scores of all landslide sites are normally distributed. The hypothesis is rejected when the calculated significance level is less than 0.05. The Kolmogorov-Smirnov test has proven that the distribution of numerical scores of all landslide sites in each cluster as well as in the combined clusters is a normal distribution.

A Chi-square goodness of fit test is also performed in order to compare the observed numerical score with a normal and log-normal distribution. The Chi-Square goodness-of –fit test compares the observed frequencies, $n_1, n_2, \ldots, n_k$ of k values (or in k intervals) with the corresponding frequencies, $e_1, e_2, \ldots, e_k$ from an assumed theoretical distribution. If the assumed theoretical distribution is an acceptable model that can be used to describe the observed frequencies, the relationship is the equation as follows.

$$\sum_{i=1}^{k} \frac{(n_i - e_i)^2}{e_i} < c_{1-\alpha, f} \qquad (4.\ 3)$$

$c_{1-\alpha,f}$ is the value of the approximate χ^2 distribution at the cumulative probability (1-α). f is the degree of freedom. The assumed theoretical distribution is an acceptable model at the significance level, α. Otherwise, the assumed distribution is not sustained by the data at the α significance level. The degree of freedom of each test (normal and log-normal) can be determined as follows. There are nine intervals (k = 9) and three parameters are used in analysis (normal/log-normal distribution, sample mean, and sample variance). Therefore, the degree of freedom (f) is 9 – 3 = 6. At the significance level α = 5%, the approximateχ^2 distribution $c_{0.95,f}$= 12.6. Comparing this value with the value of $\sum_{i=1}^{k} \frac{(n_i - e_i)^2}{e_i}$ calculated in Table 4.11, I can be observed that both normal and log-normal distribution can be used to describe the observed numerical scores (see Figure 4.5) because their Chi-Square values are less than 12.6. It is also found that the log-normal distribution is superior to the normal distribution because the Chi-Square value of the log-normal is less than the normal distribution.

Table 4.11 Chi-Square test for relative goodness-of-fit

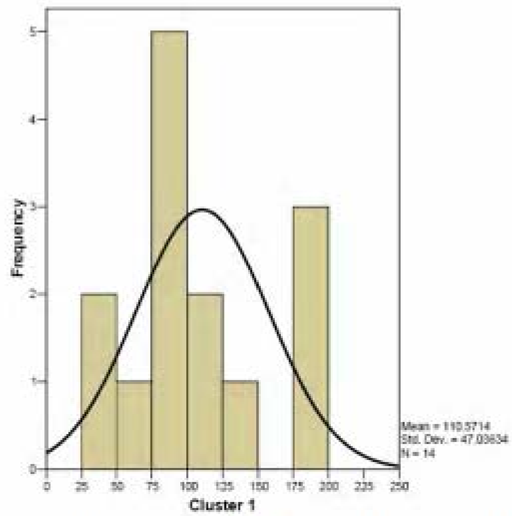
Interval	Observed frequency (n_i)	Theoretical frequency (e_i)		$\frac{(n_i - e_i)^2}{e_i}$	
		Normal	Log normal	Normal	Log normal
0-50	2	2.95	0.85	0.31	1.57
50-100	7	4.00	6.93	2.26	0.00
100-150	7	6.27	9.12	0.08	0.49
150-200	8	7.56	7.16	0.03	0.10
200-250	5	6.98	4.77	0.56	0.01
250-300	2	4.95	3.01	1.76	0.34
300-350	2	2.69	1.87	0.18	0.01
350-400	3	1.12	1.16	3.13	2.89
>400	1	0.47	2.12	0.61	0.59
		37.00	37.00	8.91	6.01

The three landslide hazard groups should ideally be statistically different. The comparison of these three hazard groups are made by using ANOVA test. The null hypothesis is that the hazard score of each landslide in an individual cluster is equal to those in other clusters $(H_o : \mu_{cluster\,1} = \mu_{cluster\,2} = \mu_{cluster\,3})$. If the hypothesis holds, it results in a relatively small value of MSTr, which is the variance of individual cluster mean compared with the grand mean. The MSE is the variance of each individual hazard score compared to the grand mean. The F can be calculated as the ratio of MSTr and MSE. It is then compared to the critical value of F. The null hypothesis is rejected when the value of F is more than $F_{critical}$. Based on the calculations shown in Table 4.12, the null hypothesis is rejected. The cluster means are not equal.

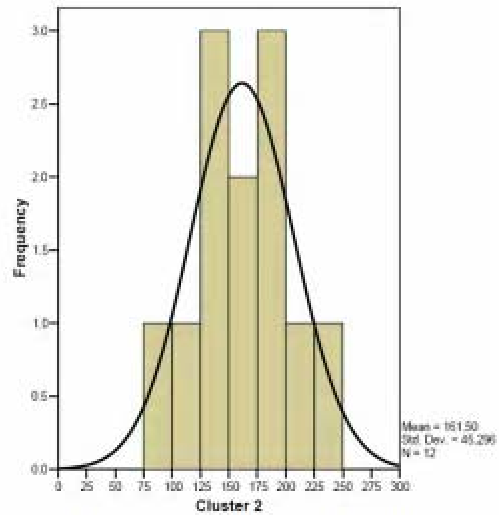
The t-test is used as a validity test of the hazard criteria where the upper bounds and lower bounds of the scoring ranges are tested using the null hypotheses as given in row 1 of Table 4.13. The t values and significances are shown in Table 4.13. According to the criteria of rejection, the null hypotheses hold. Therefore, the hazard scoring criteria are statistically sufficient for classification of three hazard groups.

Table 4.12 ANOVA test of three clusters

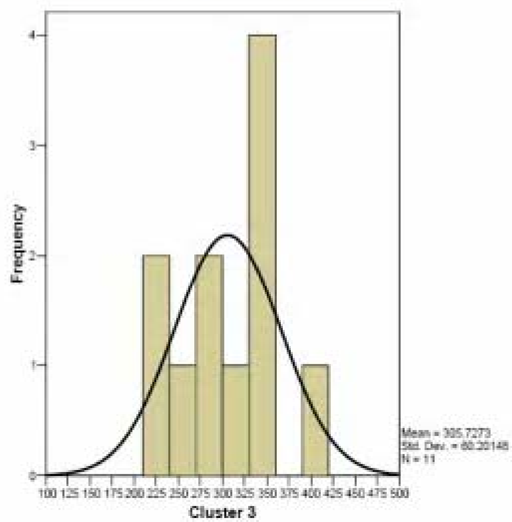
Sources of variations	Sum of Squares	df	Mean Square	F	F_{cr}
Treatments(clusters)	244507	2	122253	47	3.3
Error	87572	34	2575		
Total	332079	36			



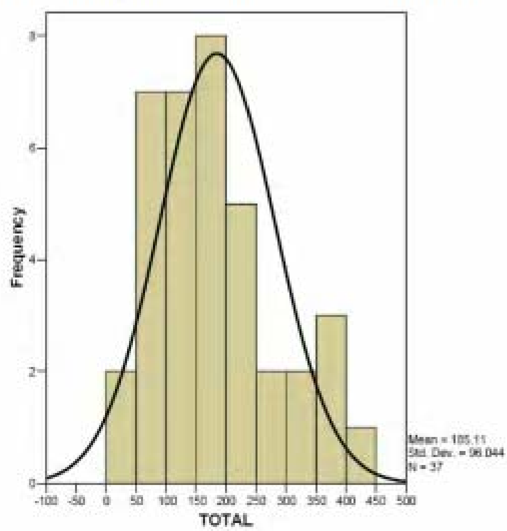
(a) A Histogram of cluster 1 (low hazard)



(b) A histogram of cluster 2 (medium risk)



(c) A histogram of cluster 3 (high hazard)



(d) A histogram of all cluster combined

Figure 4.3 Histograms of hazard groups and all hazard groups combined

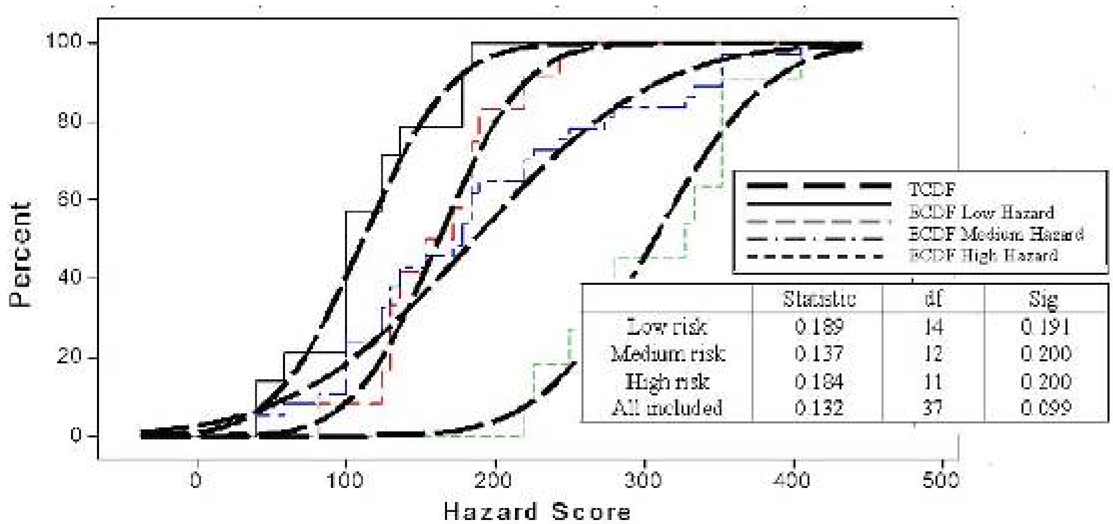


Figure 4.4 Normality test

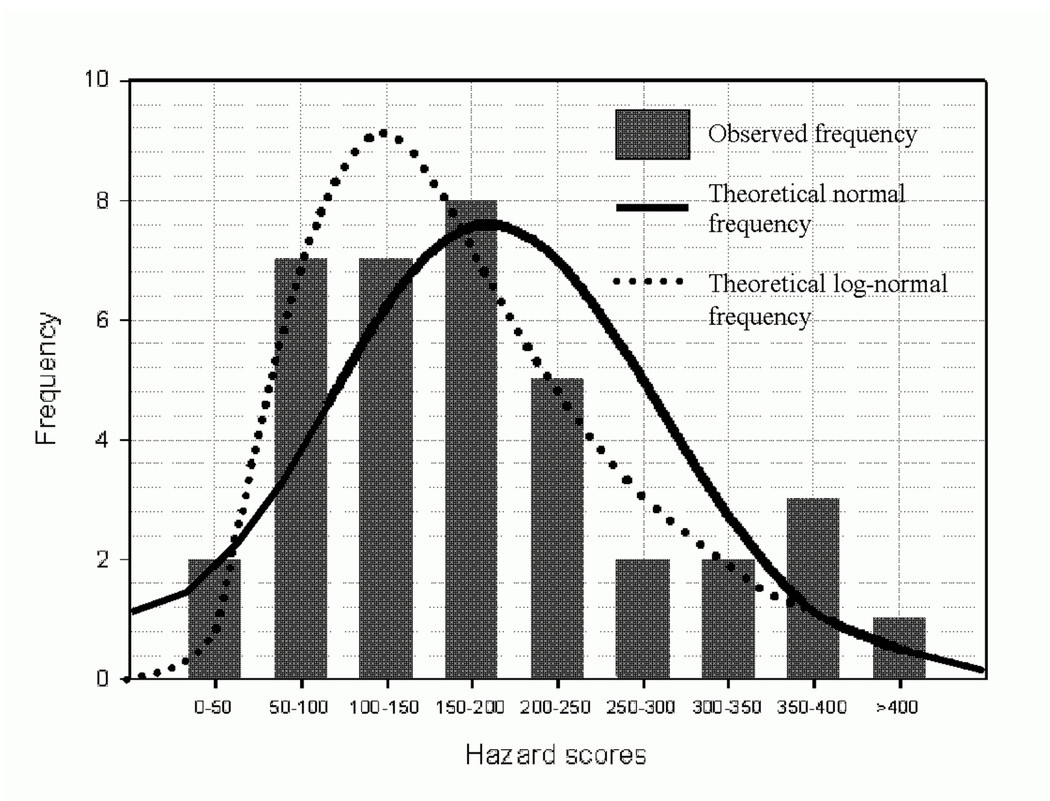


Figure 4.5 Histograms of normal versus log-normal distribution

Table 4.13 t-test of hazard scoring criteria

	Cluster1	Cluster 2		Cluster 3
Hypothesis testing α = 0.05	$H_0 : \mu \le \mu_0$ $H_1 : \mu > \mu_0$ $\mu_0 = 150$	$H_0 : \mu \ge \mu_0$ $H_1 : \mu < \mu_0$ $\mu_0 = 150$	$H_0 : \mu \le \mu_0$ $H_1 : \mu > \mu_0$ $\mu_0 = 250$	$H_0 : \mu \ge \mu_0$ $H_1 : \mu < \mu_0$ $\mu_0 = 250$
Mean	110.20	161.5	161.5	305.73
Std. Dev.	47.04	45.30	45.30	60.20
t	-3.14	0.88	-6.77	3.07
Sig. (2-tailted)/2	0.004	0.200	0.000	0.006
Rejection region for a level α test (α=0.05)	$\frac{Sig.(2-tailed)}{2} < \alpha$ and $t > 0$	$\frac{Sig.(2-tailed)}{2} < \alpha$ and $t < 0$	$\frac{Sig.(2-tailed)}{2} < \alpha$ and $t > 0$	$\frac{Sig.(2-tailed)}{2} < \alpha$ and $t < 0$
Rejection of H_0	Failed to reject	Failed to reject	Failed to reject	Failed to reject

4.6 Comparisons of Different Hazard Scoring System

This section shows that the scoring technique of the exponential scoring system of 3, 9, 27 and 81 would give ODOT the most effective approach to assess and differentiate the risk among the pilot data set of 37 landslide sites. The exponential scoring system is compared with the arithmetic (1, 2, 3, and 4) and the odd number (1, 3, 5, and 7) scoring system, respectively. The comparisons of different numerical scoring systems are illustrated in Figure 4.6. The exponential scoring system can delineate the hazard among the pilot dataset and yields less repetitiveness of the numerical hazard scores. Thus, the exponential scoring system is the most effective and reliable way for landslide hazard scoring.

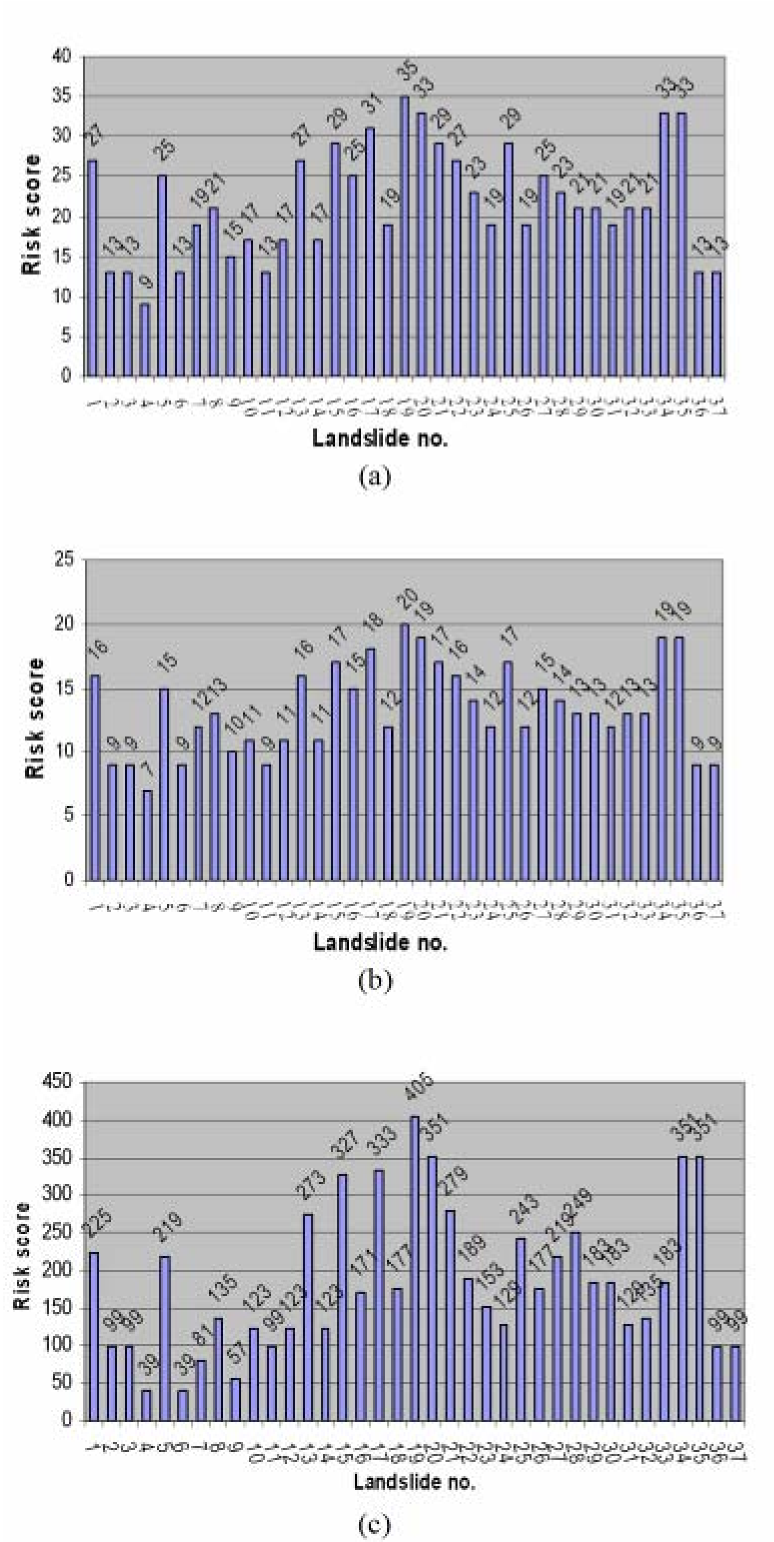


Figure 4.6 Comparisons of distributing of different numerical scoring system (a) odd number, (b) arithmetic, and (c) exponential scoring systems

CHAPTER V

MULTI-CRITERIA DECISION MAKING AND FACTOR ANALYSIS APPROACH TO HIGHWAY SLOPE MANAGEMENT

5.1 Overview

Roadway slope/embankment failures can put traveling public and the nearby roadway facilities at risk. Failures of highway slopes/embankments could cause car accidents, property damages, and associated fatalities and economic losses. The highway operational fund for state highway agencies is usually limited. Thus, the development of proper decision making approach for strategic planning for mitigating risk of failed slopes/embankments is essential. In this chapter, the parameters critical for assessing risk/hazard potentials of the failed slopes/embankments are proposed, which include qualitative and quantitative assessments. The quantitative assessment utilizes the risk features that can be directly measured from the failure site. The qualitative assessment requires applying knowledge and judgment of experts to assign numerical values associated with risk. The expert judgment, as it relies on individual technical background, part experience, and influences by institutional practices, may not be quantified objectively. However, it cannot be neglected in a decision-making process because it provides valuable information (Kikuchi and Perincherry, 1993).

Choi et al (2004) have recommended different approaches that can be used for assessment of risk. The details of analyses depend upon the availability of information.

For example, when historical data are sufficient and available, the probability on each risk/hazard can be evaluated using simple frequency analysis. In case of insufficient data, the probability theories such as Mote Carlo simulation (MCS) or Bayesian approach can be used. Generally speaking, if the data is incomplete or insufficient, simulation or updated data is suitable. When the data is not available at all, the risk/hazard can be assessed using the subjective judgment based on experts' experience and knowledge. The approach to corporate this subjective judgment can be incorporated using the linguistic fuzzy approach.

In this study, the expert judgment is represented using fuzzy linguistic descriptions, which offer an alternative to modeling the system that involves informal language used by human in daily life. All parameters involving with different scales and units in decision-making are systematically standardized and combined with the multiple criteria technique. The parameters to be used in the decision-making are usually selected based on personal judgments and past experiences. The unadjusted factor weight can easily generate bias and create an irrational decision. Also, the factor analysis technique is used to evaluate the importance of each risk parameter. By taking into account of importance of risk parameters, it would yield more rational decision-making for mitigation decision of the failed slopes/embankments.

5.2 Review of Previous Research in Decision Making

The numerical rating method has been used for decision-making on infrastructure related rehabilitation projects. The infrastructure condition is often represented by discrete rating, which is based on expert judgment using numerical scales. A bridge rating system developed by Federal Highway Administration (FHWA) in 1979 is commonly used for bridge deck condition assessment. Bridge inspector used the rating scores of 0 to 9. In case, a bridge deck of the rating condition of 9 is the near perfect bridge deck condition. The U.S. Army Corp of Engineers (McKay et al, 1999) also developed a condition index (CI) scale for assessment of its civil works structures. The CI index is a number from 0 to 100 and is the indicative of a structure condition, which is decrypted with a consistent language or definition. Using a number to describe a structure condition has some advantages in that it is easy to store in a computer and can be manipulated in mathematical expression. The idea of using a number to describe the infrastructure condition is adopted throughout this paper.

The use of deterministic and probabilistic have been devoted for infrastructure maintenance and rehabilitation decision making to obtain the performance models that can relate environment conditions, traffic levels, infrastructures, etc, to predict the future performance of the infrastructures. Al-Mansour and Sinha (1994) used regression technique to obtain the relationship between pavement serviceability index (PSI) and pavement age. Ullidtz (1999) presented a number of mechanistic-empirical deterioration model for managing flexible pavements, in which a simple mechanic method using the critical stresses and strains in pavement materials was combined with deterioration models to predict pavement deterioration in term of roughness, rutting, and cracking, respectively, as a function of traffic loading, climate, and age.

The progression of deterioration of an infrastructure over time as a function of age, environment factors, design factors, etc can be modeled by using Markovian process model, which are developed from estimates of probability that a given condition state will either stay the same of move to another state. The probability of each of these events is estimated based in historical field data or the experience of investigators. Madanat et al (1995), Destefano et al (1998), and Guignier and Madanat (1999) adopted the Markovian process models for bridge performance prediction. Takeyama (1993) and Wang et al (1994) applied the Markovian process for predicting pavement performance. Micevski et al (2002) used the Markovian process model for storm and sewer pipe management.

Kay et al (1993) used Bayesian regression analysis to develop prediction models to relate fatigue life to asphalt concrete properties by using subjective and objective data. The subjective data was obtained from opinion of experienced personnel. Many agencies have developed hazard/risk assessment system for landslides along highways. Examples include Oregon DOT (Pierson,1992 and ODOT, 2002), Washington DOT (Lowel and Morin, 2000), New York DOT (Hadjin, 2001), Utah DOT (Pack and Boie, 2002), and Ohio DOT (Liang et al, 2006).

The multiple criteria analysis has been used in many disciplines. The purpose is to standardize and combine many parameters (criteria) into a standardized decision value. Kikuchi and Miljkovic (2001) used multiple criteria analysis to predict the degree of ridership of bus at the bus stops. Dissanayake et al (1999) used multiple criteria approach to identify the most critical highway safety needs for different population groups. The importance of groups impacting highway safety was identified using the opinion of highway safety professionals and an index was developed for the corresponding critical highway safety issues and concerns. Choi et al (2004) utilized linguistic fuzzy concept together with multiple criteria concept in risk assessment for underground construction project. Sanchez et al (2005) used multiple criteria approach to represent and synthesize different variables in the evaluation of project's value.

Many research efforts in decision-making have devoted to factor analysis, which can be used for data reduction, and identification of critical parameters. For example, Ghosh and Jintanapakanont (2004) utilized the factor analysis to classify various types of risk parameters in a mass rapid-transit underground rail project. Importance of risk factors was evaluated by ranking their importance indices, which confirms with the results obtained from experts' opinion. Love et al (2004) used factor analysis to identify the chemical signature for groundwater quality management. The factor analysis yields the similar results as the conventional groundwater quality methods. Factor analysis was also used in other disciplines for example; identifying important parameters in, mortgage loan decision (Lui and Lee, 1997), critical factor identification in Knowledge Management (Moffett et al, 2002).

5.3 Risk Parameters Used in Decision-Making Model

Various risk parameters have been used in risk/hazard assessment for failed highway slopes due to landslide and rockfall. The selection of the risk parameters was generally based on expert judgment and past practices of highway agencies, and information regarding geologic setting of the failed highway slopes. A literature review reveals agencies such as Oregon DOT (Pierson, 1992 and ODOT, 2002), Washington DOT (Lowel and Morin, 2000), New York DOT (Hadjin, 2001), Utah DOT (Pack and Boie, 2002), Hong Kong Geotechnical Engineering Office (Koirala and Watkins, 1988), Ohio DOT (Liang et al, 2006) have developed landslide hazard rating matrix, involving a total of 23 different risk parameters as seen previously in Table 4.3.

Altogether, six risk parameters, including both qualitative and quantitative parameters, have been used in assessing risk/hazard of an unstable slope. The qualitative parameters are (i) location of slope failure and its impact on the highway, (ii) extent of damage of pavement due to slope failure, (iii) maintenance response due to slope failure. The judgment criteria for the qualitative parameters are summarized in Table 5.1. The quantitative parameters are (i) decision sight distance (DSD), (ii) average daily traffic (ADT), and (iii) magnitude of slope displacement. DSD is the ratio of the actual sight distance to the ASSTHO standard sight distance (ASSTHO, 1984). The actual sight distance is measured as the shortest distance that a 6-inch tall object can be continuously visible to a driver. ADT is average daily traffic at the failure location.

Table 5.1 Qualitative parameters

Risk Parameters	(1) Low risk	(2) Moderate risk	(3) High risk	(4) Very high risk
Location of failure and its potential impact	Failure is on slope but it can not reach the roadway	Failure is on slope and it has potential to affect the roadway	Failure is on shoulder and it has potential to affect roadway	Failure is on roadway and it has potential to affect roadway and nearby structures such as bridges and buildings
Damage of pavement	Noticeable damage but no effect to driving condition	Driver must slow down	Driver must stop and pass carefully	Non traversable pavement
Maintenance response	None to low response	Require observation and periodic maintenance	Require routine maintenance	Require immediate maintenance for public safety

5.4 Approach to the Model Development

The traditional approach for decision making in engineering problems has been devoted to eliminate subjectivity and only use objective information as much as possible. It is possible to obtain the objective information but it needs time for gathering the detailed information and the additional cost of computation. Also, it may not be practical for the case of emergency and limit in project operation cost. The approximate values in term of judgment and opinion of experts may be tolerated. For example, the size of an object may be clarified as very big, big, relatively, etc. Judgment and opinion of expert relates human perception, which can be represented as words in natural language instead of numerical values. In this paper, the fuzzy linguistic description is used to capture this emotional expression.

The fuzzy set theory was first introduced by Zadeh (1965). The classical set theory rather limits membership to a set, which characterizes elements or entities that either belongs to or does not belong to the set. In contrast, the fuzzy set theory provides a more flexible representation of membership by a number between 0 and 1. The nature of the characteristic function is changed by expanding the evaluation set, which is called membership function ($\mu_A(x)$).

Since the interval [0,1] contains infinite number; therefore, infinite degrees of memberships are possible. Thus, Equation 5.1 can be used to map every element of X in the interval [0,1].

$$u_A(x) : X \rightarrow [0,1] \tag{5.1}$$

The membership grade $\mu_A(x)$ identifies how much x belongs to set A; in other words $\mu_A(x)$ is the "strength" or "truth value" of the following statement: "x belongs to the set A" (Kikuchi and Perincherry, 1993).

Expert knowledge can be expressed using linguistic variables. Herrera et al. (2000) proposed a set of linguistic descriptions that can be used to represent the emotional expression of expert. The linear trapezoidal membership functions are usually used in literature to represent expert knowledge and judgment. The crisp or defuzzification value of each trapezoidal fuzzy value can be quantified as shown in Table 5.2.

Table 5.2 Linguistic fuzzy number of "degree of belief" (after Herrera, 2000)

Linguistic fuzzy term	Abbreviation	Linguistic Fuzzy Number (Trapezoidal) (x1, x2, x3, x4)	Defuzzification value (x1+x2+x3+x4)/4
Impossible	I	(0, 0, 0, 0.0)	0.0
Extreme unlikely	EU	(0, 0, 0.1, 0.2)	0.075
Very low chance	VLC	(0.1, 0.2, 0.2, 0.3)	0.2
Small chance	SC	(0.2, 0.3, 0.4, 0.5)	0.35
It may	IM	(0.4, 0.5, 0.5, 0.6)	0.5
Meaningful chance	MC	(0. 5, 0.6, 0.7, 0.8)	0.65
Most likely	ML	(0.7, 0.8, 0.8, 0.9)	0.8
Extreme likely	EL	(0.8, 0.9, 1, 1)	0.925
Certain	C	(1, 1, 1, 1)	1

The fuzzy sets can be presented in many ways. If X is a universe and x is a particular element of X, then fuzzy set A defined on X can be written as a collection of ordered pairs as Equation 5.2.

$$A=\{(x, u_A(x))\}, x \in X \quad (5.2)$$

Each pair (x, $u_A(x)$) is called a singleton where x indicates the order of element, followed by its membership in A, $u_A(x)$.

Let's a fuzzy set A represents a qualitative parameter. Based on the judgment criteria shown in Table 5.1, each qualitative risk parameter has four risk levels: low, moderate, high, and very high risk, respectively. Therefore, the qualitative risk parameter can be described as a fuzzy set given Equation 5.3.

$$A = \{(1, u_A(1)), (2, u_A(2)), (3, u_A(3)), (4, u_A(4))\} \quad (5.3)$$

Let's the condition value of a qualitative risk parameter be 10 and let's each singleton in Eq. (3) be represented by the score interval of 2.5. Therefore, the low, medium, high, and very high risk criteria can be described by the score interval of, 0 to 2.5, 2.5 to 5.0, 5.0 to 7.5, and 7.5 to 10, respectively. For example, if a risk factor is characterized as very high and the judgment is "most likely", the singletons of the fuzzy number can be written as $A = \{(1, (2.5\times1)),(2, (2.5\times1)), (3, (2.5\times0.8), (4, (2.5\times0))\} = 2.5 + 2.5 + 2.0 + 0 = 7.0$.

Decision making may involve many risk parameters, which are not only the risk parameters that come from experts' judgment but also from measurement of the site features as well as other statistical information such as site history, traffic, etc. A single decision value may be determined based on the combination of the risk parameters that involve safety of the failed highway section. These risk parameters usually have different scales and units, which require an optimization technique before they can be combined. In this paper, a mathematical technique, so called multiple criteria decision making, is used for the combination of the risk parameters.

Li and Yen (1995) introduced the mathematical concept of multiple criteria decision making that is suitable for processing both fuzzy and non-fuzzy information into standard dimensionless values. The complete factor space of a set of parameters can be written as follows.

$$X(f) = \prod_{j=1}^{m} X(f_i) \tag{5.4}$$

Where $f_1, f_2, \ldots, f_m$ denotes parameters (criteria) and $X(f_i)$ denotes the state space of f_i, i = 1, 2,…,m. Corresponding to each parameter, there is an objective function (φ_j).

$$\varphi_j : X(f_i) \rightarrow \Re^+ \tag{5.5}$$

where $\Re^+$ is nonnegative real numbers, which can be transformed into the closed unit interval [0,1]. Therefore, Equation 5.5 can also be written as

$$\varphi_j = X(f_i) \rightarrow [0,1] \tag{5.6}$$

The complete objective function (φ) can be obtained as follows.

$$\varphi = \prod_{j=1}^{m} X(f_i) \rightarrow [0,1]^m \tag{5.7}$$

$$x = (x_1, x_2, \ldots, x_m) \mapsto \varphi(x) = (\varphi_1(x_1), \varphi_2(x_2), \ldots, \varphi_m(x_m)) \tag{5.8}$$

By writing the parameters in this form of equation, the decision-making problem is transformed into an optimization problem where the decision function can be written as

$$D_m(u_i) = \frac{1}{m}\sum_{j=1}^{m} \varphi_j(f_j(u_i)) \tag{5.9}$$

In case, there are many alternative projects (n = 1, 2,…,p) to be selected. The objective functions of the p alternative projects can be listed as Equation 5.10.

$$
\begin{aligned}
\varphi^{(1)} &= (\varphi_1^{(1)}, \varphi_2^{(1)}, \ldots, \varphi_m^{(1)}) \\
\varphi^{(2)} &= (\varphi_1^{(2)}, \varphi_2^{(2)}, \ldots, \varphi_m^{(1)}) \\
&\vdots \\
\varphi^{(p)} &= (\varphi_1^{(p)}, \varphi_2^{(p)}, \ldots, \varphi_m^{(p)})
\end{aligned} \tag{5.10}
$$

Based on Equations 5.9 and 5.10, the project can be selected according to the maximum decision value as shown in Equation 5.11.

$$
D_m(u_0) = \max\{D_m(u) \mid u \in U\} \tag{5.11}
$$

Equation 5.11 can be used for decision making when importance of risk parameters is not considered. It is not true in the sense in that a risk parameter may post higher risk than other risk parameters. Therefore, importance of risk parameters, when used in decision making, should be treated differently. The traditional mode to determine importance of risk parameters can be made by asking experts' opinion by using a set of questionnaire. However, quantification of parameter importance by the use of questionnaire is not reliable because experts usually bias in some parameters more than others. This problem is the result of different degree of training, knowledge, and some intuition preference. In order to reduce bias, instead of using expert opinion to quantify parameter importance, statistical correlation of parameters' information should be used.

In this paper, the importance of each risk parameter is investigated using the factor analysis. When the importance of each risk parameter (b_{ij}) is determined, the relationship between the risk parameters (X_i) and their responses or factor score (F_i) can be written as Equation 5.12.

$$
\begin{aligned}
F_1 &= b_{11}X_1 + b_{12}X_2 + \ldots + b_{1n}X_n \\
F_2 &= b_{21}X_1 + b_{22}X_2 + \ldots + b_{2n}X_n \\
&\vdots \\
F_n &= b_{1n}X_1 + b_{2n}X_2 + \ldots + b_{nn}X_n
\end{aligned} \tag{5.12}
$$

where F_1 to F_n are factor scores for 1st to nth factor, n is the number of factors, b_{1n} to b_{nn} are weights for each factor, and $X_1, X_2, \ldots, X_n$ are values of the n factors.

According to Guertin and Bailay (1970), the relationship between the correlation matrix (R) and the matrix of loading coefficient, b_{ij}, (B) is written as Equation 5.13.

$$[B][B]^T = R \tag{5.13}$$

The correlation (similarity) matrix (R) can be calculated using Pearson Correlation method, which is as given in Equation. 5.14, where Z_{Xi} and Z_{Yi} are the standardized score of parameter X_i and Y_i.

$$R_{X,Y} = \frac{\sum_{i=1}^{n} Z_{Xi} Z_{Yi}}{n - 1} \tag{5.14}$$

Conducting the factor analysis involves the following processes. The first step is to define the problem and identify the parameters to be analyzed. Based on the values of selected parameters, the correlation matrix (R) can be developed and therefore, the loading coefficient matrix (B) can be determined. Next, the factors that account for most variance of data are selected. The criterion for selection of factors is based on their eigen values, which have to be greater than 1. The eigen value is the sum of square of all parameter coefficients (b_{ij}) in a factor. The next step is to plot the loading coefficients on the factors' axes. The last step is to turn the factor reference axes about the origin to reach the more meaningful positions such that, interpretation of selected parameters can be made.

5.5 Criteria for Describing Risk Factors

Before overall risk of a failed highway slope can be evaluated, a risk criterion for each risk parameter is defined. The objective functions that are adopted as criteria to describe six risk parameters are presented in Table 5.3. These functions normalized the risk parameters' values to be in the range of 0 and 1, so that all risk parameters' values can be easily combined. Risk induced by each risk parameter is assumed to increase exponentially as a cubic function (x^3), which provides a rapid increase in numerical scores (Pierson, 1992). The criteria to standardize the risk parameters may be different among individuals or agencies. The criteria adopted for evaluating risk also depend upon technical background and past experiences of persons who are in charge of making decision. The numerical criteria described in the following for the proposed six risk parameters are defined based on judgment and experience of authors.

Location of failure and its potential impact is used to describe the slope failure location relative to the highway pavement. The condition value of 0 to 10 is used to describe this risk parameter. Risk value is assigned to be 1 when the condition value exceeds 8. The risk is low when the condition value is between 0 and 2. In this case, the risk value is assigned as 0. For the condition between 2 and 8, the power function of x^3 is used to describe the risk level in this interval.

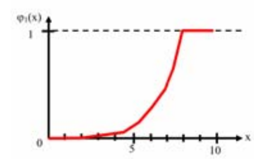
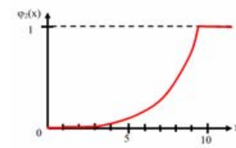
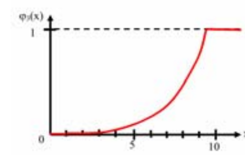
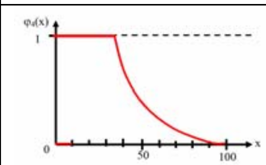
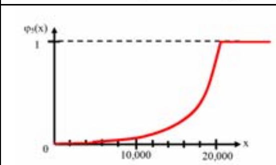
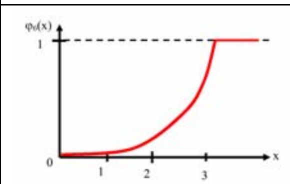
Risk associated with the effect of *decision sight distance (DSD)* can be described as follows. The failed highway slope/embankment is at high risk when the failed roadway suddenly appears to a motorist and he/she does not have enough time to make decision to avoid the collision. The standard to measure DSD can be found in AASHTO (1984). When *DSD* is less than 40%, the roadway section should be regarded as high risk;

therefore, numerical value of 1 is assigned. In contrast, when *DSD* is greater than 90%, the motorist should have enough time to avoid the danger on roadway. The cubic function (x^3) is used to describe risk when *DSD* is in the range of 40 to 90%.

Average Daily Traffic (ADT) indicates the daily traffic volume passing through the failed slope section. The higher the traffic volume, the more vehicles could potentially be prone to accident due to the effect of slope failure. The *ADT* may range from a few hundreds in rural area to several hundred thousands in the major interstate highway. It is proposed that when the traffic volume is less than 5,000 cars/day, the risk value of 0 is assigned. If *ADT* is greater than or equal to 20,000 cars/day, the risk level of 1 is assigned. For *ADT* between 5,000 and 20,000 cars/day, the risk value is described by the cubic function (x^3).

The effect of the failed slope may be the development of surface crack and dip (undulation), on pavement, which can endanger the traveling traffic. The larger the cracks or displacements on pavement, the higher the risk to the moving vehicles. *Magnitude of displacement* is used to represent this effect as follows. If there is no displacement on pavement surface, there is no risk to moving vehicles. If the displacement is greater than 3 inches in either vertical or horizontal direction, the risk value of 1 is assigned. The cubic function (x^3) is used to describe the risk when the displacement is in between 0 and 3 inches. The decision regarding *Maintenance Response* and *Damage of Pavement* is based on the personal judgment and experience. When the condition value is less than 2, the risk level of 0 is assigned. When the condition value is greater than or equal to 9, the risk level of 1 is assigned. The cubic function (x^3) is used to describe the condition value in between 2 and 9.

Table 5.3 Parameters and their objective functions

Parameter	Objective function ($\varphi_n(x_n)$)	Graph of objective function
Location of failure and its potential impact	$\varphi_1(x_1)=\begin{cases}0, & 0\le x_1<2\\ \left(\frac{x_1-2}{6}\right)^3, & 2\le x_1<8\\ 1, & x_1>8\end{cases}$	
Damage of pavement	$\varphi_2(x_2)=\begin{cases}0, & 0\le x_2<2\\ \left(\frac{x_2-2}{7}\right)^3, & 2\le x_2<9\\ 1, & x_2\ \ge\ 9\end{cases}$	
Maintenance response	$\varphi_2(x_2)=\begin{cases}0, & 0\le x_2<2\\ \left(\frac{x_2-2}{7}\right)^3, & 2\le x_2<9\\ 1, & x_2\ \ge\ 9\end{cases}$	
Decision sight distance	$\varphi_3(x_3)=\begin{cases}0, & 90<x_3\le 100\\ \left(\frac{90-x_3}{50}\right)^3, & 40<x_3\le 90\\ 1, & x_3\le 40\end{cases}$	
ADT	$\varphi_4(x_4)=\begin{cases}0, & 0\le x_4<5{,}000\\ \left(\frac{x_4-5{,}000}{15{,}000}\right)^3 & 5{,}000\le x_4<20{,}00\\ 1, & x_4\ge 20{,}000\end{cases}$	
Magnitude of displacement	$\varphi_5(x_5)=\begin{cases}0, & x_5=0\\ \left(\frac{x_5}{3}\right)^3, & 0<x_5\le 3\\ 1, & x_5>3\end{cases}$	

5.6 Data Analysis

5.6.1 Standardization of Data

The information of 37 landslide sites is summarized in Table 5.4. The columns 2 to 6 display the information of the qualitative risk parameters. The numbers values of 1, 2, 3, and 4 in the columns 2, 4, and 6 are used to represent low, medium, high, and very high risk potential, respectively. The columns 3, 5, and 7 give the value of degree of belief based on expert opinion formed during site reconnaissance. The defuzzification values associated with the degree of belief shown previously in Table 5.2 are applied. The crisp condition values of the qualitative parameters are shown in columns 8, 9, and 10 in Table 5.4 . The objective functions of the six risk parameters are applied to all parameters as shown in columns 2 to 7 in Table 5.5. The decision values without the factor weights are calculated using Equation 5.9, and are given in column 8 of Table 5.5.

5.6.2 Similarity Relationships

The similarity coefficient (R) of the risk parameters can be calculated using Equation 5.14. Z_{Xi} and Z_{Yi} represent the standardized values of the six risk parameters at the site i^{th} to n^{th}. Based on the information, the six by six of the similarity matrix (R) is formed, which is tabulated in Table 5.6. It can be noticed that the correlation between the maintenance response and the magnitude of displacement is highest with the correlation coefficient of 0.713. The maintenance response is also strongly related to the location of failure and the pavement damage with the correlation of coefficients of 0.62 and 0.597, respectively. Thus, these four parameters (maintenance response, magnitude of displacement, location of failure, and pavement damage) could be grouped as the same factor. The correlation between the other parameters, including DSD and ADT, is - 0.277. ADT is related to the location of failure with a correlation of -0.330. Despite the fact that the correlation of ADT and location of failure is higher than ADT and DSD, both should be grouped in the second group because they are less related to the first group.

Table 5.4 Non-standardized data

(1) Site no.	(2) V1	(3) DB1	(4) V2	(5) DB2	(6) V3	(7) DB3	(8) V1[1]	(9) V2[1]	(10) V3[1]	(11) V4	(12) V5	(13) V6
1	3	IM	1	C	2	I	6.25	2.50	5.00	46	16330	5
2	1	VLC	1	I	2	EU	0.50	0.06	2.69	100	16330	0
3	1	C	1	EL	1	IM	2.50	2.31	1.25	29	2610	1
4	1	VLC	1	VLC	1	EU	0.50	0.50	0.19	100	11530	0
5	3	ML	2	ML	3	MC	7.00	4.50	6.63	33	1470	4
6	2	SC	1	IM	2	VLC	3.38	1.25	3.00	67	2690	0
7	3	IM	1	I	3	IM	6.25	0.06	6.25	67	3170	1
8	4	ML	1	ML	2	SC	9.50	2.00	3.38	57	2010	1
9	3	IM	1	I	2	I	6.25	0.06	5.00	51	2010	0
10	4	ML	1	EU	3	I	9.50	0.19	7.50	97	3510	0
11	1	IM	1	EU	2	SC	1.25	0.19	3.38	100	28190	0
12	3	IM	1	SC	2	EL	6.25	0.88	4.81	100	28190	0
13	4	C	2	ML	4	I	10.00	4.50	10.00	40	560	6
14	3	SC	1	IM	2	SC	5.88	1.25	3.38	100	22900	0
15	4	EL	2	ML	4	MC	9.81	4.50	9.13	100	34880	5
16	4	IM	2	IM	3	IM	8.75	3.75	6.25	52	9410	1.5
17	4	C	2	C	4	ML	10.00	5.00	9.50	63	15810	5
18	2	SC	1	EU	2	SC	3.38	0.50	3.38	26	48230	0.5
19	4	C	1	I	4	EL	10.00	2.50	9.81	31	29730	3
20	4	C	2	I	4	ML	10.00	5.00	9.50	22	5900	5
21	4	MC	1	EU	4	IM	9.13	0.19	8.75	72	9750	0
22	4	EL	2	C	4	IM	9.81	5.00	8.75	40	9410	5
23	4	MC	2	MC	3	EL	9.13	4.13	7.31	44	6680	0.5
24	4	IM	2	IM	2	IM	8.75	3.75	3.75	100	7670	0.5
25	4	IM	1	SC	3	IM	8.75	0.88	6.25	29	7670	1.5
26	1	VLC	1	EU	2	EL	0.50	0.19	4.81	29	15420	0
27	4	IM	2	MC	3	IM	8.75	4.13	6.25	29	1490	1
28	4	EL	3	IM	4	C	9.81	6.25	10.00	100	720	5
29	4	SC	1	ML	2	C	8.38	1.63	5.00	34	1160	0.5
30	4	IM	2	SC	2	EL	8.75	3.38	4.81	29	700	1
31	4	EL	1	ML	3	C	9.81	2.00	7.50	93	3000	0.5
32	4	MC	2	SC	3	SC	9.13	3.38	5.88	67	2690	0.5
33	4	IM	2	IM	2	EL	8.75	3.75	4.81	23	4250	0.1
34	4	C	3	IM	4	EL	10.00	6.25	9.81	34	6140	5
35	4	C	3	EL	4	C	10.00	7.31	10.00	59	109410	0
36	1	SC	1	I	2	VLC	0.88	0.06	3.00	100	141250	0
37	1	I	1	I	1	EU	0.06	0.06	0.19	30	3080	0

Column heading designation
V1: Location of failure and its potential impact
DB1: Degree of belief of V1
V2:Damage of pavement
DB2: Degree of belief of V2
V3: Maintenance response
DB3: Degree of belief of V3

V1[1]: Quantitative value of V1
V2[1]: Quantitative value of V2
V3[1]: Quantitative value of V3
V4:Decision sight distance
V5:ADT
V6:Magnitude of displacement in inch

Table 5.5 Standardized data

(1) Site no.	(2) φ_1	(3) φ_2	(4) φ_3	(5) φ_4	(6) φ_5	(7) φ_6	(8) D_m	(9) D_{mf}
1	0.355	0.000	0.079	0.695	0.431	1.000	0.427	0.300
2	0.000	0.000	0.001	0.000	0.431	0.000	0.072	0.008
3	0.001	0.000	0.000	1.000	0.000	0.037	0.173	0.204
4	0.000	0.000	0.000	0.000	0.083	0.000	0.014	0.002
5	0.579	0.046	0.288	1.000	0.000	1.000	0.485	0.476
6	0.012	0.000	0.003	0.102	0.000	0.000	0.019	0.025
7	0.355	0.000	0.224	0.102	0.000	0.037	0.120	0.175
8	1.000	0.000	0.008	0.284	0.000	0.037	0.221	0.349
9	0.355	0.000	0.079	0.459	0.000	0.000	0.149	0.214
10	1.000	0.000	0.485	0.000	0.000	0.000	0.248	0.399
11	0.000	0.000	0.008	0.000	1.000	0.000	0.168	0.021
12	0.355	0.000	0.065	0.000	1.000	0.000	0.237	0.136
13	1.000	0.046	1.000	1.000	0.000	1.000	0.674	0.759
14	0.269	0.000	0.008	0.000	1.000	0.000	0.213	0.099
15	1.000	0.046	1.000	0.000	1.000	1.000	0.674	0.575
16	1.000	0.016	0.224	0.444	0.025	0.125	0.306	0.438
17	1.000	0.079	1.000	0.152	0.374	1.000	0.601	0.601
18	0.012	0.000	0.008	1.000	1.000	0.005	0.337	0.227
19	1.000	0.000	1.000	1.000	1.000	1.000	0.833	0.767
20	1.000	0.079	1.000	1.000	0.000	1.000	0.680	0.766
21	1.000	0.000	0.897	0.047	0.032	0.000	0.329	0.502
22	1.000	0.079	0.897	1.000	0.025	1.000	0.667	0.743
23	1.000	0.028	0.437	0.756	0.001	0.005	0.371	0.548
24	1.000	0.016	0.016	0.000	0.006	0.005	0.174	0.296
25	1.000	0.000	0.224	1.000	0.006	0.125	0.392	0.546
26	0.000	0.000	0.065	1.000	0.335	0.000	0.233	0.224
27	1.000	0.028	0.224	1.000	0.000	0.037	0.381	0.550
28	1.000	0.224	1.000	0.000	0.000	1.000	0.537	0.597
29	1.000	0.000	0.079	1.000	0.000	0.005	0.347	0.510
30	1.000	0.008	0.065	1.000	0.000	0.037	0.352	0.510
31	1.000	0.000	0.485	0.000	0.000	0.005	0.248	0.399
32	1.000	0.008	0.170	0.102	0.000	0.005	0.214	0.350
33	1.000	0.016	0.065	1.000	0.000	0.000	0.347	0.510
34	1.000	0.224	1.000	1.000	0.000	1.000	0.704	0.800
35	1.000	0.437	1.000	0.232	1.000	0.000	0.612	0.683
36	0.000	0.000	0.003	0.000	1.000	0.000	0.167	0.020
37	0.000	0.000	0.000	1.000	0.000	0.000	0.167	0.203

Column heading designation
φ_1: Objective function value of V1[1]
φ_2: Objective function value of V2[1]
φ_3: Objective function value of V3[1]
φ_4: Objective function value of V4
φ_5: Objective function value of V5
φ_6: Objective function value of V6

D_m: Decision function value
D_{mf}: Decision function value with loading factors

Table 5.6 Similarity correlation matrix (R)

	Location of failure	Damage of pavement	Maintenance response	DSD	ADT	Magnitude of disp.
Location of failure	1.000					
Damage of pavement	0.332	1.000				
Maintenance Response	0.620	0.597	1.000			
DSD	0.137	-0.012	0.059	1.000		
ADT	-0.330	0.120	0.021	-0.277	1.000	
Magnitude of disp.	0.351	0.317	0.713	0.270	0.013	1.000

5.6.3 Factor Loading Determination

The system equations that can be used as the decision-making equation are shown in Equation. 5.12 where the number of decision-making equations is equal to the number of risk parameters. In this study, six risk parameters are used in the decision making. Therefore, the coefficient matrix of 6× 6 can be formed. The relationship between the correlation matrix (R) and the loading coefficient matrix (B) can be written in Equation 5.13.

The loading coefficient matrix of the system equations can be determined as shown in Table 5.7. The preliminary selection of the decision-making equation can be made based on their eigen values. The eigen value can be calculated based on the summation of the square of each loading coefficient in each system equation. Many literatures have recommended that the system equations having the eigen values greater than 1.0 are suitable to be used to explain the system behavior. Based on Table 5.7, the two equations having the eigen values greater than 1.0 are selected as the decision-making equations, which can account for the variance of 65.40%.

Table 5.8 depicts the two equations, where the variance of 42.35% and 23.05%, can be explained by the first and second equation, respectively. The loading coefficients or components are plotted in a 2-dimensional plan as seen in Figure. 5.1. The rotation of axes can be made in order to achieve more meaningful factor pattern. The reference axes are kept at 90 degree and rotated to other optimum positions to redistribute the variance between the two equations. Table 10 shows the importance coefficients after their variances are redistributed. Also, Figure. 5.1 shows the loading coefficients plot after the axes' rotation.

Table 5.7 Loading coefficients (b_{ij}) of six decision-making equations

Parameters	Loading coefficients of the system equations					
	1	2	3	4	5	6
Location of Failure	.744	-.257	-.430	-.093	.414	.123
Damage of Pavement	.666	.395	-.118	.593	-.165	.088
Maintenance Response	.925	.200	-.029	-.131	-.013	-.294
Decision Sight Distance	.257	-.655	.613	.307	.183	-.045
ADT	-.134	.831	.398	-.024	.362	.025
Magnitude of Displacement	.778	.030	.415	-.368	-.236	.175
Eigen Value	2.542	1.382	0.906	0.607	0.419	0.142
Variance Explained (%)	42.36	23.04	15.10	10.13	6.983	2.376

Table 5.8 Component analysis

Variables	Component		Communality
	1	2	
Maintenance response	0.925	0.200	0.896
Magnitude of disp.	0.778	0.030	0.606
Location of failure	0.744	-0.257	0.620
Damage of pavement	0.666	0.395	0.600
ADT	-0.134	0.831	0.709
Decision sight distance	0.257	-0.655	0.495
Sum of square (Eigenvalue)	2.541	1.383	3.924
Variance explained (%)	42.35	23.05	65.40

Table 5.9 Rotated component analysis factor matrix

Variables	Component		Communality
	1	2	
Maintenance response	0.946	0.018	0.895
Magnitude of disp.	0.764	0.150	0.606
Location of failure	0.739	-0.231	0.599
Damage of pavement	0.665	0.421	0.619
Decision sight distance	0.099	0.696	0.494
ADT	0.061	-0.840	0.709
Sum of square	2.480	1.443	3.924
Variance explained (%)	41.33	24.05	65.40

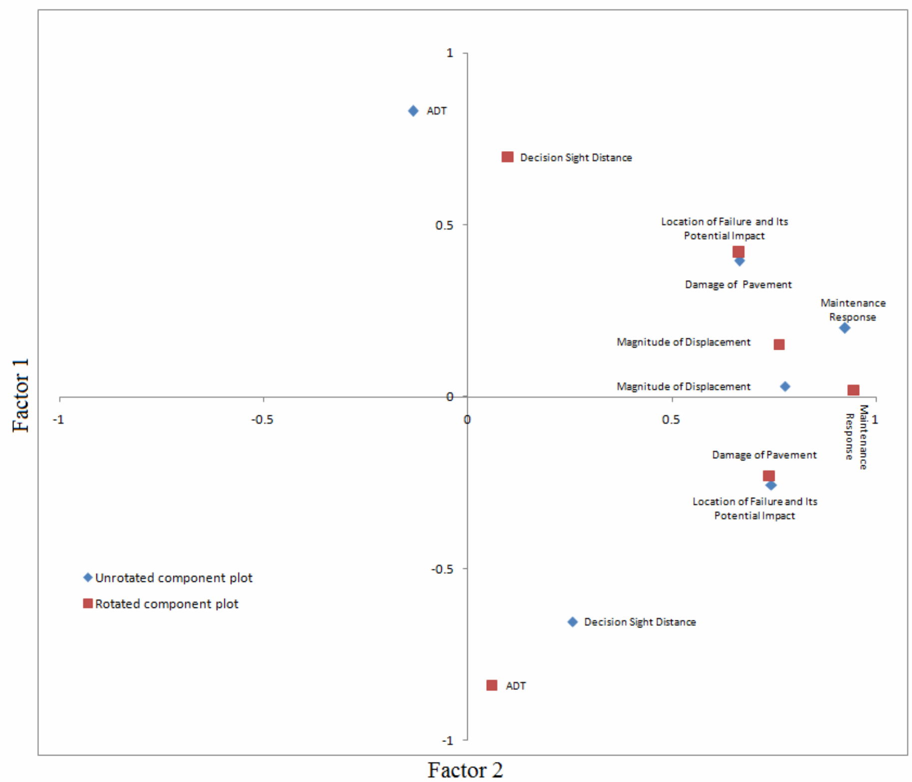


Figure 5.1 Unrotated and rotated component plot

The components of the first equation after redistribution of variance can account for most of variance of the risk parameter. Based on the analysis results given in Table 5.9, *Maintenance Response* is the most significant risk parameter, which is the most importance having the importance index of 0.946. *Magnitudes of Displacement, Location of Failure, Damage of Pavement, DSD, and ADT* are less importance. Based on the importance indices that are obtained from the analysis, the coefficients of all proposed risk parameters can be determined by constraining the sum of all important indices to be equal to 1. The loading coefficients of the risk parameters of *Maintenance Response, Magnitude of Displacement, Location of Failure, Damage of Pavement, Decision Sight Distance, and ADT* are 0.289, 0.233, 0.226, 0.203, 0.030, and 0.019, respectively. The decision-making equation with the risk parameter coefficient can be written as Equation 5.15. The decision values based on Equation 5.15 are displayed in column 9 in Table 5.5. A comparison of the decision values with and without consideration of parameter importance is shown in Figure. 5.2.

$$\mathrm{D_{mf}} = 0.289X_3 + 0.233X_6 + 0.226X_1 + 0.203X_2 + 0.030\varphi_4 + 0.019X_5 \quad (5.15)$$

where X_1, X_2, X_3, X_4, X_5, and X_6 are the standardized parameters for the *location of failure and its potential impact, damage of pavement, maintenance response, decision sight distance*, *ADT, and magnitude of displacement,* respectively.

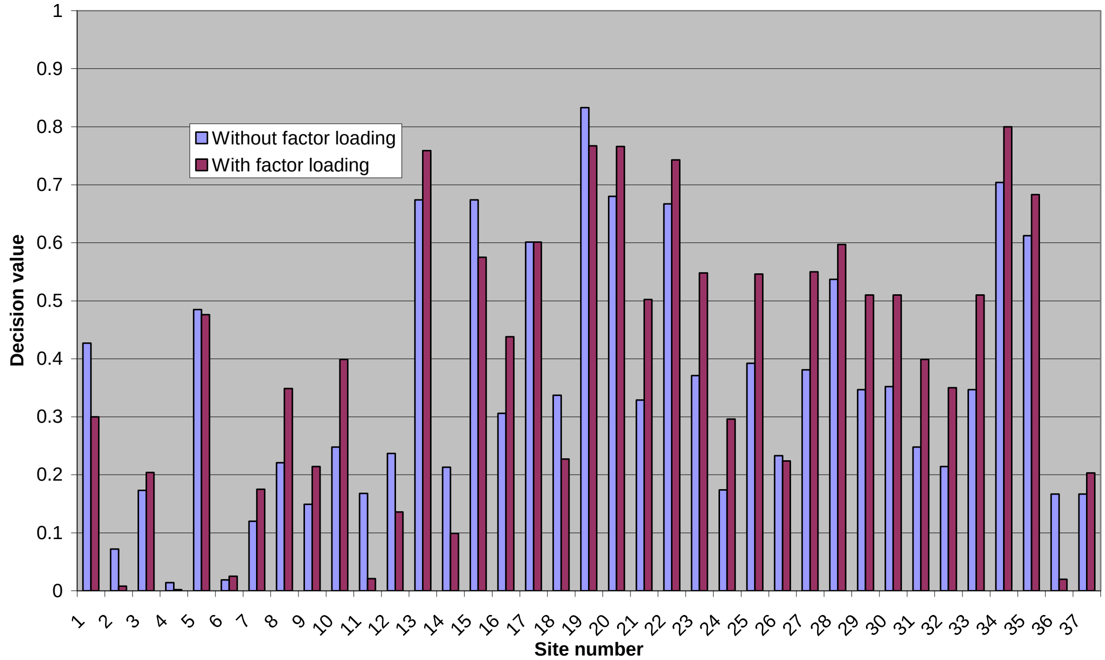


Figure 5.2 Comparison of decision value with and without factor loading

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of Important Research Results

A landslide hazard rating matrix and its database are developed for landslide risk/hazard management for ODOT. The landslide rating matrix is developed based on the syntheses of expert knowledge, in-house experience of ODOT engineers, and the existing systems developed by other agencies. The developed landslide hazard rating system is customized to fit the particular landslide characteristics in Ohio. Various statistics methods are used to verify the validity of the developed system to ensure that the system yields a rationally prioritized landslide hazards. The system developed for ODOT is different from other agencies. Most agencies' systems are developed purely based on experience and judgment of experts. The current ODOT system relies extensively on statistical correlations studies. Based on the analysis results of 37 landslide sites collected as a pilot database, the landslide numerical rating system gives reasonable prioritizations. The cluster analysis technique is used to classify the 37 landslide sites and the results show that the rating system can distinguish groups: low, medium, and high hazard potentials.

The validity of the proposed system is ascertained through the use of the inferential statistics, including the K-S, Chi-Square goodness-of-fit, ANOVA, and t-test. The K-S test is used for the test of normality of the hazard scores for the low, medium, high and all combined clusters. The results show that they fit normal distribution. The rating system yields a wide spread of the hazard score to allow for making prioritization decisions. The distribution of hazard scores is further investigated using the Chi-Square goodness-of-fit test. The goodness-of-fit of normal and log-normal distributions is compared. The results show that the distribution of hazard scores can be described by both normal and log-normal distributions. The ANOVA results show that the three hazard groups are statistically different. The t-test results reveal that the scoring criteria used to classify the hazard groups are effective. The comparisons of different hazard scoring systems support the use of exponential scoring system. It tends to increase the differences and maximize the effectiveness of the numerical risk/hazard scores for the 37 pilot landslide data.

An alternative approach to determine risk that can be used for the failed highway slope management is also developed. The six risk parameters that are crucial for repair decision of a failed highway slope are proposed. The study provides an alternative approach to utilize the expert opinion and judgment in making decision by using the fuzzy set and multi-criteria technique. Factor analysis can be used to determine the importance of risk parameters. With the developed research approach, the decision maker can reduce expert bias toward the importance of risk parameters. Also, the expert judgment and opinion are standardized, which make the process in making decision easier and more consistent. These will provide an alternative for highway agencies to effectively manage the highway operational fund and reduce risk in highway operational safety.

The development of the Ohio landslide database system provides ODOT a systematic approach to manage landslides and slope failures along its highways. The landslide reconnaissance forms and a Landslide Observation Report are developed for uniform and consistent collection of landslide site data throughout ODOT organization. The tasks of inventory of landslide data are distributed to different levels of ODOT personnel. The daunting tasks of collecting, managing landslide information become more manageable due to the development of web enabled, GIS based landslide database applications.

A total of 37 landslide sites information are stored in the GIS database. The use of GIS database system for landslide management provides a near real-time management capability. Because the landslide data are centrally stored, they can be accessed or exchanged readily among different constituents. The data inventory is uniform, consistent, comprehensive, and intelligent. The ODOT personnel can quickly manipulate sort, group, and report pertinent landslide information in an effective way. The time for gathering and analyzing landslide data is shortened. The condition of a landslide can be closely monitored as the monitoring schedule can be dynamically set up. As a note, there are limitations of the current landslide rating matrix due to the fact that statistical analysis was performed on a limited number of landslide data sets. However, the landslide database is expected to continue to grow, a re-evaluation of the rating system is recommended in the near future.

6.2 Recommendations for Implementation and Future Research

- The developed system is designed to reflect the hazard potential created by landslide at a specific highway section. It can not be used as a mathematical model to predict the failure probability of a site. It can not be used as a prediction tool to predict when or which landslide will fail first.
- The application of the landslide hazard rating system is developed based on both subjective and objective data. For determining the subjective rating, experience and judgment are often involved. To ensure uniform scoring approach, it is recommended that training sessions be held for all personnel involved.
- The system is developed using limited data information. For example, information pertaining to maintenance history and accident history was not always available. In the future research, the collection of landslide information should be as complete as possible. As the database is grown and the information is more complete, the landslide hazard rating matrix needs to be further evaluated. This requires adjustment of the scoring criteria as well as additional statistical analyses.

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APPENDICES

APPENDIX A

SLOPE RATING SYSTEMS BY OTHER AGENCIES

Washington State DOT (1993)

Table A.1 Wsdot's landslide rating system

Criterion	Points = 3	Points = 9	Points = 27	Points = 81
Problem Type: Soil	Cut, or Fill Slope Erosion	Settlement of Piping	Slow-Moving Landside	Rapid Landslide or Debris Flows
Problem Type: Rock	Minor Rockfall, Good Catchment	Moderate Rockfall, Fair Catchment	Major rockfall, Limited Catchment	Major Rockfall, no Catchment
Average Daily Traffic	<5,000	5,000-20,000	20,000-40,000	>40,000
Decision Site Distance	Adequate	Moderate	Limited	Very Limited
Impact of Failure on Roadway	<50 ft	50-200ft	200-500 ft	>500 ft
Roadway Impedance	Shoulder Only	½ Roadway	¾ Roadway	Full Roadway
Average Vehicle Risk	< 25% of the Time	25-50% of the Time	50-75% of the Time	>100% of the Time
Pavement Damage	Minor-Not Noticeable	Moderate-Driver Must Slow	Severe Driver Must Stop	Extreme Not Traversable
Failure Frequency	No Failure in Last 5 years	One Failure in Last 5 Years	One failure Each Year	More Than One Failure Each Year
Annual Maintenance Costs	<$5,000 per Year	$5,000-10,000 per Year	$10,000-50,000 per Year	>$50,000 per Year
Economic Factor	No Detour Required	Short Detour < 3 Miles	Long Detours> 3 Miles	Sole Access, No Detours
Accident in Last Ten Years	1	2-3	4-5	>5

Hong Kong (1988)

Table A.2 Consequence score and instability score components, weighing and formulae

(Cut Slope)

Component	Score		Max. score
e) Height, H (meter)	Soil slope, H × 1 Rock slope, H × 0.5 Mixed slope, H× 1		Unlimited
f) Slope angle	Rock 90° = 10 ≥80° = 8 ≥70° = 5 ≥60° = 2 <60° = 0	Other ≥60° = 20 ≥55° = 15 ≥50° = 10 ≥45° =5 ≥35° =3 <35 °=0	20
g) angle of slope above, or presence of road above	Slope ≥ 45° = 15 Slope ≥ 35°, or major road =10 Slope ≥ 20°, or minor road =5 Slope < 20° =0		15
i) Associated wall	Height of associated wall (meters)×2		unlimited
j) Slope condition	Loose blocks = 10 Sign of distress = 10 Poor = 5 Good = 0		10
k) Condition of associated wall	Poor =10 Fair =5 Good =0		10
l) Adverse jointing	Adverse joints noted =5		5
m) Geology	Colluvium/ shattered rock Thin soil mantel =15 Thick volcanic soil =10 Thick granitic soil =5 Sound rock (massive)=0		15
n) Water access impermeable surface on and above slope	None = 15 50% (partial) = 8 Complete – poor = 5 Complete – good = 0		15
o) Ponding potential at crest	Ponding area at crest = 5		5
p) Channels	None, incomplete =10 Complete-major cracks =10 Complete = 0		10

Table A.3 Consequence score and instability score components, weighing and formulae (Cut Slope) (continued)

<table>
<tr><td>Component</td><td colspan="3">Score</td><td>Max. score</td></tr>
<tr><td>q)Water carrying services</td><td colspan="3">Service within “H” of crest
-yes = 5
-no =0</td><td>5</td></tr>
<tr><td rowspan="3">r) Seepage</td><td colspan="3">Amount</td><td rowspan="3">15</td></tr>
<tr><td>Position</td><td>heavy</td><td>Slight</td></tr>
<tr><td>Mid-height and above
Near toe</td><td>15
10</td><td>5
2</td></tr>
<tr><td>t) distance to building road or playground form toe of slope (meters)</td><td colspan="3">Buildings = Actual distance
Roadways = distance +2 meters
Playground= greater of actual distance or ½ H</td><td>Unlimited</td></tr>
<tr><td>u) distance to buildings, roads or playgrounds form toe of slope</td><td colspan="3">As for (t)</td><td></td></tr>
<tr><td>v) extensive slope at toe or slope</td><td colspan="3">Extensive slope at top 0.5
Extensive slope below 20</td><td>25</td></tr>
<tr><td>w) Multiplier for type of property at risk at top</td><td colspan="3">Hospital, school, residential = 2
Factories, playgrounds = 1.5
Major roads =1.0
Minor road =0.5
Open space =0</td><td>2</td></tr>
<tr><td>x) Multiplier for type of property at rest at toe</td><td colspan="3">As above</td><td>2</td></tr>
<tr><td>y) Multiplier for risk factor</td><td colspan="3">For densely populated area or where building may collapse =1.25
Otherwise=1.0</td><td>1.25</td></tr>
<tr><td colspan="5">Instability score = ∑(e, f, g, I, j, k, l, m, n, o, p, q, r)
Consequence score = $y\{20w(\frac{1.5(e+i)-t}{1.5(e+i)})+40w(\frac{e+i)-u}{e+i})+(vx)+2(e+i)\}$</td></tr>
</table>

Table A.4 Criteria for calculating "x" score (Fill Slope)

Main component	Subcomponent	score
Surface quality and susceptibility to infiltration (S)	(i) Vegetation of bare earth 100% bare/ 50% bare/None (ii) condition of paving or other seal poor/fair/good (iii) Surface drainage Blocked or Broken/ Inadequate/ good Max for this component	20/10/0 10/5/0 10/5/0 20
0Potential access to water (W)	(i) Observed seepage (ii) Watermain or sewer in the fill (iii) Fill blocking or natural water course (iv) None of the above Max for this component	10 5 5 0 20
Slope angle(O)	- Max for this component	80(tanϕ-0.5) 20
Slope height (H)	- Max for this component	1 point for every four meter of height 10
	Maximum x total	90

Table A.5 Classification of squatter area

Terrain category Landslide potentiality	Dangerous	Moderate	Safe
Chance of landslide causing casualties	High	Moderate	Low
Classification criteria	All terrain with natural angle 30° or of GLUM Class IV	Terrain not classed as dangerous and of GLUM Class III	All other terrain

Table A.6 Geotechnical Land Use Map (GLUM) classification system

GLUM Class Characteristics	Class I	Class II	Class III	Class IV
Geotechnical Limitations	Low	Moderate	High	Extreme
Suitability for Development	High	Moderate	Low	Probably unsuitable
Engineering Costs for Development	Low	Normal	High	Very high
Intensity of Site Investigation Required	Normal	Normal	Intensive	Very intensive
Examples of Terrain in GLUM Class	• In situ terrain < 15°, minor erosion. • Cut platforms in in situ terrain. • Cut slope <15°, no instability or severe erosion.	• In situ terrain 15-30°, no instability or severe erosion. • In situ terrain < 15°, severe erosion. • Colluvium <15°, no instability or severe erosion	• In situ terrain 30-60°, no instability or severe erosion. • In situ terrain < 15°, history of landslides. • Colluvium <15°, general instability.	• In situ terrain >60° • In situ terrain 30-60°, instability or severe erosion • Colluvium 30-60°, moderate erosion.

<u>Oregon DOT (1993)</u>

Table A.7 Preliminary rating system

Class Criteria	A	B	C
Estimate potential for rockfall on roadway	High	Moderate	Low
Historical rockfall activity	High	Moderate	Low

Table A.8 Oregon Dot's Rockfall Hazard rating System (1993)

<table>
<tr><td colspan="3" rowspan="2">Category</td><td colspan="4">Rating Criteria and Score</td></tr>
<tr><td>Points 3</td><td>Points 9</td><td>Points 27</td><td>Points 81</td></tr>
<tr><td colspan="3">Slope Height</td><td>25 Feet</td><td>50 Feet</td><td>75 Feet</td><td>100 Feet</td></tr>
<tr><td colspan="3">Ditch Effectiveness</td><td>Good Catchment</td><td>Moderate Catchment</td><td>Limited Catchment</td><td>No Catchment</td></tr>
<tr><td colspan="3">Average Vehicle Risk</td><td>25% of the Time</td><td>50% of the Time</td><td>75% of the Time</td><td>100% of the Time</td></tr>
<tr><td colspan="3">Percent of Decision Sight Distance</td><td>Adequate sight distance, 100% of low design value</td><td>Moderate sight distance, 80% of low design value</td><td>Limited sight distance, 60% of low design value</td><td>Very limited sight distance, 40% of low design value</td></tr>
<tr><td colspan="3">Roadway with Including Paved Shoulders</td><td>44 feet</td><td>36 feet</td><td>28 feet</td><td>20 feet</td></tr>
<tr><td rowspan="4">Geologic Character</td><td rowspan="2">Case 1</td><td>Structural Condition</td><td>Discontinuous joints, favorable orientation</td><td>Discontinuous joint random orientation</td><td>Discontinuous joints adverse orientation</td><td>Continuous joints adverse orientation</td></tr>
<tr><td>Rock Friction</td><td>Rough irregular</td><td>undulation</td><td>planar</td><td>Clay infilling or slickenside</td></tr>
<tr><td rowspan="2">Case 2</td><td>Structural Condition</td><td>Few differential erosion features</td><td>Occasional differential erosion features</td><td>Many differential erosion features</td><td>Major differential erosion feature</td></tr>
<tr><td>Different in Erosion Rates</td><td>Small difference</td><td>Moderate difference</td><td>Large difference</td><td>Extreme difference</td></tr>
<tr><td colspan="3">Block Size

Volume of Rockfall/Event</td><td>1 Foot
----
3 cubic yards</td><td>2 Feet
----
6 cubic yards</td><td>3 Feet
----
9 cubic yards</td><td>4 Feet
----
12 cubic yards</td></tr>
<tr><td colspan="3">Climate and Presence of Water on Slope</td><td>Low to moderate precipitation no freezing period; no water on slope</td><td>Moderate precipitation or short freezing period or intermittent water on slope</td><td>High precipitation or long freezing period or continual water on slope</td><td>High precipitation and long freezing periods or continual water on slope and long freezing periods</td></tr>
<tr><td colspan="3">Rockfall History</td><td>Few falls</td><td>Occasional fall</td><td>Many fall</td><td>Constant fall</td></tr>
</table>

OREGON DOT (2001)

Table A.9 Oregon (2001)'s numerical score system

1. Failure Type/ Hazard	Vary small or insignificant failure that do not affect the roadway (not score)	Low Hazard; slower slide with potential for causing a road hazard (9 points)	Medium Hazard; slide that have not moved suddenly in the past, but have the potential to cause a road hazard (27 points)	High Hazard; rapid slide that have created a road hazard in the past. Includes debris flow and rockfalls (81-100 Points based on sight distance)

		Low hazard receive 0 point	Medium hazard receive maximum of 54 points				High hazard can receive full point range		
2. Roadway impact (pick one)	Landslides:	All low hazard slide above (0 point)	Would only affect shoulder during major failure (3 points)	Two-way traffic would remain after major failure (9 points)	One way traffic would remain after major failure(2 7 points)	Total closer in the vent of major failure 0-3 miles detour(54 points)	Total closure in the event of major failure; 3-10 mile detour (70 points)	Total closure in the event of major failure; 10 -60 mile detour (85 point)	Total closure in the event of major failure > 60 mile detour (100 points)
	or								
	Rockfalls:		Rockfall are completely contained in ditch (3 points)	Rocks fall into shoulder only (9 points)	Rock are enter roadway (27 points)	No ditch, all falling rocks enter roadway (81 points)	Rock occasionally fill part or all of a lane (100 points)		

3. Annual Maintenance Frequency	0-5 Failure Per Year Sliding scale from 1-100 points

4. Average Daily Traffic	0-40,000 Cars per day Sliding scale from 1-100 Points

5. Accident history	No accident (3 points)	Vehicle of Property Damage (9 points)	Injury (27 Points)	Fatality (100 Points)

Table A.10 Highway Classification Factors

Highway type	Highway Factor
District Highway	1.0
Regional Highway	1.05
Statewide highway	1.1
Interstate highway	1.2

Table A.11 Maintenance Benefit –Cost Factors

20-Yr Maintenance Cost / Repair Cost	Maintenance Benefit-Cost Factor
>0.0-0.2	0.5
≥0.2-0.4	0.75
≥0.4-0.6	1
≥0.6-0.8	1.06
≥0.8-1.0	1.12
≥1.0-1.2	1.18
≥1.2-1.4	1.24
≥1.4-1.6	1.3
≥1.6-1.8	1.36
≥1.8-2.0	1.42
≥2.0	1.5

NYS DOT (1988)

Table A.12 New York Rock Slope Rating System (1988)

Category	1 Point	3 Points	9 Points	27 Points	81 Points
Slope Height	4.6 m	4.6 to 7.6 m	7.6 to 10.7	10.7 to 13.7 m	13.7 m or more
Slope Length	15 m	15 to 30 m	30 to 46 m	46 to 61 m	61 m or more
Visibility	Adequate stopping distance	Good visibility	Moderate visibility	Limited Visibility	Very limited visibility
Traffic	Very light	Light	Moderate	Heavy	Very heavy continuous
Ditch dimension/ set back	Meets Ritchie Criteria	Adequate width, inadequate depth	Moderate catchment	Limited catchment	Nil
Geology (Xtal)	Massive, no fractures dipping out of slope	Discontinuous fractures, random orientation	Fracture from wedges	Discontinuous fractures dipping out of slope	Continuous fractures out of slope
Geology (sedimentary)	Horizontally slightly dipping	Raveling occasionally small blocks	Small overhangs or columns numerous small blocks	Overhang some large unstable blocks, high columns	Bedding or joint dipping out of slope, over steepened cut face
Block size	150 mm	150 to 300 mm	0.3 to 0.6 m	0.6 to 1.5 m	1.5 m or more
Rock friction	Rough, irregular	Undulating	Planar	Smooth , slickenside	Clay, gouge faulted
Water ice	Dry	Some seepage	Moderate seepage	High seepage/Brush	High seepage with long back slope/ brush
Rockfall	No falls	Occasional minor spells	Occasional falls	Regular falls	Major falls/ slides
Backslope above cut	Flat to gentle slope (15°)	Moderate slope (15°-25°)	Steep slope (25°-35°)	Very steep slope (35°)or steep with boulder	Very steep slope with boulders

Ranking	Point total	Risk of rock fall
5	Greater than 500	High risk
4	400 to 500	Moderate risk
3	250 to 400	Low risk
2	150 to 250	Very low risk
1	less than 150	Minimal risk

APPENDIX B

DESIGN OF GIS-BASED WEB APPLICATION

1. Introduction

The GIS based web application allows for landslide site information to be managed in database. The task such as adding, updating, modifying, or deleting a landslide site information can be done via the web application. Data searching, data query and data analysis, as well as user group management, are the unique features of the developed web-enabled GIS landslide database. The main technologies used in the system include the following:

- ESRI ArcPad and ArcIMS
- J2EE and Apache and tomcat services
- MSSQL database server

2. System Architecture

2.1 Overall System

The system is composed of several sub components, as shown in Figure 1. The function of each component is listed as follows:

- Web server: Apache web server is applied. It provides the interface for web user access, handling user login, administration, data browsing, and data modification.

- Servlet engine: Apache tomcat is used for this purpose. It is used as the connection between the web server and the GIS application server. The request from a user can be processed through and passed back and forth between the GIS application server and web application.
- GIS application server: ArcIMS application is used for this function. It provides for the main GIS information processing, map services, and the GIS associated data searching and data analysis. Also, it provides for the map operations such as zooming, panning, etc. Several services are included, which allow for the map to be processed based on the user requests. The detailed connection of the servlet engine is shown in Figure 2.
- PDA data collection: A customized ArcPad application is used for the PDA deployment. It provides a user interface for the field data collection and storage. The data is collected in a form of a standard shapefile format and will be used as a part of GIS application services.
- Data repository: MSSQL Database is the main data repository for all data storage and data management. However, at present, the GIS spatial information is stored in the file system. Association of the spatial information and data is established through the uniquely defined landslide ID. Manual merger of the shape file into the entire GIS application server is necessary.

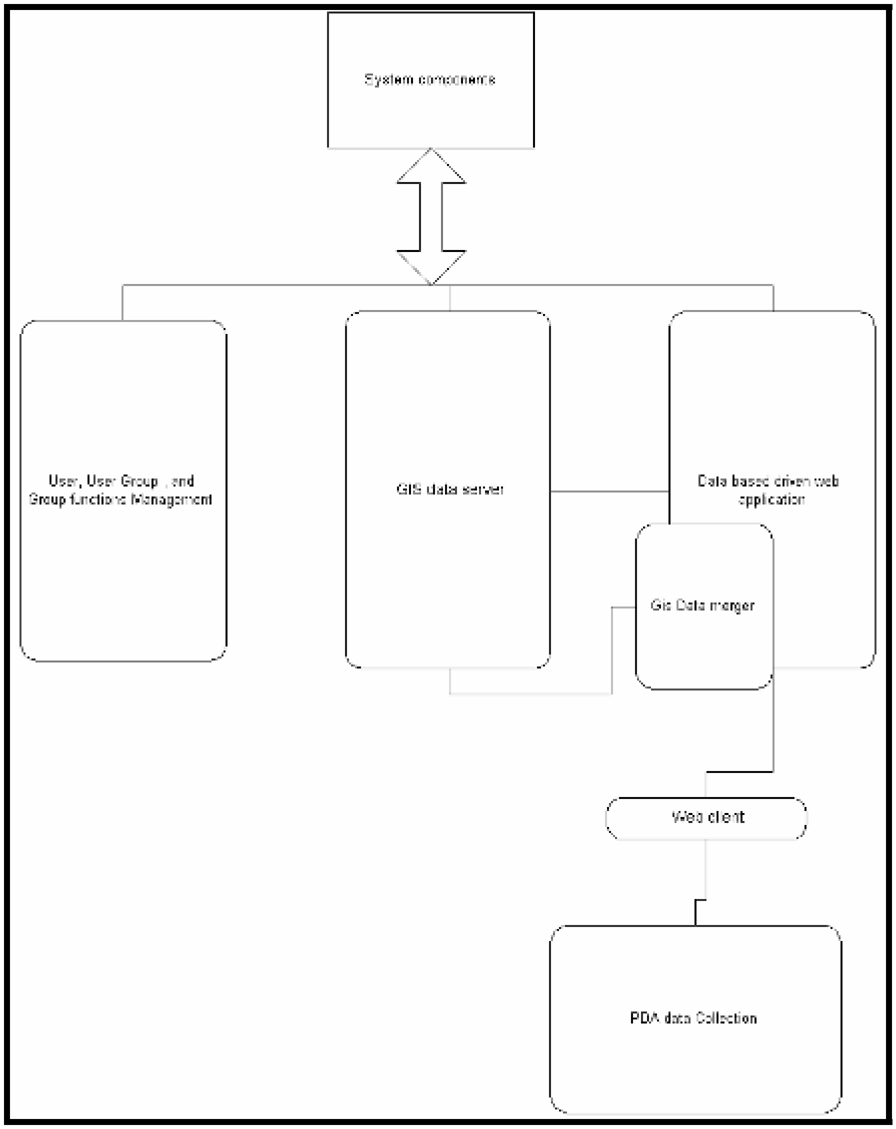

Figure 1 Overall system diagram of the system

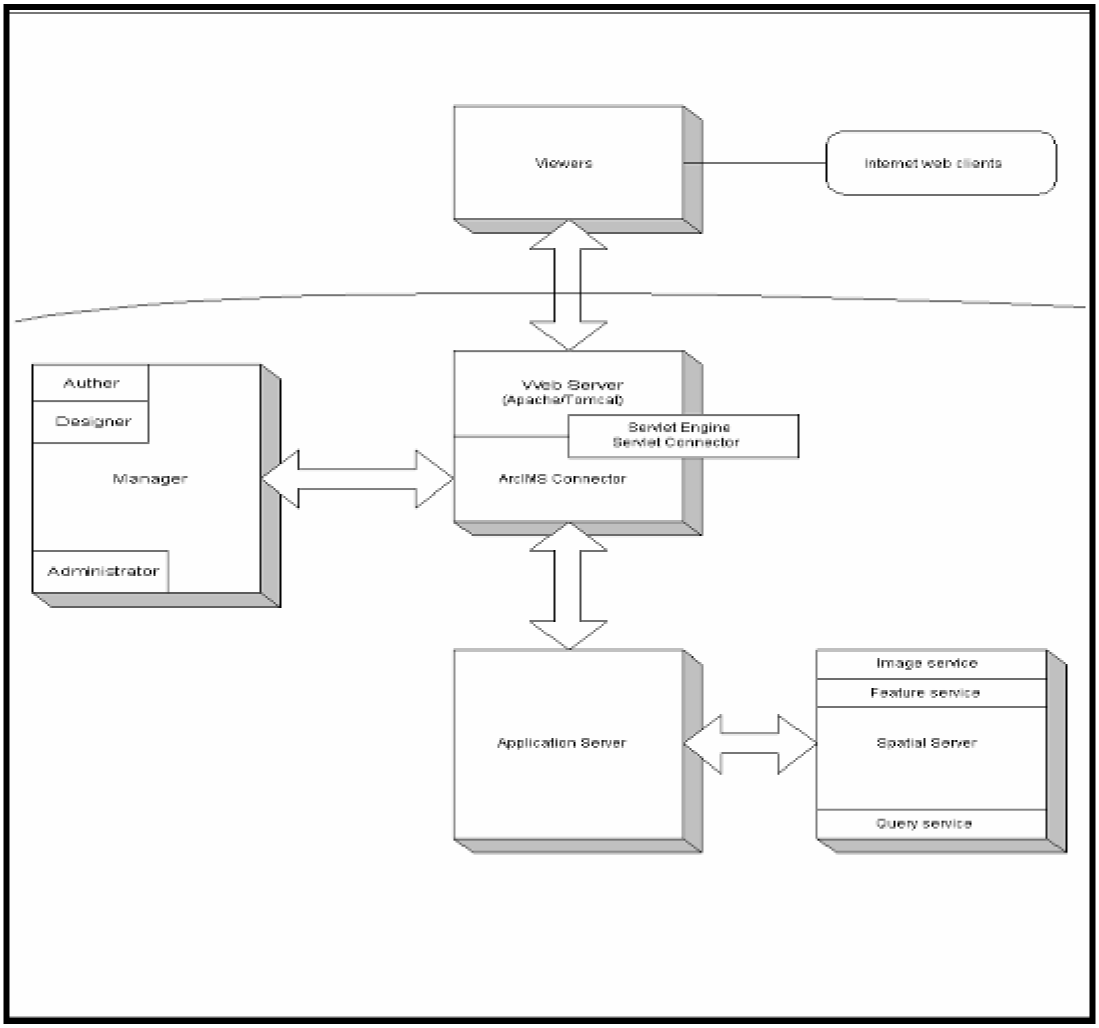

Figure 2 ArcIMS component connections

3. Data Flow

Several components are designed and implemented in order to meet the requirements of the data collection and data processing. Meanwhile, the roles of persons involved in the system data processing are defined. As shown in the Figure 3, the landslide site is first reported by a highway worker using a paper format. The paper report is submitted to the District Highway Office. County Manager (CM) is responsible for data evaluation and performing initial site visit for preliminary site evaluation. During the site visit, a part of the landslide data (Part A) is collected. The site is classified as either "Rated" or "Non-Rated" site. The site information is uploaded to the system by the CM/TM. For the "Rated" and "Non-Rated" sites, the scheduled visits should be assigned, while the Part B data are compiled and recorded into the system. These landslide sites are further evaluated by a District Geotechnical Engineer (DGE) using Part C of the form for more detailed information as well as for the rating of the potential hazard of the sites. Figure 4 depicts the flow chart showing how data is routed from initial report to the final repository.

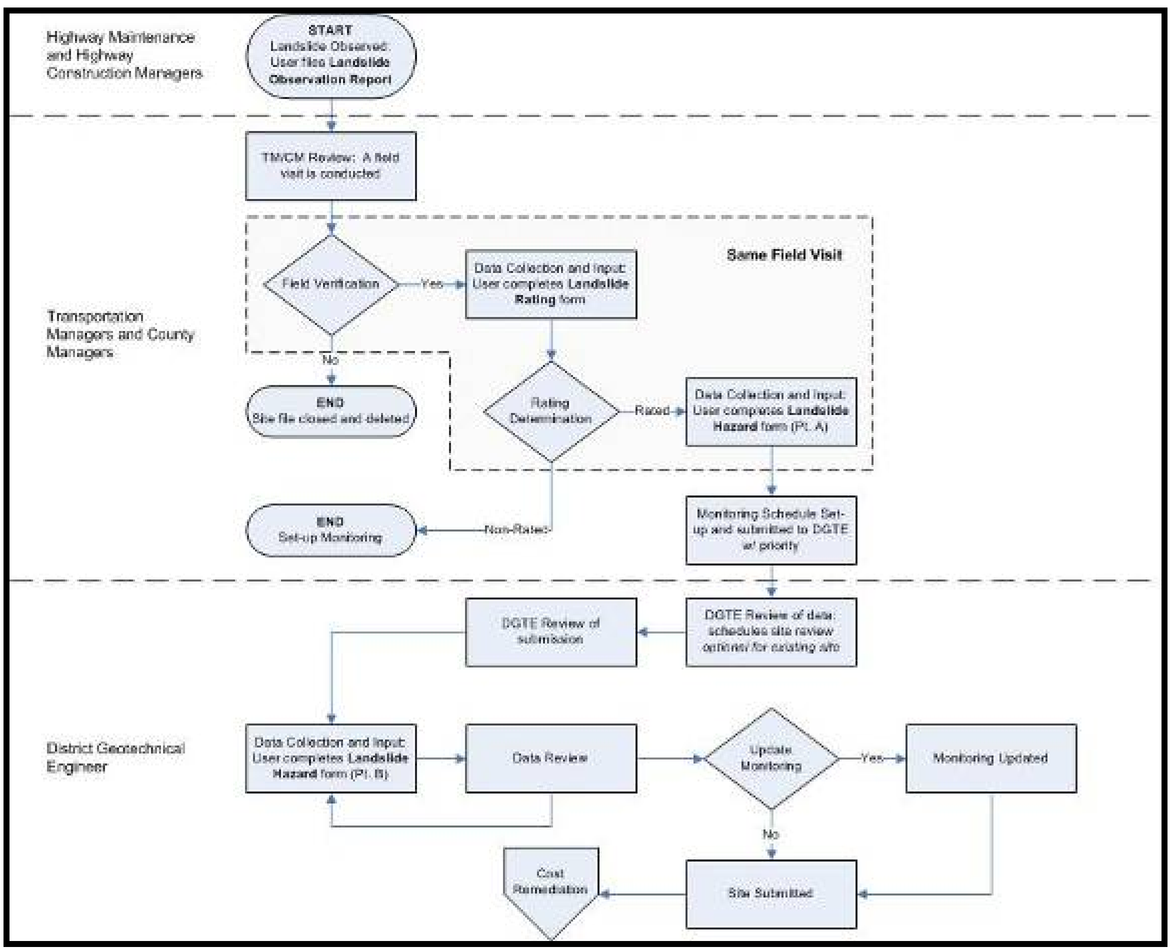

Figure 3 Data process steps

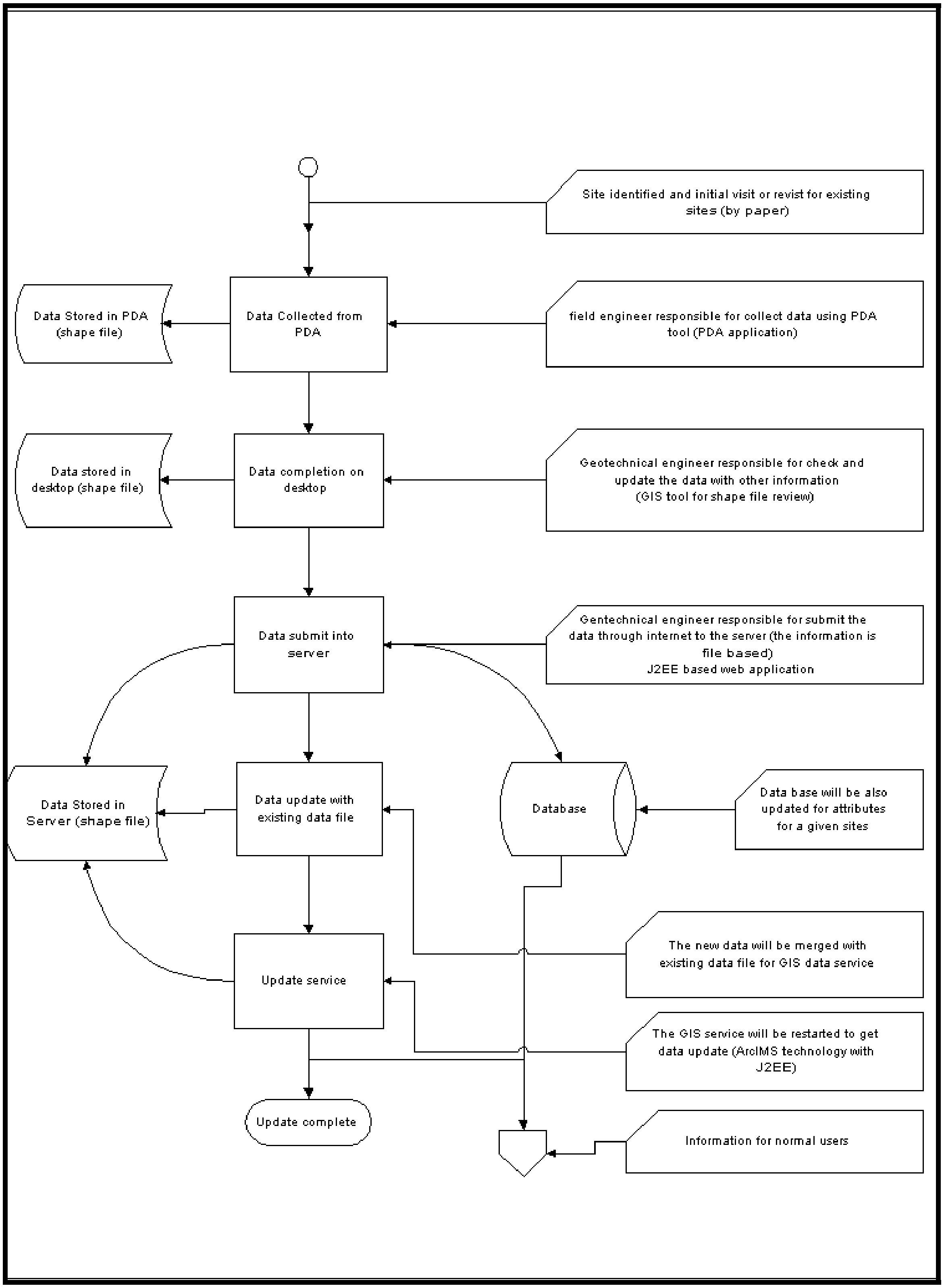

Figure 4 Data flow in the system

4. User Access Right Design

The control of the user access is important for the data management. In this system, the different levels of users and their corresponding functions are identified. The functions are assigned according to the user groups. Each user group can have a set of pre-defined user privileges. The system is designed to be flexible so that the system administrator can dynamically setup a new user group with the prescribed privileges. These functions of the system administrator include adding new groups, defining group functions, and moving around a user from one group to the other. Note that since the web page is dynamically created based on the user group, certain web pages may not be seen by certain user group due to the restrictions imposed on that user group. The typical user groups for the system are defined and their functions are listed as shown in Figure 5.

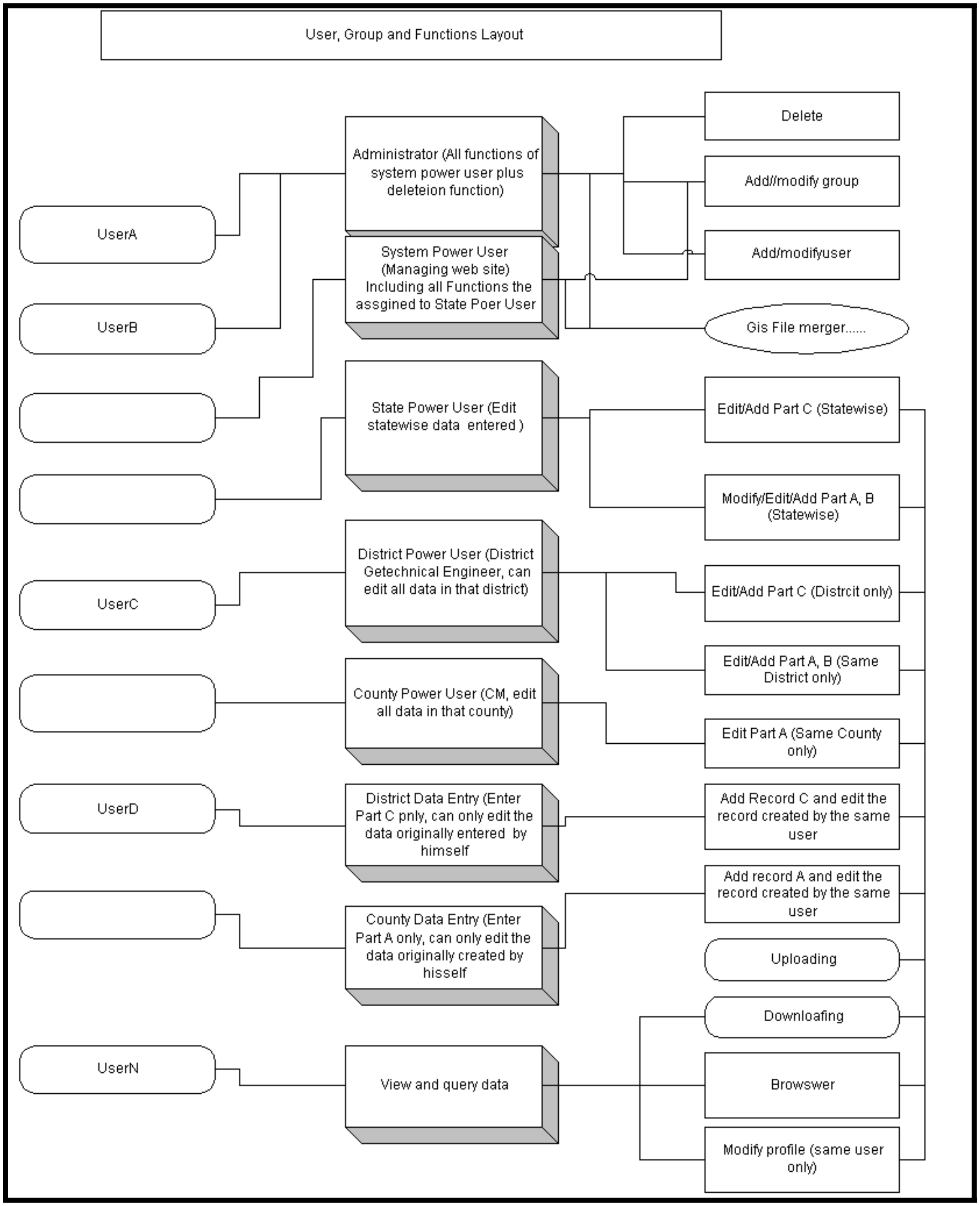

Figure 5 Typical users/user group and their functions

5. Web Application Architecture

The web application is built on the technology of Struts, Spring and iBATIS. Struts are the open source frameworks for building Servlet/JSP based web applications, which are based on the Model-View-Controller (MVC) design paradigm. In this system, Struts are used for expressing layers. They are the essential components of the work flow in the design logic including web page management and user data validation, etc. This framework deals with the client requests and it is incorporated into the page management and the security management functions.

The spring framework provides the database transaction support. It is a light weight J2EE framework. This framework processes the business data control functions. iBATIS is simple and complete framework, which is to map the objects to the SQL statements and to store the procedures. For the use of the xml file format, we can easily modify the SQL statements. It can also generate the map query results into the java beans. In this system, the iBATIS framework is the data layer. It makes the system more flexible. The web application architecture is shown in Figure 6.

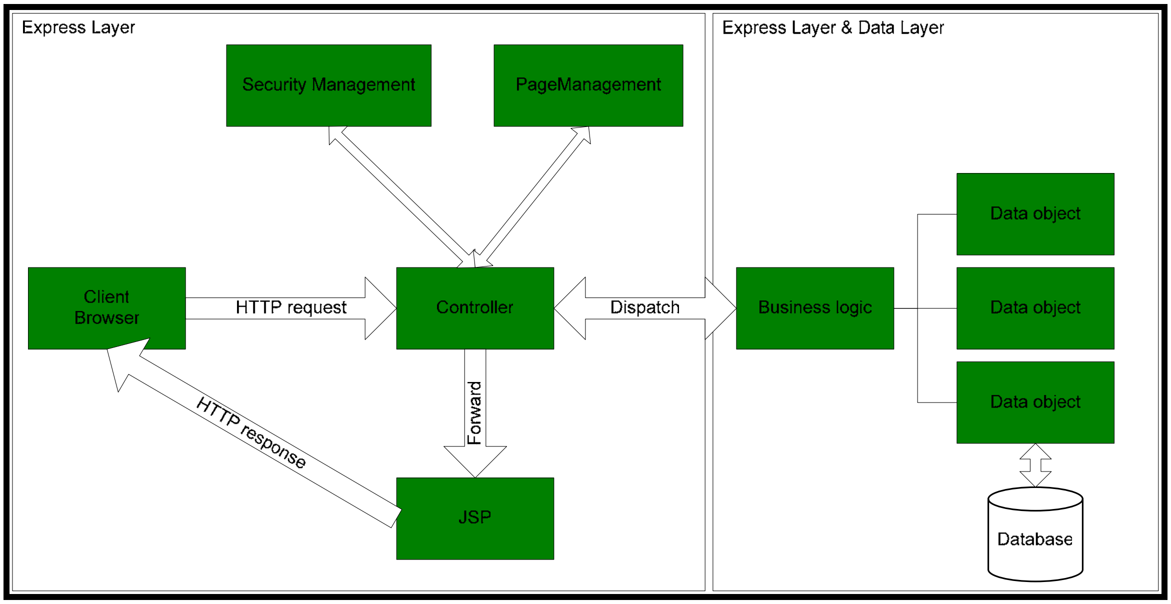

Figure 6 Web application architecture

6. Data Collection Application on PDA

The field data application was designed based on the ArcPad® technology. The customized application allows Part A, B and C data collection for a given landslide site. The output is in standard shape file format containing the data and the GIS spatial information. The customization is implemented by VB script. The application can also be deployed on a PC where ArcPad is installed.

7. File Management

At present, the spatial data, pictures and sketches are maintained in the sever file system. The following folder structures are created to manage these files.

The root folder is: C:\DataFile, underneath of it, there are several subfolders including:

- mergeDBFile
- un_merged
- merged
- finalefiles
- file.

Under each of the above subfolders, there are multiple (layers) subfolders. Depending on the operation, the files involved will be stored in these folders. Each saved file path and name are carefully prepared and recorded in the database for the application reference. As a result, the folder structure is essentially designed for the internal use only by the system. The folder structure can be viewed through the web application. Changing the files or folders may break the application or produce the unpredicted results. Thus, it is not recommended to browse the folders and the files manually, which may accidentally alter the file structures. Note that these folders must be located in server machine where the database service is installed.

"mergeDBFile" folder stores the dbf file temporarily for file uploading process. When uploading is complete, *.dbf file will be moved to "un_merged" folder. As a result, levels of subfolders will be created based on the following convention:

- District name will be used as subfolder under c:\DataFile
- County name will be used as subfolder under c:\DataFile\District
- User name plus date together will be used as the third level subfolder under \..\..\county. Between user and date, there is character “!” for easy file processing.

For example, one user named Peter, has uploaded one dbf file named test.dbf at 23:12:12 on 4/6/2006 , and this dbf file is related to district "1" and county "Allen". Thus, the folder structure is "c:\DataFile\un_merged\1\Allen\Peter!2006-4-6_23\test.dbf. The whole structure is shown in Figure 7.

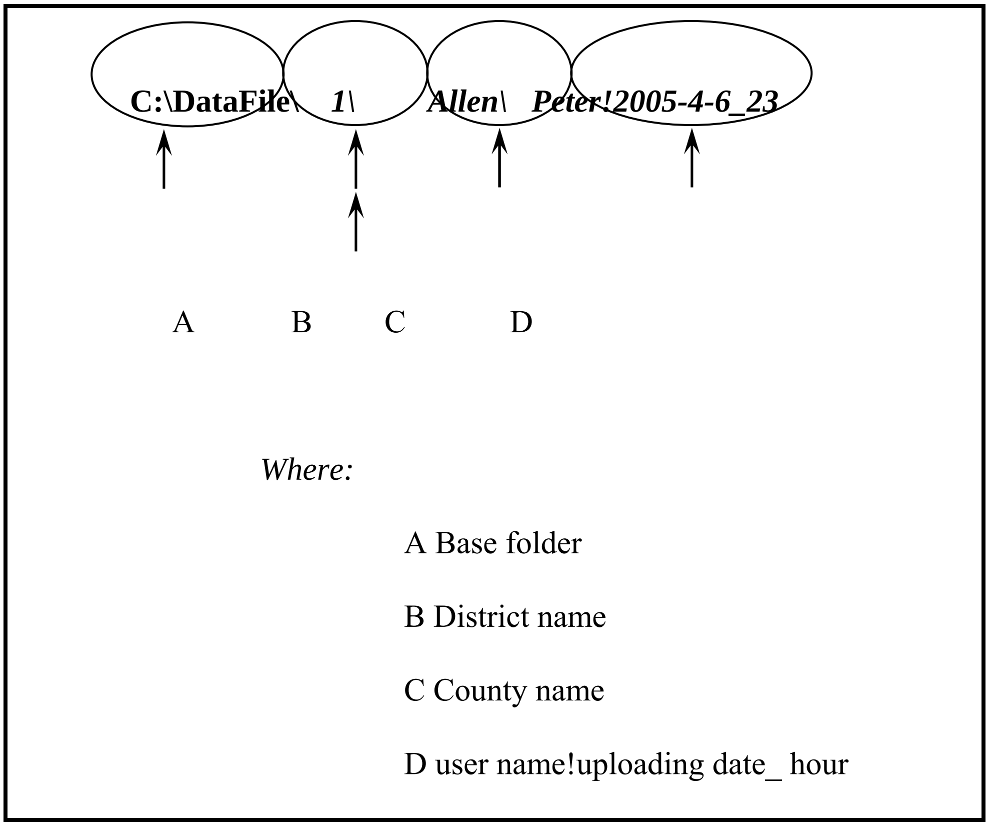

Figure 7 Folder structure for un-merged files

Similar to "un_merged" folder, the "merged" folder stores the dbf files, which have been merged. However, the deepest folder was further modified when it is merged by adding the merged date information. For example, on 5/6/2006, at 12:09:56, the test.dbf file was successfully merged by Peter, then the sub-folder in the merged folder is as follows "merged\1\Allen\Peter!2006-4-6_23!2006-5-6_12\test.dbf". After the merge of dbf, the file merged in the sub-folder will be deleted from "un_merged" folder as shown in Figure 8.

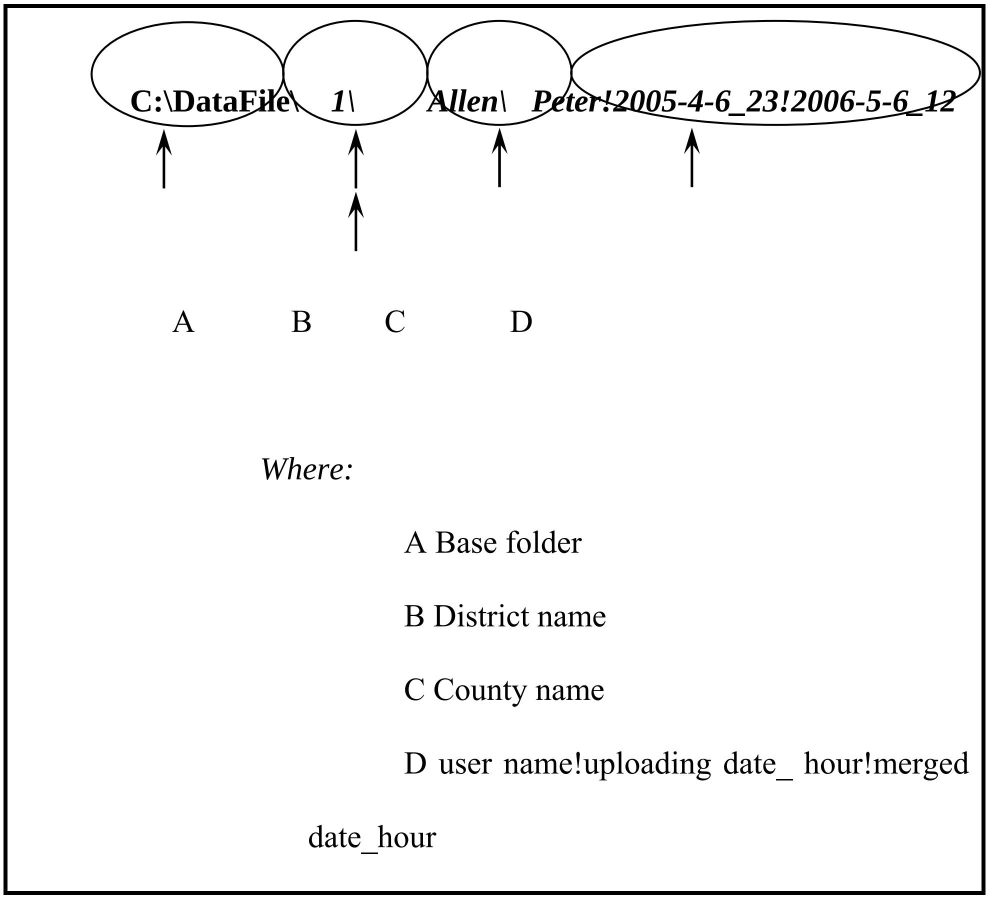

Figure 8 File folder structure for merged files

"Finalfiles" folder stores the final merged files. The master file is currently running in the map services. The folder structure is the same as "un_merged" but the last folder did not have the hour information. For example, one user named Peter, after he uploads one final file named test.dll on 4/6/2006, at 23:12:12 and this dll file is related to district "1" and county "Allen". Thus, the folder structure is "c:\DataFile\finalFiles\1\Allen\Peter!2006-4-6\test.dll. The whole folder is shown in Figure 9.

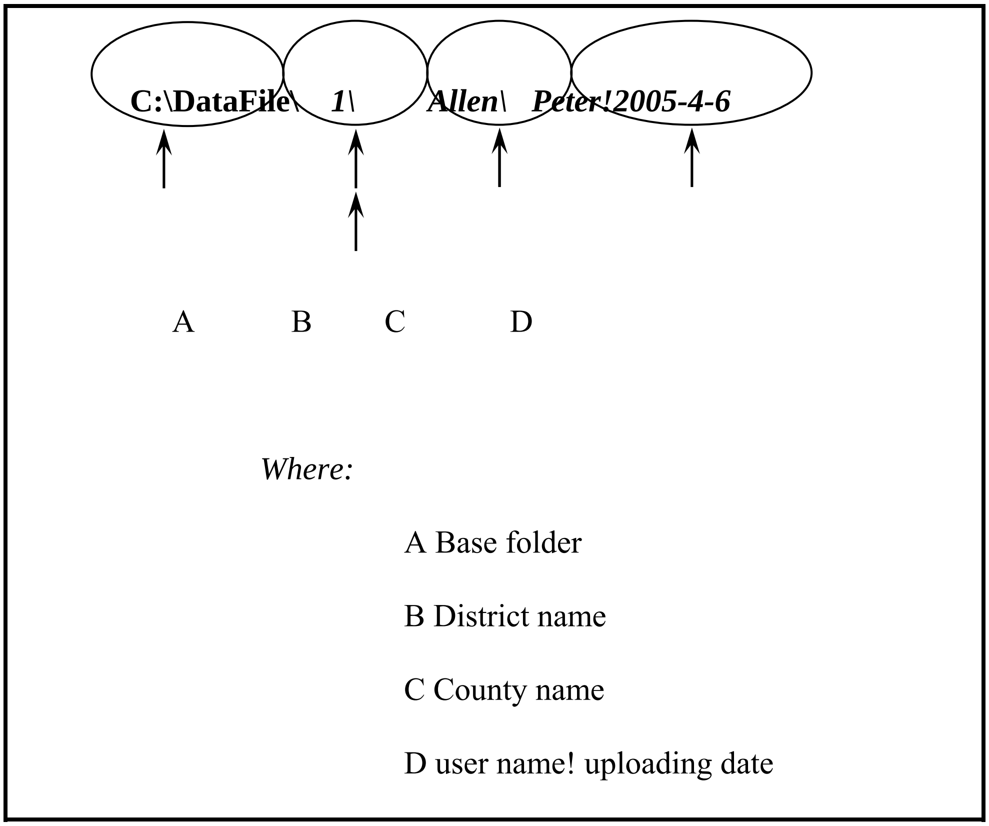

Figure 9 File folder for final file which contain entire shape information

The "file" folder is used to store the pictures and, sketches in PartA and PartC. The sub-folder is created by the date when the picture is uploaded. The link is stored into database. It is not recommend to browse the picture here.

APPENDIX C

USER'S MANUAL

A landslide management user's manual for Ohio DOT use is presented in this section. The user's manual provides a systematic approach to collect, identify, and manage landslides that are associated with instable highway slopes and embankments in the state of Ohio. The user's manual provides step-by-step to inventory landslide by using a global positioning system device (GPS) and Landslide GIS-Enabled Database Website. The locations of collected landslides are displayed on the Landslide GIS-Enabled Database Website, which provides Ohio DOT workers a dynamic management tool for the landslide risk assessment and decision-making.

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CHAPTER I

INTRODUCTION

1.1 Introduction

The rehabilitation decision for highway slope failure is one of the many important tasks to be tackled by Ohio Department of Transportation (ODOT). A rational approach to manage the unsafe or failed slopes/embankments should ideally include a systematic process for collecting the information needed for decision making. This involves the database management by recording the descriptive inventory and risk assessment of the failure slope. Essentially, this manual provides the information about the following: (i) procedure for landslide data collection, (ii) landside hazard assessment using ODOT rating matrix, and (iii) guidance on the use of a global positioning system (GPS) and an internet website for ODOT landslide database.

1.2 Objectives of This Manual

The objective of this user manual is three-fold (i) to provide definitions of terms used in landslide reconnaissance form, (ii) to provide guidance on the use of ODOT landslide hazard rating procedure, and (iii) to provide explanation and guidance on how to use the ODOT landslide website. The intention of the manual is not for design of slope stabilization scheme or forecasting which landslide will fail first. It is also not applicable for the risk assessment of rockfall.

1.3 Benefits of the Systtem

The implementation of the system provides the users with a proactive and systematic approach in gathering the unstable and/or failed slope information to support the decision-making in allocating limited fund for slope remediation. The benefits of the GIS internet database lies on the following: (a) Minimal paper work, (b) Real time monitoring, (c) Centralized information, (d) Uniform data collection, (e) Shortened office works, (f) Interchangeable information, (g) Searching and sorting ability, (h) Scheduling and reporting, (i) Effective management of limited resources and assets.

1.4 Implementation

The success of the system depends upon cooperations among various constituents of potential users. Full implementation of the system needs the properly trained staffs to contribute knowledge to the new users in assessing failure slopes and developing their remedial programs. The different remedial approaches will give the benefit and cost comparisons. These will facilitate the process of decision more flexibility.

1.5 Limitations

The system provides ODOT a decision support to prioritize failed slopes by providing relative hazard rating scores. Since the assessment is partially subjective, the use of the subjective factors may cause a user to over assess the slope failure risk. However, researchers have tried to make the assessment of risk score of each factor as straightforward as possible. Thus, the potential hazard score of a landslide site should be in an acceptable range. Furthermore, it is encouraged to have users attend the training course before they have a field work. This would not only minimize error but also produce more consistency in hazard potential scoring.

CHAPTER II

LANDSLIDE INVENTORY

2.1 Landslide Reconnaissance Form

The landslide reconnaissance form is developed for the collection of pertinent information of the landslide affected area. The form is divided into three parts to allow different groups of ODOT employees to collect information. The form can be filled in a paper format, or in a portable computer, or a handheld computer GPS unit. The information collected in the form can be conveniently uploaded to a GIS based database system through an internet website. The detailed description of the use of the GIS database is illustrated in Chapter V. The use of the GPS handheld unit for collecting landslide inventory is explained in Chapter VI.

2.2 Components of Landslide Reconnaissance Form

The landslide reconnaissance form is divided into 4 parts: a landslide observation report and Form A, B, and C. A complete landslide reconnaissance form is provided in Appendix A. The flow chart showing the process of data collection and the relevant data to be collected is given in Figure 2.1.

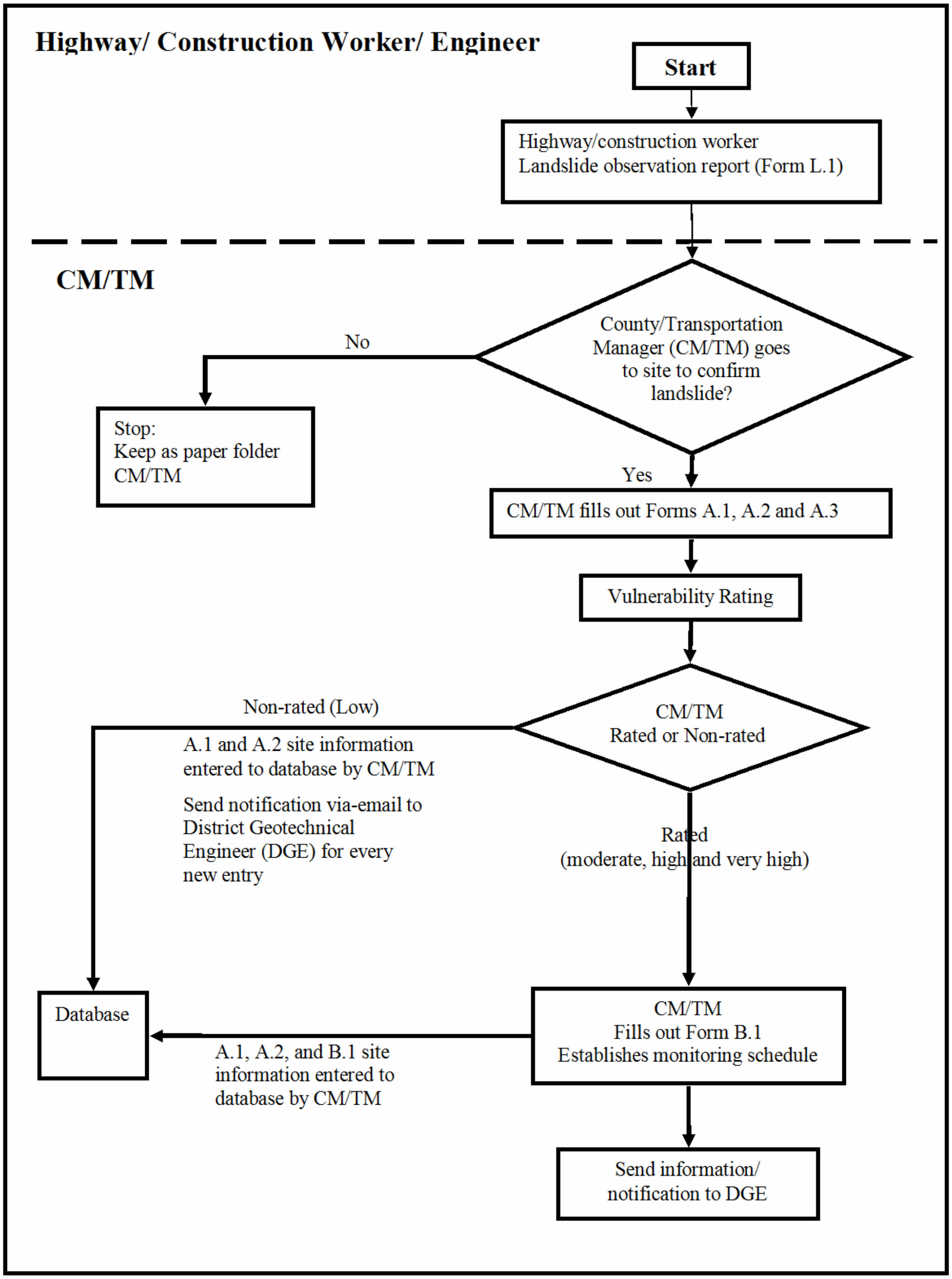


Figure 2.1 Landslide reconnaissance processes

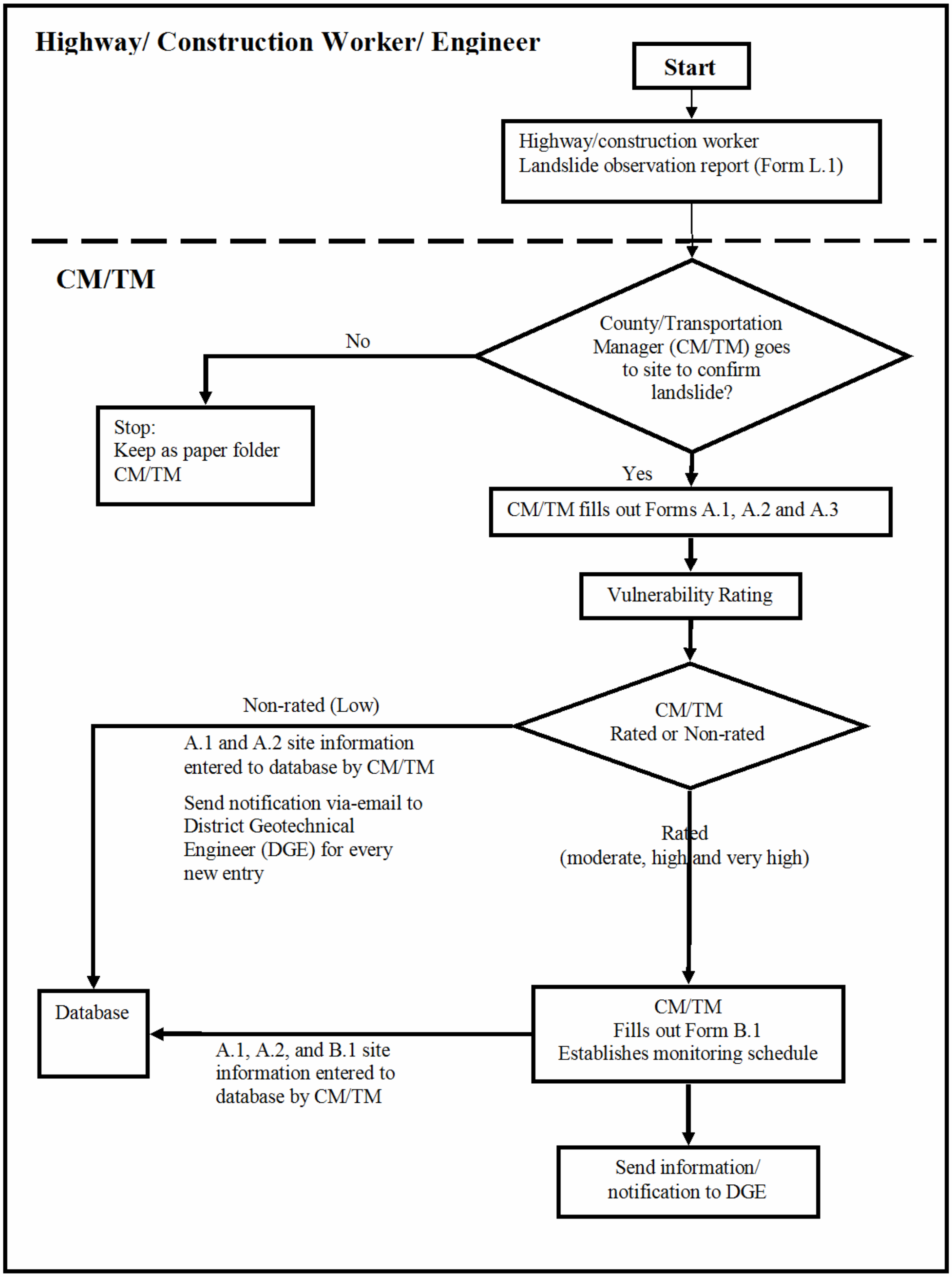


Figure 2.1 (continued) Landslide reconnaissance process

2.2.1 Landslide Observation Report

Initiation of reporting a potential landslide site is triggered by filing of the landslide observation report (Form L.1), which is generally filled out by highway maintenance crew, construction workers, or crew members from county office. The form is to be filled in a paper format and to be turned in to County Manager (CM) or to Transportation Manager (TM) of the respective county.

2.2.2 Landslide Reconnaissance Form Part A

After receiving the landslide observation report, CM/TM makes a trip to the site to verify the reported information. CM/TM needs to confirm if indeed it is a landslide. If CM/TM determines that it is not a landslide; there is no need to have any other following activities. CM/TM simply keeps the landslide observation report in a folder for future reference. If, on the other hand, CM/TM determines that the site is a landslide site, then part A (Form A.1 to A.3) needs to be completed. The CM/TM determines whether the site is to be using the judgment and vulnerability table provided in Form A.2. CM/TM enters Form A into database via internet. If the site is classified as rated, CM/TM continues to fill out Form B.1 in his/her office. Then CM/TM submits data into database via internet. Again, for every new landslide entry into database, CM/TM should send the information via e-mail to District Geotechnical Engineer (DGE).

Preparation for the field work

The equipment needed for field work is shown in Table 2.1. Since physical measurement of distance may be needed, it is recommended that at least a two-person team is formed for site visit.

Table 2.1 Field Equipments

No.	Equipment
1.	Trimble GeoXT or GeoXH GPS unit or equivalent (Window CE installed with ESRI ArcPad® Application)
2.	300-ft measuring tape
3.	Laser based distance measuring device
4.	16 or 25-ft personal measuring tape
5.	Clinometer (A surveying instrument used for measuring the inclination of a slope is usually equipped with a compass)
6.	Two-way radio
7.	Geologist hammer
8.	Reflecting vest
9.	Grid paper for landslide sketch
10.	Write-in-rain paper
11.	Rain jacket
12.	Hard hat
13.	Field shovel

Landslide identification

The first task of the CM/TM is to verify whether the reported activity is a landslide. The highway worker may mistakenly report a site that is not related to landslide. The signs of ground movements are evidenced by the formation of tension cracks, hummocky of a slope surface, misalignment of drainage pipe, guardrail, or power lines, tilting of trees, cracking of surface drainage channel, expansion and closing of the bridge joints, loss of alignment of building foundation, etc. The series of pictures presented in Figure 2.2 to Figure 2.7 are used to illustrate the telltale signs of slope movement.

Figure 2.2 Misalignment of power line

Figure 2.3 Misalignment of drainage channel

Figure 2.4 Separation of slope and bridge structure

Figure 2.5 Tension cracks on road

Figure 2.6 Sunken guardrail

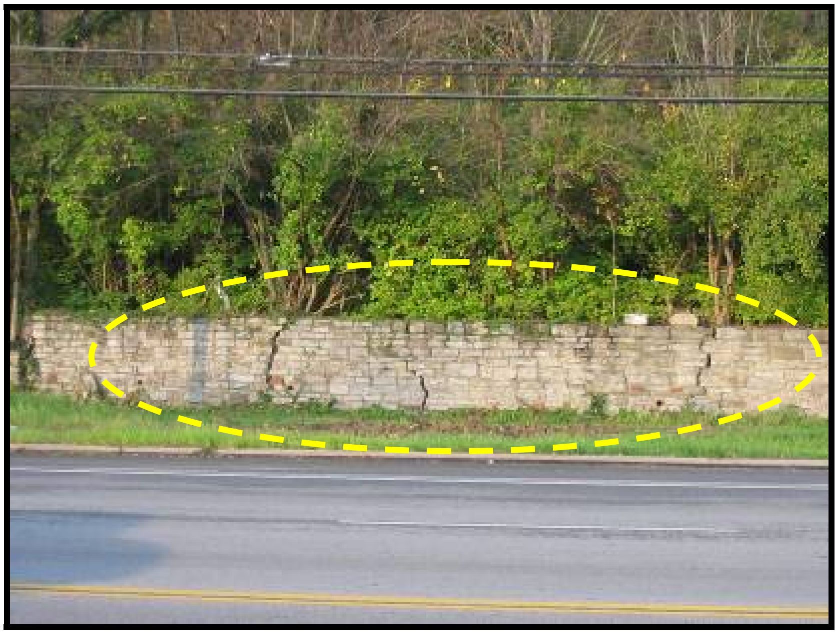


Figure 2.7 Failure of earth retaining structure

Site location

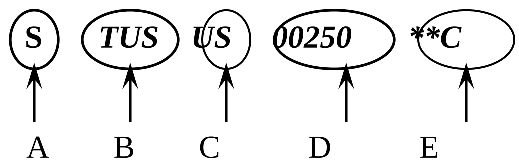
If the site is confirmed as a landslide site, CM/TM proceeds with the collection of the information for Form A. The recording of landslide location is important because it can be used for future site reference in the database. The following information is required to complete during the inventory of site location.

Network Linear Feature Identification (NLFID)

The NLFID is the code designation consisting of the components shown in Figure 2.8.

NFLID Coding Standard

NFLID CODE - S*TUSUS00250C***



Where:

A = the Jurisdiction Code
B = the County Code
C = the Classification Code
D = the Route Number
E = the Default Code.

Figure 2.8 Determination of the NLFID code

Beginning Mile Point (BMP)

The BMP should be determined based upon the Digital Mileage Indicator (DMI) reading recorded at the beginning point of the site. The BMP should always be the lowest Straight Line Mileage (SLM) point of the Site. If the DMI reading at the BMP starts at SLM 0.00, then the BMP is the adjusted DMI reading. However, if the DMI reading recorded at the BMP starts at a location other than SLM 0.00, the BMP needs to be calculated by adding the starting point SLM and the adjusted DMI reading. The adjusted DMI reading is the true log mile reading adjusted for the station equations to calculate the SLM.

Ending Mile Point (EMP)

The EMP should be calculated by dividing the measured length of the site by 5280 ft/mile to determine the site length in miles. Add the calculated site length in miles to the BMP to obtain EMP.

Centroid

After calculating the EMP, the crew members determine the center position, or centroid, for the site by dividing the calculated length by 2 and adding to the BMP. The location of centroid should be marked on the right shoulder by placing a "*" using surveyor's paint, The location of BMP, EMP and Centroid points are illustrated in Figure 2.9.

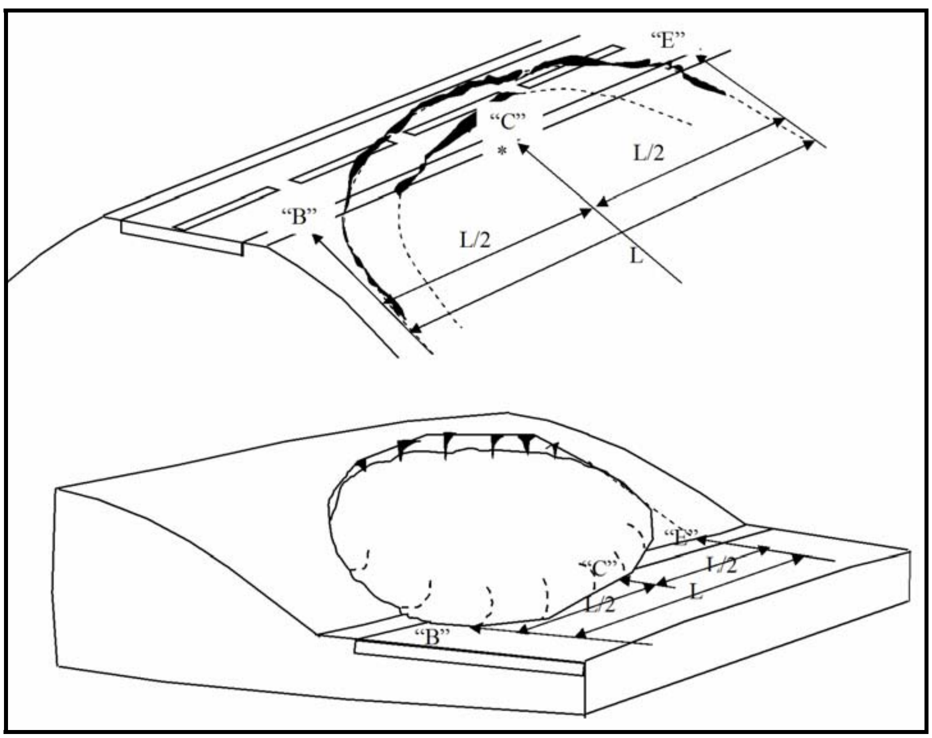


Figure 2.9 BMP, EMP and Centroid of a landslide site

The GPS coordinates should be collected at the centroid, BMP and EMP by using a Trimble GeoXT or GeoXH GPS unit or equivalent. The GPS coordinates are based on the WGS 1984 datum collected as **latitude**, **longitude,** and **elevation,** respectively. The site centroid coordinates are used to identify the location of the landslide on the GIS map on the website. The state coordinates as well as the USGS Quad name and number are generated based on the GPS coordinates of the site centroid.

If a GPS reading can not be taken on the shoulder of the roadway at the landslide site due to the poor satellite signal, the investigator should measure the offset distance so as to receive the strong signal. After recording the GPS coordinates at the offset location, the investigator collect and record a bearing and the offset distance. The bearing should be obtained in degrees from north (azimuth coordinate), and the offset distance is recorded to the nearest foot. If there is an elevation change from the centroid position to the offset point, the change can be determined by the use of any of the following means: a hand level, an abney level, a clinometer and a tape.

General dimensions of landslides

The general features and definitions of the dimensions of a landslide are provided in Appendix C. The length of the landslide is determined as the minimum distance from the tip of the landslide to its crown. The width of a landslide is the maximum breadth of the displaced mass perpendicular to the length. In the landslide reconnaissance form, the width of a landslide is measured directly along the highway based on visible evidence of a landslide effect on highway. The beginning and ending points of the affected area are assigned as the beginning mile point (BMP) and the ending mile point (EMP), respectively (see Figure 2.9). The measuring tape or a laser based distance measuring device is used for measuring the dimensions.

The depth to the slip surface is estimated by the engineer's experience and judgment. If no other field evidences suggested otherwise, the depth to slip surface could be estimated as the distance from the crest of slope back to the furthest shear crack (see Figure 2.10). For the failure beyond the toe of a slope as also shown in Figure 2.10, the depth of the slip failure surface at the toe is usually about one-third of the distance from the toe to the edge of mud wave (McGuffy, 1991). If the mud wave exits on the slope, the outlet of the failure surface is usually near the top of the visible mud wave.

The depth of the failure plane could also be estimated from the tilting of trees on slope. As seen in Figure 2.11, the depth of the slip surface may be estimated from the tree root, which is approximately less than 10 feet. If the depth of the slip surface is less than 10 feet, the trees on the sliding mass usually tilt down slope. Breaks in the buried utilities, such as culverts and sewer pipes can give a direct visual identification of where the failure surface exists.

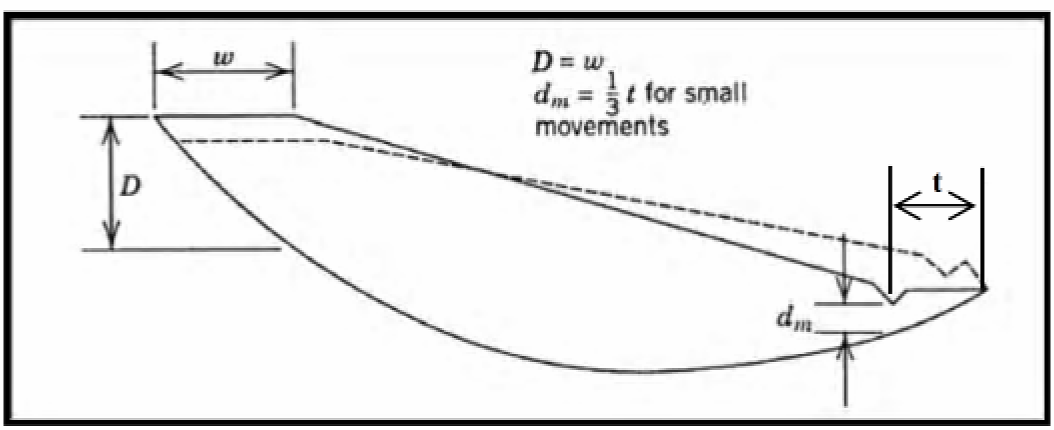


Figure 2.10 Distance from the toe to the edge of mud wave (McGuffy, 1991)

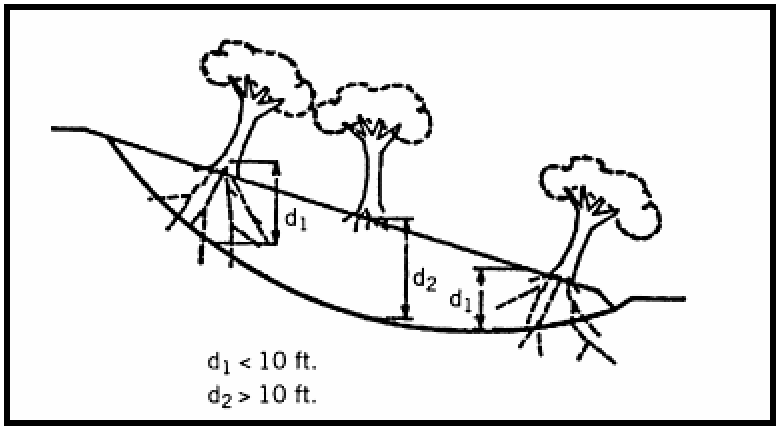


Figure 2.11 Depth of the failure surface estimated from trees with deep roots (McGuffy, 1991)

Preliminary rating and inspection frequency

The CM/TM determines the preliminary rating by visual evaluation as to whether the landslide should be "rated" or "non-rated". The landslide vulnerability table shown in Table 2.2 should be used to derive the subjective decision. The empirical scale used to estimate the hazard in terms of probability of impact on structures and additional movements includes: very high, high, moderate, and low. If the intersection of the subjective rating of these two categories is low, the site is classified as "non-rated"; otherwise it is classified as "rated".

An example of "non-rated" landslide site is shown in Figure 2.12. Since the failure was minimal to non-exist on the slope, the probability of additional movement is low. The distance from the toe of the slope to the roadway is large. If landslide takes place, it is unlikely to reach the roadway. The site location is in countryside. There was no facility or building existing on the upslope. Therefore, the probability of significant impacts to the roadway, structures adjacent property or features was low.

A “rated” landslide is a slope with potential to affect the safety of public and may cause future failure to the roadway. Several examples of “rated” landslide sites are shown in Figures 2.13 and 2.14. A landslide site in Figure 2.13 has a high effect on the pavement shoulder. The failure has a severe failure with the significant horizontal vertical displacements and high potential to advance to the traffic lanes. Another picture of this landslide site was took at the retaining structure down the slope. As seen in Figure 2.14, the landslide has caused movement of the retaining wall. The standing water behind the wall could induce additional pressure on the retaining structure.

The decision of the site in Figures 2.13 and 2.14 based on landslide vulnerability criteria was reached as follows. The probability of additional movement was rated as “very high” because the pavement and the retaining structure were highly affected. Moreover, the existing standing water may exert the additional pressure to the wall. The probability of the significant impact to the roadway, structure, adjacent properties or feature was also rated as “high”. The failure could potentially affect the surrounding bridge and the railroad. Based on the intersection of these two categories, this site is rated as “very high” according to the vulnerability table.

Figure 2.15 presents another example of “rated” landslide. The failure was localized on the roadway slope. The failure was speculated to be triggered by rainfall or improper use of fill material. When this unstable slope experiences more rainfall, the larger failure could be triggered and eventually affects the above roadway. Therefore, a special attention should be paid to this unstable slope.

If the landslide is “rated”, the notification is sent to the district geotechnical engineer for the future investigation. The rough sketches and digital photo graphs of the slope should be taken. All information is submitted via internet and stored in the GIS database.

Table 2.2 Landslide Vulnerability Table

Probability of additional movement	Probability of significant impacts to the roadway, structures, adjacent property or features			
	Very High	*High*	*Moderate*	*Low*
Very High	Very High	Very High	High	Moderate
High	Very High	High	High	Moderate
Moderate	High	High	Moderate	Low
Low	Moderate	Moderate	Low	Low

Figure 2.12 “Non-rated” slope

Figure 2.13 “Rated” slope

Figure 2.14 Displacement of retaining wall and standing water behind the wall

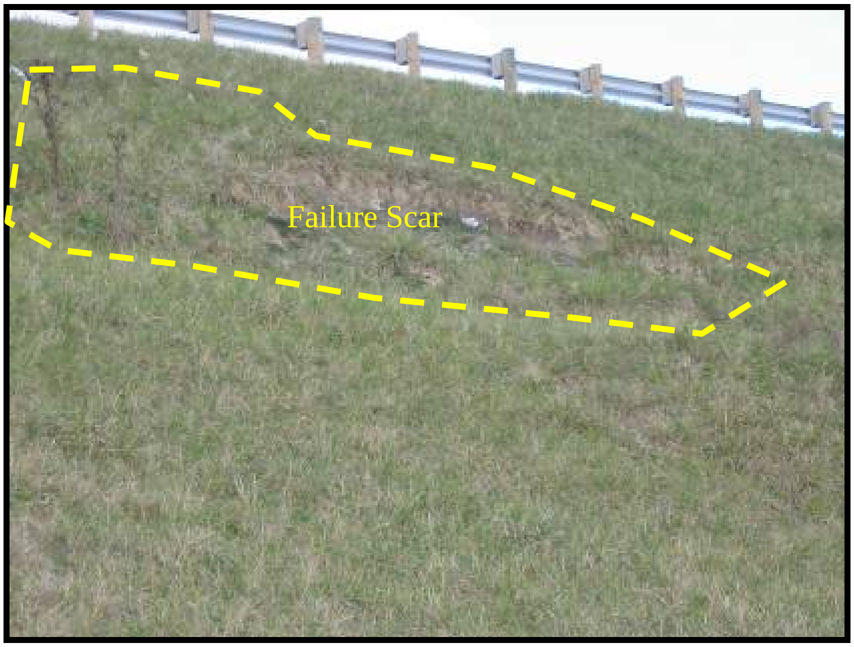


Figure 2.15 Another example of “rated” slope

2.2.3 Landslide Reconnaissance Form Part B

Part B is intended for the collection of site history and traffic information of the site. The site history includes the date of original construction, the date of alignment modification, the date of remediation activities, past and the existing remediation activities, annual maintenance frequency and cost, and maintenance response.

The CM/TM also fills in the traffic information, including the average daily traffic (ADT), the number of accidents in past ten years, estimation of detour length, posted speed limit, and estimated traveling time of detour. The information is uploaded by CM/TM to the database. The sources of information for Part B are listed in Appendix F.

2.2.4 Landslide Reconnaissance Form Part C

Once the CM/TM identifies a "rated" site, he/she sends a notification to a District Geotechnical Engineer (DGE). The DGE schedules his/her time to conduct the site visit and to complete part C of the Landslide reconnaissance form. DGE also verifies the information collected by CM/TM in Parts A and B.

The team for site reconnaissance ideally should include at lease two people. One would be the DGE and the other is a highway maintenance person who knows the site history and activities well. The field equipment used in the detailed site reconnaissance is the same as previously mentioned.

Required information for data collection

The amount of information to be collected for Part C is based on the criteria set in Table 2.3. The tiered approach in information collection is to facilitate more expeditious completion of landslide database built-up. The detailed information to be collected in each of the three tiers is given in Table 2.4.

Table 2.3 Landslide Vulnerability Table (numerical score shown in parenthesis)

Probability of additional movement (A)	Probability of significant impacts to the roadway, structures, adjacent property or features (B)			
	Very High(4)	*High(3)*	*Moderate(2)*	*Low(1)*
Very High(4)	Very High (16)	Very High (12)	High (8)	Moderate (4)
High(3)	Very High (12)	High (9)	High (6)	Moderate (3)
Moderate(2)	High (8)	High (6)	Moderate (4)	Low (2)
Low(1)	Moderate (4)	Moderate (3)	Low (2)	Low (1)

Vulnerability score (X) = A× B

Table 2.4 Information to be collected in each tier

Low (0< X ≤ 2 points)	Moderate and High (2< X ≤ 9 points)	Very high (X > 9 points)
• Verify and fill out C.1 • Very rough sketches by CM/TM • Take additional photos C.14	• Verify and fill out C.1 • Fill out C.2 to C.11 • Verify rough sketches by CM/TM • Take additional pictures C.14	• Verify and fill out C.1 • Fill out C.2 to C.13 • Take additional photos C.14

The information in Part C includes the following categories: slope characteristics, slope materials, landslide characteristics, observed remediation, preliminary determination of causes of landslide, observed traffic information, impact assessment, adjacent structures and areas, information for estimation of landslide remediation cost, initial suggested remediation measures, sources of supplemented information, landslide hazard assessment, photographs, and sketches. Explanations of the definitions and terms are provided in Appendix C.

Digital photographs should be taken and sketches of plan and cross-section of the landslide site should be drawn in scale by using the grid paper. The photos and sketches are important as they serve as a reference for future slope monitoring as well as for possible slope remediations. The sketches and photographs include locations of crown, root, edges, spring, water sources, cracks, toe bulge, sloughing, scarps, guardrail distortions, linear deflections, stream deflections, toe erosion, hydrophilic vegetation, slanted poles /trees, etc. The landslide hazard rating is assessed by using the rating matrix describe in Chapter III.

2.3 Additional Recommendation for Slope Failure Reconnaissance

To conduct field reconnaissance, it is recommended that two persons are assigned to each team. In the beginning, the investigation may seem to be burdensome. The reconnaissance should start from identifying visible features, such as cracks on the pavement, broken utility lines, movement of guardrail, etc. The affected slope adjacent to the highway is usually taken as the width of the landslide. The length of landslide is measured from the toe of the slope to the observed furthest cracks. Useful tips for landslide site reconnaissance are provided in Appendix B.

The historical information of a landslide site such as maintenance history, accident history, is often not easy to obtain due to poor documentation or simply missing records. One could search for supplemental sources by conducting interviews with local people. Taking photographs and sketching plan and cross-section of the landslide site constitute one of the most important tasks in a site reconnaissance. These photos and sketches provide detailed chronicle information of the site, from which more accurate assessment of landslide hazard potential can be made. A list of information needed for Form C is summarized below.

- Location of landslide activity is recorded by Global positioning system (GPS) and highway mile markers. The GPS positions can be determined by using a GPS hand held unit, with latitude, longitude, and elevation.
- Type of movement of landslide is determined using by visual inspection of evidences on the slope.
- Physical characteristics of landslide material are determined by visual inspection.

- The estimated dimensions of a landslide site, particularly “depth to slip surface” are difficult to ascertain. The engineer needs to exercise reasonable judgment in estimating the dimensions.
- Previous site works and past remediations are determined by visual inspection.
- Accident history could be obtained from a county record or from an interview with local people.
- The landslide causes are determined by judgment.
- The frequency of a landslide activity can be determined by consulting county maintenance record.
- Take effort to capture features of a landslide site in photographing and sketching.

CHAPTER III

LANDSLIDE HAZARD RATING SYSTEM

3.1 Overview

This chapter provides a detailed explanation of a set of factors used in the landslide hazard rating matrix. The landslide hazard is assessed based on the total numerical hazard score, which is calculated as sum of each numerical score of each factor.

3.2 Landslide Hazard Potential Assessment

Six factors are used for assessing the hazard potential of a landslide site. Each factor has four scoring scales, with the degree of hazard increases from left to right. The numerical score of 3, 9, 27 and 81 is used to represent the increasing hazard of each factor. The use of a scoring system in a form of x^3 is intended to heighten and differentiate the hazard potential of several thousand landslide sites eventually to be built in to the database.

The six factors used for assessing the hazard potential of a landslide site are as follows: (i) Movement Location and Impact, (ii) Hazard to Traveling Public, (iii) Decision Sight Distance (DSD), (iv) Average Daily Traffic (ADT), (v) Maintenance Frequency and Maintenance Response, and (iv) Accident History. The landslide hazard numerical rating matrix is presented in Table 3.1.

Table 3.1 Landslide Hazard Rating Matrix

CATEGORY		RATING CRITERIA and SCORE			
		Points 3	Points 9	Points 27	Points 81
Movement location/ impact (select higher score)	Current and potential impact of landslide on roadway	On slope with a low potential to affect shoulder	On slope with a low potential to affect roadway	On shoulder, or on slope with a moderate potential to affect roadway	On roadway, or On slope with a high potential to affect roadway or structure
	Current and potential impact of landslide on area beyond right of way	On slope with a low potential to impact area beyond right of way (A)	On slope with moderate potential to impact area beyond right of way (B)	On slope with high potential to impact area beyond right of way (C)	On slope with high potential to impact structure beyond right of way (D)
Hazard to traveling public (Select higher score)	Rate of displacement in roadway if known	<1-inch/year	1 to 3-inches/year No single event ≥1-inch	3 to 6-inches/year No single event ≥3-inches	>6-inches/year Single event ≥3-inches
	Evidence of displacement in roadway	Visible crack or dip no vertical drop (E)	≤1-inch of displacement (F)	1 to 3-inches of displacement (G)	≥ 3-inches of displacement (H)
Maintenance (Select higher score)	Maintenance frequency	None to rare	Annually (one time/year)	Seasonal (1 to 3 times/ year)	Continuous throughout year (> 3 times/year)
	Maintenance response	No response (I)	Requires observation with periodic maintenance (J)	Requires routine maintenance response to preserve roadway (K)	Requires immediate response for safe travel or to protect adjacent structure (L)
ADT		<2000 (M)	2001-5000 (N)	5001-15000 (O)	>15001 (P)
%Decision Sight Distance (DSD)		≥ 90 (Q)	89 -50 (R)	49-35 (S)	< 34 (T)
Accident history		No accident (U)	Vehicle or property damage (V)	Injury (W)	Fatality (X)

3.2.1 Movement Location and Its Impact

The location of the slope movement and its impact is broken down into two subcategories: (i) impact of landslide on roadway, and (ii) impact of landslide beyond right of way. Figure 3.1 illustrates the concept of the impact of a landslide on both roadway and beyond the right of way. The higher score from these two categories is used to represent the hazard score associated with this factor.

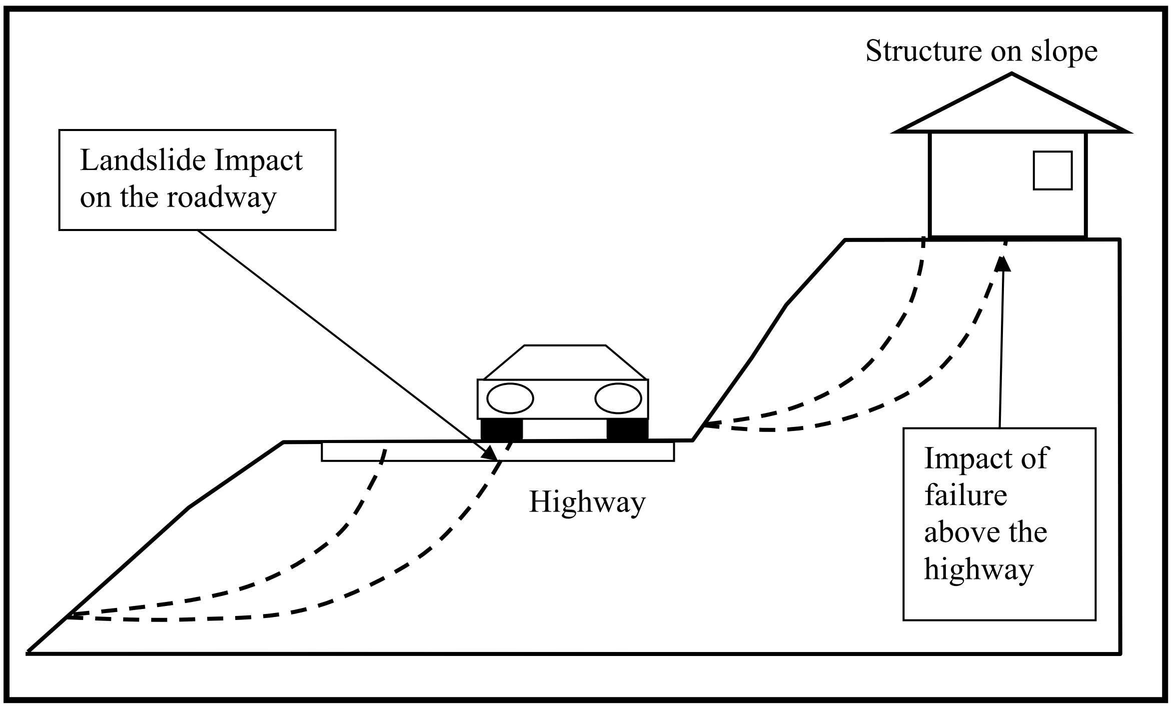


Figure 3.1 The slope failure above and below the roadway

Current and potential impact of landslide on roadway

- 3 points: On **SLOPE** with a **LOW** potential to affect **SHOULDER**
- 9 points: On **SLOPE** with a **LOW** potential to affect **ROADWAY**
- 27 points: On **SHOULDER**, or on slope with a **MODERATE** potential to affect **ROADWAY**
- 81 points: On **ROADWAY**, or On slope with a **HIGH** potential to affect **ROADWAY** or **STRUCTURE**

Current and Potential Impact of landslide on area beyond right of way

- 3 points: On **SLOPE** with a **LOW** potential to impact area beyond right of way
- 9 points: On **SLOPE** with **MODERATE** potential to impact area beyond right of way
- 27 points: On **SLOPE** with **HIGH** potential to impact area beyond right of way
- 81 points: On **SLOPE** with **HIGH** potential to impact structure beyond right of way

An example of high potential to affect roadway is shown in Figure 3.2. The cause of failure is the Lake Erie waves near the toe of the slope. Dips and cracks are not found on the pavement. However, this site is judged to have a "high" potential because the failure slope has a head scarp and relatively close to the roadway as shown in Figure 3.3.

Furthermore, there are evidences of roadway shifting from its old position several times. This landslide site receives 81 points for this hazard factor.

Figure 3.2 Slope with high potential to affect the roadway

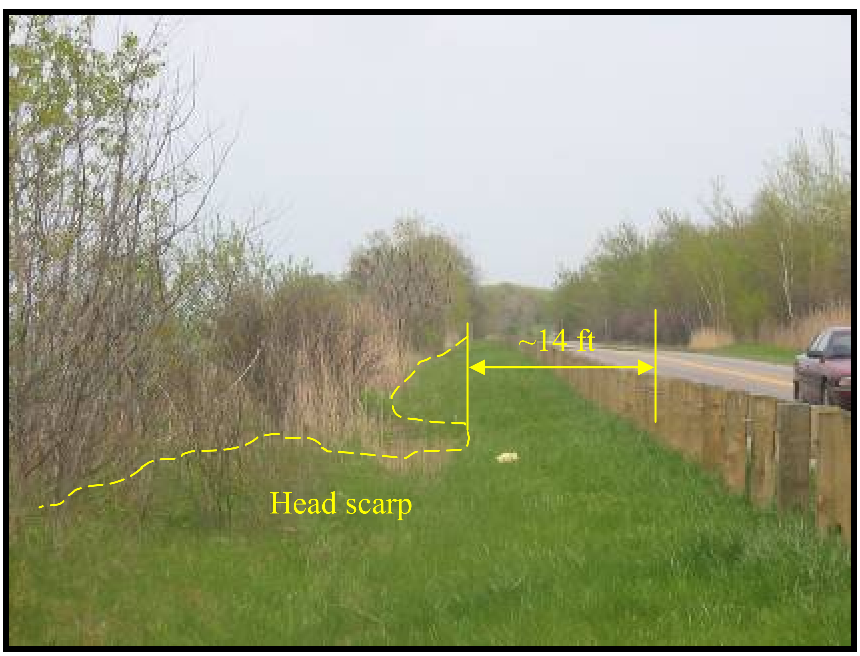


Figure 3.3 Distance from head scarp to roadway

Figure 3.4 shows a photograph of a slope failure on the roadway shoulder. The landslide site is judged to have a moderate potential to cause a larger slope movement. The risk score of 27 points is assigned.

Figure 3.5 shows an example of a cut-through highway slope. This landslide site only needs debris clean up. Since there is no structure on the top of slope, the risk score of 9 points is assigned. Figure 3.6 shows the cracking of a retaining wall due to the slope movement. Since the retaining wall is right adjacent to the roadway, a risk score of 81 point is assigned.

Figure 3.4 Impact on roadway shoulder with potential to affect roadway

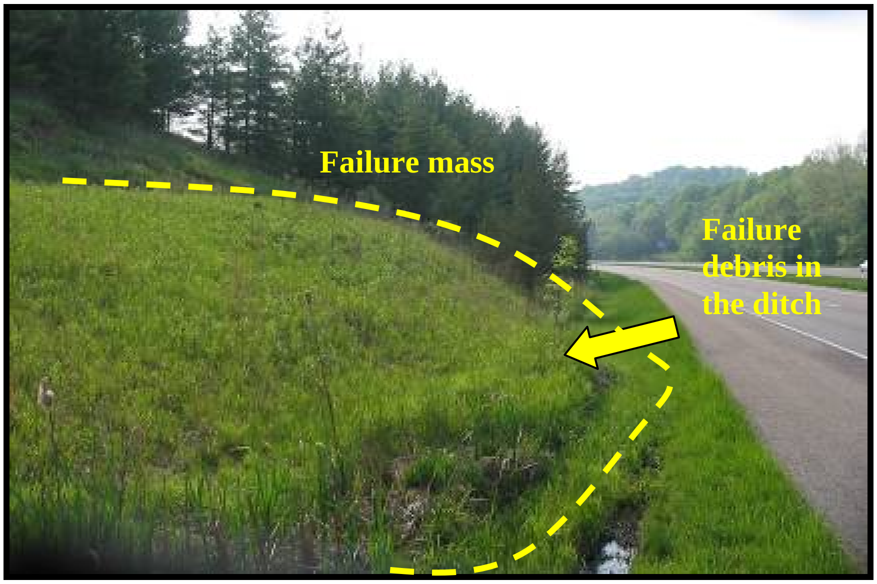


Figure 3.5 Landslide with low potential to impact shoulder

Figure 3.6 Impact of slope movement to a structure

3.2.2 Hazard to Traveling Public

Hazard to the traveling public is hazard factor assessed by the slope movement rate or the amount of total movement of a slope. The movement rate of a slope can only be quantified by using a slope monitoring device such as inclinometers. Since the quantitative data on the rate of slope movement may not be available at the time of investigation, an alternative approach is to estimate the total movement in terms of vertical and horizontal displacement of visible cracks and dips on the roadway or structure.

Cracks and dips are the telltale signs of a slope moment. Dips or cracks on a roadway affect the safety of traveling public. The larger the displacements on a road, the higher the risk to the moving vehicles. The following criteria are used for assessing the hazard according to the rate of movement or the total movement. The higher numerical score from those two subcategories is used to represent the hazard to traveling public according to slope movement.

Rate of displacement in roadway if known

- 3 points: <1-inch/year
- 9 points: 1 to 3-inches/year, no single event ≥1-inch
- 27 points: 3 to 6 inches/year, No single event ≥3-inches
- 81 points >6-inches/year, single event ≥3-inches

Evidence of total displacement in roadway

- 3 points: Visible crack without vertical drop
- 9 points: ≤1-inch of displacement
- 27 points: 1 to 3-inches of displacement
- 81 points: ≥ 3-inches of displacement

Figure 3.7 shows a displacement greater than 3 inches. Since this is a high potential causing accident when the vehicles are traveling at high speed, a risk score of 81 points is assigned. Figure 3.8 shows minor cracks, with a displacement less than 1 inch. The corresponding risk score is 9 points. Figure 3.9 and 3.10 show undulation of a roadway. This type of roadway surface is sometimes difficult to be noticed when motorists are driving at a high speed. The vehicles may lose control and suffer a serious accident due to roadway unevenness. The risk score of 81 points is assigned for this case.

Figure 3.7 Displacement or cracks more than 3", receiving a risk score of 81

Figure 3.8 Displacement less than 1", receiving a risk score of 9 points

Figure 3.9 Roadway undulation/dip

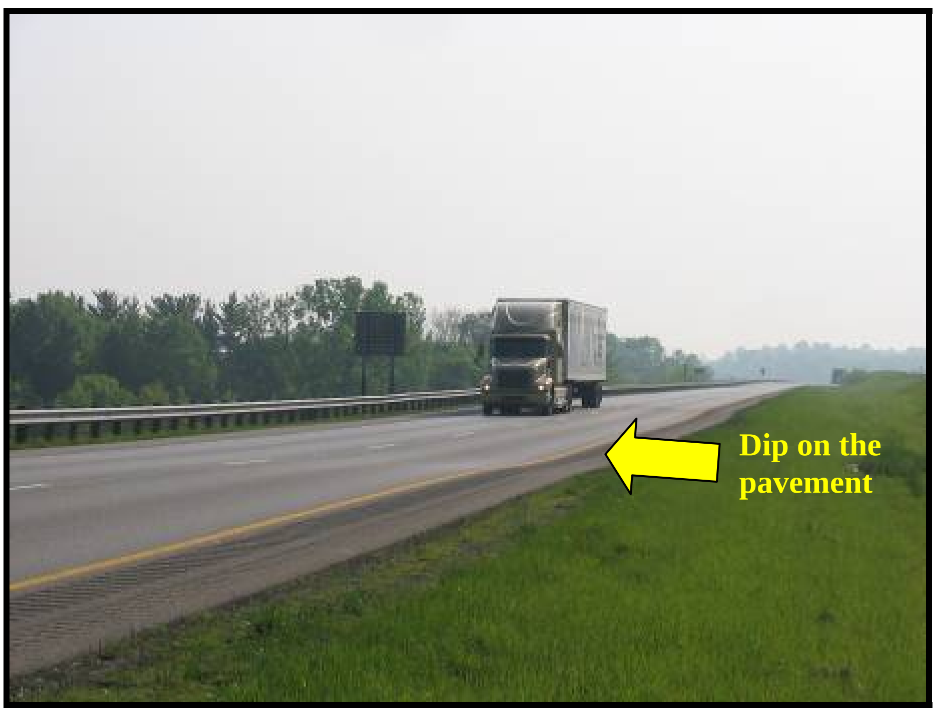


Figure 3.10 Roadway undulation/dip

3.2.3 Maintenance

Maintenance frequency is used to reflect the intensity/frequency of the past maintenance activity of a landslide site. The site with a high maintenance frequency indicates that the slope movement at that location is persistent. Therefore, as maintenance frequency increases, certain degree of emergency to mitigate the problem becomes heightened.

Most of the time, the maintenance frequency may not be available; as an alternative, the investigator could determine the appropriate maintenance response. Figure 3.11 and 3.12 show a failing slope that affects the stability of a bridge. By judgment, this slope requires an immediate response to preserve the stability of the bridge structure and the roadway. Thus, a hazard score of 81 points is assigned based on the consideration of maintenance response.

Maintenance history should be considered as one of the priority information to be obtained. At a recently paved roadway, the failure condition may be hidden. An example of a newly paved site is shown in Figure 3.13. Without checking into maintenance history, an investigator may fail to notice the distress, thus underestimating the need for maintenance response. The criteria for determining numerical scores for the maintenance factor are as presented below.

Maintenance frequency

- 3 points: None to rare
- 9 points: Annually (one time/year)
- 27 points: Seasonal (1 to 3 times/ year)
- 81 points: Continuous throughout year (> 3 times/year)

Maintenance response

- 3 points: No response needed
- 9 points: Requires observation with periodic maintenance
- 27 points: Requires routine maintenance to preserve roadway
- 81 points: Requires immediate response for safe travel or to protect adjacent structure

Figure 3.11 Separation of the slope and a bridge structure

Figure 3.12 Effect of a slope failure to the stability of a bridge structure that requiring immediate response

Figure 3.13 Newly paved roadway surface with evidence of failure that may not be obvious to the investigator

3.2.4 Decision Sight Distance (DSD)

The decision sight distance (DSD) is a comparison between the actual sight distance and the standard sight distance recommended by AASHTO (Table 3.2). Sight distance is the shortest distance along highway, at which an object of 6 inches high is continuously visible to a driver.

Calculating DSD

The actual sight distance is measured by placing a six-inch object at both BMP and EMP. The shortest distance that this object disappears from eye sight at the height of 3.5 ft above the road surface is the actual sight distance. In some cases, the view of the landslide site may be obstructed by the vertical and horizontal curves. The actual sight distance is determined from the distance that a driver emerges from the curve and sees the six-inch object. Figures 3.14 through 3.16 show the measurement of the actual sight distance of a straight, vertically curved, and horizontally curved highway, respectively.

When the roadway is straight and flat, the actual sight distance can be measured by using the maximum distance that the six-inch object disappears from the driver's sight. In case of the vertical or horizontal curve, the actual sight distance is the furthest distance that a six-inch object is immediately disappeared from the driver's sight. After the actual sight distance is determined, the DSD can be calculated by using Equation 3.1.

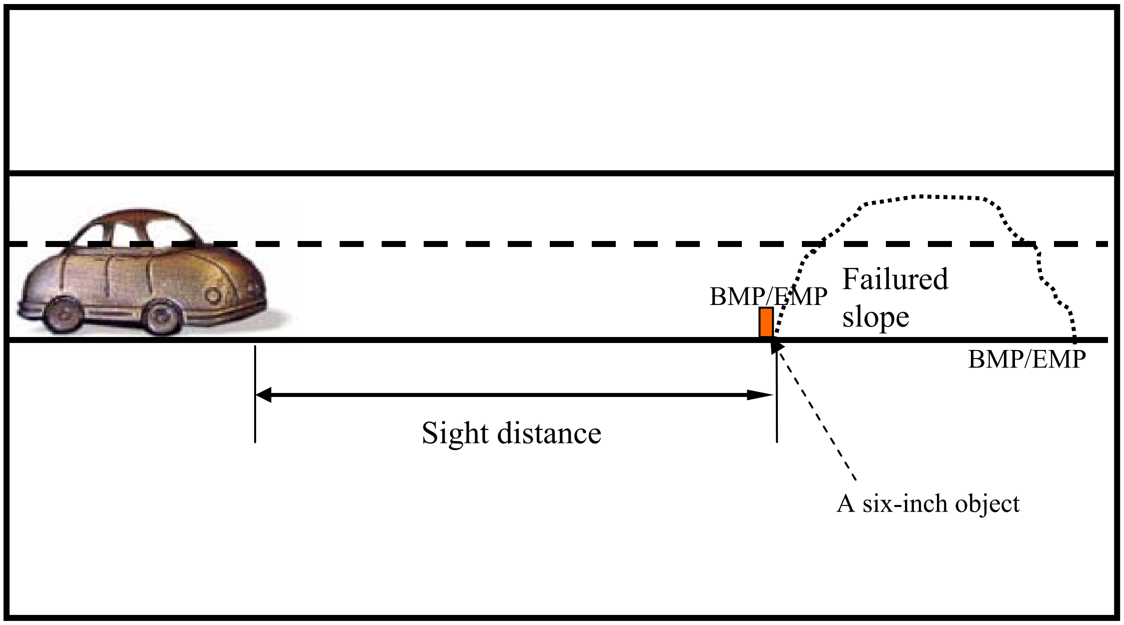


Figure 3.14 Sight distance measurement (straight roadway)

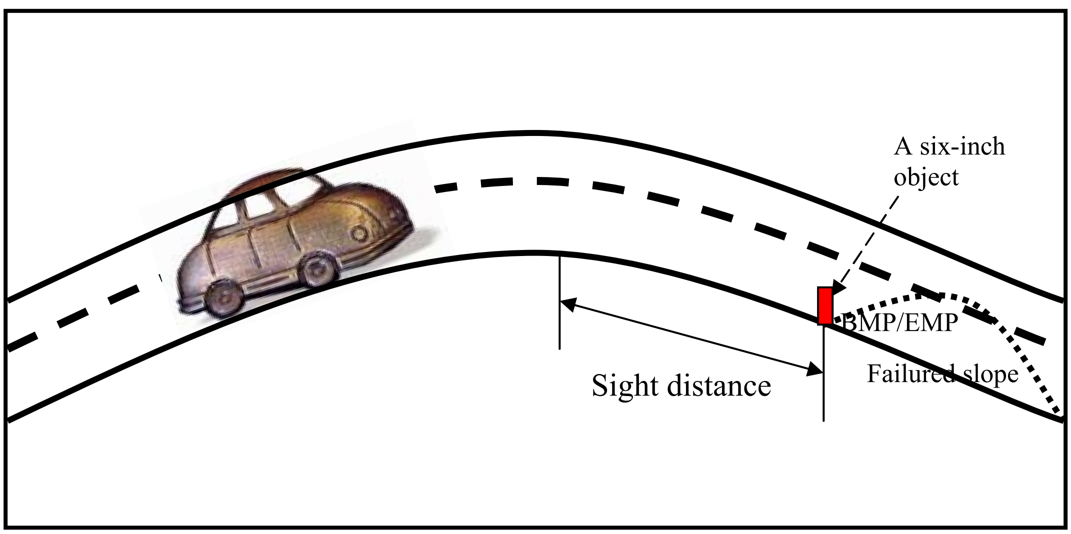


Figure 3.15 Sight distance measurement (vertical curve roadway)

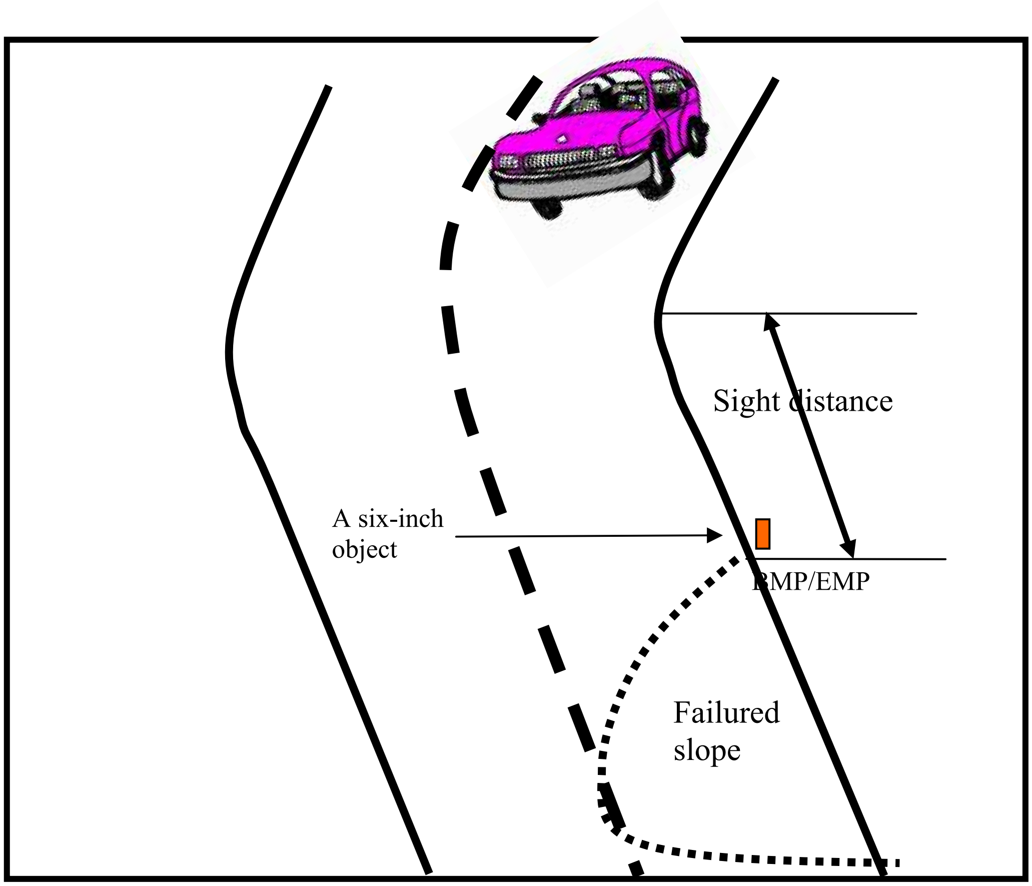


Figure 3.16 Sight distance measurement (horizontal curve roadway)

$$\frac{\text{Measured Sight Distance}}{\text{AASHTO Decision Sight Distance}} \times 100 = \text{Decision Sight Distance} \qquad (3.1)$$

Table 3.2 AASHTO Standard Decision Sight Distance

Posted speed limit (mph)	Decision sight distance (ft)
25	375
30	450
35	525
40	600
45	675
50	750
55	865
60	990
65	1050
70	1105
75	1180

The numerical scoring based on the decision sight distance follows the following criteria.

Decision Sight Distance (DSD) (%)

- 3 points: ≥ 90
- 9 points: 89 -50
- 27 points: 49-35
- 81 points: < 34

Figure 3.17 Example of a horizontal curve that could hide the slope hazard on the road ahead

Figure 3.18 A restrict sight distance due to vertical curve

3.2.5 Average Daily Traffic (ADT)

ADT is an average number of vehicles passing a landslide location per day. A landslide site with a high ADT number may imply that higher number of accidents could occur due to landslide related to hazards. ADT number also indicates the importance of the highway. Closing the highway for remediation may affect the regional economy. Therefore, at high ADT highway, earlier remediation of a landslide should be considered as a priority, thus a higher numerical score. The traffic number can be obtained from the web link provided in the Appendix F. An example of an ADT map is shown in Figure 3.19. The scoring criteria for taking into account of ADT are specified as follows.

ADT

- 3 points: <2000 cars/day
- 9 points: 2001-5000 cars/day
- 27 points: 5001-15000 cars/day
- 81 points: >15001 cars/day

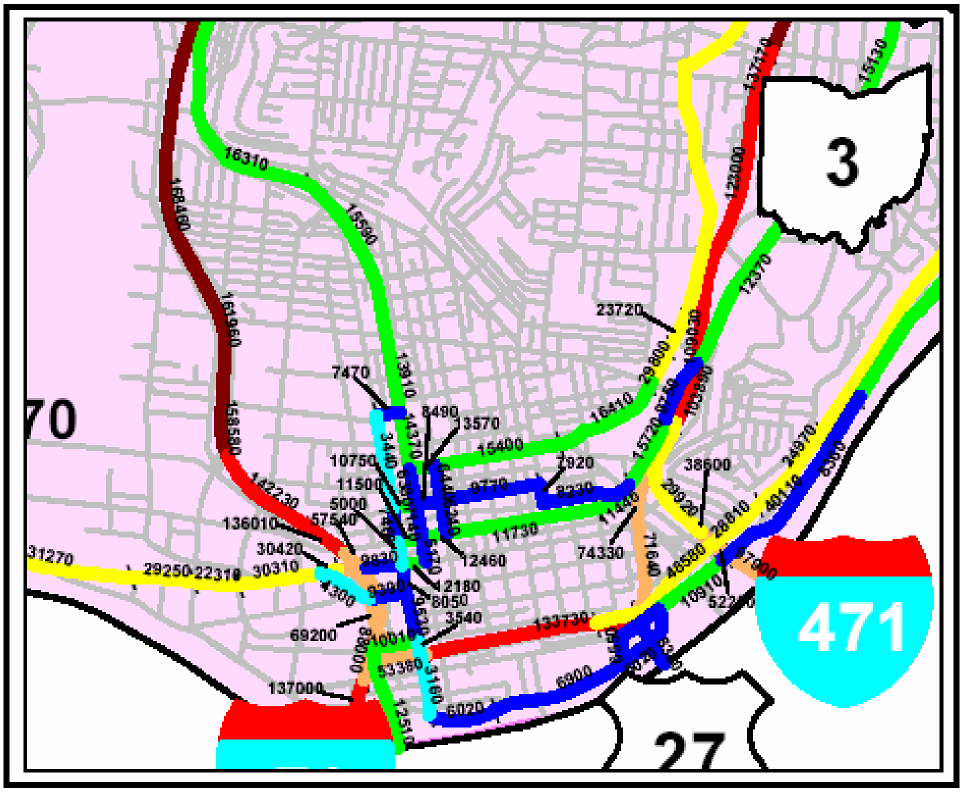


Figure 3.19 ADT map

3.2.6 Accident History

The accident history can be obtained from a highway traffic database if it is available. Alternative source of information can be obtained from local organizations, such as police office, highway patrol office, or sheriff department. The accident history is important in the landslide hazard assessment. In the case that a landslide location has shown records of injury or fatality due to landslide, the landslide site should receive high priority for remediation. The scoring criteria for the accident history factor are shown as follows.

Accident history

- 3 points: No Accident
- 9 points: Vehicle or Property Damage
- 27 points: Injury
- 81 points: Fatality

CHAPTER IV

LANDSLIDE RISK ASSESSMENT EXAMPLES

4.1 Objective of Landslide rating Exercise

This chapter provides three examples of rating a landslide site by using the developed rating matrix. The site sketches and collected data using the landslide reconnaissance form are provided as well. The exercise of going through the three examples should help demonstrate the proper application of rating factors in determining numerical scores.

4.2 Example 1

4.2.1 Site Description

The slope was mainly constructed with the fill material. The general description of fill material is given in Appendix C. The fill material on the existing natural slope consisted of a combination of gravel, clayey silt, silty clay, rock fragment, and shale. The embankment was constructed for the bridge approach. During the time of investigation, pavement patching was noticed. Dips and drops of the pavement were noticeable. Multiple cracks were observed on both traffic directions.

The slope failure was speculated as a translational slide. There was a stream located at the toe of the slope, which may have caused erosion and aggravated the slope instability. The degradation of the fill material may also have caused the instability of the slope. The investigator also considered that the fill material may be compacted directly on the existing slope without benching or without elimination of vegetation. The failure was speculated to occur along the interface between the original ground and the fill material.

Figure 4.1 Northbound lane direction

Figure 4.2 Southbound lane direction

4.2.2 Risk Assessment

Movement Location and Impact

The slope failure may have impacted on both traffic lanes, as shown in Figure 4.1 and 4.2. Dips and cracks on pavement surface were noticeable on both traffic directions as well. Significant drops and separation between the fill material and bridge structure as well as misalignment of guardrail were noticeable as shown in Figure 4.3. There were multiple cracks on the bridge abutment, as shown in Figure 4.4. A hazard score of 81 points was assigned for this factor.

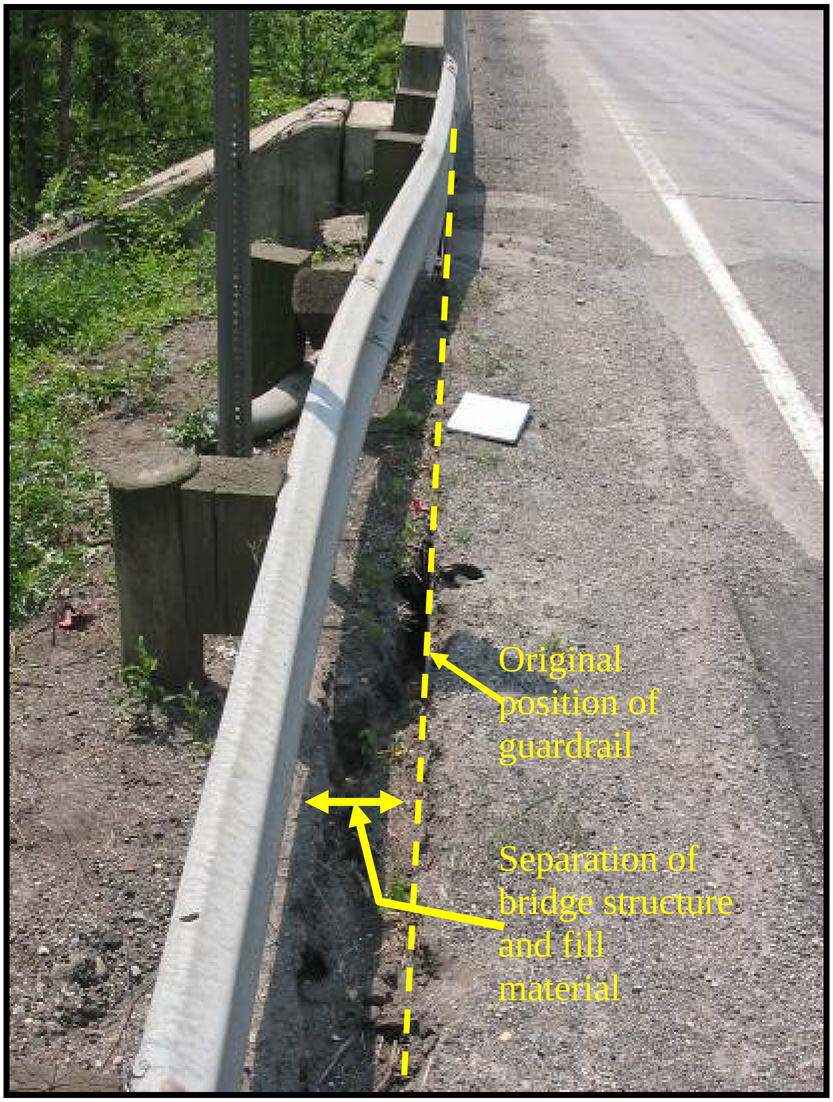


Figure 4.3 Separation between embankment and bridge structure

Figure 4.4 Cracks at the bridge foundation

Hazard to Traveling Public

The rate of movement was not available at the time of site investigation. The displacement observed on the roadway was used to assign the numerical score for this risk factor. As seen in Figure 4.3, there was approximately a foot of separation between the bridge structure and the fill material. Due to recently paved roadway surface, the displacement on the pavement surface was not visible at the time of investigation. The hazard score of 81 points was assigned to this risk factor.

Maintenance

Maintenance history was not available at the time of site investigation. However, some cracks on the bridge substructure and separation between the fill material and the bridge structure were observed. Therefore, the response for maintenance required immediate response for safety of vehicles and stability of the bridge structure. The hazard score of 81 points was assigned to this risk factor.

Decision sight distance (DSD)

The posted speed limit at the site location is 55 miles/hr. A six-inch object was placed on the edge of pavement closest to where the failure has started as shown in Figure 4.5. The sight distances were measured in both traffic directions. The shortest sight distance of 300 ft was taken, which is the distance that the six-inch object disappeared from the sight at the height of 3.5 ft above the road surface. According to ASSHTO standard, at the speed limit of 55 mph, the standard sight distance is 875 feet.

Therefore, the DSD is calculated as 34%. The hazard score of 81 points was assigned to this risk factor.

Figure 4.5 Location of six-inch object

Average Daily Traffic

The traffic count was obtained from ODOT traffic map as shown in Figure 4.6. The traffic volume at the site is 10,110 cars per day. Therefore, the hazard score of 27 points was assigned to this risk factor.

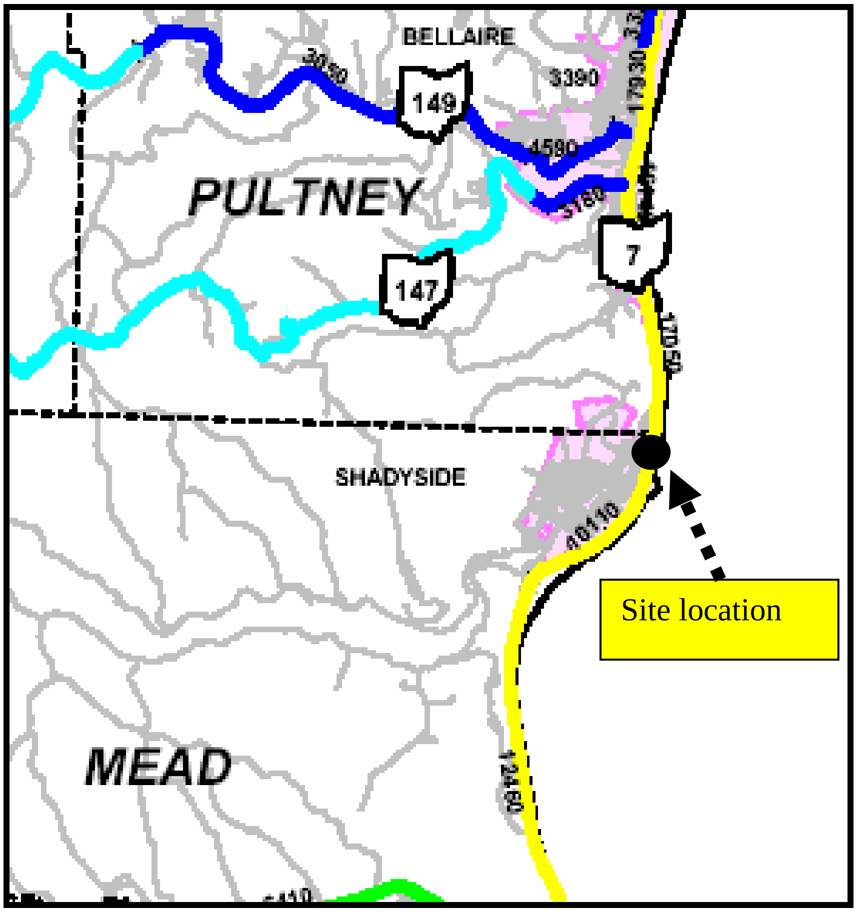


Figure 4.6 A traffic map for example 1

Accident History

Accident history can be obtained from the ODOT district office and the website link provided in Appendix F. Sometimes, accident history may not be well documented. Interviewing local people could be an alternative approach to obtain accident history. This accident history at the site was classified to be “injury”. The hazard score of 27 points was assigned to this category.

Total Risk/Hazard Score

The total hazard score of this site is tabulated in Table 4.1. The numerical hazard score of 378 indicates that this landslide site is in the category of high hazard potential.

Table 4.1 Total risk/hazard score potential of example 1

Parameter	Risk/hazard Score
Movement Location and Impact	81
Hazard to Traveling Public	81
Maintenance	81
Decision sight distance (DSD)	81
Average Daily Traffic	27
Accident History	27
Total	378

4.3 Example 2

4.3.1 Site Description

The slope failure is located at the roadway shoulder of a state route highway. The cracks, shown in Figure 4.7, were approximately 1 to 5 inches wide. Also, as shown in Figures 4.7 and 4.8, the guardrail was moved from the original location. The area in the middle of the failed slope was very wet, where cattails can be seen. The evidence of this type of vegetation suggests perhaps the pipes connected to the catch basin upslope were leaking. The materials of the slope are combinations of silty clay with trace of gravels. The drainage ditch connected to the lake is at the toe of slope as shown in Figure 4.9. The fluctuation of water level in the lake may have triggered the slope instability. The toe out area may be located in the drainage ditch or beyond.

4.3.2 Risk Assessment

<u>Movement Location and Impact</u>

The impact of the landslide is on the roadway shoulder. Based on judgment, the hazard to the roadway was considered as moderate. The hazard score of 27 points was assigned to this risk factor.

<u>Hazard to traveling public</u>

The displacement on the pavement shoulder was more than 3 inches. Therefore, the hazard score of 81 was assigned to the risk factor.

Maintenance

The maintenance response for this site was classified as “requires routine maintenance response to preserve roadway” as the cracks on the roadway shoulder were significant, and somewhat close to the traffic lane. Thus, the hazard score of 27 points was assigned to this risk factor.

Decision sight distance (DSD)

The post speed limit was 55 mile/hr. The actual sight distance was longer than 1,000 feet. The decision sight distance was 100%, which is greater than 90%. Therefore, the hazard score of 3 points was assigned to this risk factor.

ADT

Based on the traffic map, there are about 16,330 cars/day. Thus, the hazard score of 81 was assigned to this risk factor.

Accident history

There is no accident history for this landslide site. The hazard score of 3 points was assigned to this risk factor.

Figure 4.7 Cracks on roadway shoulder and displacements of guardrails

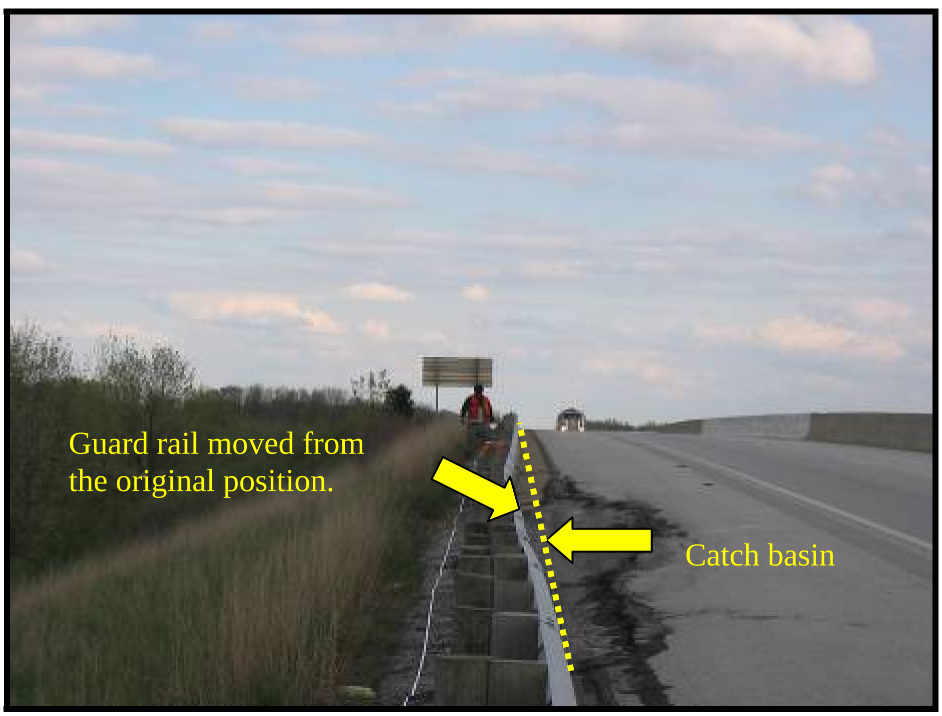


Figure 4.8 Guardrail movement, location of catch basin

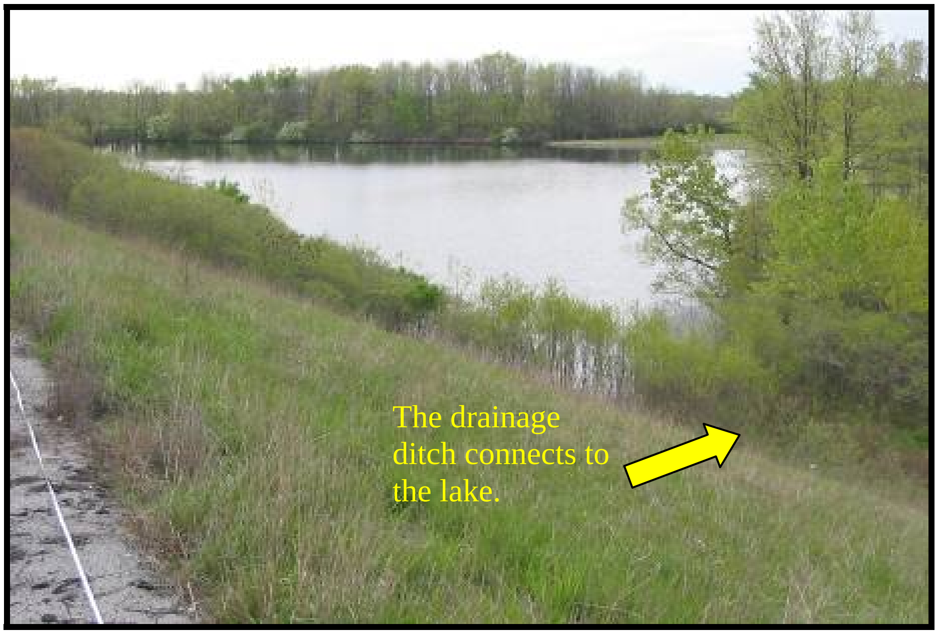


Figure 4.9 Lake at the toe of embankment

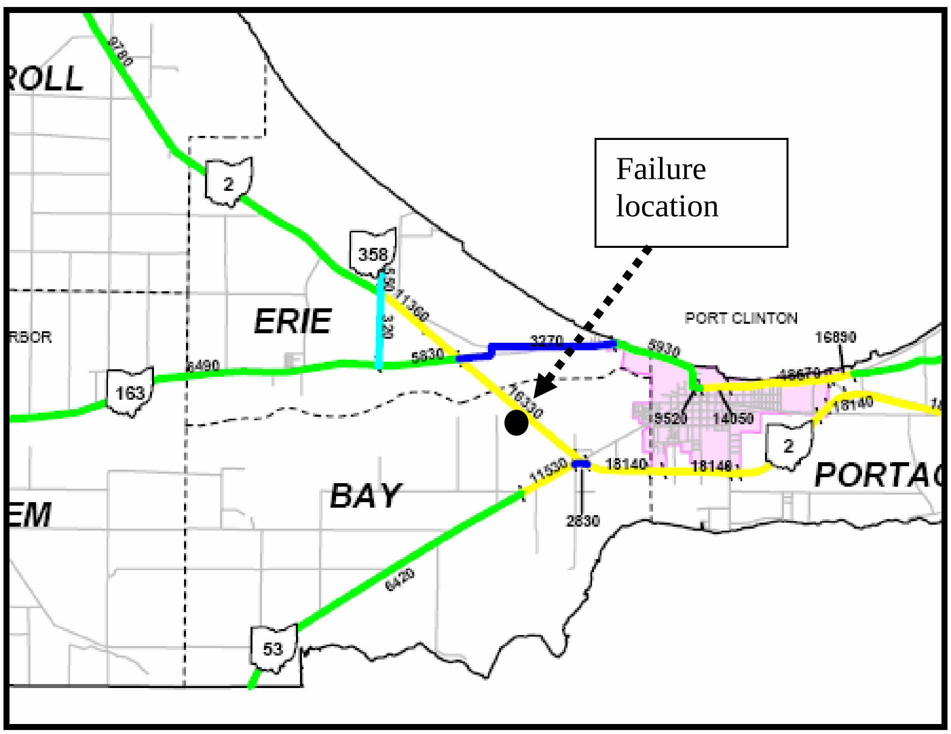


Figure 4.10 A traffic map for example 2

Total Risk/Hazard Potential

The total hazard score of this site is summarized in Table 4.2. The numerical hazard score of 222 points indicates that this site is in the category of "moderate hazard".

Table 4.2 Total risk/hazard score potential of example 2

Parameter	Risk/hazard Score
Movement Location and Impact	27
Hazard to Traveling Public	81
Maintenance	27
Decision sight distance (DSD)	3
Average Daily Traffic	81
Accident History	3
Total	222

4.4 Example 3

4.4.1 Site Description

The site is a hillside fill slope. Cracks and surface patching exist in many places on the pavement as shown in Figures 4.11, and 4.12. The cause of this slope failure may be the result of the deterioration of the fill materials and improper method of construction. There is a creek at the toe of the fill slope, which is suspected to be one of the causes of erosion. The old ripraps were found along the toe of slope where the creek is located. This indicates that the site was experienced the failure movement and was repaired in the past.

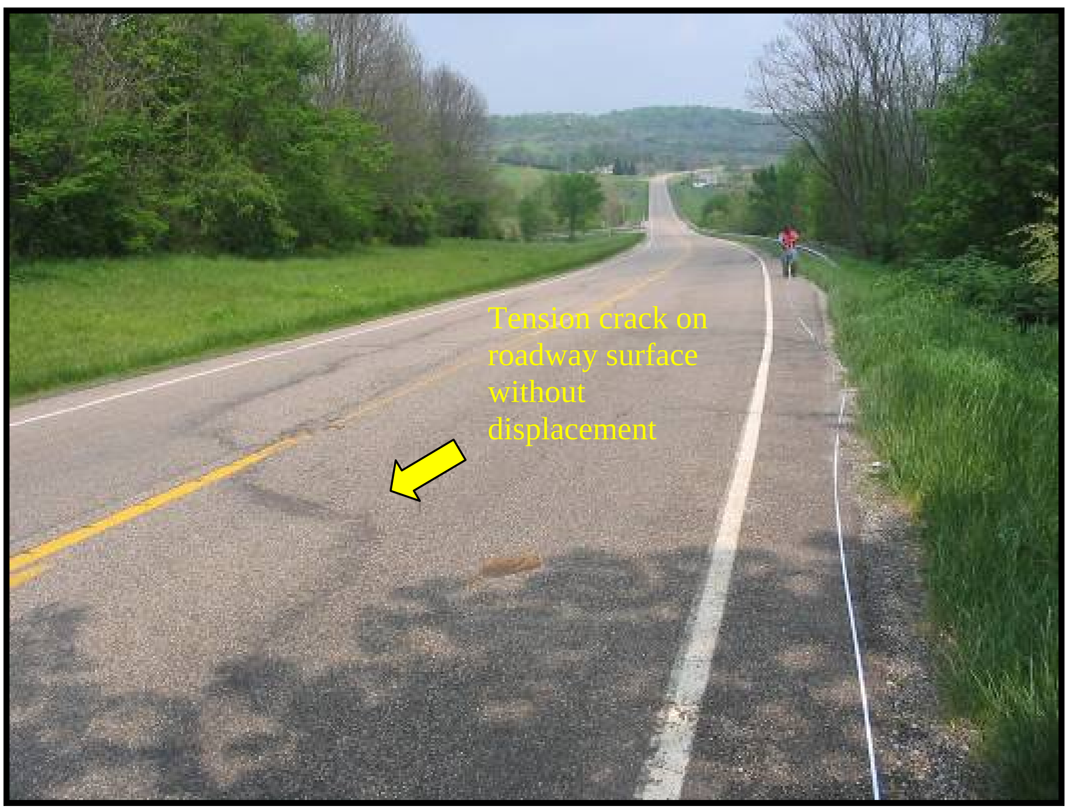


Figure 4.11 Crack line on pavement

Figure 4.12 Surface patching and transverse cracks

4.4.2 Risk Assessment

Movement Location and Impact

The impact of the landslide is on both directions of the traffic lanes. Based on the judgment, the hazard to the roadway was considered as high hazard. The hazard score of 81 points was assigned to this risk factor.

Hazard to traveling public

The hairline cracks were visible on roadway. The horizontal and vertical displacements were not observed. The hazard score of 3 points was assigned for this risk factor.

Maintenance

The maintenance response for this site required observation and periodic maintenance. The hazard score of 9 was assigned to this risk factor.

Decision sight distance (DSD)

The speed limit was 55 mile/hr. The decision sight distance for this landslide side is restricted, which is approximately 34%. Thus, the hazard score of 81 points should be given to this category.

ADT

Based on the traffic map, there are about 1,610 cars/day. Thus, this site location should receive the score of 3 points.

Accident history

There is no accident history report at the site location. The hazard score of 3 points was assigned to this risk factor.

Total Risk/Hazard Potential

The total of hazard score of this site is summarized in Table 4.3. The numerical hazard score of 180 points indicates that this site should be categorized as “moderate hazard”.

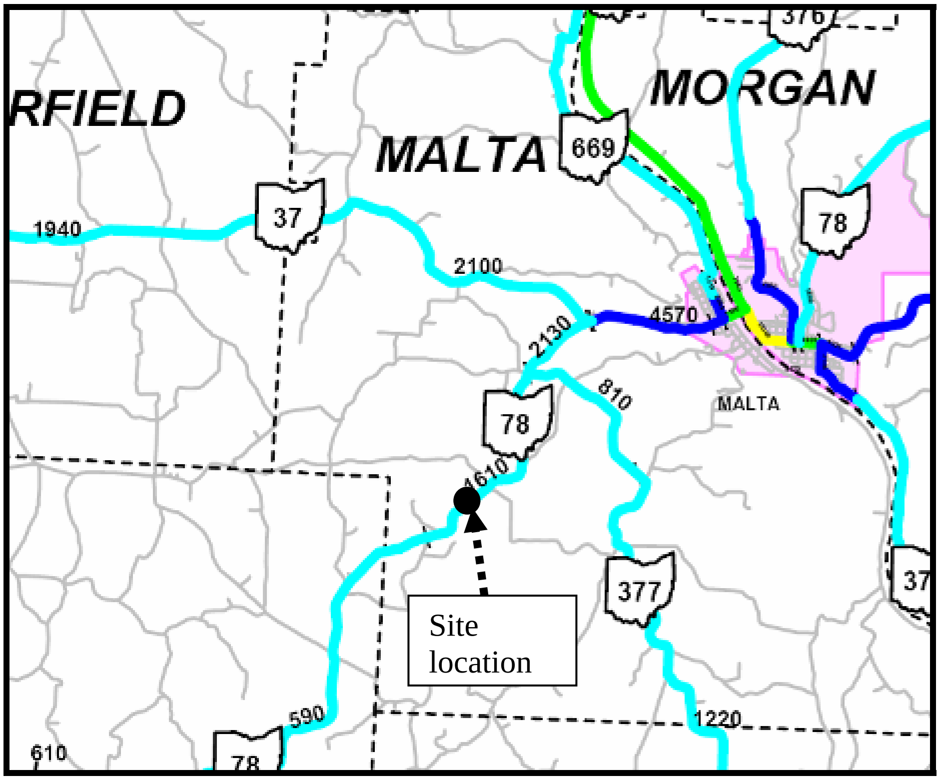


Figure 4.13 A traffic map for example 3

Table 4.3 Total risk/hazard score potential of example 3

Parameter	Risk/hazard Score
Movement Location and Impact	81
Hazard to Traveling Public	3
Maintenance	9
Decision sight distance (DSD)	81
Average Daily Traffic	3
Accident History	3
Total	180

Note: As the three examples of landslide risk/hazard rating exercises are illustrated in this chapter, we can see that the most important issue is how to consistently assess the parameters that rely on the judgment: (i) Movement Location and Impact, (ii) Hazard to Traveling Public, (iii) Maintenance. More examples in Appendix D will provide more experience and help to increase consistency in addressing these parameters. Only the parameters based on investigators' judgment are addressed.

CHAPTER V

GIS DATABASE AND ACCESS VIA INTERNET

5.1 Overview

This chapter provides instructions for a user to either actively managing or passively browsing through slope/embankment failure site information using a web-enabled, GIS database. The general functions of four key database features including: (i) Data Management, (ii) File Management, (iii) System Management, and (iv) GIS Query are described. A diagram showing functions of each database features is displayed in Figure 5.1.

5.2 User login and Privileges

A new user should request for a new username and password from a database administrator who would register and assign privileges to a new user. The users are classified into seven groups according to different responsibilities and privileges of each user. The user groups include: (i) normal users, (ii) county power users (CM/TM), (iii) district power users (DGE), (iv) state power users, (v) system power users, (vi) administrators, and (vii) supervisors. It is recommended that before requesting the user privileges online, the user should consult Table 5.1 for his/her group assignment.

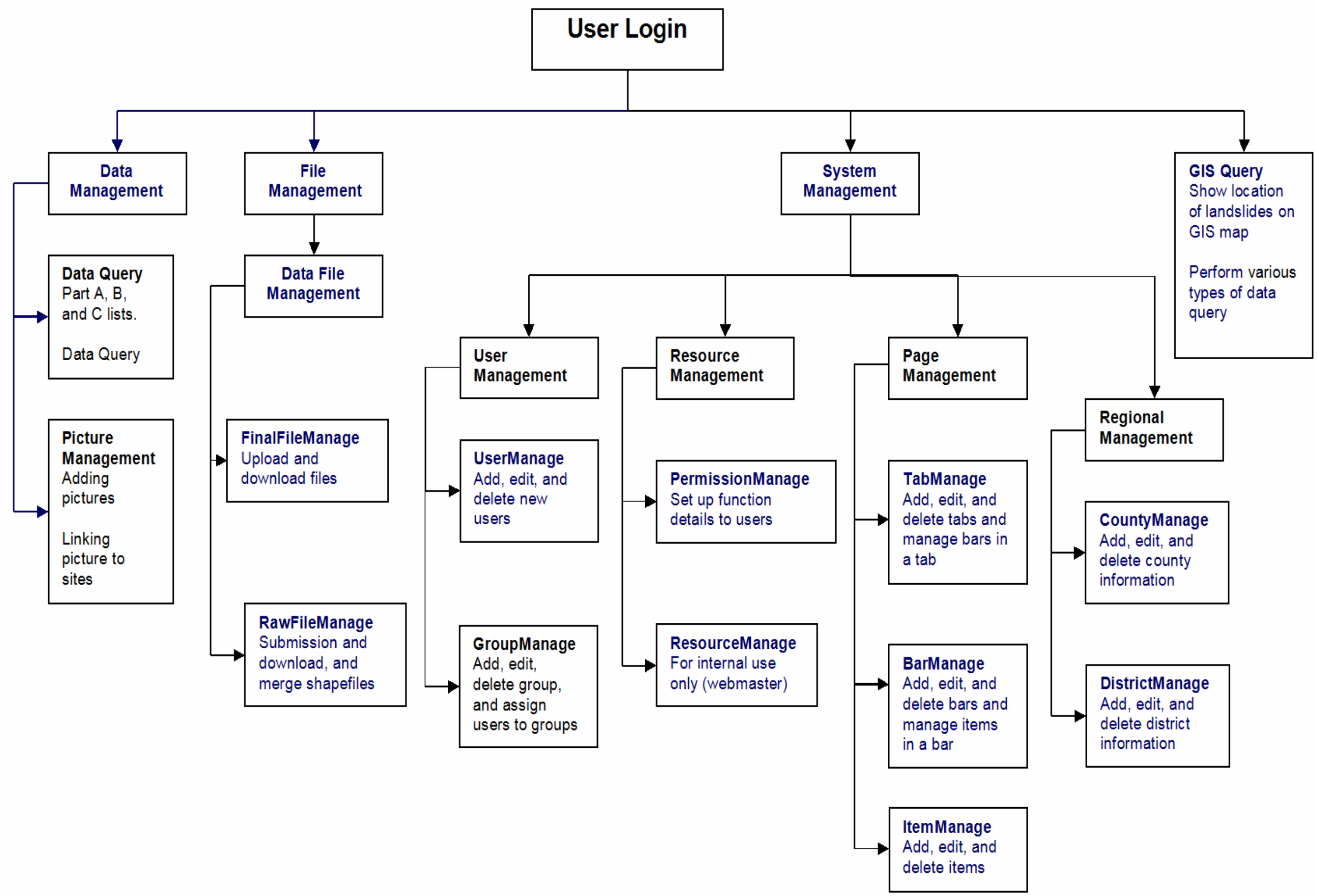


Figure 5.1 Database components

Table 5.1 User privilege

Privilege \ User	Normal User	CM/TM	DGE	State Power User	Administrator	System Power User	Supervisor
Download (Section 5.5.1 and 5.5.2)	√	√	√	√	√	√	√
Upload shapefiles and information into database (Section 5.5.1 and 5.5.2)		√	√	√	√	√	√
Data query (Section 5.4.1.4)	√	√	√	√	√	√	√
GIS query (Section 5.7)		√	√	√	√	√	√
Add/Edit Parts A and B (Section 5.4.1.1 and 5.4.1.2)		√	√	√	√	√	√
Add/Edit Part C (Section 5.4.1.3)			√	√	√	√	√
Delete Parts A, B, and C (Section 5.4.1.1, 5.4.1.2 and 5.4.1.3)				√	√	√	√
Manage landslide pictures (Section 5.4.2)		√	√	√	√	√	√
Manage regional information (County and District) (Section 5.6.4)				√	√	√	√
Merge shapefiles in GIS server (Section 5.5.1)				√	√	√	√
Design of webpage configuration (Page Manage) (Section 5.6.3)						√	√
User registration (Use Manage) (Section 5.6.1)					√		√
Set user privileges (Section 5.6.2)							√

5.3 Components of Database and Their Functionalities

This section explains each component and general functions of the landslide GIS database website. The website can be reached at http://landslide.ascn3.uakron.edu/gisView. The first page of the website is shown in Figure 5.2. The user fills in the *username, password and verifycode* and then clicks on the *login* button. It would display a new window as shown in Figure 5.3. Note: a user may not see all database components because they are limited according to the assigned privileges of different users.

In Figure 5.3, a user can see the four main components that control the functionalities of database. These components are *DataManage, FileManage, SystemManage*, and *GisQuery*, which are marked as 1, 2, 3, and 4, respectively in the figure. Clicking on each component would reveal its sub-components, which are shown on the left column in Figure 5.3. Database components and subcomponents are discussed in details in next sections.

Figure 5.2 User login window

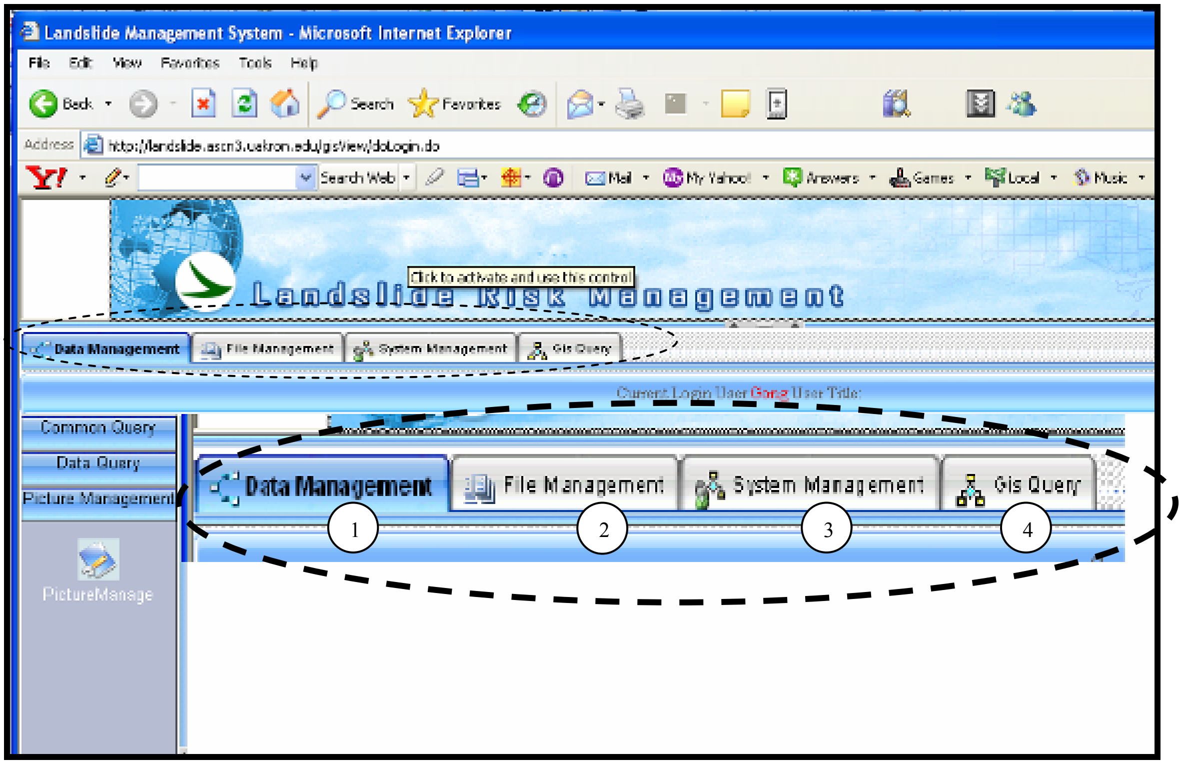


Figure 5.3 Front page

5.4 Data Management

Data Management provides a mean for a user to dynamically interact with information in the database. A user can view and query the landslide information. The user can upload and download information and pictures into and from the database as well as populate the information in the landslide GIS map. Clicking on *Data Management*, marked as 1 in Figure 5.3 would reveal two sub-components, which are *Data Query* and *PictureManage.*

5.4.1 Data Query

In *Data Query*, there are several components that a user can use to explore the landslide site information stored in the database. When a user clicks on the *Data Query* bar numbered as 1 in the figure, its sub-components are revealed as shown in Figure 5.4. A user can view, and query the landslide information. Also, a user can upload, download information and pictures, and populate the information in the landslide GIS map. A user can search for landslide information by using Parts A, B, and C lists or by inputting search criteria in *DataQuery*.

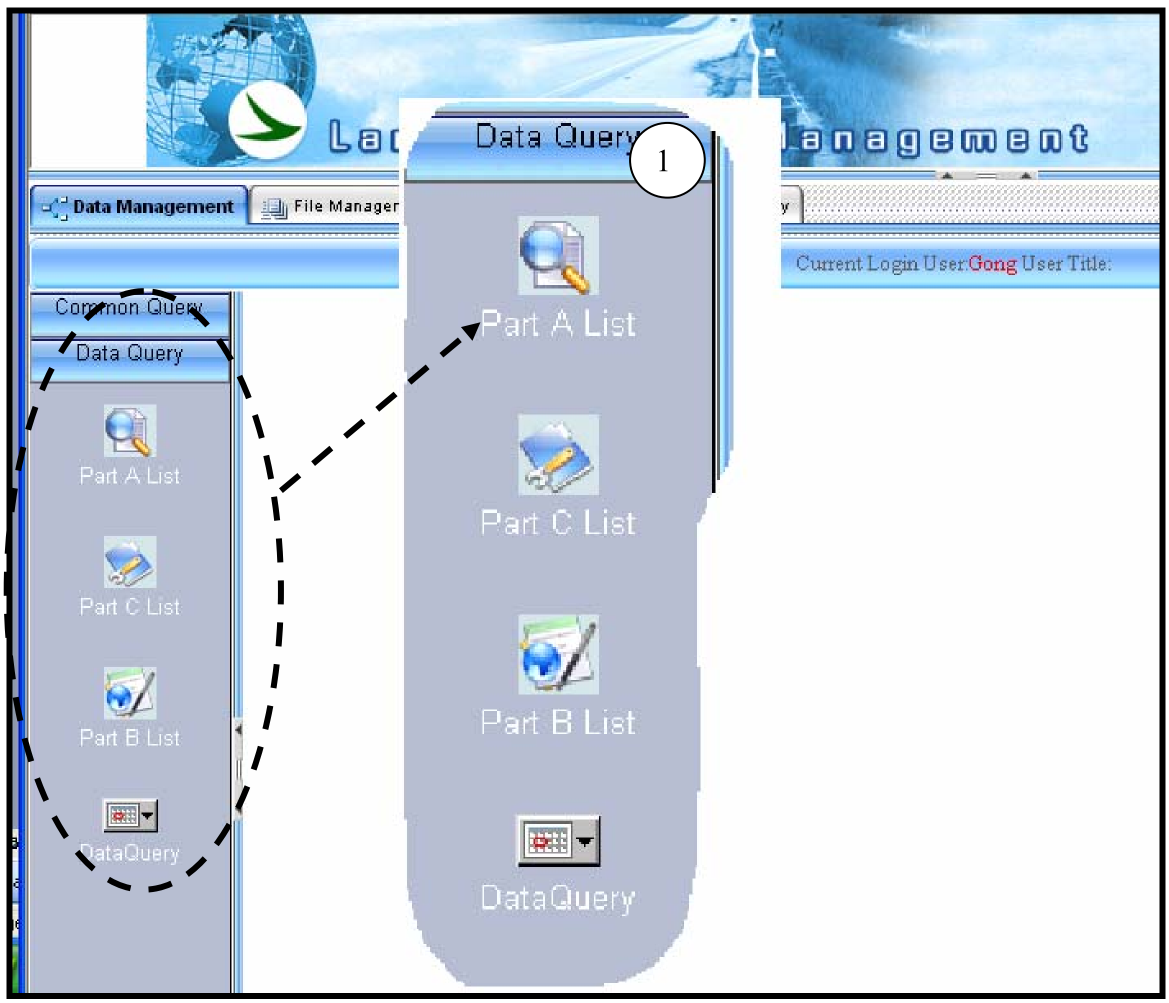


Figure 5.4 Data Query

5.4.1.1 Part A List

Part A list is used to store Part A information of the landslide reconnaissance form. Clicking on the *Part A list* icon, a user can view the information of Part A. A new window is revealed as shown in Figure 5.5. There is a search engine embedded in this section, which allows for the user to select the information of interest. To use this option, the user simply selects the search criteria embedded in the dropdown boxes and clicks *Go*. It would show a list of Par A containing information that the user is interested in.

There are also several functions in the Part A list that would help a user to manage information in the database. These functions are listed on the right top of the window, including *PictureManage, Inspection, Part B Data, Add New, Modify Data, Detail,* and *Delete,* as shown as 2 in Figure 5.5.

Managing pictures

PictureManage is used to delete and upload site pictures to *Part A list*. Before a picture can be linked to a site, it should be loaded to database. A process to load pictures into database is explained in Section 5.4.2. A procedure to link or delete a picture is as follows:

1. Make a selection on a site that you want to add a picture (Figure 5.5).
2. Click on *PictureManage* on the right top of menu. It pops up the window as shown in Figure 5.6.
3. Selecting *Add File* on the upper left corner of Figure 5.6, another window is shown as in Figure 5.7. This window shows a list of pictures that can be linked to the site.

4. Make a selection of a picture to be added. One picture can be linked to a site at a time.
5. Click on *Select Pic* on the right top of Figure 5.7. The picture is related to the site.
6. To delete a picture, make a selection on the picture to be deleted as shown in Figure 5.6.
7. Click on *Delete File*. The picture is deleted from the site.

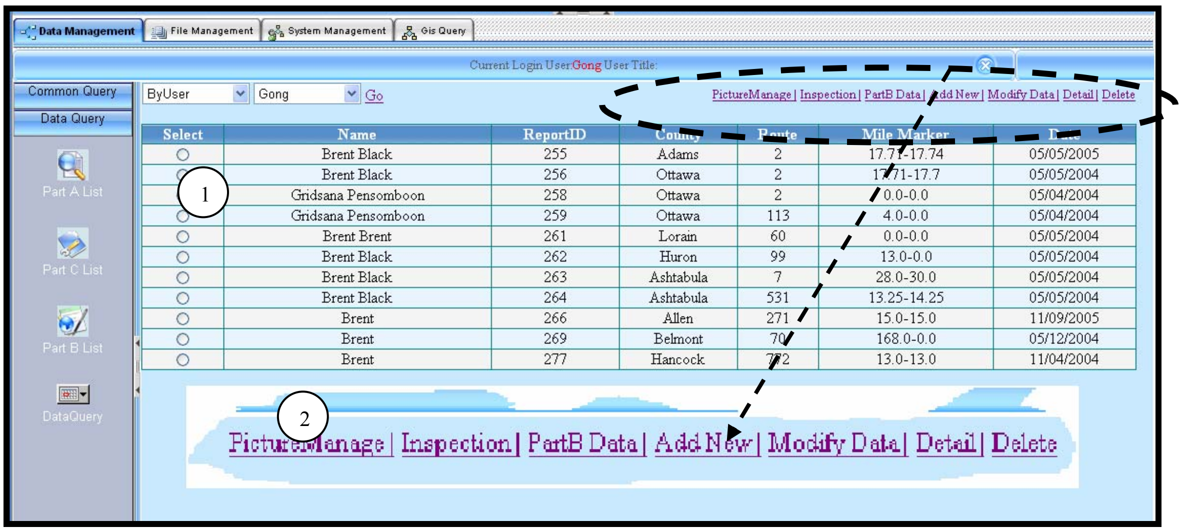


Figure 5.5 Part A List

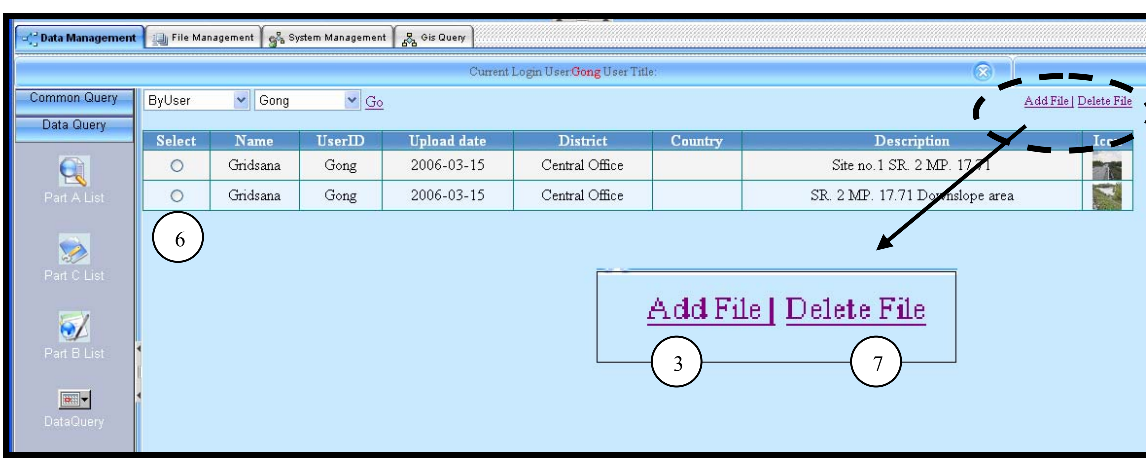


Figure 5.6 Relate and delete picture (1)

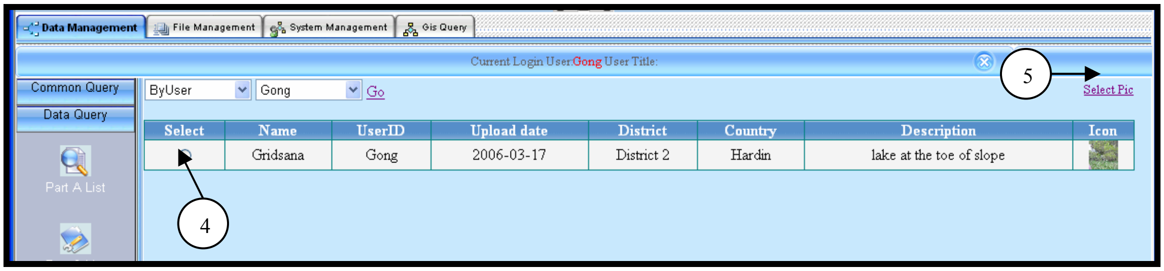


Figure 5.7 Relate and delete picture (2)

Inspection

A schedule for the next site visit is shown when clicking on *Inspection* as illustrated in Figure 5.5. Once clicked, a report in a new window appears as shown in Figure 5.8. Information regarding landslide site, such as *Site ID, District, County, Route system/number, Mile marker, Next inspection date, and Hazard score* is included in the schedule report.

Hi Gong_Countypoweruser ,there are some landslide for you inspect!

Site ID	District	County	Route system/number	Mile Marker		Next inspection Date	Hazard score
				Begin	End		
1	District 1	Allen	0/271	15.0	15.0	5/19/2006	0.0
2	District 1	Allen	0/2	10.1	10.12	6/19/2006	0.0
3	District 1	Allen	0/2	1.0	1.1	6/19/2006	0.0

Close

Figure 5.8 Schedule report

Add/Modify/Review information in Part A list

A user can add, modify, or review information of a site by selecting the site and then clicking on *AddNew*, *Modify*, and *Detail*, respectively (see Figure 5.5).

Delete information in Part A list

A user can delete the Part A information in the Part A list by selecting the site and then clicking on *Delete*. The Part A information is deleted from the Part A list.

Part B Data

A user can review, modify, or add the Part B information. To perform these tasks, the user makes a selection on the site and then clicks on the *PartB Data*, as shown in Figure 5.5. A list of Part B that has been recorded for the selected site appears as shown in Figure 5.9. The user can add, modify, review, or delete the Part B information by using the same procedure as discussed for the *Part A list*.

Part C Data

A user can go to the *Part C Data* by selecting the site and then clicking on *Part C Data*. A new window appears, showing a list of the Part C information of the selected site as demonstrated in Figure 5.10. The procedure to add, modify, review, and delete the Part C information is the same as it is previously discussed in PartA, and PartB Data.

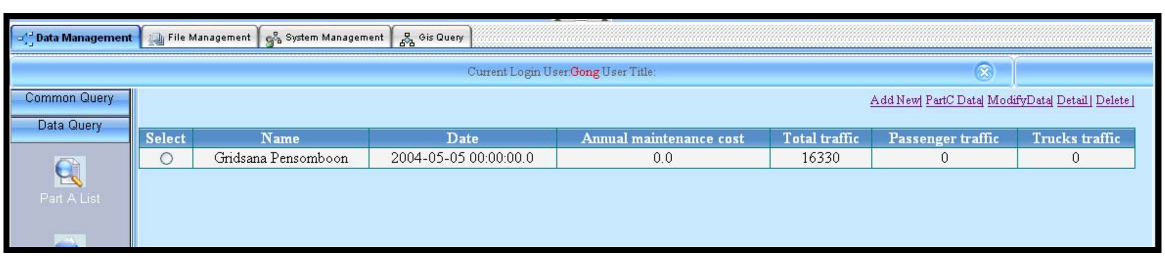
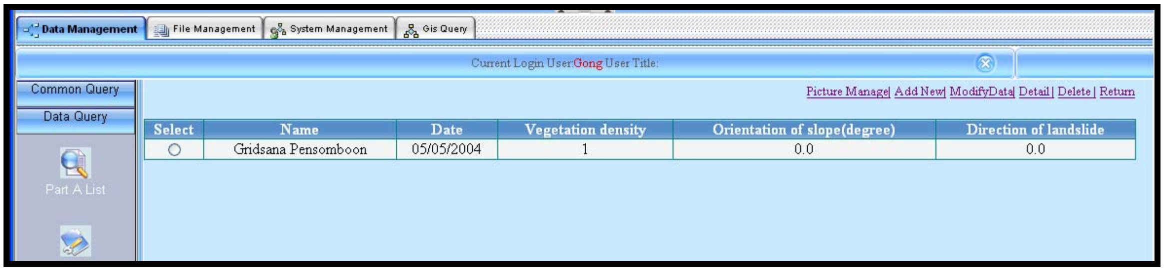


Figure 5.9 Part B Data

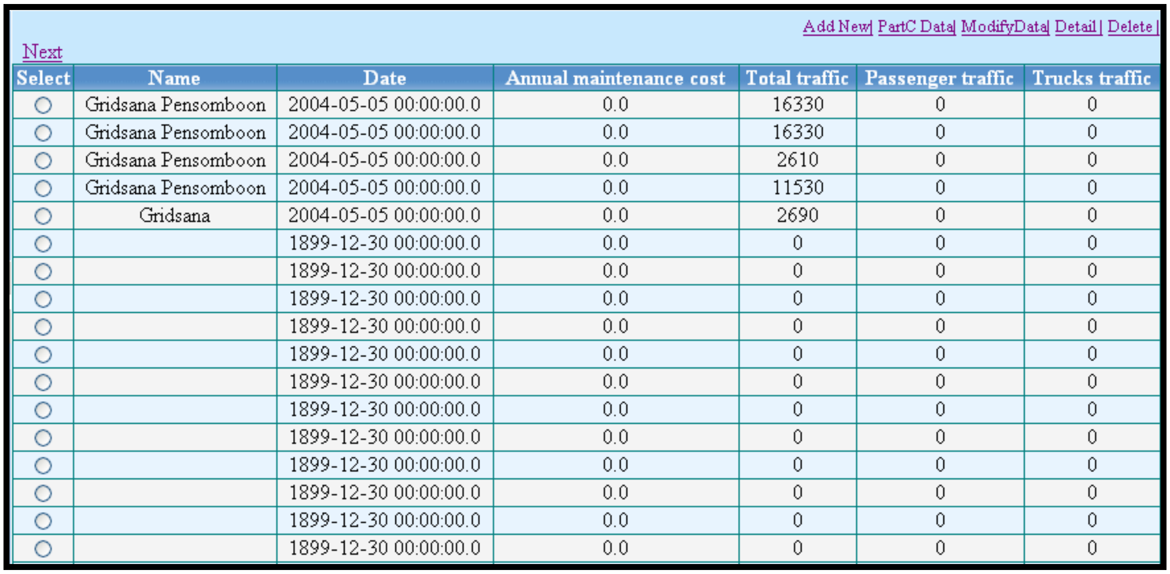


Select	Name	Date	Vegetation density	Orientation of slope(degree)	Direction of landslide
○	Gridsana Pensomboon	05/05/2004	1	0.0	0.0

Figure 5.10 Part C Data

5.4.1.2 Part B List

Part B list stores the Part B information of the entire database. By clicking on the *Part B List* icon as shown in Figure 5.4, a new window containing a list of Part B for all sites in the entire website is as shown in Figure 5.11. A user can manipulate the Part B and Part C information by following the steps as previously mentioned in section 5.4.1.1.

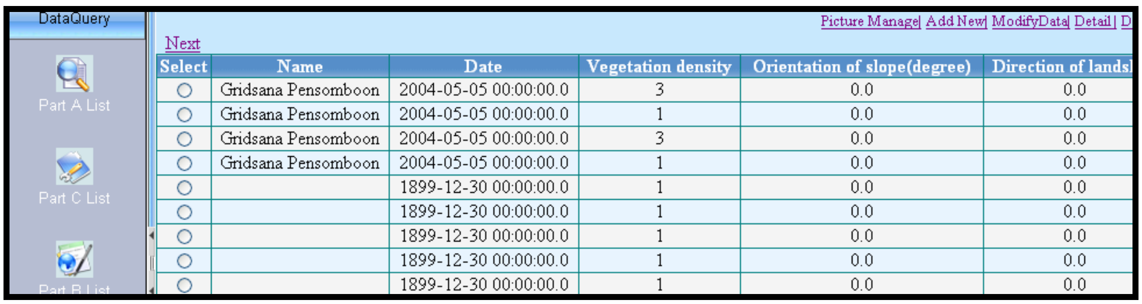


Select	Name	Date	Annual maintenance cost	Total traffic	Passenger traffic	Trucks traffic
○	Gridsana Pensomboon	2004-05-05 00:00:00.0	0.0	16330	0	0
○	Gridsana Pensomboon	2004-05-05 00:00:00.0	0.0	16330	0	0
○	Gridsana Pensomboon	2004-05-05 00:00:00.0	0.0	2610	0	0
○	Gridsana Pensomboon	2004-05-05 00:00:00.0	0.0	11530	0	0
○	Gridsana	2004-05-05 00:00:00.0	0.0	2690	0	0
○		1899-12-30 00:00:00.0	0.0	0	0	0
○		1899-12-30 00:00:00.0	0.0	0	0	0
○		1899-12-30 00:00:00.0	0.0	0	0	0
○		1899-12-30 00:00:00.0	0.0	0	0	0
○		1899-12-30 00:00:00.0	0.0	0	0	0
○		1899-12-30 00:00:00.0	0.0	0	0	0
○		1899-12-30 00:00:00.0	0.0	0	0	0
○		1899-12-30 00:00:00.0	0.0	0	0	0
○		1899-12-30 00:00:00.0	0.0	0	0	0
○		1899-12-30 00:00:00.0	0.0	0	0	0
○		1899-12-30 00:00:00.0	0.0	0	0	0
○		1899-12-30 00:00:00.0	0.0	0	0	0

Figure 5.11 Part B List

5.4.1.3 Part C List

A user can click on the *Part C* list icon to reveal a list of Part C of all sites for the entire database. The user can add picture and add, modify, review and delete Part C information. The procedure to perform these tasks is the same as previously discussed in Section 5.4.1.1.



Select	Name	Date	Vegetation density	Orientation of slope(degree)	Direction of landsl
○	Gridsana Pensomboon	2004-05-05 00:00:00.0	3	0.0	0.0
○	Gridsana Pensomboon	2004-05-05 00:00:00.0	1	0.0	0.0
○	Gridsana Pensomboon	2004-05-05 00:00:00.0	3	0.0	0.0
○	Gridsana Pensomboon	2004-05-05 00:00:00.0	1	0.0	0.0
○		1899-12-30 00:00:00.0	1	0.0	0.0
○		1899-12-30 00:00:00.0	1	0.0	0.0
○		1899-12-30 00:00:00.0	1	0.0	0.0
○		1899-12-30 00:00:00.0	1	0.0	0.0
○		1899-12-30 00:00:00.0	1	0.0	0.0

Figure 5.12 Part C list

5.4.1.4 Data Query

DataQuery provides a user with useful search options. Once a user clicks the *DataQuery* icon as shown in Figure 5.4, a new window appears as Figure 5.13. The search mode criteria in a dropdown box, as seen in Figure 5.13 can be selected. The information based on the selected search modes would appear.

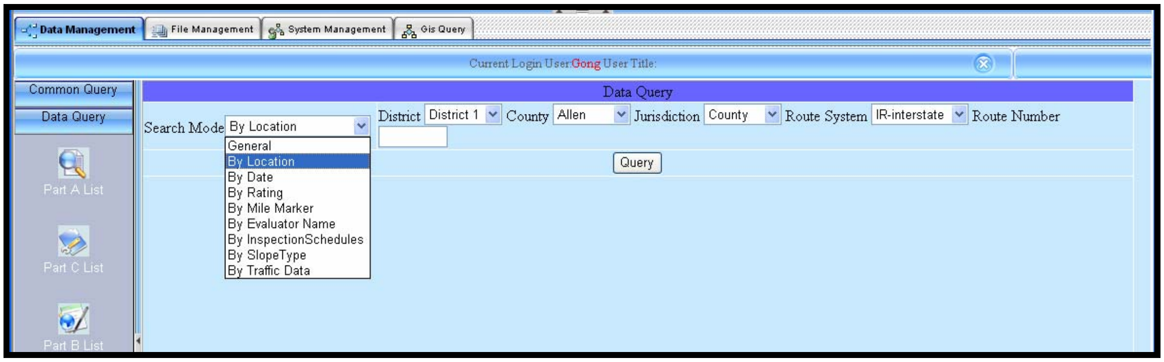


Figure 5.13 DataQuery Window

5.4.2 Picture Management

Picture Management is for a user to store landslide pictures in the database (see Figure 5.14). Once pictures are loaded into the system, the user can link them to a landslide site. The procedure to relate a picture to a landslide site is as previously mentioned in section 5.4.1.1 (*PictureManage*). To load pictures to the system, the user can follow the following processes.

<u>Loading landslide pictures to system</u>

1. Click on the *Picture Management* bar (Figure 5.14).
2. Click on the *PictureManage* icon under the *Picture Management* bar (Figure 5.14). A window as shown in Figure 5.15 appears which provides a list of landslide pictures that have been previously loaded into the system.
3. A user can use the search filters to review pictures that are previously added into the system.
4. To add a picture, click on *Add File* as seen in Figure 5.15. A window, as seen in Figure 5.16, appears where the user inputs the required information, such as name, username, district, county and descriptions. Then, the user browses to

where the picture is stored in his/her computer, and finally click on the *Submit* button. The picture is stored in the system.

5. To delete a picture, select the picture to be deleted and then click on *Delete File* (see Figure 5.15). The picture would disappear from the database.

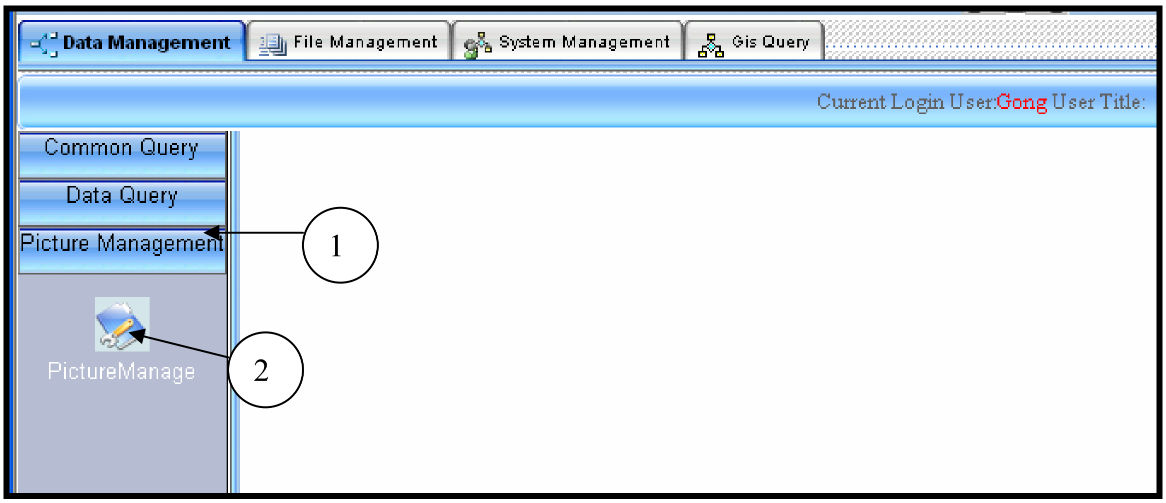


Figure 5.14 Picture manage

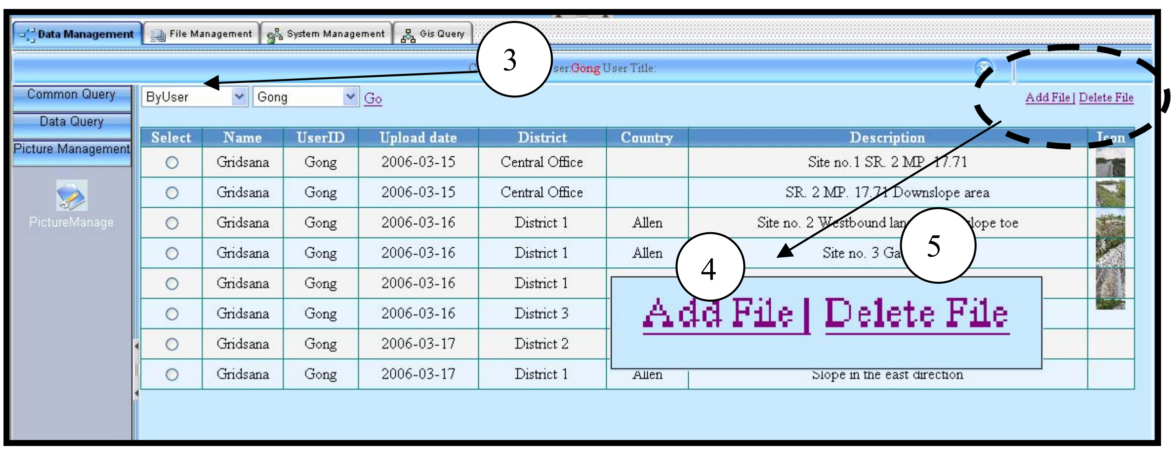


Figure 5.15 List of pictures in database

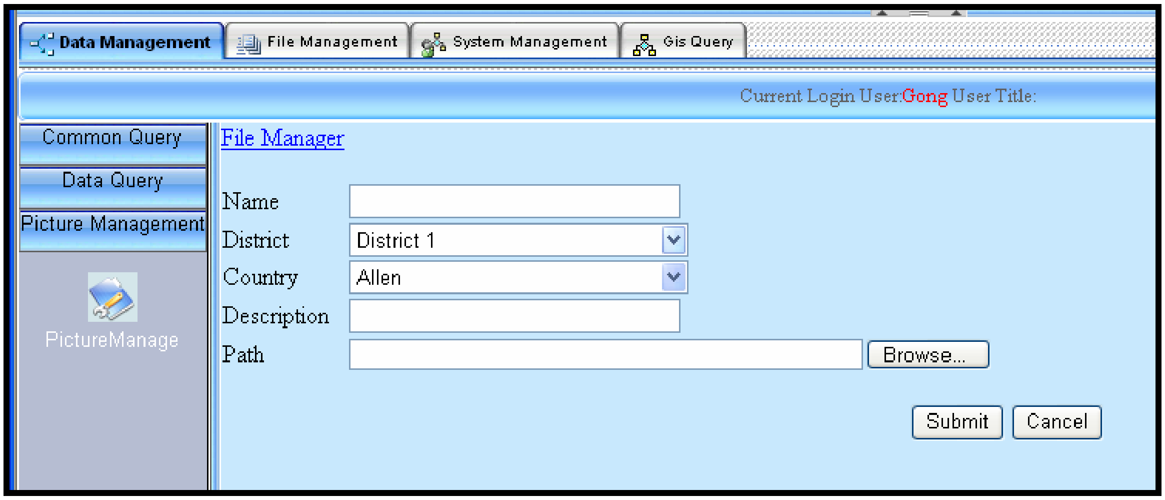


Figure 5.16 Uploading pictures.

5.5 File Management

File Management is used to manage shapefiles in the database. The shapefiles are the files obtained from using a GPS handheld device. When clicking on *File Management*, two icons appear (*RawFileManage* and *FinalFileManage*) under *Data File Management*. Once a user finishes a field work of collecting landslide information in the GPS handheld device, he/she would upload the shapefiles to *RawFileManage*. The shapefiles would then be linked into the GIS server. The landslide site appears as a dot in GIS map. *FinalFileManage* is used to keep track of the shape files being merged into the system.

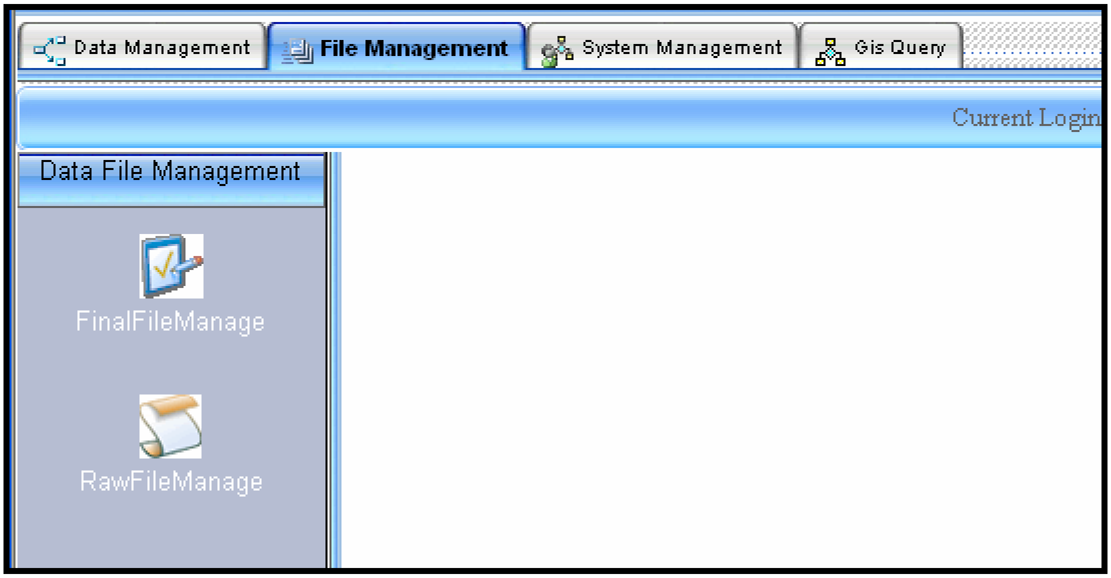


Figure 5.17 FileManage

5.5.1 Raw File Manage

Shapefiles are uploaded into the database before they are merged into main GIS server. The shapfiles contain the information of when and who upload them. Later, an authorized user can, check and merge them into the landslide GIS map. After the merging is done, the location of a new landslide site can be viewed in the GIS map.

When, a user clicks on the *RawFileManage* icon, as shown in Figure 5.17, a new window appears as shown in Figure 5.18. The user can use a search filter to view the shapefiles that have been previously uploaded into the system. The user can also check whether shapefiles have already been merged into the GIS database. If a user clicks on *MergedFile*, the window would show a list of shapefiles that have been merged into GIS server. On the other hand, the user can view a list of unmerged shapefiles in the entire database by clicking on *Un-MergedFile*. The procedures for uploading, downloading and merging shapefiles into the database are as follows:

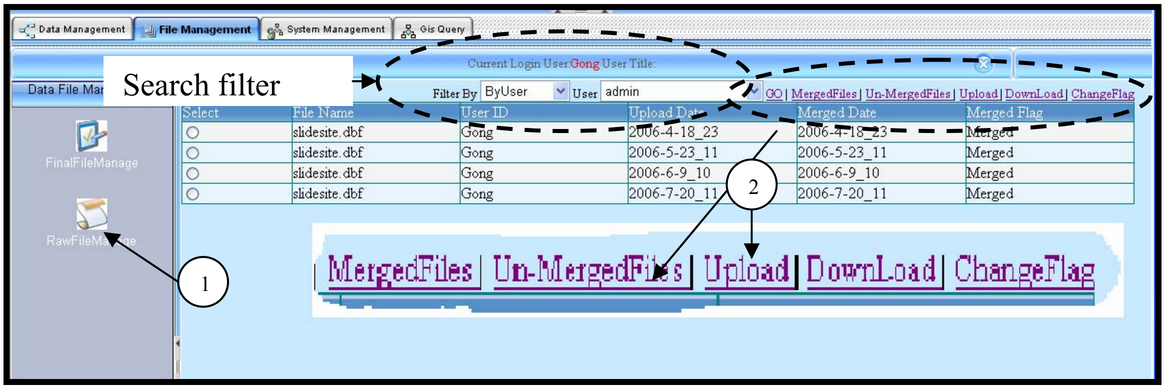


Figure 5.18 RawFileManage

<u>Uploading shapefiles into *RawFileManage*</u>

1. Click on *RawFileManage*, see Figure 5.18., a window as shown in Figure 5.19 appears.
2. Select *Upload* at the upper right corner. It reveals an upload window, as shown in Figure 5.19.
3. Fill in information and browse shapefiles that need to be submitted.
4. Click on *Submit* to store the shape files in database.

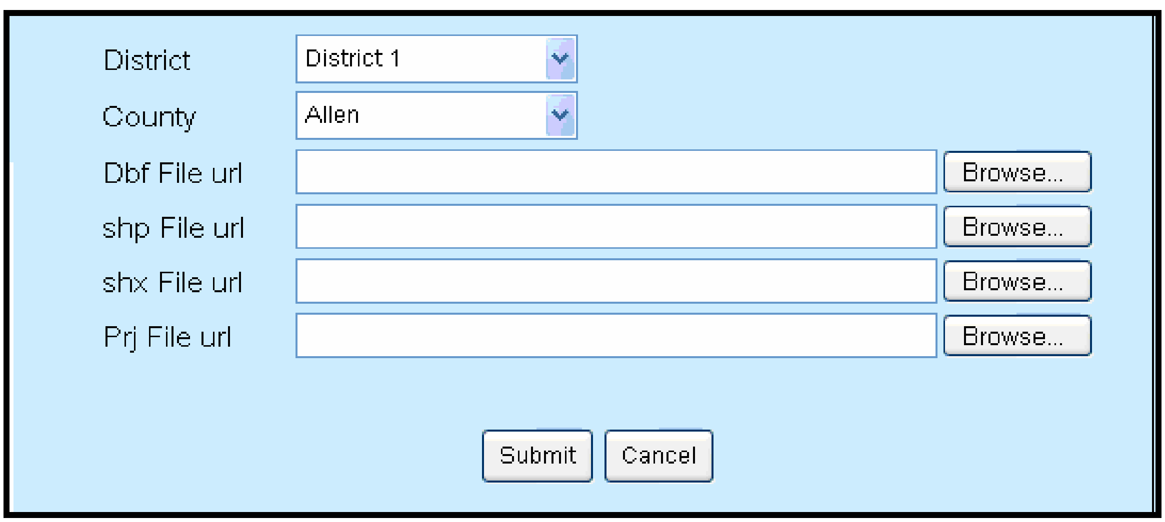


Figure 5.19 Shapefile upload window

Downloading shapefiles from "RawFileManage"

1. Click *RawFileManage*, see Figure 5.20, a list of shapefiles being loaded into the database appears.
2. Select a shapefile that needs to be downloaded.
3. Click on *Download* at the upper right corner. A new window as shown in Figure 5.20 pops up.
4. Select a shapefile type to be downloaded (see Figure 5.21). A download dialog box appears.
5. Click on *Save* to save the file in the user's local computer.

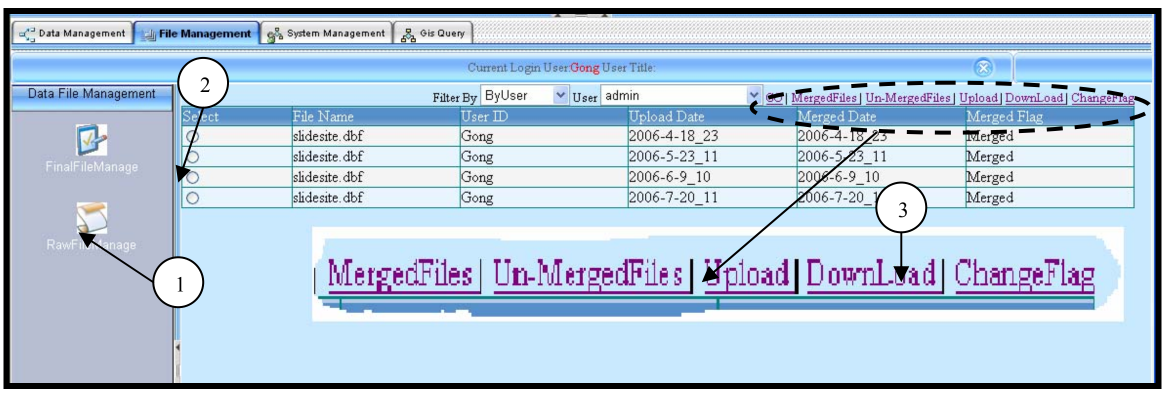


Figure 5.20 Download Shapefiles (1)

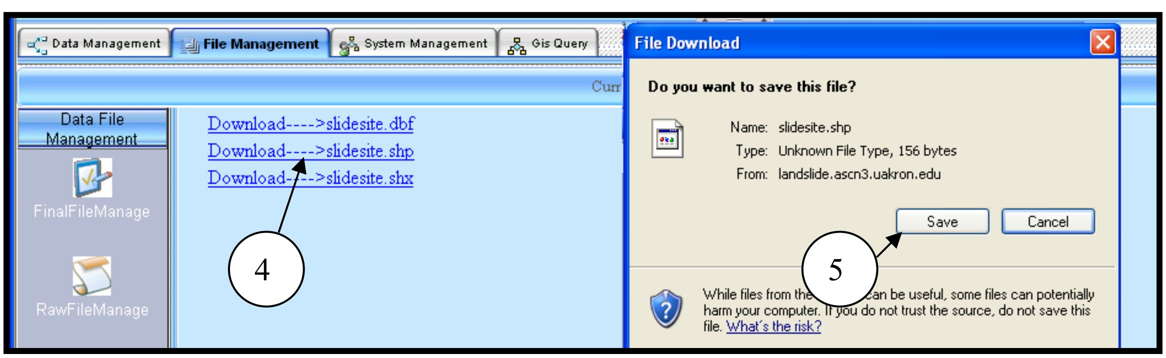


Figure 5.21 Download Shapefile (2)

Merging shapefiles into GIS server

The shapefiles that have not been merged into the GIS server are marked as *Un-Merged*. To merge a shapefile into the GIS server, a user can follow the procedures below:

1. Click on *RawFileManage* (see Figure 5.22). A list of shapefiles that have been loaded into the system reveals.
2. Select an unmerged shapefile.
3. Click on *ChangeFlag*. The status of the selected shapefile would be changed from *unmerged* to *merged*. This means that the shapefile is merged into the GIS server. The user would see the new sites on the GIS map.

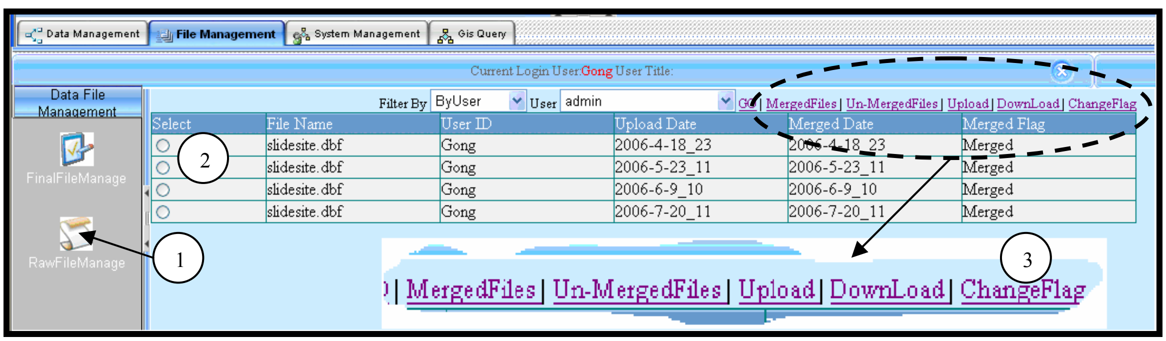


Figure 5.22 Merge shapefiles into GIS server

5.5.2 Final File Manage

The purpose of *FinalFileManage* is to keep the record of shapefiles being merged into the GIS server. A user should create a document file containing the information of when, and who has merged shapefiles. The user can also upload other types of information, such as landslide news, traffic information, design sheet, etc into this directory.

Uploading a file into *FinalFileManage.*

1. Click on *FinalFileManage* as shown in Figure 5.23.
2. Click on *Upload*. An upload window appears.
3. Fill in the information and browse the file to be uploaded.
4. Click on *Submit*. The information is now stored in database.

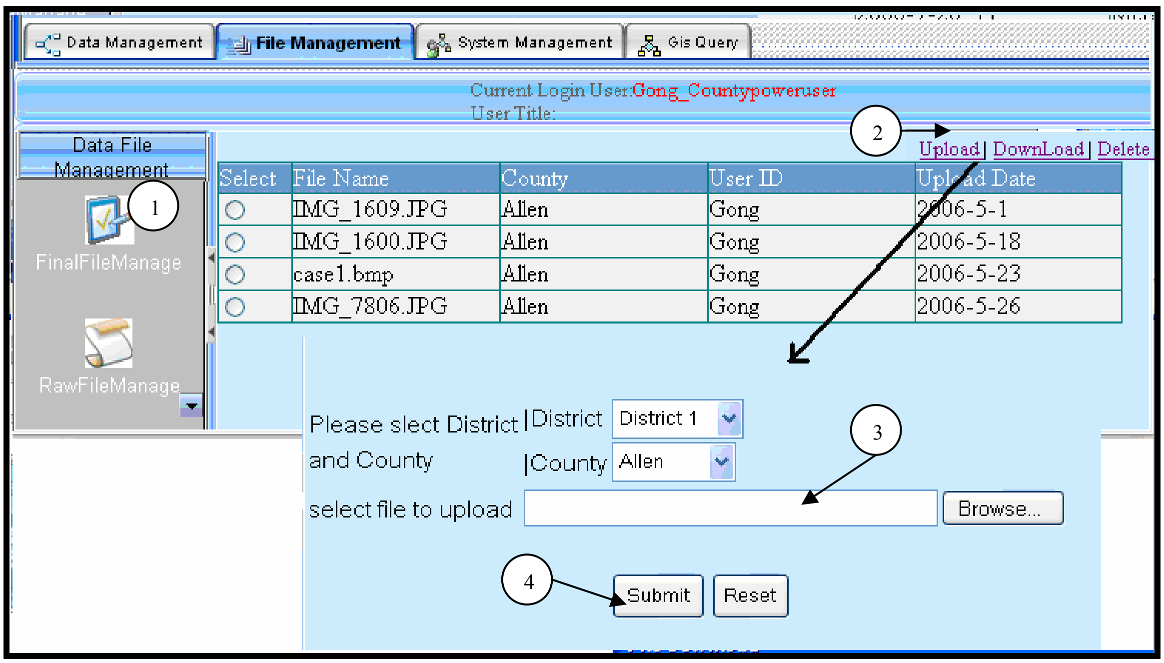


Figure 5.23 FinalFileManage

Downloading files from *FinalFileManage*

1. Select *FinalFileManage* as shown in Figure 5.24. A list of information that has been previously uploaded into the system appears.
2. Choose a file to be downloaded.
3. Click on *download.* A download dialog box appears.

4. Click on *Open* button to open the file from its current location or click *Save* button to download the file into the user's local computer.

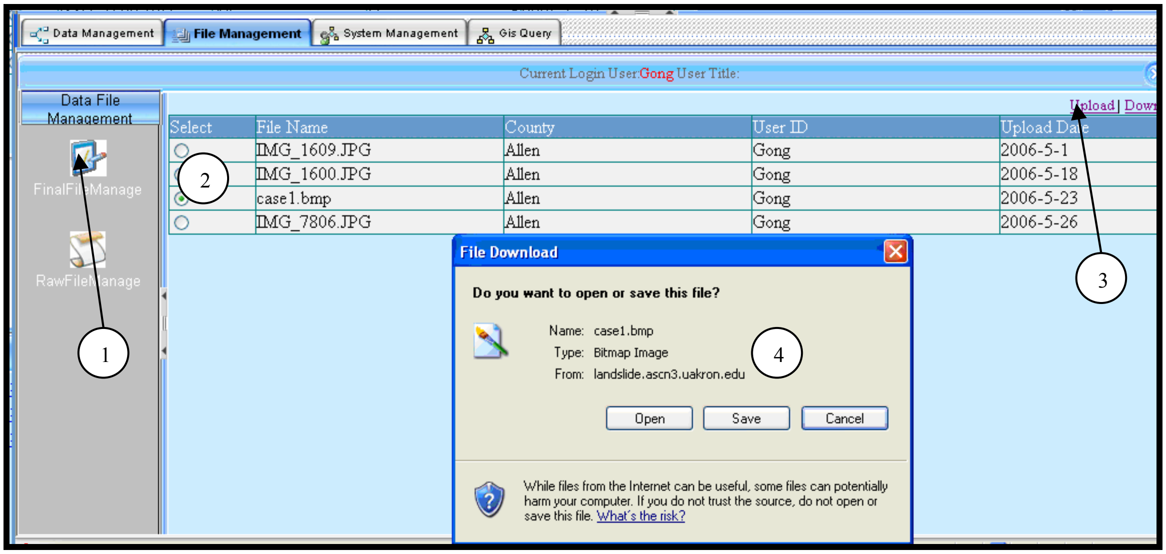


Figure 5.24 File download in FinalFileManage

<u>Deleting files in *FinalFileManage*</u>

An unwanted file in *FinalFileManage* can be deleted from the database.

1. Refer to Figure 5.23, select a file to be deleted.
2. Click on "Delete". The unwanted file is deleted from the database.

5.6 System Management

System Management provides controls for four features: *user management, resource management, page management,* and *regional management.*

5.6.1 User Management

User Management provides an authorized user to control the registered users. When a user clicks on *User Management* bar, it reveals *UserManage* and *GroupManage icons.* Users in the landslide database are categorized into the following groups.

(i) Normal users

(ii) County power users (CM/TM)

(iii) District power users (DGE)

(iv) State power users

(v) System power users

(vi) Administrators

(vii) Supervisors.

5.6.1.1 User Manage

An authorized user can use *UserManage* to register a new user. Also, he/she can edit and delete a user. The processes to add, edit, and delete a user are as follows:

<u>Adding a new user</u>

1. Click on *System Manag*ement as shown in Figure 5.25.
2. Click on *UseManage* under *User Management.*

3. Click the *add* button at the lower right corner. A new screen pops up as shown in Figure 5.26.

4. Fill up the information and then click on the *Submit* button. The information of a new user is stored in the system. Subsequently, the new user can access to the system under his UserID and password.

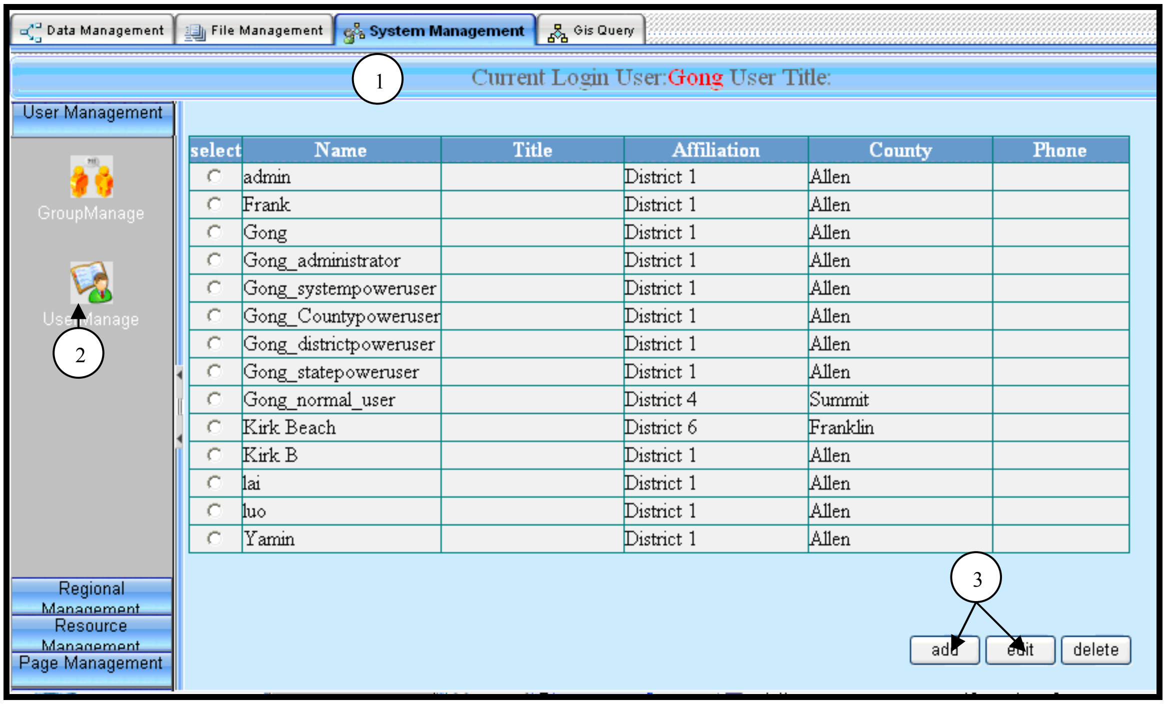


Figure 5.25 User Management

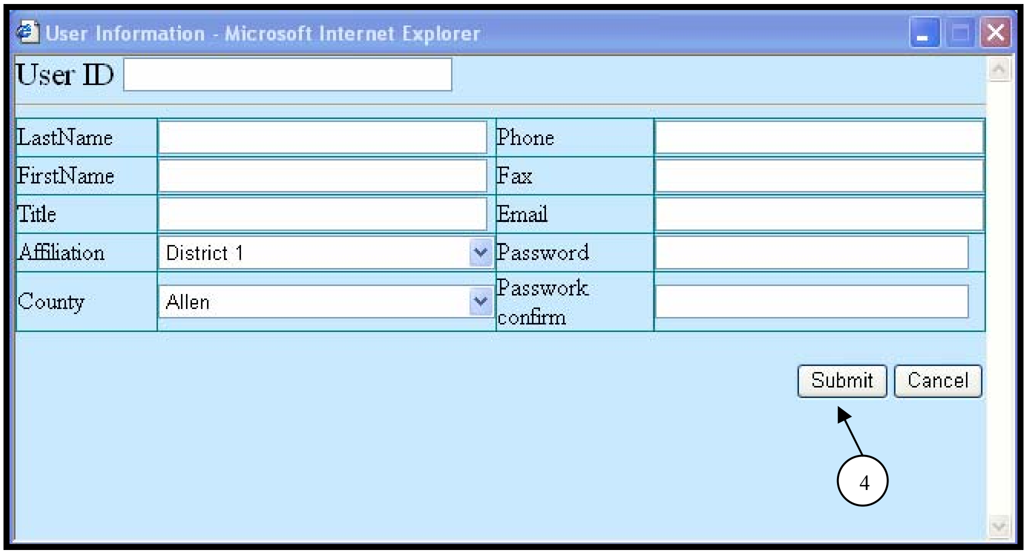


Figure 5.26 Adding new user

Editing an exiting user

1. Click on *System Management* as seen in Figure 5.25.
2. Click on *UserManage* icon under *User Management* bar.
3. Click the *edit* button at the lower right corner. A new screen pops up as shown in Figure 5.26 with the user's information stored in the system.
4. Modify the required information fields and then click on the *Submit* button. The user's new information is stored in the system.

Deleting an existing user (see Figure 5.27)

1. Select a user name to be deleted.
2. Click *delete* at the bottom right corner of the window. The user is deleted from the system.

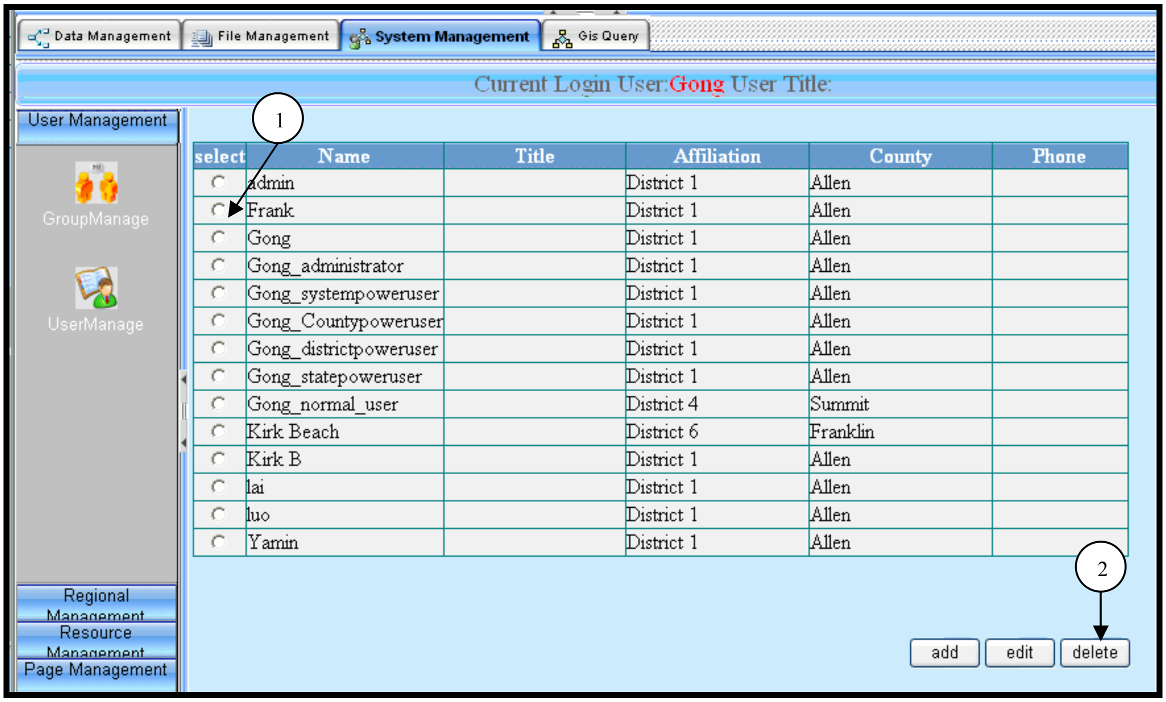


Figure 5.27 Delete a user

5.6.1.2 Group Manage

An authorized user can assign the user group for a new user using *GroupManage.* Once a new user is registered, he/she is assigned to a particular group corresponding to his/her responsibility. The system is designed to have seven groups as they are previously mentioned. In case that the system needs a new user group, the process to add the new user group is as follows.

Adding a new group of users and assign a user to a user group

1. Click on *System Management.* (see Figure 5.28)
2. Click on *GroupManage*.
3. Click on the *add* button at the lower right corner of the window. A new window shows up as seen in Figure 5.28.

4. Fill up the information and click on the *Submit* button to save the information.

5. An authorized user can assign a new user to the desired user group. Click on the *Add Users* button at the lower left corner of Figure 5.29, a new window as in Figure 5.30 appears.

6. The users that have not yet been assigned to a user group are shown in the left box. Select a user name and then tap the “>>”. The selected user is then assigned to the selected user group.

7. Press the *Submit* button to save the selection.

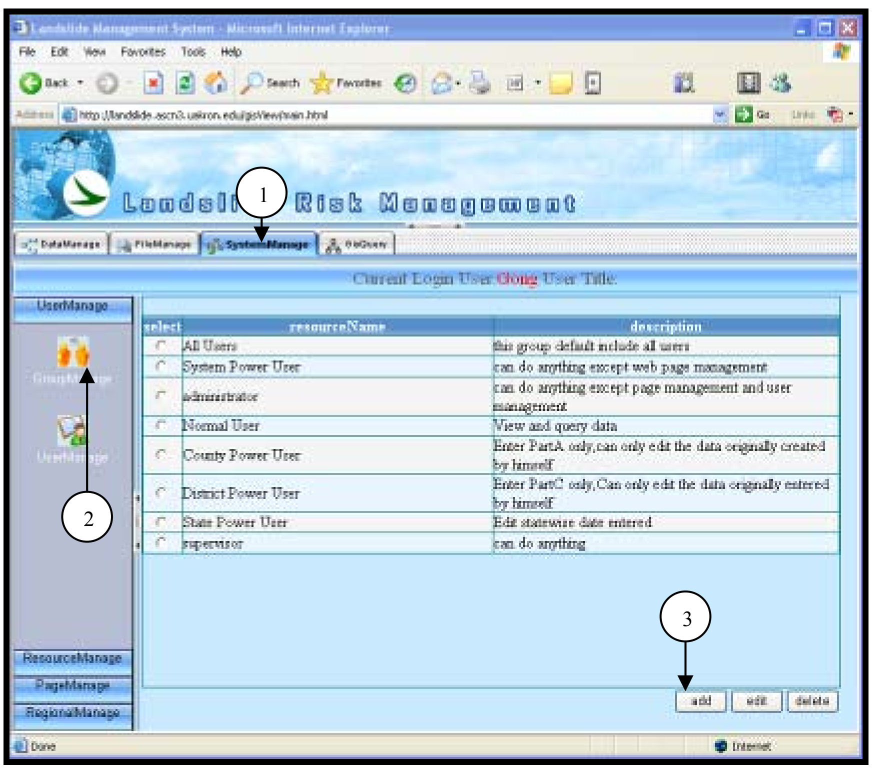


Figure 5.28 Adding user group

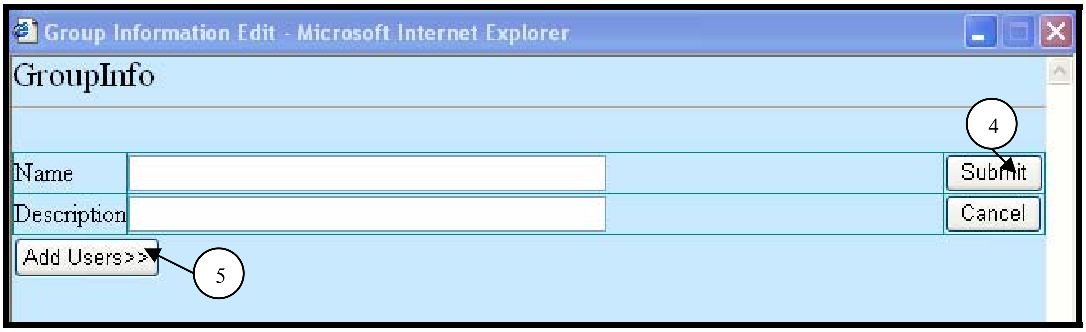


Figure 5.29 Adding a new group of user

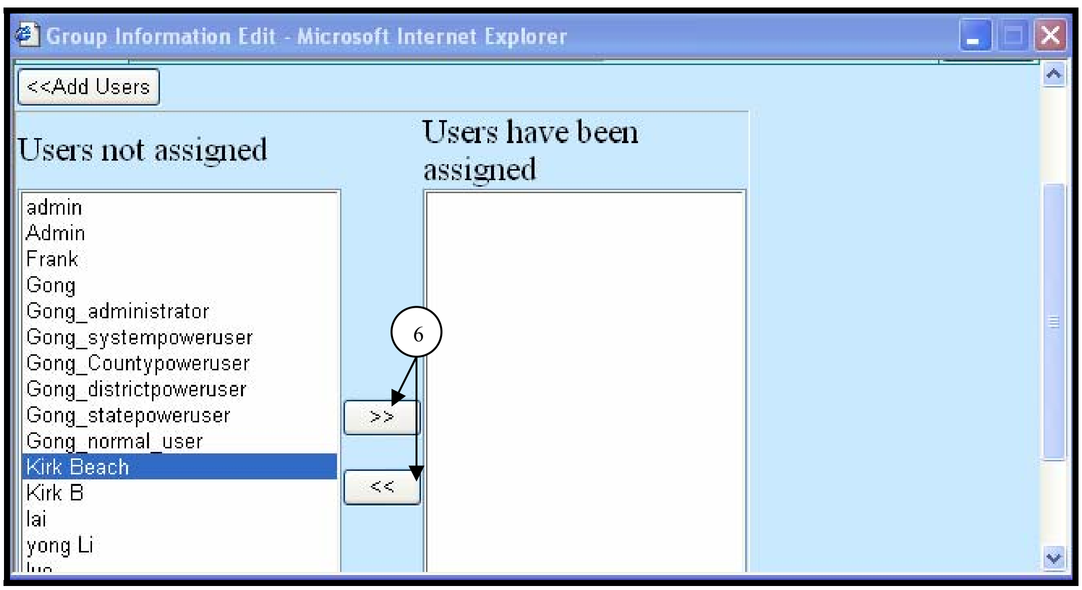


Figure 5.30 Assigning new user to a user group

<u>Editing an existing group</u>

1. Click on *System Management* in Figure 5.31.
2. Click on *GroupManage*.
3. Make a selection on a user group needs to be edited.
4. Click on the "edit" button at the right corner. A window pops up as seen in Figure 5.32.

5. Modify the existing information and then click on the *Submit* button to save and send the information to the system.
6. The authorized user can also add a user to the group using the same procedure as discussed in the "adding a new group of user" section.

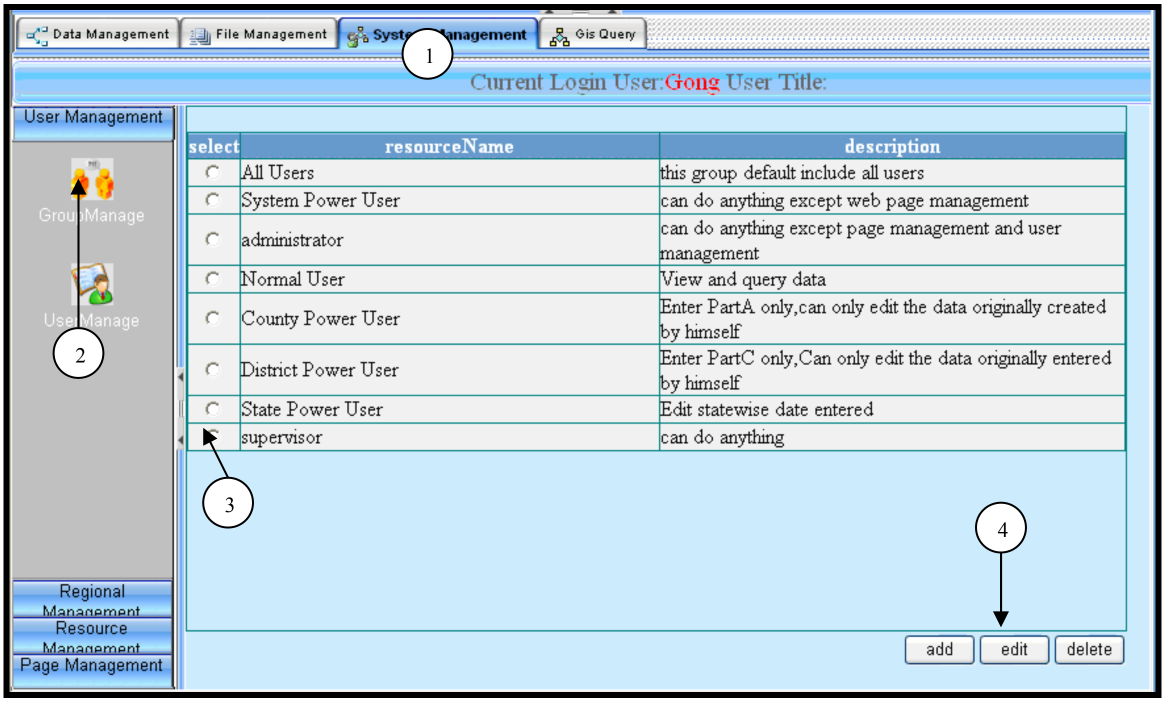


Figure 5. 31 Edit a user group

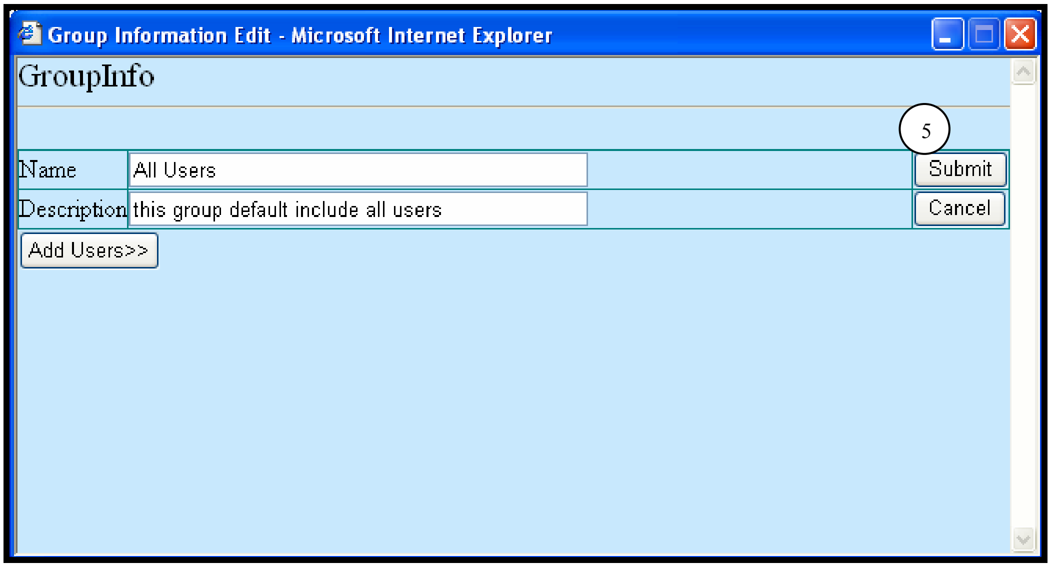


Figure 5.32 Group information editing

5.6.2 Resource Management

Under the *Resource Management*, the features of *PermissionManage* and *ResourceManage* are provided.

5.6.2.1 Permission Manage

When an authorized user clicks on the *PermissionManage* icon under the *Resource Management* bar, the two tabs including *PageURLManage* and *PageManage* are revealed. *PageURLManage* is used to assign a privilege to a group of users to modify the database webpage, such as add, edit, delete, etc. *PageManage* is used to assign a user group to view the items on the webpage. The item added through *ItemManage* (Section 5.6.3.3) is listed in *PageManage*. The new item added is assigned to a user group who has privilege to view it. If the privilege set up is not done properly, no one can view the item even if it has been added to the Bar or Tab. The user has to log off after privileges are added or deleted by clicking the *logoff* button on the top right corner as seen in Figure 5.33.

Figure 5.33 Logoff

<u>Authorizing groups of users to PageURLManage</u>

1. Click on *SystemManage* as seen in Figure 5.34.
2. Click on *ResourceManage*.
3. Click on *PermissionManage*.
4. Click on *PageURLManage*.
5. Select an item that you would like to give privilege to the new group of users. By clicking on the item, it would display the user groups that have been previously assigned the privilege to manage this item.
6. Click on the *add* button at the lower right corner. It reveals a permission window as shown in Figure 5.35.
7. Click on the *select* button, the list of different types of user groups shows up (Figure 5.36).
8. Select a user group, then click on the ">>" button.
9. By checking an appropriate item in the *action* row in the table in Figure 5.35, a user group is assigned to perform adding, editing, and deleting tasks.
10. At this stage, a user can save the selection.

11. The privilege of a user can be edited and deleted by checking or unchecking the appropriate box next to in the *action* row in Figure 5.35.

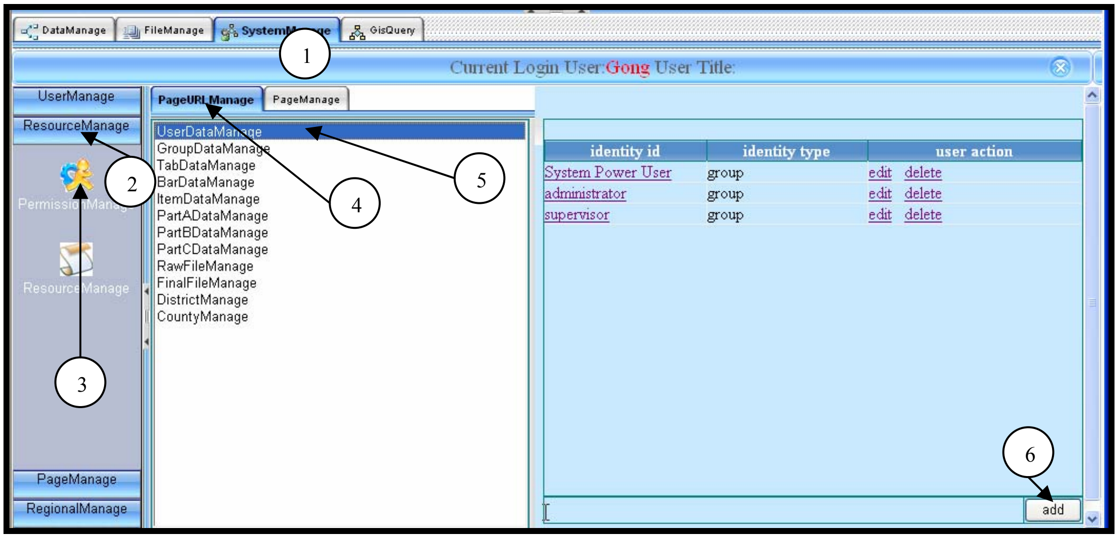


Figure 5.34 ResourceManage

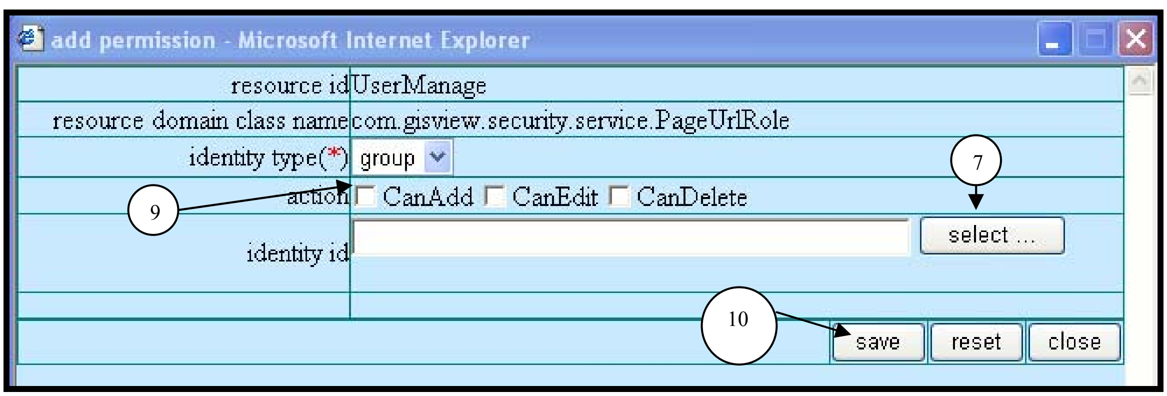


Figure 5.35 Adding permission

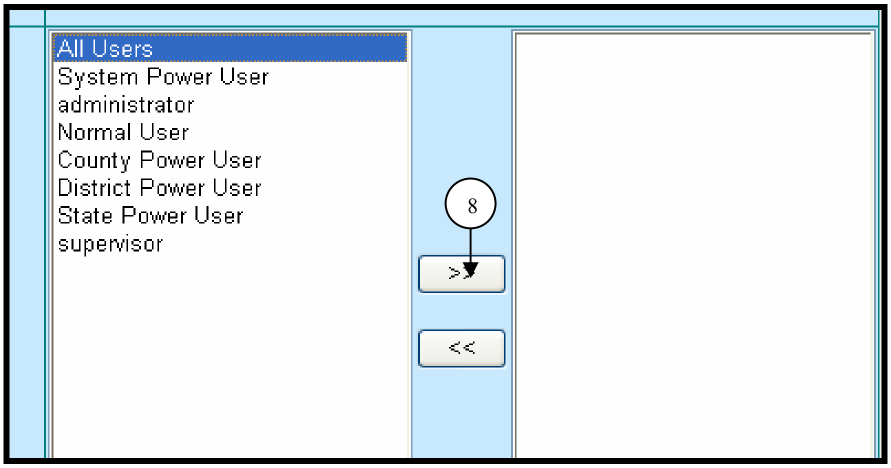


Figure 5.36 List of types of users in adding permission

<u>Authorizing a group of users to *PageManage*</u>

1. Click on *SystemManage* as seen in Figure 5.37.
2. Click on *ResourceManage.*
3. Click on *PermissionManage*.
4. Select *PageManage*.
5. Choose an item to be added in the user privilege.
6. Click on the *add* button. An add permission window is revealed as shown in Figure 5.38.
7. Click on the *Select* button. It reveals a list of user groups to be selected.
8. Authorized users can give other user groups the permission by highlighting the group, then click on the ">>" button.(Figure 5.38)
9. The privilege of a user group can also be assigned by checking mark on the *action* row. This allows an authorized group to add, edit, and delete the information.

10. Save the selection.

11. The privilege of a group can be edited or deleted by clicking on *edit* or *delete* (Figure 5.37).

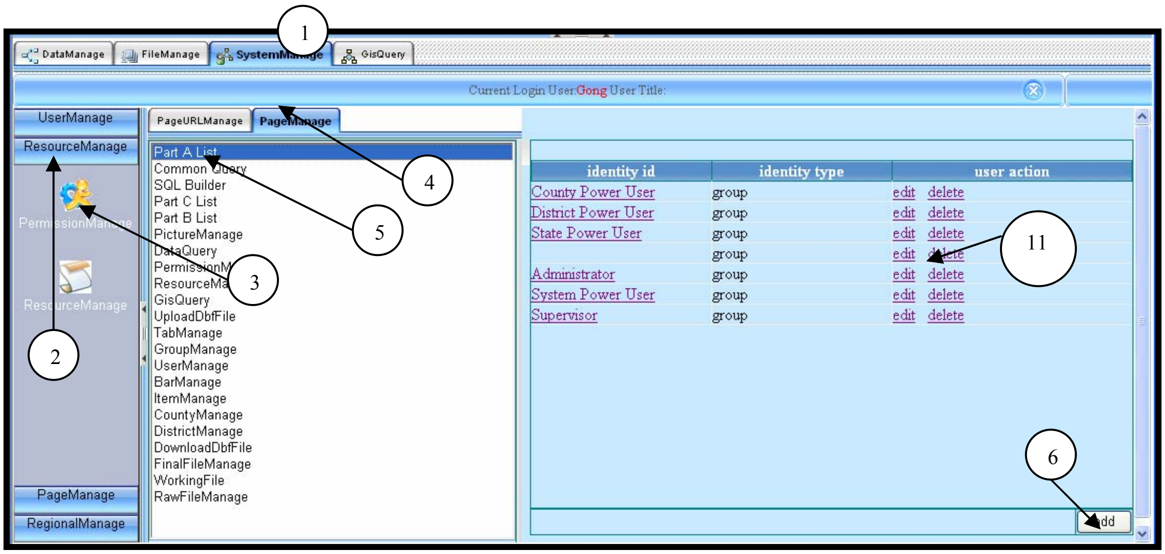


Figure 5.37 List of types of users in adding permission

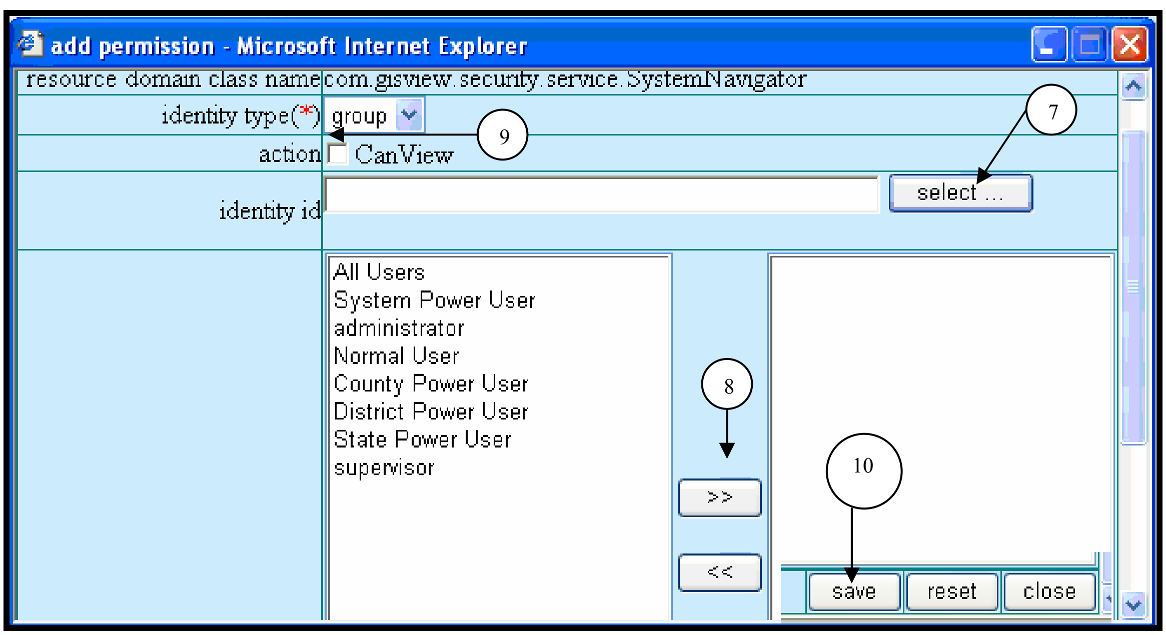


Figure 5.38 Assign some groups who have the rights to view this page

5.6.2.2 Resource Manage

The resource management is restricted only for internal users.

5.6.3 Page Management

Page Management controls the configuration of the database on the webpage including: *TabManage*, *BarManage*, and *ItemManage*. With *Page Management*, an authorized user can configure the web page layout. Within a tab, it can have several bars. Within a bar, it can have several items. Items are directly linked to URL so that when an item is clicked, the Internet Explorer will navigate to the URL that is associated with these items. Items, bars and tabs must be added at the first time that the web page is configured. The authorized user can add additional features (items, bars, and tabs see Figure 5.39) to the system for future use.

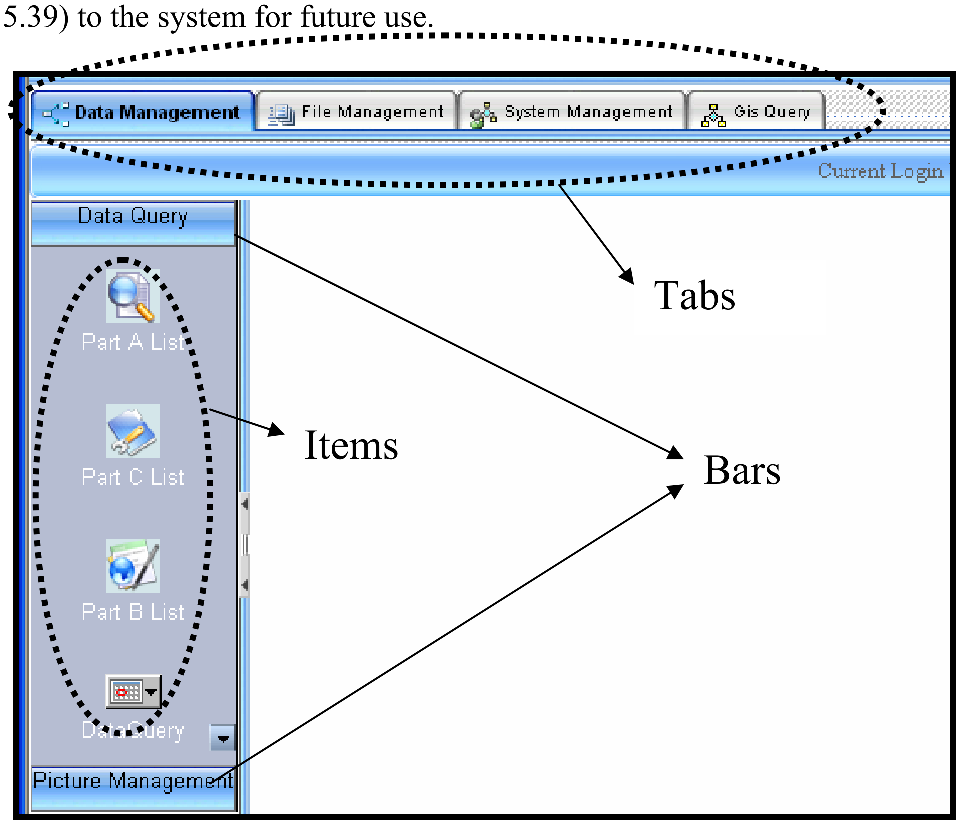


Figure 5.39 Tabs, bars, and items

5.6.3.1 Tab Manage

TabManage controls number of tabs on the webpage. Within a tab, there are several bars. An authorized user is permitted to add, edit and delete tabs in the system. For example, there are 4 tabs that have been created by *TabManage* so far, which are *Data Management*, *File Management*, *System Management*, and *GIS Query*.

<u>Adding a tab</u>

1. Click on *System Management* in Figure 5.40.
2. Click on *TabManage*.
3. Click on the *add* button at the lower right corner of the window. The *Tab Edit* window would appear as shown in Figure 5.41.
4. Fill up the information and then click on the *Submit* button to save the information.

<u>Adding a bar in a tab</u>

5. Click on *Add Bars* in Figure 5.41.
6. Highlight a bar to be added to the tab and then click on “>>” to add the bar to the tab.
7. Click on the *Submit* button.

Editing a tab

8. Make a selection on a tab to be edited in Figure 5.40.

9. Click on the *edit* button. A window as same as Figure 5.41 reveals. This window contains the information of the tab to be edited. Click *Submit* button when finishing editing.

Deleting a tab

10. To delete a tab from the webpage, a user selects a tab to be deleted and then click on the *delete* button. The tab is deleted from the system.

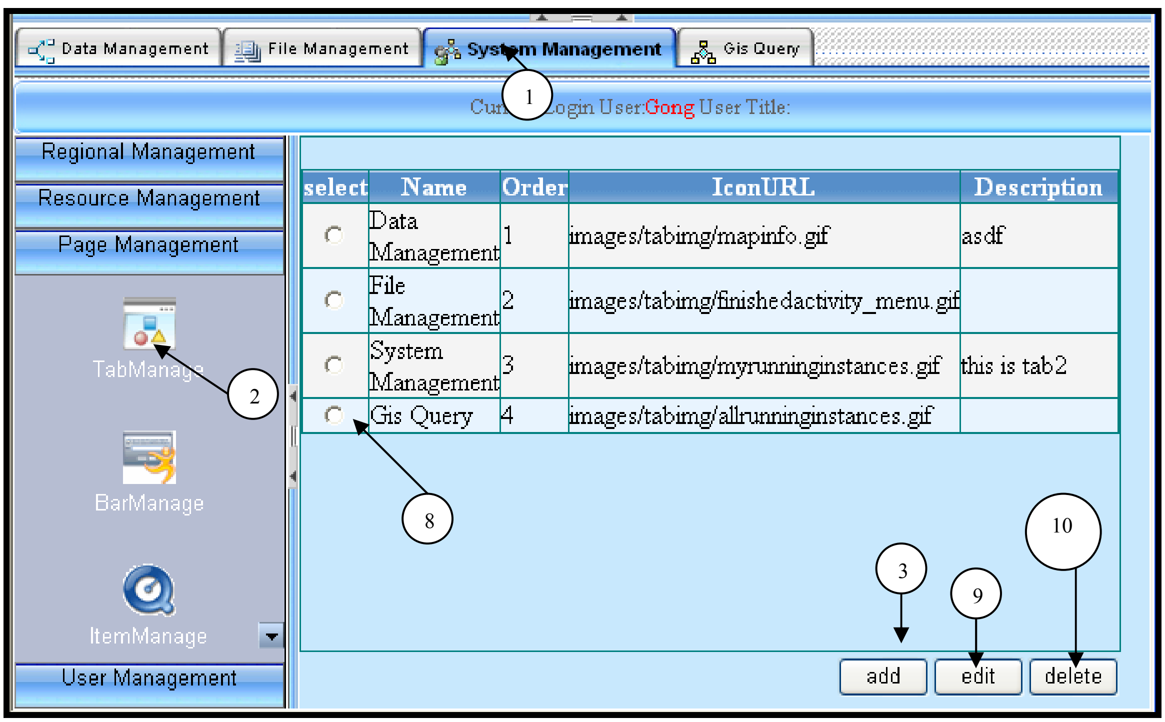


Figure 5.40 TabManage

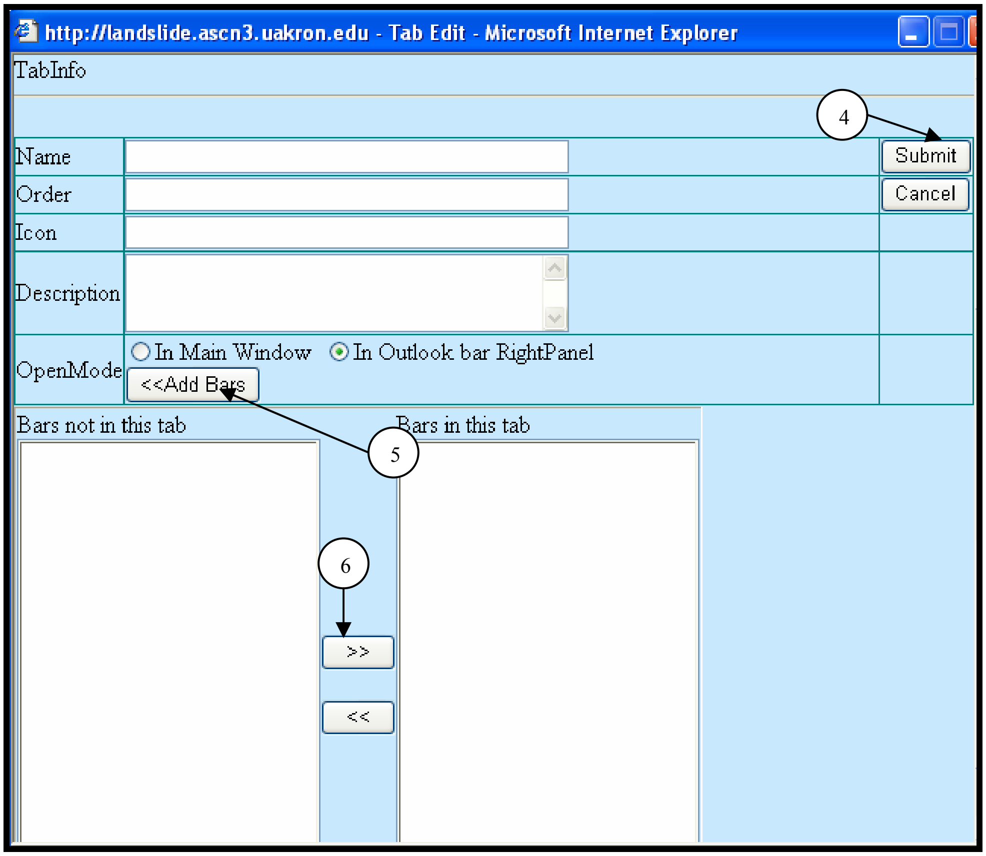


Figure 5.41 Adding Tab bars

5.6.3.2 Bar Manage

BarManage allows a user to control the number of bars on a webpage. The process to manage bars in the system is as follows:

Adding a bar

1. Click on *System Management* as shown in Figure 5.42.
2. Click on *PageManage.*
3. Click on *BarManage.*
4. Click on the *add* button at the lower left corner. It reveals a new window as shown in Figure 5.43.

5. Fill up all information and then click on *Submit* to store the bar.

Adding an item to a bar

6. The user can add items to a bar by clicking on the *Add Items* button.
7. Highlighting an item and then clicking on “>>” allows the user to add an item into a bar. In contrast, highlighting an item and then clicking on “<<” would remove the item from that bar.

Editing a bar

8. Select a bar to be edited.
9. Click on the *edit* button at the lower right corner of Figure 5.42. A window that is as same as Figure 5.43 appears. This window contains the information of the bar to be edited. Click on *Submit* button when the user finishes editing.

Deleting a bar

10. To delete a bar, a user selects a bar to be deleted and then clicks on the “delete” button. The bar would be deleted from the system.

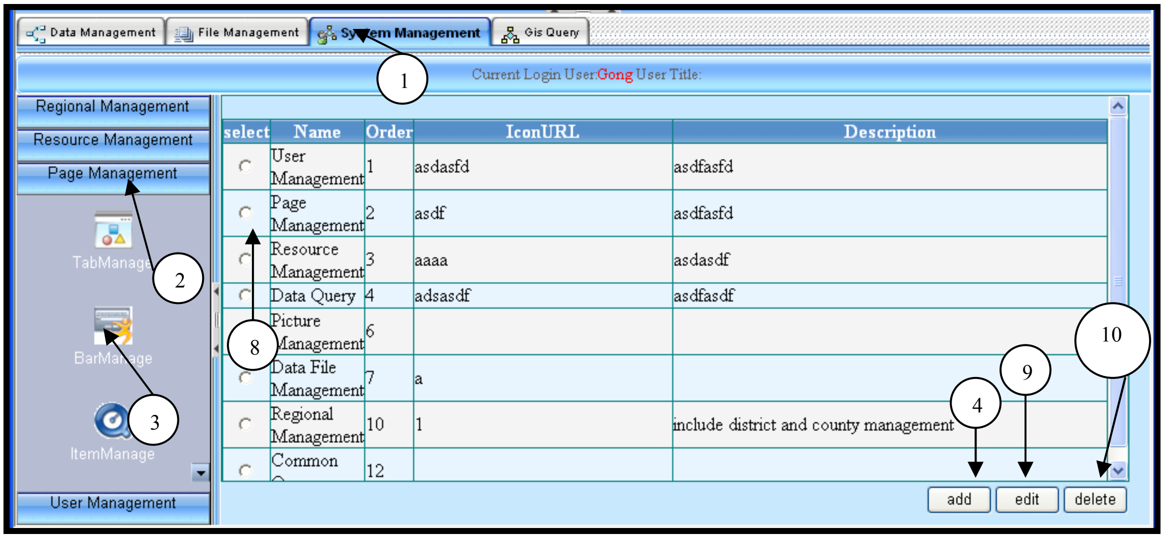


Figure 5.42 BarManage

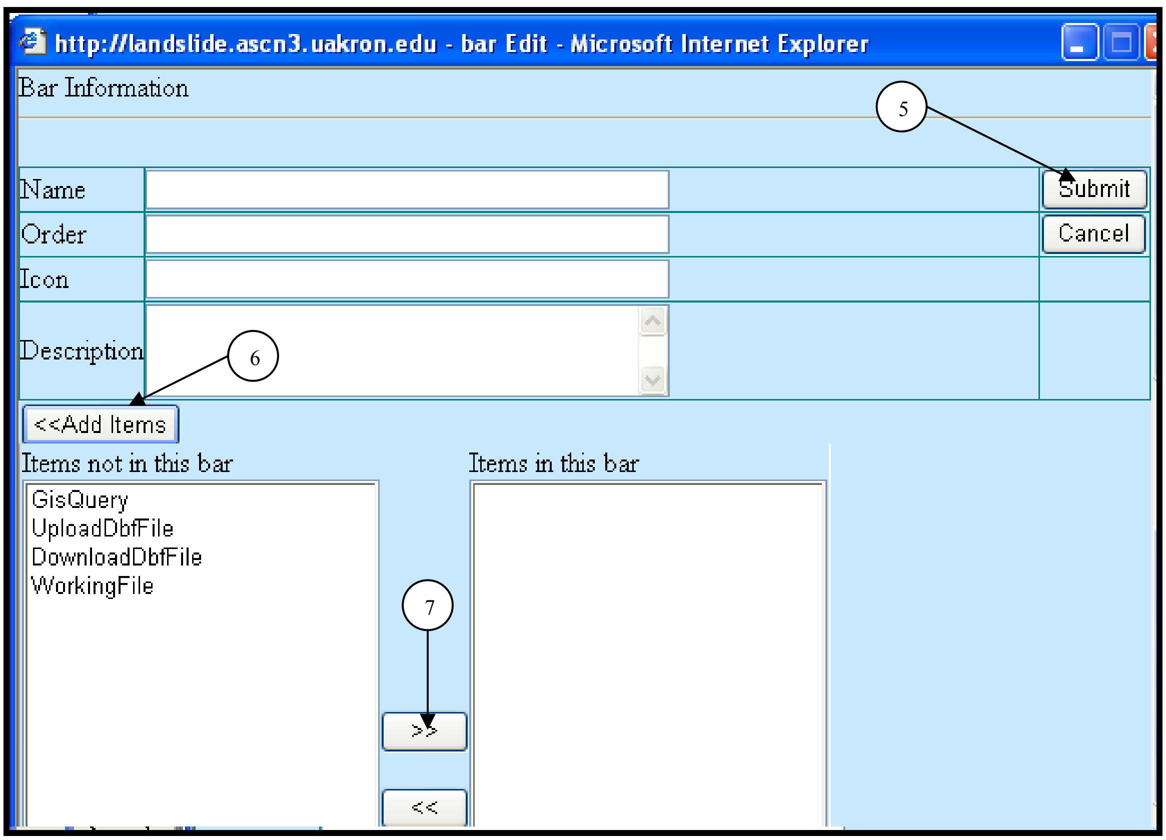


Figure 5.43 Bar Edit

5.6.3.3 Item Manage

Items are the smallest components in the *Page Management*. The *ItemManage* is used to manage items in the system by allowing an authorized user to add, edit and delete items.

Adding an item

1. Click on *SystemManage.*
2. Click on *PageManage.*
3. Click on *ItemManage.* It would show items that have been added into the system as shown in Figure 5.44.
4. Click on the *add* button at the lower right corner of the window. It would reveal a *CreateItem* window as shown in Figure 5.45.
5. Fill up the information and then click on the *Submit* button. The information is stored in database.

Editing an item

6. Select an item to be edited.
7. Click on the *edit* button. A window that is as the same as Figure 5.44 with the item information appears. Modify the information and then click on *Submit* to save editing.

Deleting an item

8. To delete an item, select an item wanted to be deleted and then click on the "delete" button. The unwanted item would be deleted from the system.

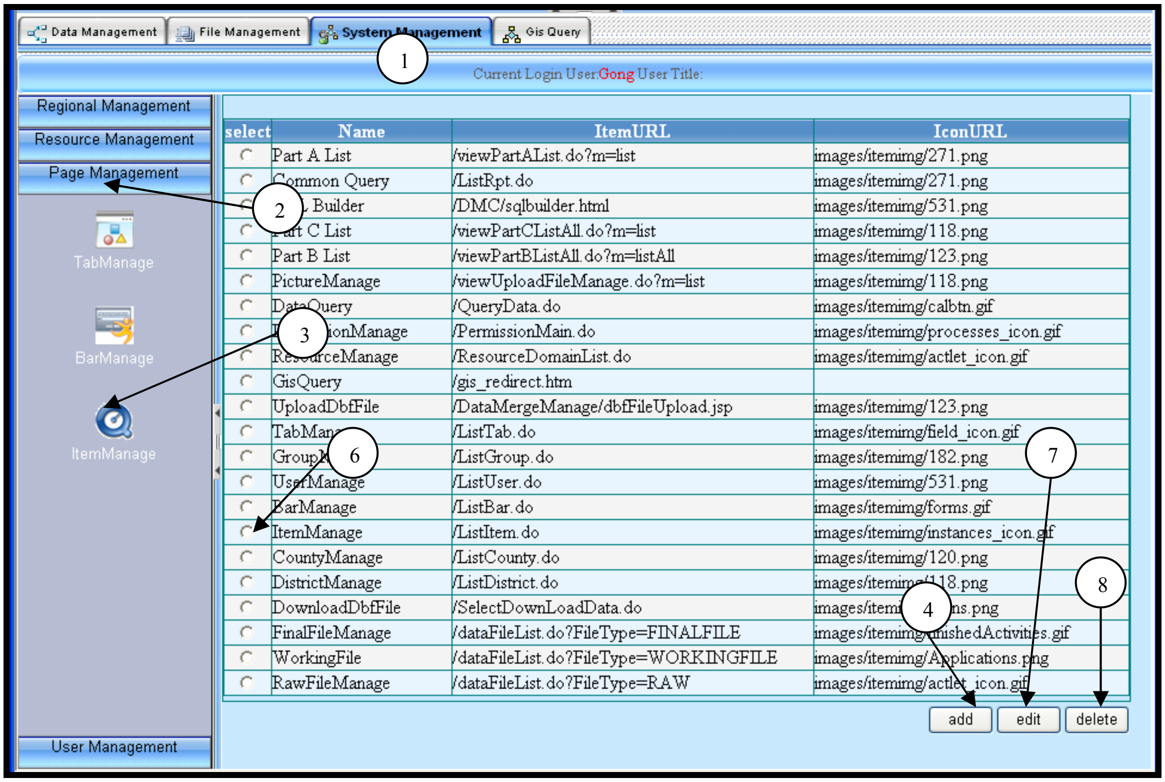


Figure 5.44 ItemManage

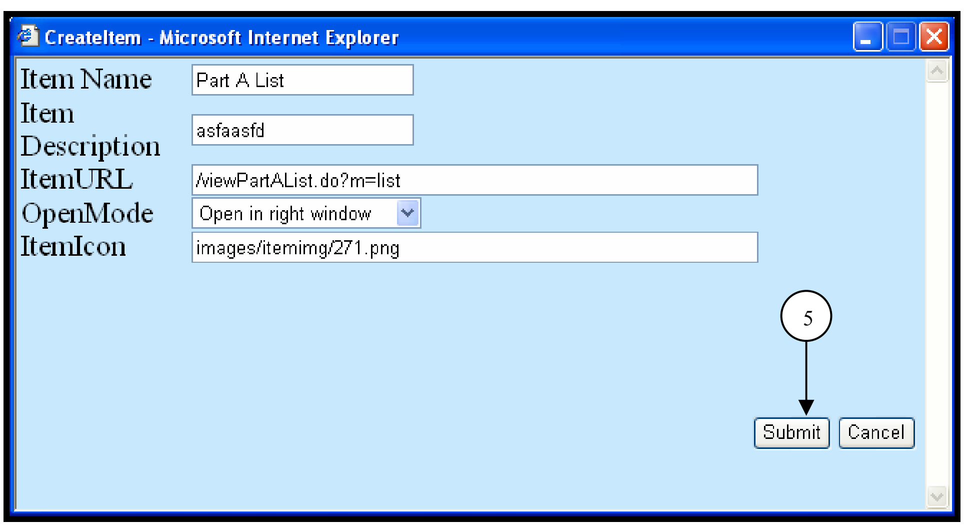


Figure 5.45 Create item window

5.6.4 Regional Management

Regional Management contains two management features, including *CountyManage* and *DistrictManage*. A user can manage county and district information in the system.

5.6.4.1 District Manage

<u>Adding a district</u>

1. Click on *SystemManage* in Figure 5.46.
2. Click on *RegionalManage.*
3. Click on *DistrictManage.*
4. Click on the add button at the lower right corner of the window. A district information window appears as shown in Figure 5.47.
5. Fill up the district information and then click on the *Submit* button to save the information.

<u>Editing a district</u>

6. Editing the district information can be made by first selecting the district to be modified.
7. Click on the *edit* button in Figure 5.46. A window as seen in Figure 5.47 appears. Modify the information as needed. Click on the *Submit* button to save the modified information.

Deleting a district

8. Select the district to be deleted. Click on the *delete* button at the lower right corner of Figure 5.46. The district is deleted from the system.

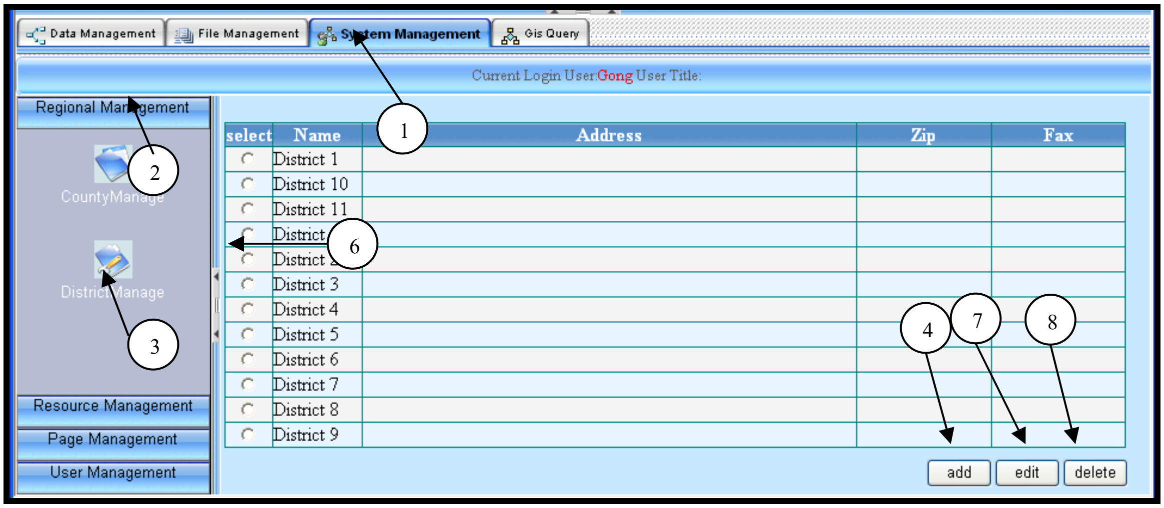


Figure 5.46 DistrictManage

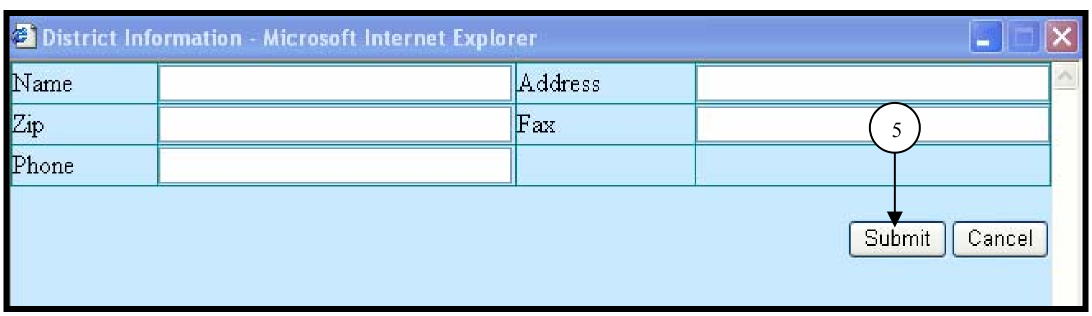


Figure 5.47 Adding and editing district

5.6.4.2 County Manage

A user can input county information in the system. However, before adding the county information in the system, district information is needed so that a county can be related to a district. The user can also edit and delete the county information stored in the system.

Adding a county

1. Click on *SystemManage* as seen in Figure 5.48.
2. Click on *RegionalManage.*
3. Click on *CountyManage.* It reveals a list of the counties that has been added into the system.
4. Click on the *add* button on the lower right corner of the window. A county information window appears as seen in Figure 5.49.
5. Relate the county to the correspondent district by selecting the district name from the dropdown list as shown in Figure 5.49.
6. Click on the *Submit* button to save the county information.

Editing a county

7. First select the county to be edited.
8. Click on the *edit* button in Figure 5.48. Edit the information and then click on the *Submi*t button. The information is saved.

Deleting a county

9. A user can delete a county. Select the district to be deleted and then click on the *delete* button. The district is deleted from the system.

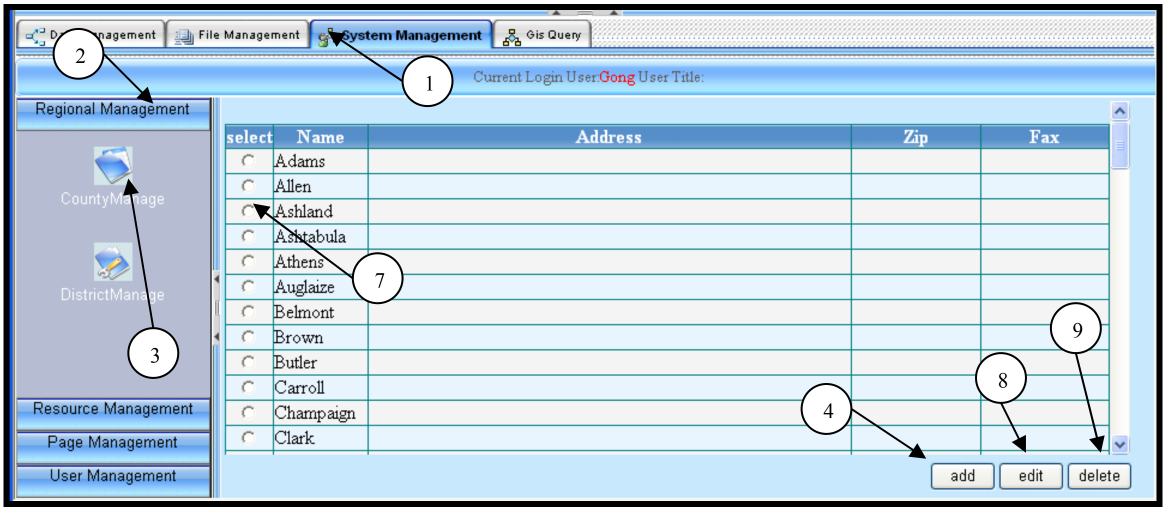


Figure 5.48 County Manage

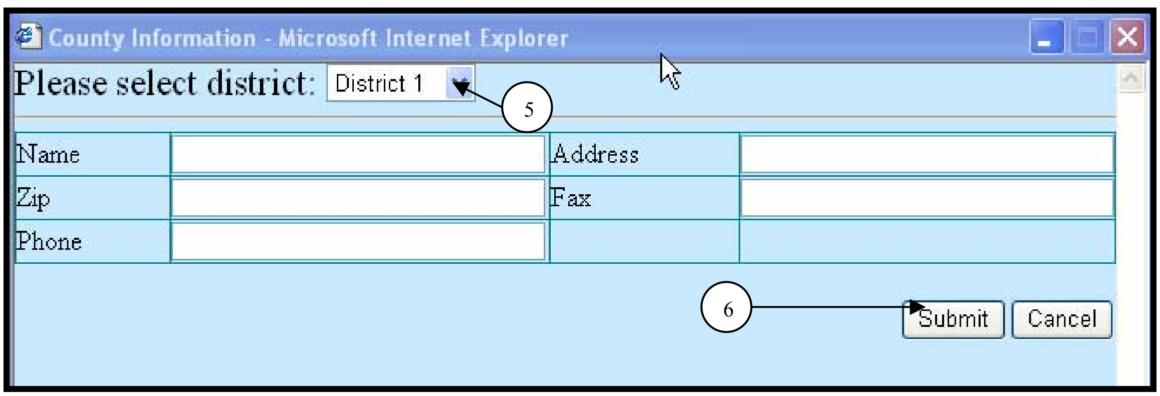


Figure 5.49 adding and editing county information

5.7 GIS Query

A GIS map with landslide locations can be viewed by clicking on the *Gis Query* tab, as shown in Figure 5.50. The query features of the *GIS Query* are listed on the left column.

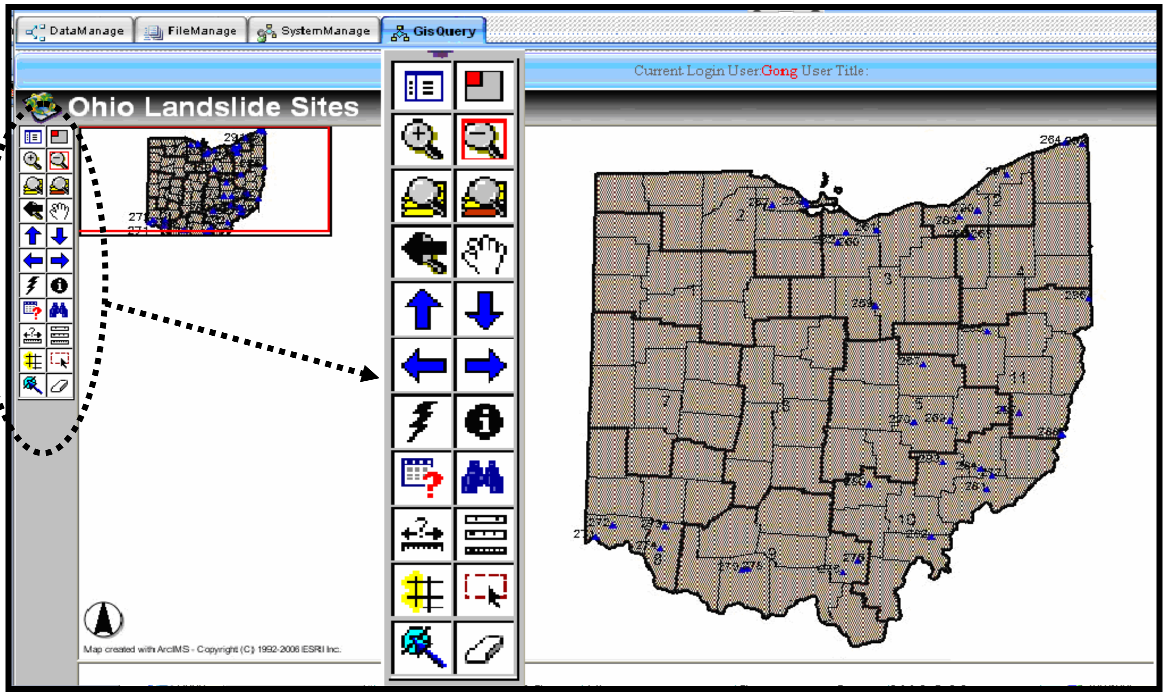
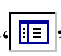
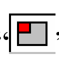


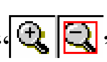
Figure 5.50 GisQuery

5.7.1 GIS Query Features

Search functions of the *GIS Query* are explained as follows.

1. The "" is used for a toggle between a list of legends and a list of map layers.

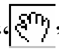
2. The "" is for a toggle of a small overview map at the left upper corner of the GIS map.

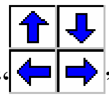
3. The magnify glass "" icons are for zooming in and out, respectively. To zoom in and out, click on the icon, and drag the pointer over the GIS map.

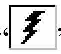
4. The icons of "" is used for zooming to the fully extend.

5. The "" icon is for zooming to the active map layers.

6. Clicking on the "" will go back to the last extent.

7. Click on the “”. A user can pan the GIS map. Move the pointer over the map area to be panned, hold the left mouse button and then drag the pointer to the location as needed.

8. The “” are used for map panning to left, right, up and down.

9. Tap on the hyperlink “” button and then select the dot on the map (landslide site). It pops up the landslide information as seen Figure 5.51. Click on 1, 2, or 3 would reveal the information in Part A, B, or C, respectively.

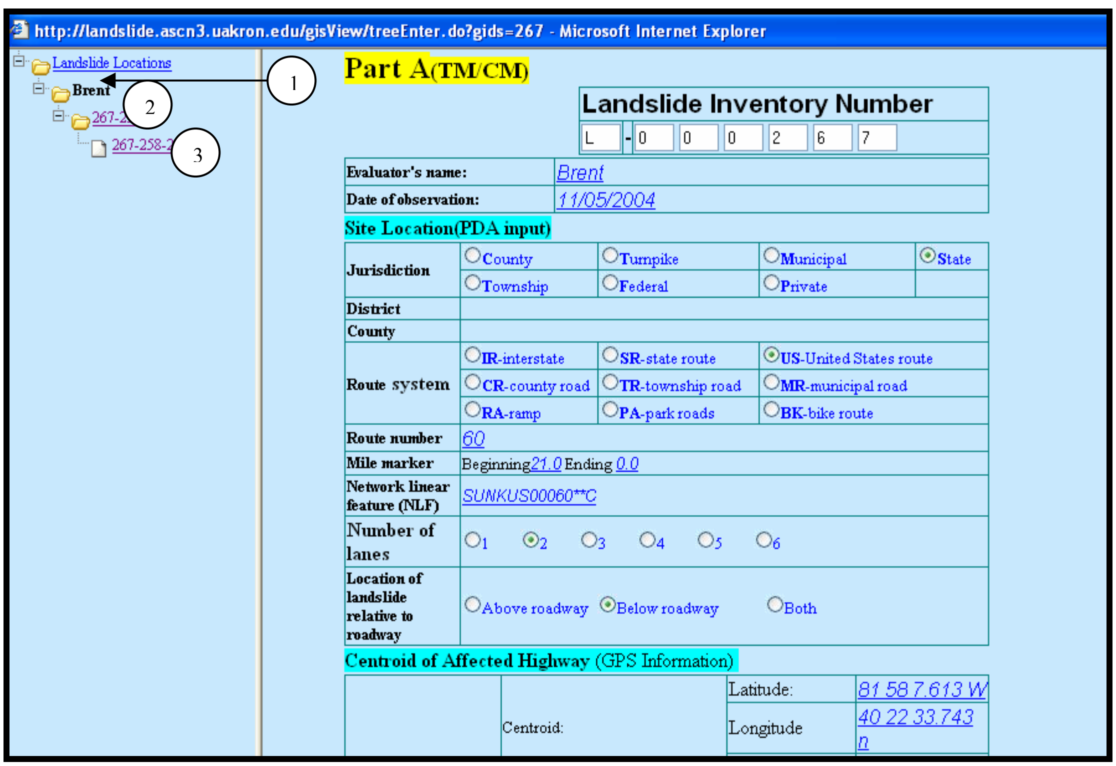
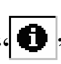


Figure 5.51 Hyperlink features

10. The identification button “” is used to identify the landslide information on the landslide map. Simply click on the *identification* icon, move cursor onto a site

and then click. The site information is popped up as shown in Figure 5.52. Click on “1”. The page similar to Figure 5.51 pops up. A user can explore information in part A, B, or C, respectively.

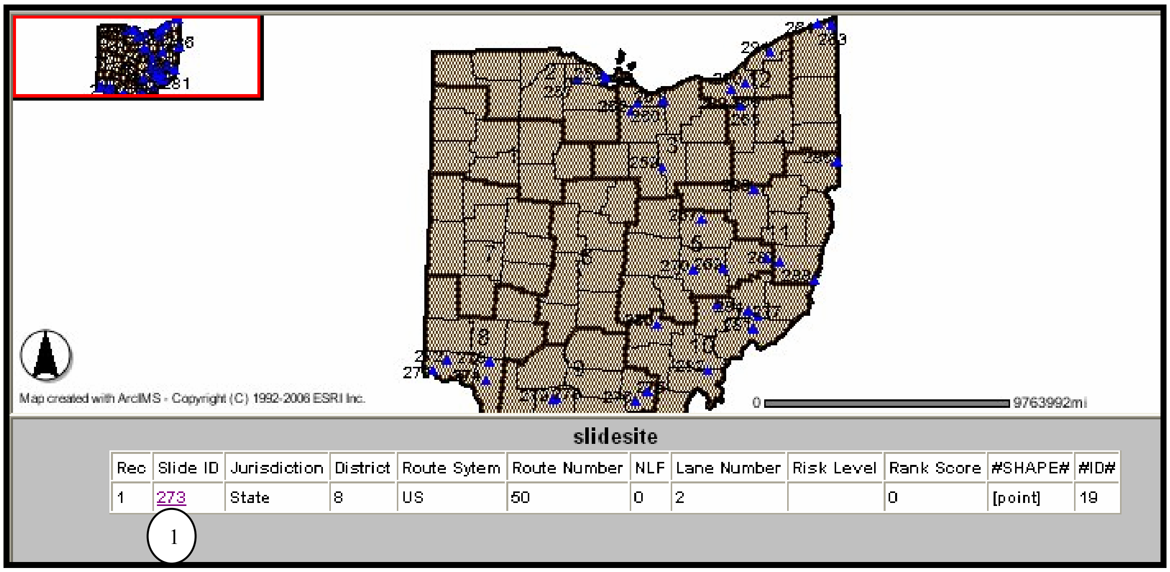
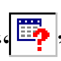


Figure 5.52 Identification feature

11. The query engine “” is used to search for specific information in a landslide site. Click on the *query* icon. The search engine appears as in Figure 5.53. The Boolean search technique (*And*, *Or*, *Not*) provides the powerful searching tools to the users.

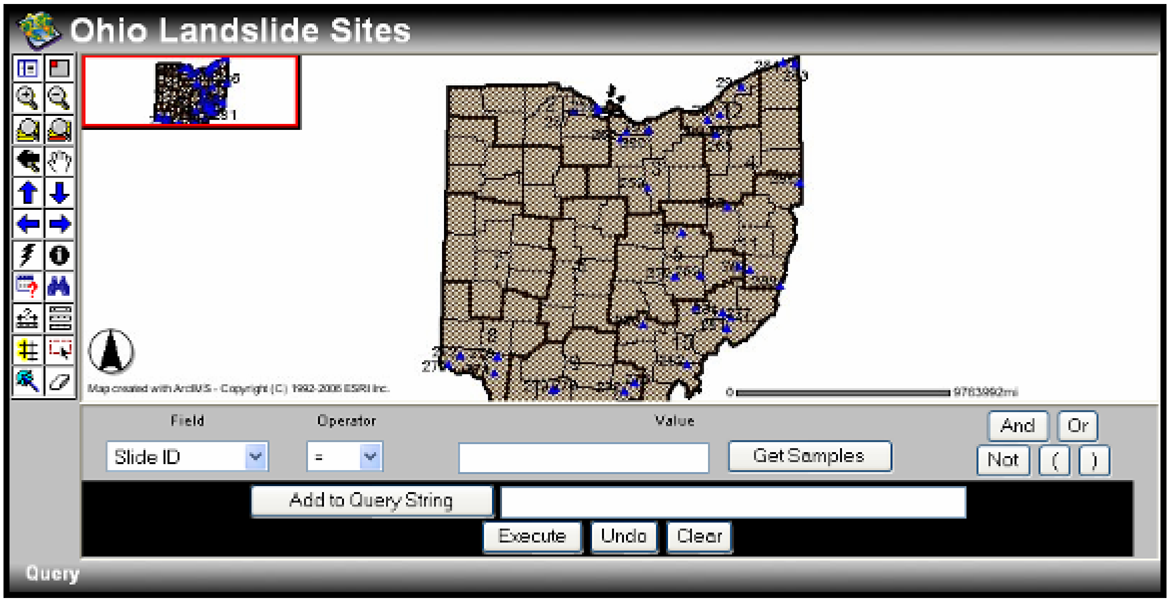
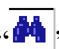


Figure 5.53 Query engine

12. The find icon "" is used as another search option. Click on the icon. It pops up a window as shown in Figure 5.54. To search, type the key words or numbers in the box (mark as 1) and then tap the *Find String* button.

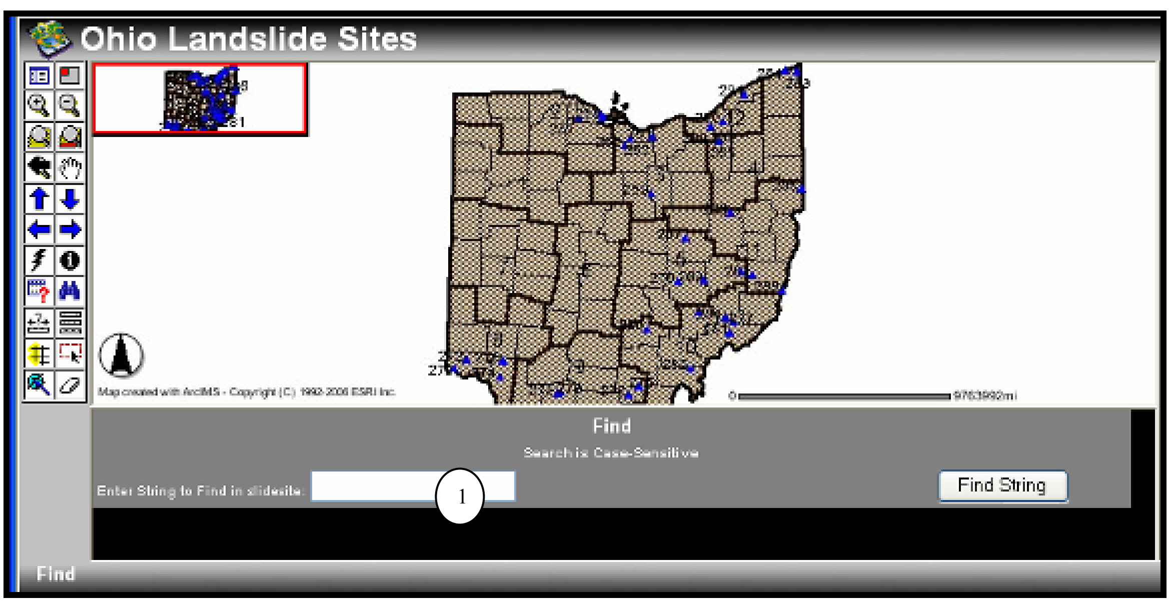
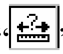
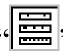
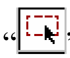
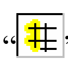


Figure 5.54 Find feature

13. A measure icon "" is used as a measuring tool to determine the distance between two or more points. It works by simply selecting the measure icon. Then click on the first and second point to be measured. The program automatically calculates the distance between the two points.

14. The measurement unit in the GIS map can be changed by using the set unit icon "". The distance measurement units are foot, mile, meter, and kilometer.

15. Multiple selections of landslide sites can be made either by *select by rectangle* or *select by Line/Polygon*. To select by rectangular, tap the "" icon. Point the cursor to a pint on map. Hold the left mouse button, and drag it over the area of interest. The landslide sites inside the rectangular are highlighted. To select by *Line/Polygon*, the user selects the "" icon. Use the cursor to connect the point over the area of interest. The landslide sites that are located in the polygon are highlighted and listed in the box under the map.

16. The landslide sites that are selected by the previous methods can be buffered. Buffers can be drawn by using a distance around the selected landslide site. To buffer the selected landslide sites, first simply select the landslide sites by the methods mentioned earlier, and then click on the "buffer" icon "". The buffer feature pops up as shown in Figure 5.55. Specify the distance around the selected sites and then click on the *Create Buffer* button. The buffer is created around the selected features.

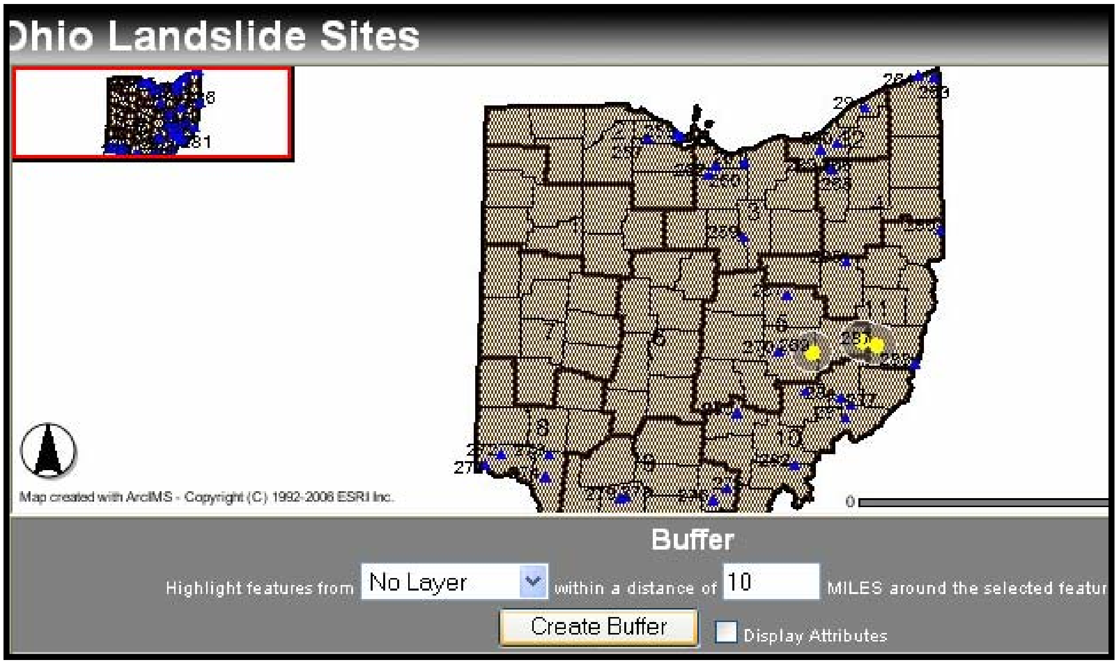


Figure 5.55 Buffer

17. The selection that has been made on the map can be cleared by using the *clear selection* "" button.

CHAPTER VI

USING ARCPAD AND WINDOW CE

FOR LANDSLIDE DATA COLLECTION

6.1 Overview

The landslide field form can be filled in electronically through the use of a GPS Handheld device or a laptop computer. This chapter provides the users with the step-by-step guides on some basic ArcPad skills that the users need to perform during the landslide data collection in the field. When finishing the data collection processes, the users can update the shapefiles in the GIS database map.

6.2 Setting the Data Path

1. Select start on the window CE, go to programs and then start ArcPad. The ArcPad will open with a blank map window as seen in Figure 6.1.
2. Select the tool button ""on the top of the main toolbar in Figure 6.1. This will open the ArcPad option dialog box.

Figure 6.1 A blank map window

3. Use the left and right arrow to find the Path tab.
4. Locate the file that contains the default map and data file for the landslide site to be visited. Select the browse to navigate through these folders. Normally, these files can be stored in the My Document folder in the window CE computers. (see Figure 6.2)
5. Then tap Ok.

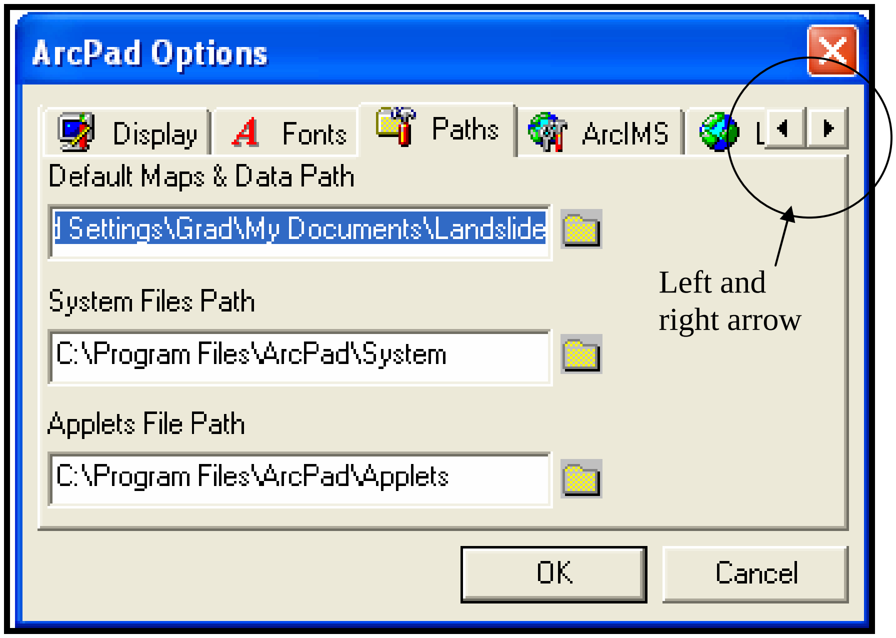
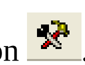


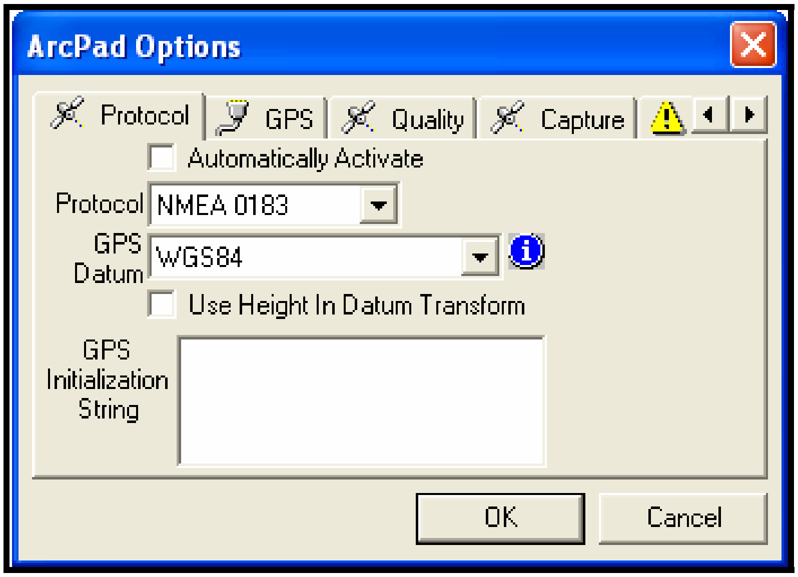
Figure 6.2 Setting the default map and data path

6.3 Setting the Communication Between ArcPad and GPS

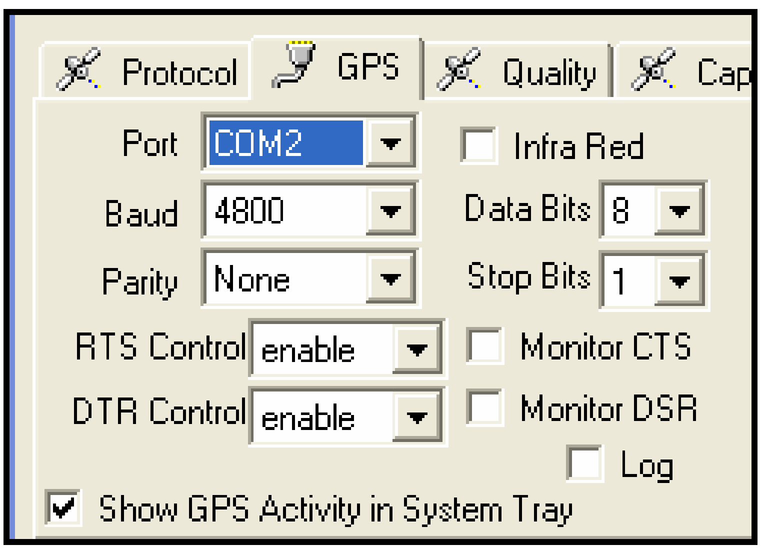
Before the user activates the GPS, he/she has to set the GPS communication parameters to match those that have been set on your GPS receiver.

1. Open the *ArcPad Options* dialog box by clicking on .
2. Locate the protocol page by using the left and right arrow as seen in Figure 6.3.
3. Click the *Protocol* dropdown arrow to find the protocol used by your GPS receiver to the output data (NMEA 0183).
4. Click the *GPS Datum* dropdown arrow to select the datum used by the GPS receiver to the output coordinates (WGS84).
5. Click the *GPS* tab on the ArcPad option dialog box to display the GPS page.

6. Select the serial port on your GPS handheld device. Set The *Port* to *COM2* for ArcPad application.
7. Set the remaining communication parameters to match the settings on your GPS receiver as shown in Figure 6.3(b).



(a)



(b)

Figure 6.3 Setting communication between the ArcPad and the GPS

6.4 Activating the GPS

There are two ways to activate the GPS.

1. A user can activate the GPS by tapping the GPS position window button “”. The message box will pop up the message “The GPS is not activated. Would you like to activate it now?” (see Figure 6.4). Selecting “Yes” will activate the GPS and open the GPS position window.

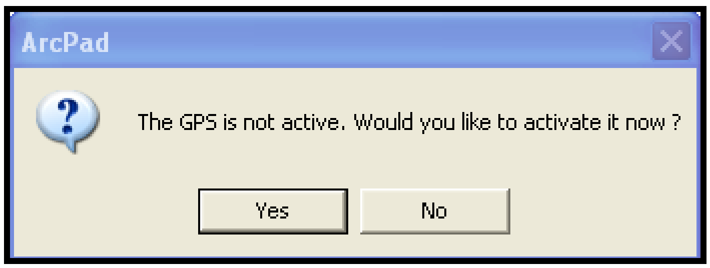


Figure 6.4 Activating the GPS (1)

2. A user can also activate the GPS by tapping the arrow next to the GPS position window. Selecting the *GPS Active* allows the GPS to activate.

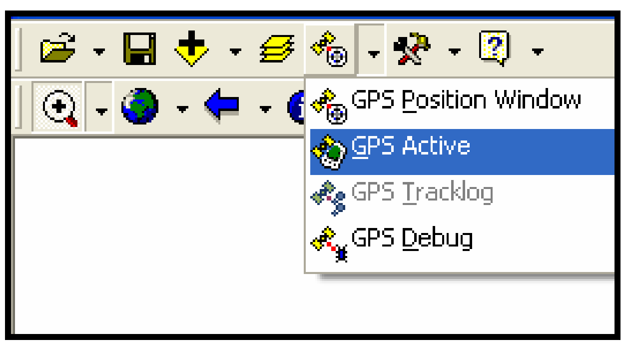


Figure 6.5 Activating the GPS (2)

6.5 Adding Layers

1. Tap the Add Layer button "" on the Main tool bar.
2. Tap the Folder button to navigate to the directory that stores the data.
3. Select the folder that contains the layer to be added on the map.
4. Tap O.K.
5. Check mark on the file you want to add.
6. Tap O.K. The selected data layer will be added to the ArcPad map.

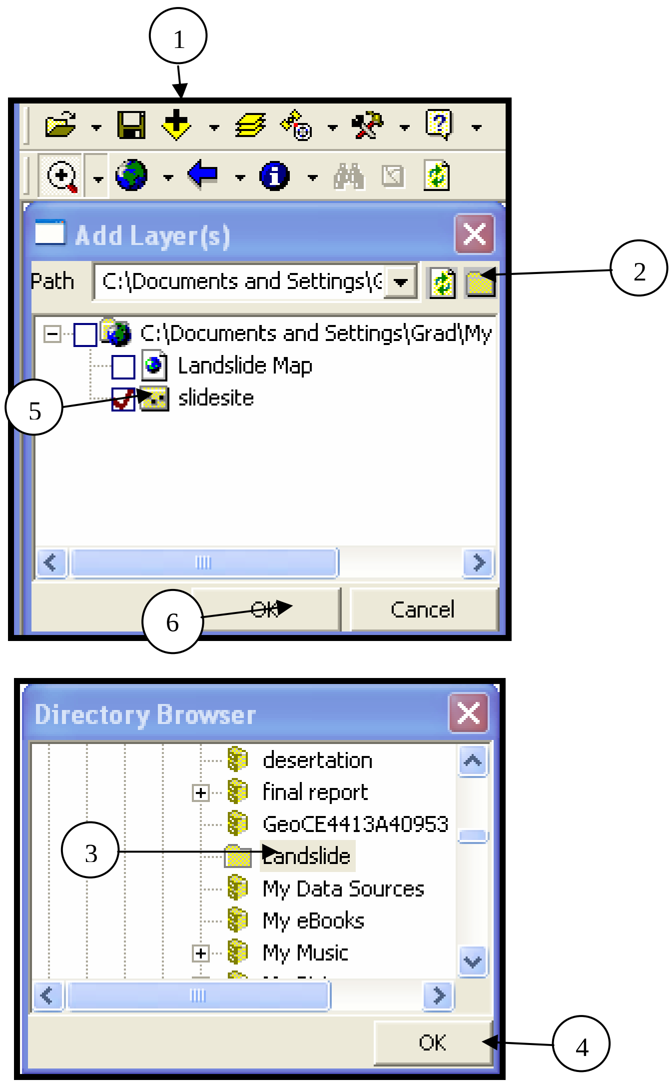


Figure 6.6 Adding Map layers on ArcPad

6.6 Turning a Layer's Visibility On or Off

Once a layer has been added to the ArcPad map, the layer can be turned on or off. (See Figure 6.7)

1. Tap on the layers button. The layer dialog box opens and displays a list of the layers that have been added to the map.
2. Check the visible check box to turn the layer on. To uncheck the check box turns the layer off.
3. Check mark on the identify tool allows a user to view the attribute information.
4. Check mark on the editing check box allows the user to edit information (landslide reconnaissance form) in the shape file.
5. Tap O.K.

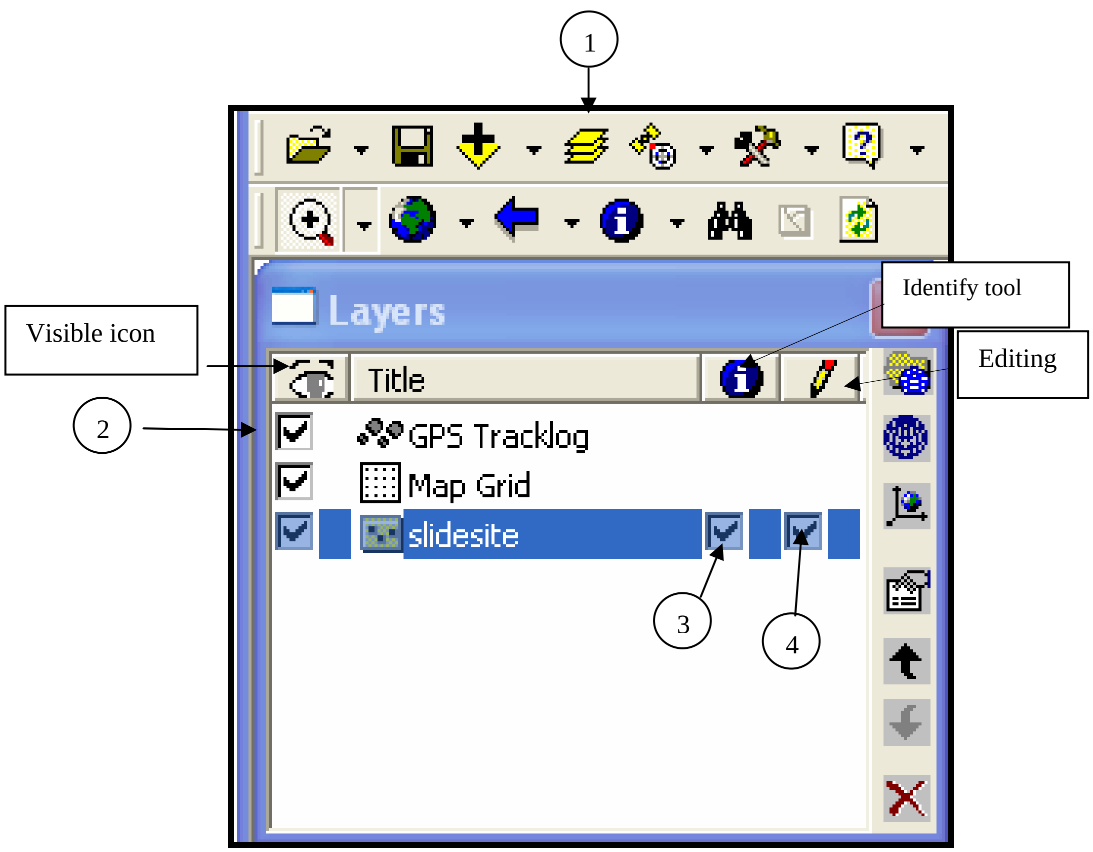


Figure 6.7 Manipulating data layers

6.7 Using the Landslide Reconnaissance Form in ArcPad

Once the working layers have been added in the ArcPad map, then the data collection process can begin. A user can work on the form with or without the GPS being activated.

1. Without the GPS being activated, the user can locate the point button “” on the third row of the menu bar shown in Figure 6.8.
2. Tap the point button. The landslide reconnaissance form pops up and a point appears representing a landslide location on the map. Note: this is used when the GPS signal is not available.
3. When the GPS signal is available, the coordinates can be edited on the last page of the form shown in Figure 6.9.
4. Tap O.K., the point moves to the right location on the ArcPad Map.

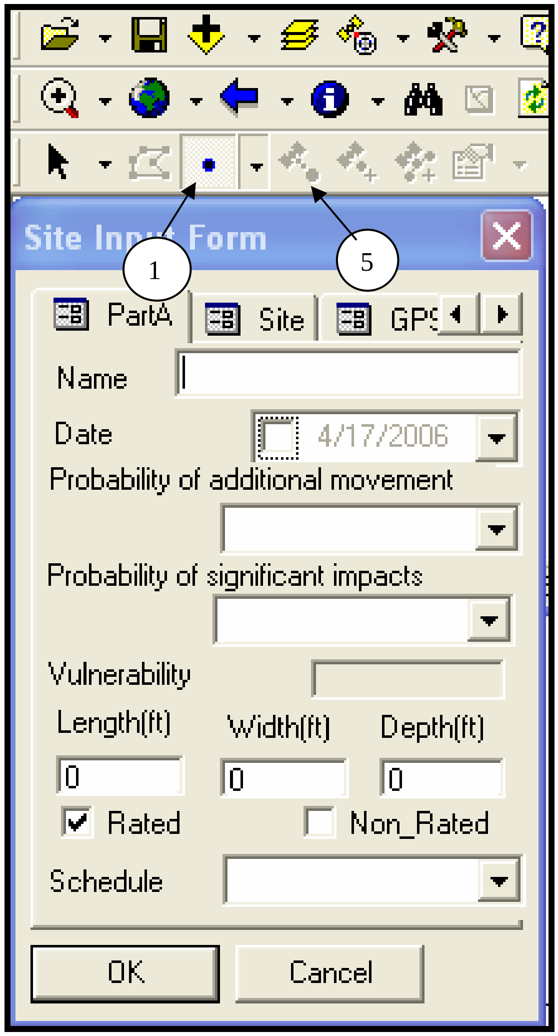


Figure 6.8 Activate the landslide reconnaissance form with and without GPS

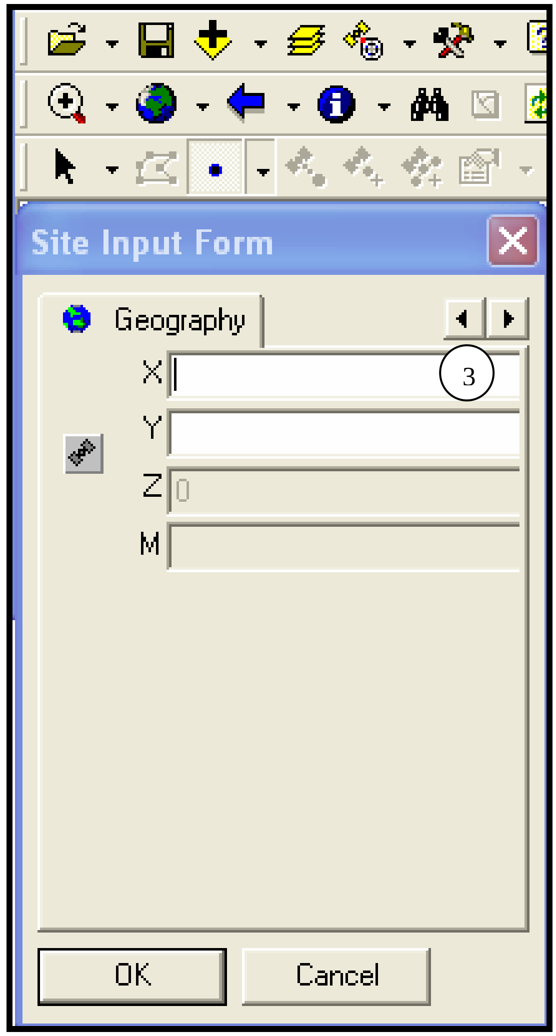


Figure 6.9 Updating the GPS coordinates

5. When the GPS signal is available, a user can tap the capture point button "" in Figure 6.8.
6. By selecting this button, the form pops up. When finishing filling out the information, the user clicks O.K. The information is stored as the location of landslide on the GIS map.

6.8 Updating the Database Using the Information Collected by ArcPad

Once a user finishes landslide data collection by using ArcPad, he/she needs to upload the files to the landslide database. The process is as follows.

1. Synchronize the handheld unit with the local computer.
2. Locate the file directory in the handheld unit that contains the landslide data by the local computer.
3. The files needed for uploading are dbf, shp, shx, and prj files.
4. Create a new folder in the local machine and copy and paste these files into this folder.
5. Login the landslide database website.
6. Select the *File Management*. (See Section 5.5 in Chapter 5)
7. Click on *RawFileManage*.
8. Select the *upload* option on the upper right menu tab.
9. Fill up the information as needed, browse the information files, and then click on submit. The data will be uploaded into the database.

APPENDICES

APPENDIX A

LANDSLIDE RECONNAISSANCE FORM

Landslide Observation Report filed by Highway/construction worker

Name of reporter		
Affiliation (District)		
Date		
Site Location	**County**	
	Route	
	Mile marker (county basis)	

Description (Visual Inspection)

Landslide material(s)	__Soil __Rock __Both
Number of lanes (one direction)	__1 __2 __3 __4 __5 __6
Posted speed limit (miles/hr)	__15 __20 __25 __30 __35 __40 __45 __50 __55 __60 __65 __70
Location of landslide relative to roadway	__Above roadway __Below roadway __both
Position of impact on roadway	Position of cracks/dips: __Pavement __Shoulder __Ditch __None
	Position of earth debris: __ Pavement __Shoulder __Ditch __None
Impact to adjacent structures or properties	__Roads __Railroads __Residential __Buildings __Commercial __Bridge __Utilities __Others____
Vegetation	Barren__% Grass __% Shrub__% Tree __% Other______________________
Presence of surface water	__Yes __No
Presence of groundwater	__Yes __No __Unknown
Previous site works (Based on observation at the site)	__Temporary __Failed temporary __Permanent __Failed permanent __Patching of asphalt __Guardrail work __Other____ ____
Recent precipitation	__Heavy __Moderate __Light
Duration	__24-hr __3-d __7-d __15-d
Date identifying first evidence of instability	
Name of verifier (CM/TM)	
Date of verification	
Signature	

Part A filed by Transportation/County Manager

Evaluator's name	
Date of observation	

Site Location

Jurisdiction	__**C**ounty __**T**urnpike __**M**unicipal __**S**tate __**T**ownship __**F**ederal __**P**rivate
County	
District	
Route system	__**IR**-interstate __**US**-United States route __**SR**-state route __**CR**-county road __**TR**-township road __**MR**-municipal road __**RA**-ramp __**PA**-park roads __**BK**-bike route
Route number	
Mile marker (county basis)	Beginning: Ending:
Network linear feature (NLF) (auto generation)	
Number of Lanes (one direction)	__1 __2 __3 __4 __5 __6
Location of landslide relative to roadway	__Above roadway __Below roadway __Both

Centroid of Affected Highway (GPS Information)

GPS coordinates	Centroid: Latitude: ______________________________ Longitude: ______________________________ Elevation: ______________________________ft
	Beginning point: Latitude: ______________________________ Longitude: ______________________________ Elevation: ______________________________ft
	Ending point: : Latitude: ______________________________ Longitude: ______________________________ Elevation: ______________________________f
State coordinates (Mid-point) (Auto generation)	Zone: ____ Northing: ____ Easting: ____
USGS Quad (Auto generation)	Name: ____ Number: ____

A.1/3

Landslide vulnerability table

Probability of additional movement	Probability of significant impacts to the roadway, structures, adjacent property or features			
	Very High	***High***	***Moderate***	***Low***
Very High	Very High	Very High	High	Moderate
High	Very High	High	High	Moderate
Moderate	High	High	Moderate	Low
Low	Moderate	Moderate	Low	Low

Remark: A landslide site having "low" vulnerability is non-rated.

General information

General dimensions (Rough estimate)	Length (ft): ___________________________ Width (ft):____________________________ Estimated maximum depth of sliding surface (ft)______
Preliminary rating (Use landslide vulnerability table)	__Rated __Non-rated
Inspection frequency	__Hourly __Daily __Weekly __Biweekly __ Monthly __Quarterly __Yearly __Others______________

A.2/3

Part A (continued)

Pictures and simple or rough sketches:

- No actual measurement, only rough visual observations.
- Require to take at lease 3 pictures of landslide at BMP, EMP, centroid of affected highway. Additional pictures may include each with downslope, upslope, and cross slope pictures.

A.3/3

Part B filed by Transportation/County Manager

Evaluator's name	
Date of observation	

Site Location

Jurisdiction	__**C**ounty __**T**urnpike __**M**unicipal __**S**tate __**T**ownship __**F**ederal __**P**rivate
County	
District	
Route system	__**IR**-interstate __**US**-United States route __**SR**-state route __**CR**-county road __**TR**-township road __**MR**-municipal road __**RA**-ramp __**PA**-park roads __**BK**-bike route
Route number	
Mile marker (county basis)	Beginning: Ending:
Network linear feature (NLF) (auto generation)	
Number of lanes (one direction)	__1 __2 __3 __4 __5 __6
Location of landslide relative to roadway	__Above roadway __Below roadway __Both

Site History

Date of original construction (m/d/y)	_______/________/________
Date of alignment modifications (m/d/y)	_______/________/________
Date of remedial activities (m/d/y)	_______/________/________
Past remedial activities	__Drainage __Bio-stabilization __Slope geometry correction __Retaining structures __Internal slope reinforcement __Erosion control __Chemical stabilization __Others____
Existing remediation	__Drainage __Bio-stabilization __Slope geometry correction __Retaining structures __Internal slope reinforcement __Erosion control __Chemical stabilization __Others____
Annual maintenance frequency (times/year)	
Annual maintenance cost (Average Over the Past 5 to 10 Years) (dollars/year)	
Maintenance response (Based on judgment)	__No response __Require observation with periodic maintenance __Require routine maintenance response to preserve roadway __Require immediate response for safe travel or to protect adjacent structure

Traffic Data

Average daily traffic (ADT)	Total traffic: ____________________________vehicles/day Passenger traffic: ________________________vehicles/day Trucks traffic: ___________________________vehicles/day
Accident history in past 10 years (Number of occurrence)	Number of accident in past 10 years_____________ Number of accident without loss______________ Number of accident with vehicle and property damage____________ Number of accident with injury_______________ Number of accident with fatality______________
Estimated detour route length (miles)	___________miles
Posted speed limit (miles/hr)	__15 __20 __25 __30 __35 __40 __45 __50 __55 __60 __65 __70
Estimated traveling time of detour (hr)	Truck_________________hr Passenger______________hr

B.2/2

Part C (District Geotechnical Engineer)

Evaluator's name	
Date of observation	

Site Location verified by DGTE (provide O.K. click button)

Jurisdiction	__**C**ounty __**T**urnpike __**M**unicipal __**S**tate __**T**ownship __**F**ederal __**P**rivate
County	
District	
Route system	__**IR**-interstate __**US**-United States route __**SR**-state route __**CR**-county road __**TR**-township road __**MR**-municipal street __**RA**-ramp __**PA**-park roads __**BK**-bike route
Route number	
Mile marker (county basis)	Beginning: Ending:
Network linear feature (NLF) (auto generation)	
Number of lanes (one direction)	__1 __2 __3 __4 __5 __6
Location of landslide relative to roadway	__Above roadway __Below roadway __Both

Centroid of Affected Highway (GPS Information) verified by DGTE (provide O.K. click button)

GPS coordinates	Centroid:	Latitude: ______________________ Longitude: ______________________ Elevation: ______________________
	Beginning point:	Latitude: ______________________ Longitude: ______________________ Elevation: ______________________
	Ending point: :	Latitude: ______________________ Longitude: ______________________ Elevation: ______________________
State coordinates (Mid-point) (Auto generation)	Zone: ______________________________ Northing: ____________________________ Easting: ______________________________	
USGS Quad (Auto generation)	Name: ______________________________ Number: _____________________________	

C.1/14

Part C (continued)

Required information for data collection (use landslide vulnerability table)

Low (0< X ≤ 2 points)	Moderate and High (2< X ≤ 9 points)	Very high (X > 9 points)
• Verify and fill out C.1 • Very rough sketches by CM/TM • Take additional photos C.14	• Verify and fill out C.1 • Fill out C.2 to C.11 • Verify rough sketches by CM/TM • Take additional pictures C.14	• Verify and fill out C.1 • Fill out C.2 to C.13 • Take additional photos C.14

Landslide vulnerability table

Probability of additional movement (A)	**Probability of significant impacts to the roadway, structures, adjacent property or features (B)**			
	Very High(4)	***High(3)***	***Moderate(2)***	***Low(1)***
Very High(4)	Very High (16)	Very High (12)	High (8)	Moderate (4)
High(3)	Very High (12)	High (9)	High (6)	Moderate (3)
Moderate(2)	High (8)	High (6)	Moderate (4)	Low (2)
Low(1)	Moderate (4)	Moderate (3)	Low (2)	Low (1)

Vulnerability score (X) = A× B

Inspection schedule

Inspection frequency	__Hourly __Biweekly __Yearly	__Daily __ Monthly __Others______________	__Weekly __Quarterly

C.2/14

Part C (continued)

Slope Characteristics

Slope type		__Natural __Cut __Fill __Cut and fill
Average slope angle (α_{ave}°)		$\alpha_{ave} = \frac{\alpha_1 \cdot l_1 + \alpha_2 \cdot l_2 + ...\alpha_n \cdot l_n}{L} =$ ____________________________ °
Slope surface appearance		__Straight __Concave __Convex __Hummocky __Terraced __Complex
Vegetation cover		__Grass__% __Shrub__% __Cultivated land__% __Reforestation__% __Woodland__% __Other ____
Vegetation density		__Sparse __Moderate __Dense
Hydrogeology	**Surface water**	**Types of water sources** __Reservoir __Lake __River __ Creek __Pond __Surface drainage __Others____________ __None **Location of water sources that may affect landslide** __Above __Below __Both
	Groundwater (use visual inspection)	**Groundwater flow** __Into landslide __ Off landslide __Both __Unknown __None **Groundwater condition** __Spring __Seep __Both __Unknown __None **Location of ground water:** __Above __Below __Middle __None **Presence of monitoring or water well** __Artesian __Flowing artesian __Pooled __None observed
Erosion area		__Head __Toe __Flank __Body __None
Possible cause of failure		__Erosion of the toe __Precipitation __Failure of drainage __Drainage outlet __Surface water __Weathering of materials __Deforestation __Change of water level
Orientation of slope (Azimuth; The clockwise angle from the north)		__________degree
Direction of landslide (Azimuth; The clockwise angle from the north)		__________degree

C.3/14

Part C (continued)

Slope Materials (by Visual Inspection and Judgment)

Soil origin	__Colluvium __Alluvium __Till __Residual soil __Weather rock __Unweathered rock __Fill __Combination __Others______________________________
Soil type	__Boulders/cobbles __Stone fragments __Gravel __Sand __Fine sand __Silty gravel __Silty sand __Clayey gravel __Clayey sand __Silty soil __Clayey soil __Organic __Combination __Others______________________________
Rock type	__Shale __Mudstone /claystone __Siltstone __Sandstone __Limestone __Coal __Interbedded __Dolomite __Combination __Others______________________________

Landslide Characteristics

Type of Movement (Rockfall is not included.)	**Slide**	__Rotational rock slide __Translational rock slide __Rotational earth slide __Translational earth block slide __Debris slide __Complex
	Flow	__Slow earth flow __Loess flow __Dry sand flow __Debris avalanche __Debris flow __Block stream __Complex
	Spread	__Rock spread __Earth spread __Complex spread
Rate of movement		______________inches/year __unknown
State of landslide activity		__Active __Inactive __Mitigated

Observed Remediation

Past remedial activities	__Drainage __Bio-stabilization __Slope geometry correction __Retaining structures __Internal slope reinforcement __Erosion control __Chemical stabilization __Others______________________________
Existing remediation	__Drainage __Bio-stabilization __Slope geometry correction __Retaining structures __Internal slope reinforcement __Erosion control __Chemical stabilization __Others______________________________

C.4/14

Part C (continued)

Preliminary Determination of Causes of Landslide

Human activities	__Excavation/under cutting __Groundwater pumping __Deforestation __Loading __ Defective maintenance __Failure of drainage __Water leakage from pipes __Artificial vibrations __Loose waste dumping __ Construction related __Others____
Natural activities	__Rainfall __ Snowmelt __Earthquake __Ground water __ Loss of vegetation __Toe erosion __ Inadequate long term strength __Surface water level change/rapid drawdown __Degradation of construction material __Others____
Comment (limit no more than 50 words)	

Observed Traffic Information

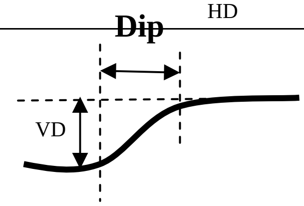
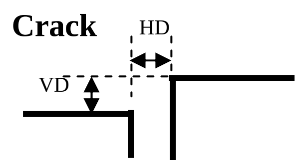
Actual sight distance (ASD) (ft.)	______________ft
Percent decision sight distance (%DSD) %DSD=(ASD/DSD)*100	______________%DSD

Decision sight distance (DSD)

Posted speed limit (mph)	Decision sight distance (ft)
25	375
30	450
35	525
40	600
45	675
50	750
55	875
60	1000
65	1050
70	1100

Part C (continued)

Impact assessment on roadway and beyond right of way

<table>
<tr><td rowspan="1">Current and potential impact of landslide on roadway</td><td colspan="2">__On slope with a low potential to affect shoulder
__On slope with a low potential to affect roadway
__On shoulder or on slope with a moderate potential to affect roadway
__On roadway, or on slope with a high potential to affect roadway or structure</td></tr>
<tr><td>Current and potential impact of landslide on the area beyond right of way</td><td colspan="2">__On slope with a low potential to impact area beyond right of way
__On slope with a moderate potential to impact area beyond right of way
__On slope with a high potential to impact area beyond right of way
__On slope with a high potential to impact building or structure beyond right of way</td></tr>
<tr><td rowspan="3">Evidence of impact on roadway</td><td>Dip
__Yes __No
Maximum displacement of dip
Vertical displacement (VD) (inch)________
Horizontal displacement (HD) (inch)______</td><td>
</td></tr>
<tr><td>Crack
__Yes __No
Maximum displacement of crack
Vertical displacement (VD) (inch)________
Horizontal displacement (HD) (inch)______</td><td>
</td></tr>
<tr><td colspan="2">Earth debris on roadway
__Yes __No
Estimated volume (Yd^3) ____________</td></tr>
</table>

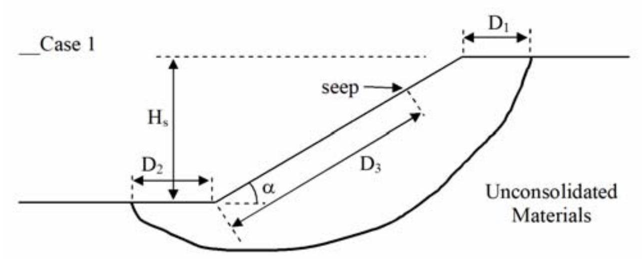
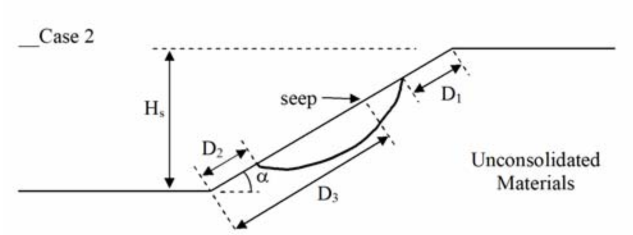
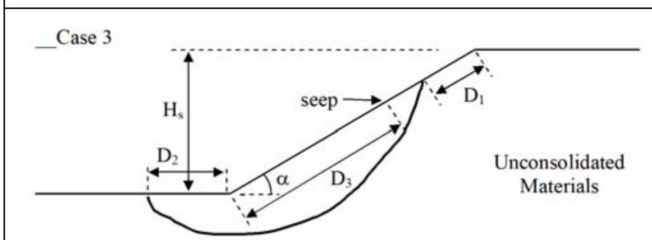
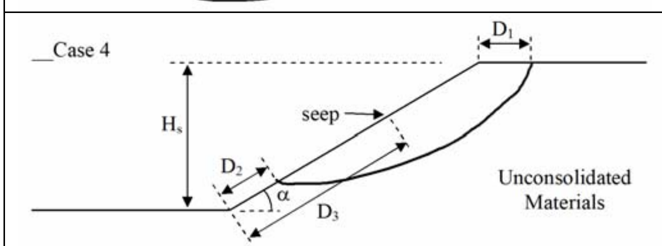
Adjacent Structures and Areas

Adjacent structures	__Roads __Railroads __Residential __Buildings __Bridge __Utilities __Others____
Surrounding area	__Forest __Agriculture __Rural __Urban __Housing development __Others____

C.6/14

Part C (continued)

Information for estimation of landslide repair cost

	1. Average slope angle, α,_________ 2. Height of slope, H_s (ft)__________ 3. Length of slope repair, L, parallel to highway (ft)___________________ 4. Distance from crest of slope to failure surface, D_1(ft)_____________ 5. Distance from toe of slope to failure surface, D_2 (ft)________________ 6. Distance along slope (measured from toe) to groundwater seeps, D_3, and approximate quantities of groundwater (ft)________________
	1. α,______________________ 2. H_s (ft)___________________ 3. L(ft)____________________ 4. D_1(ft)___________________ 5. D_2(ft)____________________ 6. D_3(ft)____________________
	1. α,______________________ 2. H_s (ft)___________________ 3. L(ft)____________________ 4. D_1(ft)___________________ 5. D_2(ft)___________________ 6. D_3(ft)___________________
	1. α,______________________ 2. H_s (ft)___________________ 3. L(ft)____________________ 4. D_1(ft)___________________ 5. D_2(ft)___________________ 6. D_3(ft)___________________

Cost Estimate

Repair cost	
Benefit cost ratio	
Estimated time required for remediation (days)	_________days

C.7/14

Part C (continued)

Suggested Remediation Measure

__Benching & regarding
__ Counter berm & regrading
__Flattening Slope
__Soil Drainage
__Bedrock Drainage
__Retaining Walls
__Light Weight Fills
__Dynamic Compaction
__Bio-engineering
__Geofabrics
__Sheet Piling
__H Piling
__Drilled Piling
__Soil Nailing
__Tieback Walls
__Remove & Replace
__Shear Key
__Chemical Treatment
__Relocation
__Bridge
__Change Line or Grade
__Other________________

Part C (continued)

Sources of Supplemental Information

__Aerial photos	__Field visit
__Satellite imaginary	__Local people
__County-ODOT	__Dist-ODOT
__State-ODOT	__City and county engineer
__Soil/Rock/Water samples	__GPS features
__Folder/ File location	__Academia with engineering or geology program
__USGS publications and files	__USGS Quadrangles
__USGS open file map series #78-1057 “Landslide related features”	
__Division of geological survey (ODNR)	
__Division of mineral resource management (ODNR)	
__Division of soil and water (ODNR)	
__Others____	

Part C (continued)

Landslide hazard rating matrix

CATEGORY		RATING CRITERIA and SCORE: Points 3	Points 9	Points 27	Points 81	Total Item Scores
Movement location/ impact (select higher score)	Current and potential impact of landslide on roadway	On slope with a low potential to affect shoulder	On slope with a low potential to affect roadway	On shoulder, or on slope with a moderate potential to affect roadway	On roadway, or On slope with a high potential to affect roadway or structure	
	Current and potential impact of landslide on area beyond right of way	On slope with a low potential to impact area beyond right of way	On slope with moderate potential to impact area beyond right of way	On slope with high potential to impact area beyond right of way	On slope with high potential to impact structure beyond right of way	
Hazard to traveling public (Select higher score)	Rate of displacement in roadway if known	<1-inch/year	1 to 3-inches/year No single event ≥1-inch	3 to 6-inches/year No single event ≥3-inches	>6-inches/year Single event ≥3-inches	
	Evidence of displacement in roadway	Visible crack or dip no vertical drop	≤1-inch of displacement	1 to 3-inches of displacement	≥ 3-inches of displacement	
Maintenance (Select higher score)	Maintenance frequency	None to rare	Annually (one time/year)	Seasonal (1 to 3 times/ year)	Continuous throughout year (> 3 times/year)	
	Maintenance response	No response	Requires observation with periodic maintenance	Requires routine maintenance response to preserve roadway	Requires immediate response for safe travel or to protect adjacent structure	
%Decision Sight Distance (%DSD)		≥ 90	89 -50	49-35	< 34	
ADT		<2000	2001-5000	5001-15000	>15001	
Accident history (Related to landslide)		No accident	Vehicle or property damage	Injury	Fatality	
					Total Score	

C.10/14

Part C (continued)

Hazard calculation sheet

Hazard category	Explanation	Item Scores
1. Movement Location/ Impact		
2. Hazard to Traveling Public		
3. Maintenance		
4. %DSD		
5. ADT		
6. Accident history (Related to landslide)		
	Total score	

C.11/14

Part C (continued)

Detailed mapping with physical measurement

Include all locations of crown, root, edges, spring, surface water, cracks, toe bulge, sloughing, head scarps, guardrail distortion, linear deflections, stream deflections, toe erosion, hydrophytic vegetation, J-trunk trees, slanted poles /trees and etc. The sketch should indicate direction (north arrow), draw to scale, and include reference points for cross section.

Plan:

C.12/14

Part C (continued)

Cross-section:

C.13/14

Part C (continued)

Additional Pictures

Provide additional pictures of physical evidence as stated in page C. 12 (provide a folder for storing digital pictures)

C.14/14

APPENDIX B

OBSERVATION TIPS

Abramson et at (1996) have summarized the important tips for slope failure observation as follows.

1. **<u>Look for Ground Movements:</u>** Sign of ground movements are evidenced by formation of tension cracks, hummocky surfaces of slopes, breakage of pipe or power lines, tilting of trees, spalling or other signs of distress in highway structures, such as guardrails, cracking of drainage channels on slope beam, closure expansion joint in bridges plate or rigid pavements, and loss of alignment of building foundations.

2. **<u>Identify patterns of surface cracks:</u>** Surface cracks are not necessary normal to direction of ground movement. For example, cracks near the crown are normal to the direction of horizontal movement but cracks along the flank are nearly parallel to it. Small echelon cracks commonly develop in the surface soil before other signs of rupture take place. Cracks parallel to slope are indicative of block slide.

3. **<u>Look for troublesome Hydrologic or soil formations:</u>** If the formation has alternate weak and competent soil layers, slides may occur along the weak layers. Other areas have soil that is subject to liquefaction. For example, some of embankments, and steep hillsides, erosion removes support from the toe of engineered and natural structure, and landforms.

Naturally occurring springs located at toes or crests of slope may soften the soil, causing it to lose strength and allowing the slopes to fail. Often locations of spring can be found in densely vegetated areas. River banks, natural escarpments, quarries and highway and railway cuts may reveal, through the presence of seeps or springs, information on ground water flow in the area. Fill most likely to be unstable are those in stream valley where the depth of highway weathered material is the greatest, and those constructed on hill side areas where the potential sliding surface is inclined.

4. **Determine existing drainage patterns:** Site drainage is one of the most important factors involving slope instability. Surface water may saturate and weaken the soils of embankments, foundations, and naturally soils. The result often leads to a landslide. Surface water, if not properly drained away from the slope, it may saturate the soil. Therefore, it is necessary to look for any drainage flow that may have a potentially adverse effect on slope stability.

   During the field reconnaissance, all stream courses, channels, nullahs, ditches, catch pits, and culverts should be mapped. The details, sizes, and condition should be plotted on the geotechnical site plan. This information will prove useful when assessing surface drainage characteristics of the existing site, and how these existing surface drainage measures will have to be modified or proved to accommodate the future slope stability.

Slope stability along an existing roadway may sometimes be attributed to the inadequate maintenance of existing drainage features. Therefore, all the existing drainage features should be checked for inadequacy and leakage.

5. **Always Take Note of Natural or Engineered Earth Structure (natural, cut, or fill slope and retaining structure) in the vicinity of site:** These structures often gives clues as to the most likely and practical way of designing, constructing, and remediating slopes, the potential problem that may occur after construction, and the types of remedial measure to be undertaken should the slope experience instability.

6. **Use common sense to explain features associated with ground movements and to determine the causes of ground movements:** Ground movements occur if the ground experiences "something" that undermines its equilibrium. This "something" could be natural causes, such as weathering, intense rainfall, and existence of soft layers, or human causes, such as under cutting toe of slopes, overstress the ground and so on.

All observation should be recorded in writing, drawing and photographs so that they can be reviewed at a later time in the office. In each landslide investigation, surveyors have to take some photograph to be used as the illustration of the real condition. Photographs also will be good references in case of the rating score criteria are necessary to be modified. An observation that seems insignificant at the time often served as the key to the solution of a difficult design, construction, or remediation problems later on. For example, a small hole on a slope that is thought to be an animal borrow may turn out to be an exit tunnel. Another example is daylighting relict joints residual soil slopes, which may be an adverse factor that will trigger slope instability.

The following figures are the useful evidences for the slope failure observation.

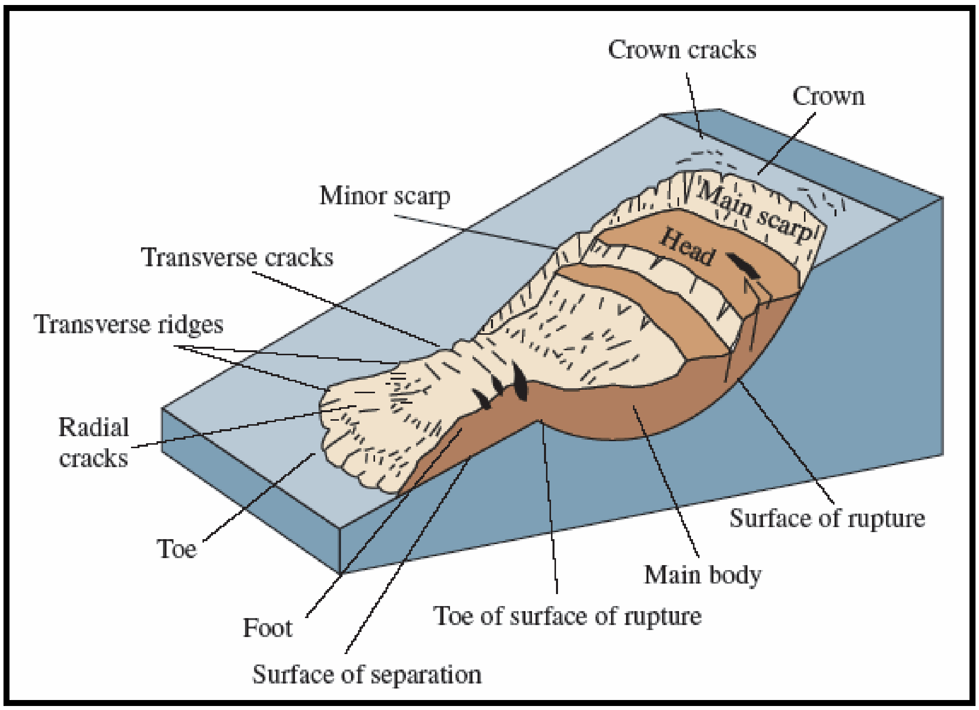


Figure B. 1 An Idealized slump-earth flow showing commonly used nomenclature for a landslide (USGS Fact Sheet 2004-3072, July 2004)

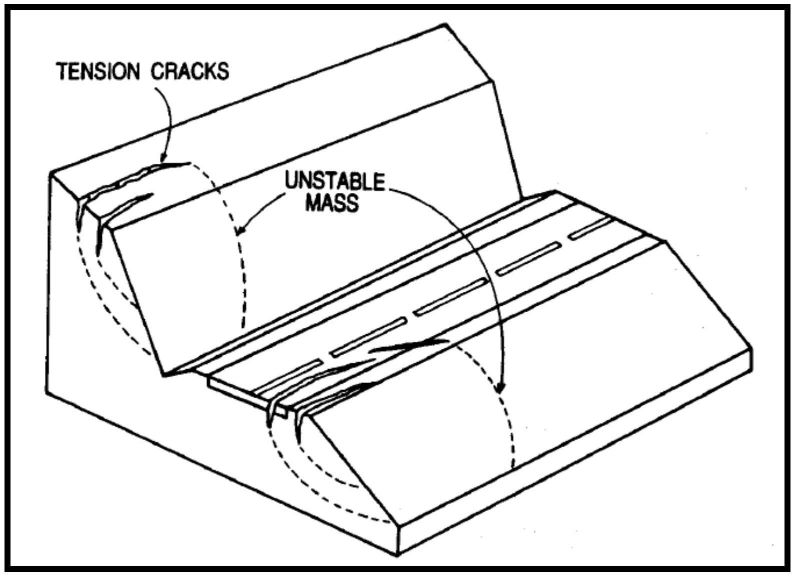


Figure B. 2 Development of tension cracks at top of roadway or cut slope (FHWA, 1988)

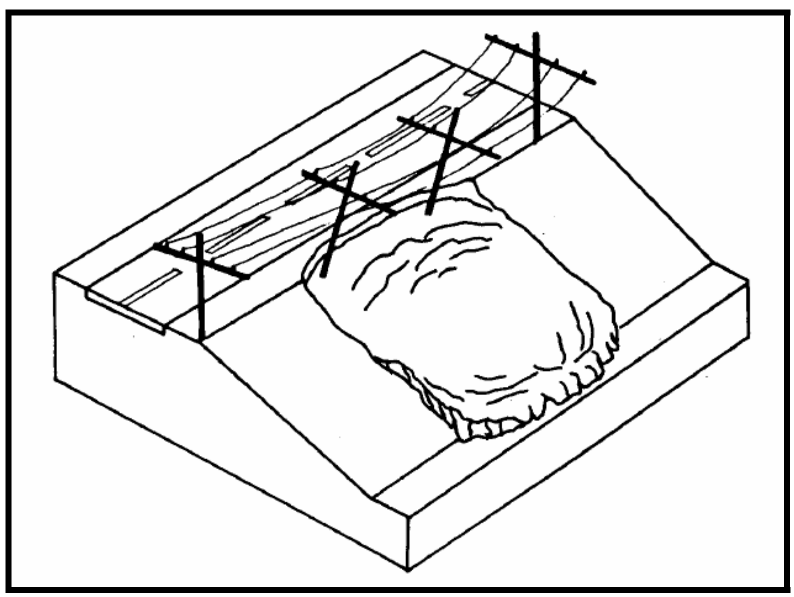


Figure B. 3 Leaning of telephone pole (FHWA, 1988)

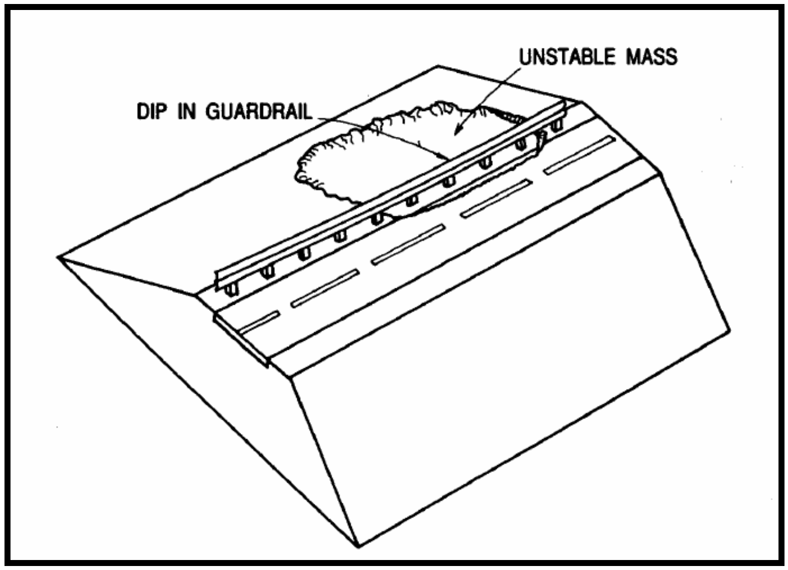


Figure B. 4 Dip in guardrail (FHWA, 1988)

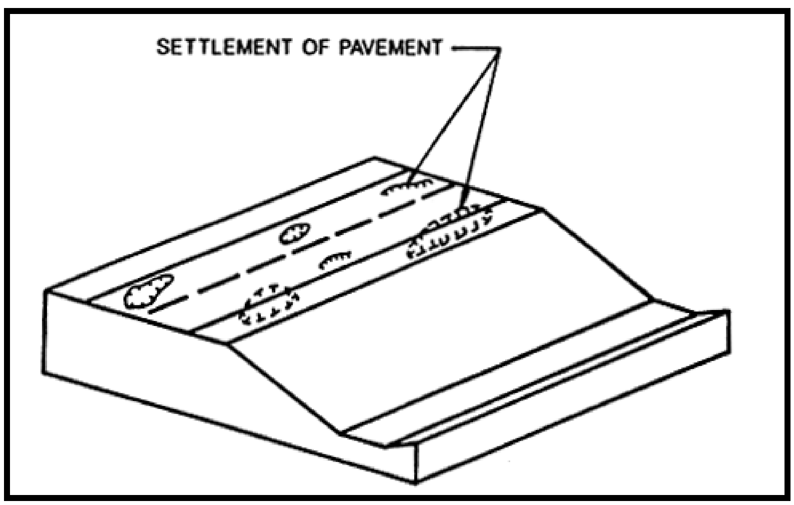


Figure B. 5 Settlement of roadway (FHWA, 1988)

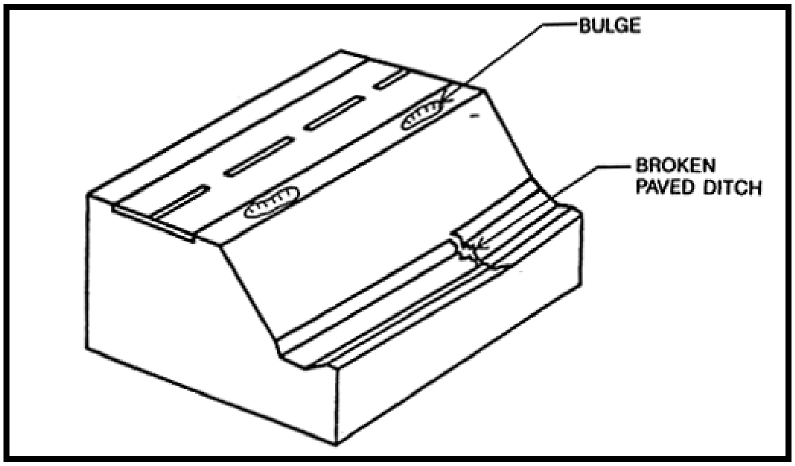


Figure B. 6 Bulge of pavement and broken paved ditch (FHWA, 1988)

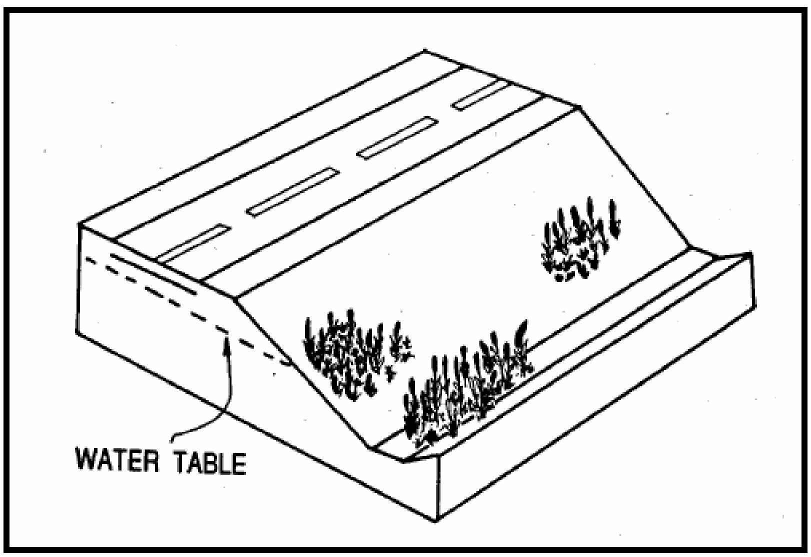


Figure B. 7 Cattails or willow trees warn of subsurface seepage (FHWA, 1988)

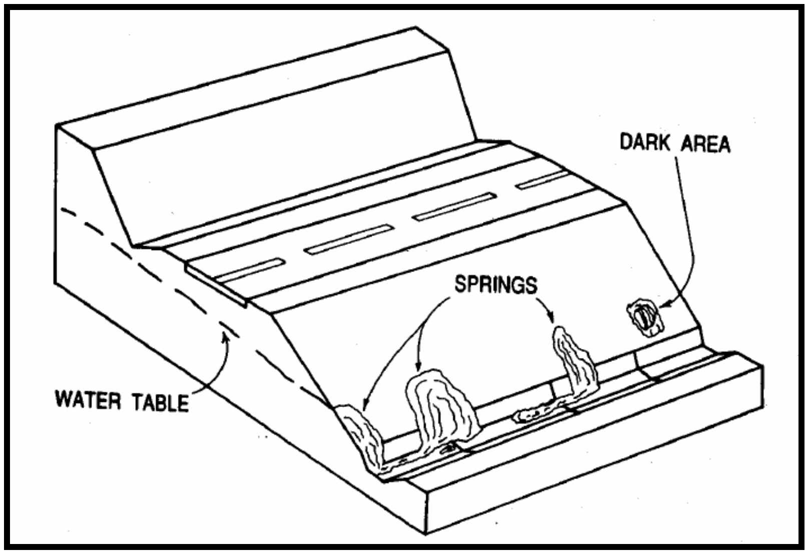


Figure B. 8 Naturally occurring springs on highway slopes (FHWA, 1988)

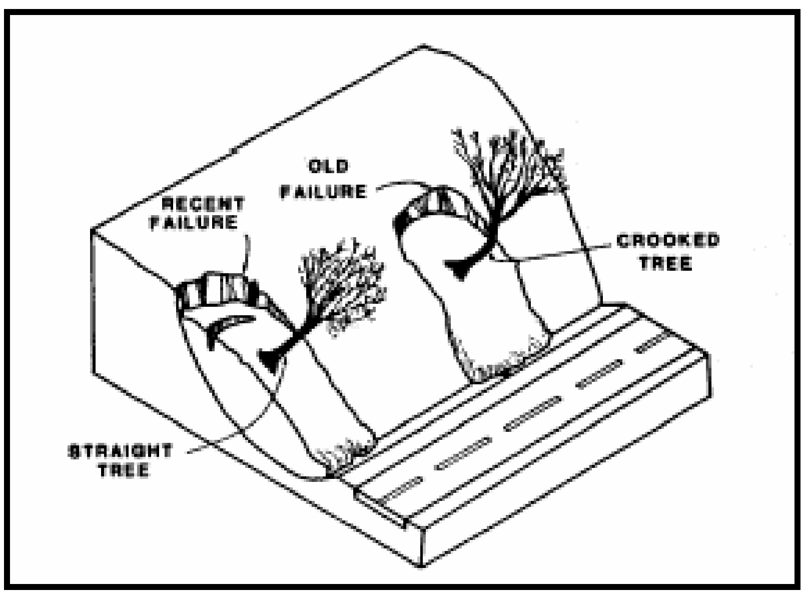


Figure B. 9 Tilted and curved trees (FHWA, 1988)

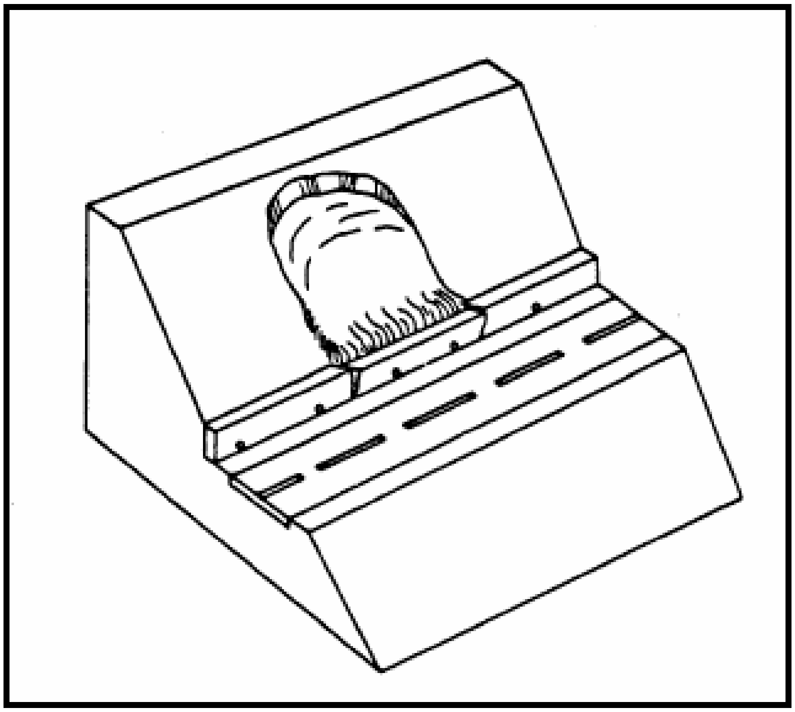


Figure B.10 Impact on retaining structure (tilted on retaining wall) (FHWA, 1988)

APPENDIX C

SOME ADDITIONAL DEFINITIONS AND TERMS

1. <u>Features and dimensions of landslides</u>

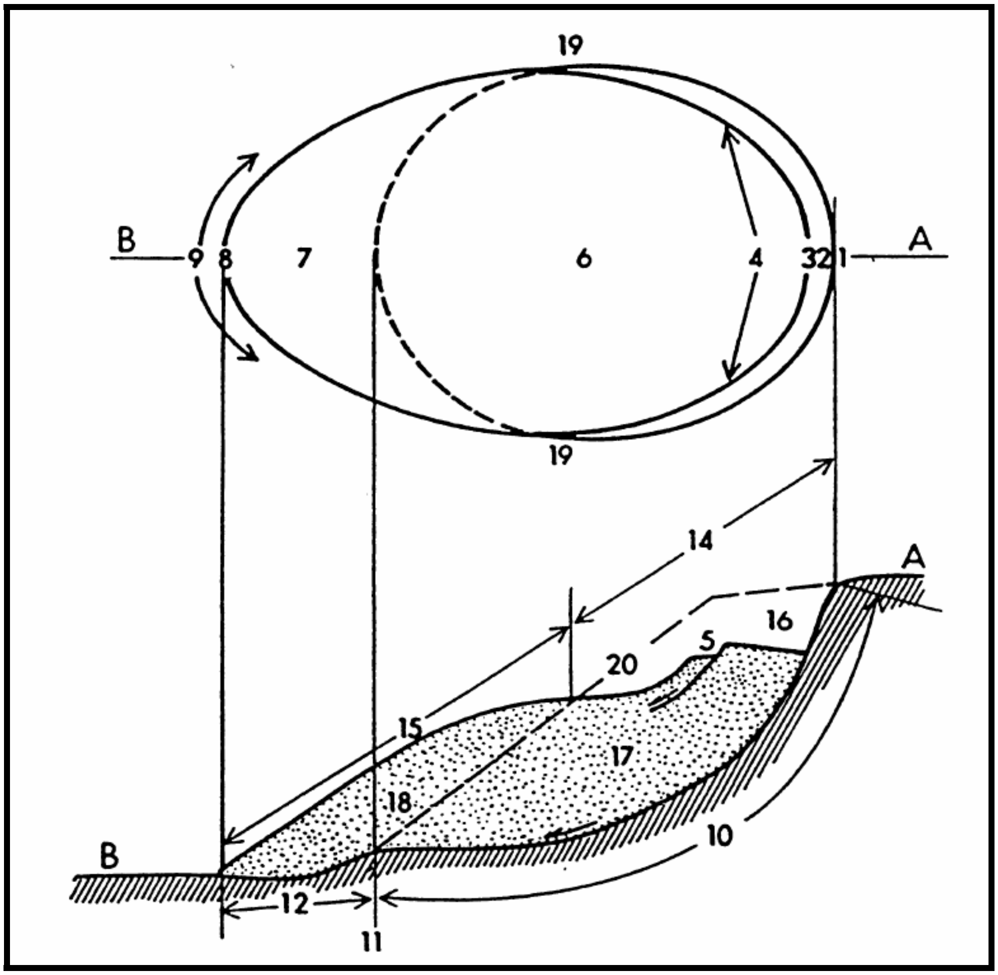


Figure C.1 Landslide features (Cruden and Varnes, 1992)

Table C. 1 Features and dimensions of landslides (Cruden and Varnes, 1992)

No.	Name	Definition
1	Crown	The practically undisclosed material above the main scarp
2	Main scarp	A steep surface on undisturbed ground at the upper edge of the landslide.
3	Top	The highest point of contact between the displaced material and main scarp.
4	Head	The upper parts of the landslide between the displaced material and main scarp.
5	Minor scarp	Steep surface on the displaced material of landslide produced by differential movements.
6	Main body	The part of displaced material of landslide that overlies surface of rupture.
7	Foot	The portion of landslide that has moved beyond the toe.
8	Tip	The point on toe farthest from top.
9	Toe	The lower margin of the displaced material.
10	Surface of rupture	The surface that forms the lower boundary of the displaced material.
11	Toe of surface of rupture	The intersection between the lower part of the surface of rupture and the original ground surface.
12	Surface of separation	The original ground surface now overlain by the foot of the landslide.
13	Displaced material	Material displaced from its original position by landslide movement.
14	Zone of depletion	The area within which the displaced material lies below the original ground surface.
15	Zone of accumulation	The area within which the displaced material lies above the original ground surface.
16	Depletion	The volume bounded by main scarp, the depleted mass, and the original ground surface.
17	Depleted mass	The volume of displaced material that overlies the rupture surface but underlies the original ground surface.
18	Accumulation	The volume of displaced material that lies above the original ground surface.
19	Flank	The undisclosed material adjacent to the sides of the rupture surface.
20	Original ground surface	The surface of the slope that existed before the landslide took place.

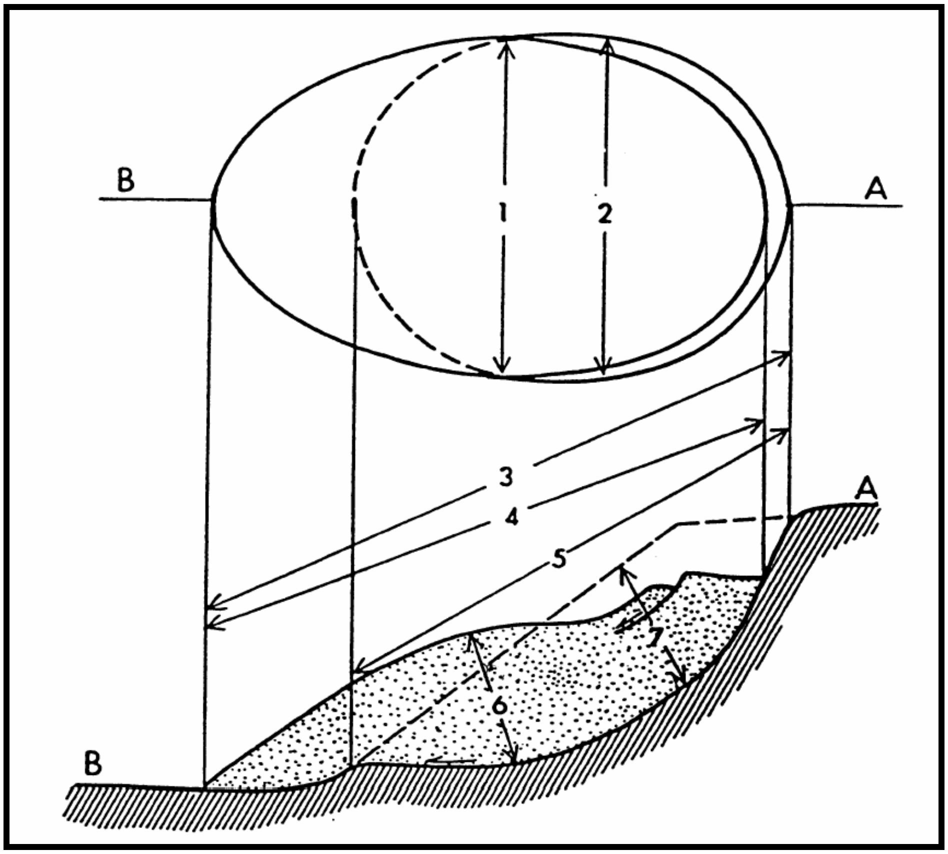


Figure C. 2 Landslide Dimensions (Cruden and Varnes, 1992)

Table C. 2 Definition of landslide dimensions (Cruden and Varnes, 1992)

No.	Name	Definition
1.	Width of displaced mass, W_d	The maximum breadth of the displaced mass perpendicular to the length L_d.
2.	Width of the rupture surface, W_r	The Maximum width between the flanks of the landslide, perpendicular to the length L_r.
3.	Total length, L	The minimum distance from the tip of the landslide to its crown.
4.	Length of displaced mass, L_d	The minimum distance from tip to the top.
5.	Length of the rupture surface, L_r	The minimum distance from toe of the surface of rupture to the crown.
6.	Depth of displaced mass, D_d	The maximum depth of the displaced mass, measured perpendicular to the plane containing W_d and L_d.
7	Depth of the rupture surface, D_r	The maximum depth of the rupture surface below the original ground surface measured perpendicular to the plane containing W_r and L_r.

2. Slope type:

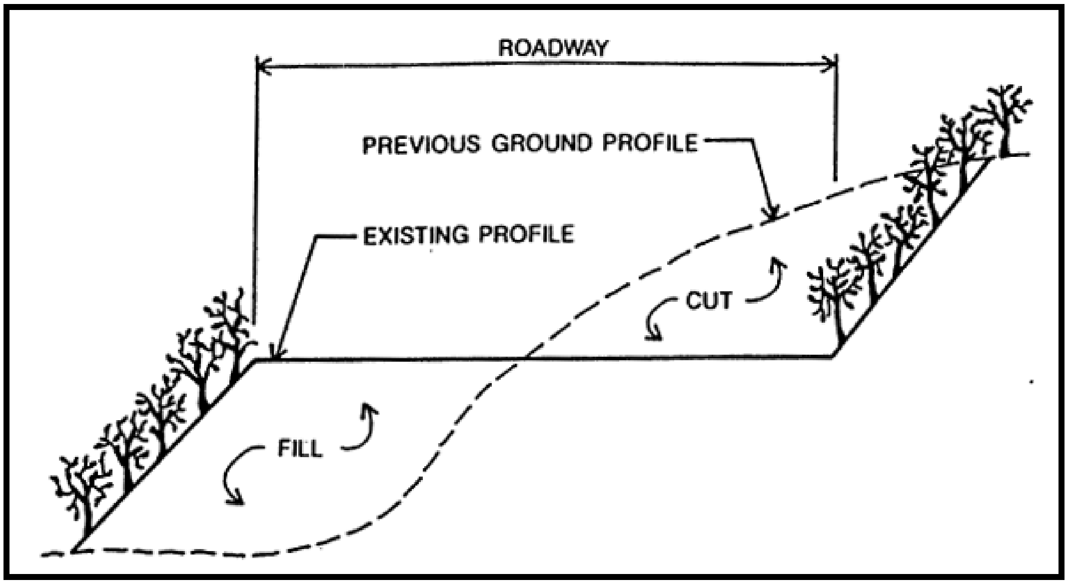


Figure C.3 Cut and Fill observed by vegetation (Abramson et al, 1996)

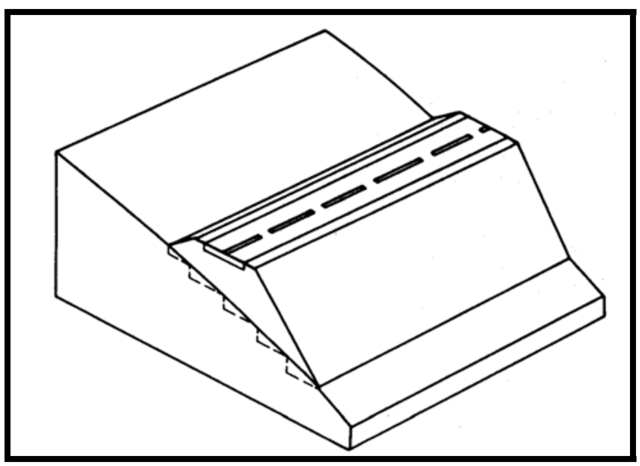


Figure C.4 Fill Slope (FHWA, 1988)

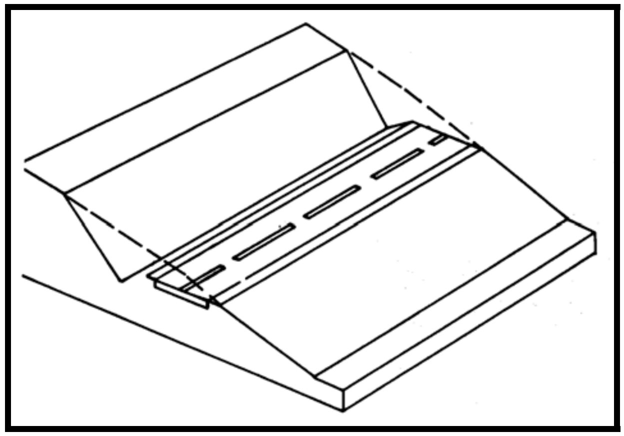


Figure C.5 Cut-slope (FHWA, 1988)

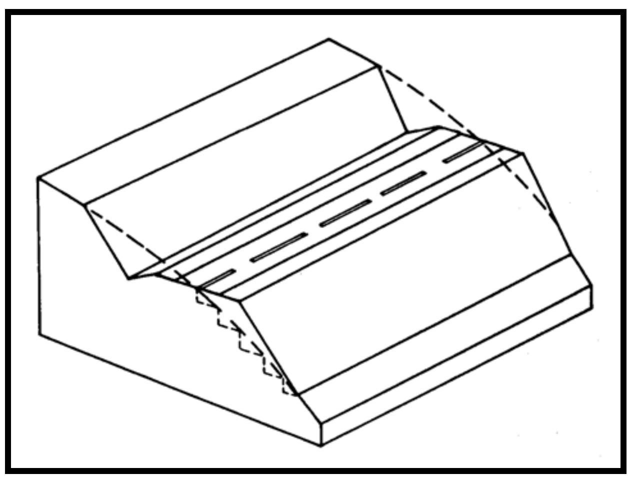


Figure C.6 Cut and fill slope (FHWA, 1988)

3. Average slope angle:

The slope angle is the inclination of the slope relatively to the horizontal ground surface. In case of many slope breaks on the slope, the angle of slope can be quantified by summation of multiplication of the small portions of slope lengths and slope angles and then it is divided by the total length of slope.

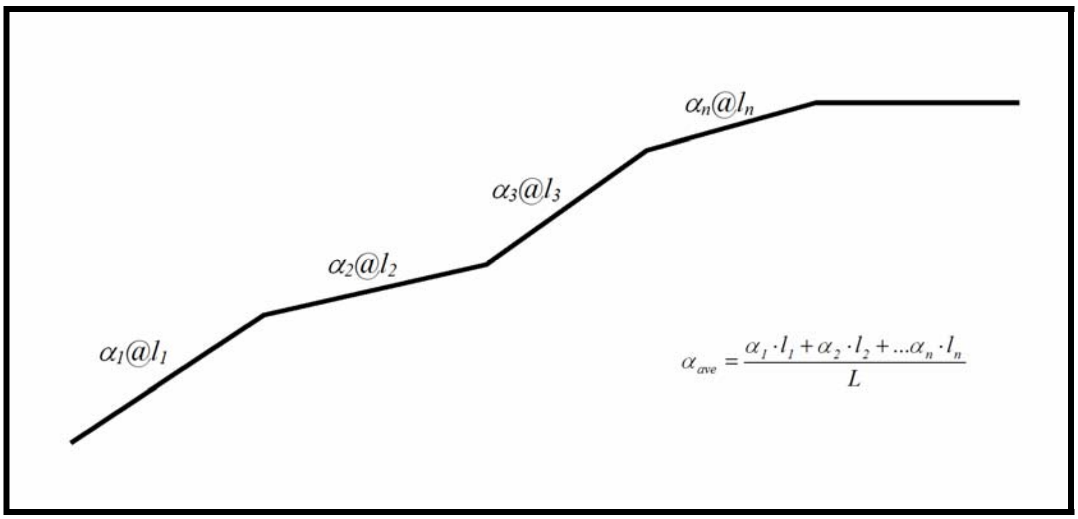


Figure C.7 Average slope angle calculation

4. Slope surface appearance:

Straight: Designate more or less even gradient down the slope

Concave: Steep near the top of the slope and flatten out towards the toe

Convex: Flatter near the top, steepening towards the bottomlands

Hummocky: Rounded knoll or hillock with multidirectional slopes, where a rise of ground is of no great extent above a level surface

Terraced: Existence of step or terrace features along the contour of steep or long slopes

Complex: Slope with the combination of two or more principal forms or irregular in shape.

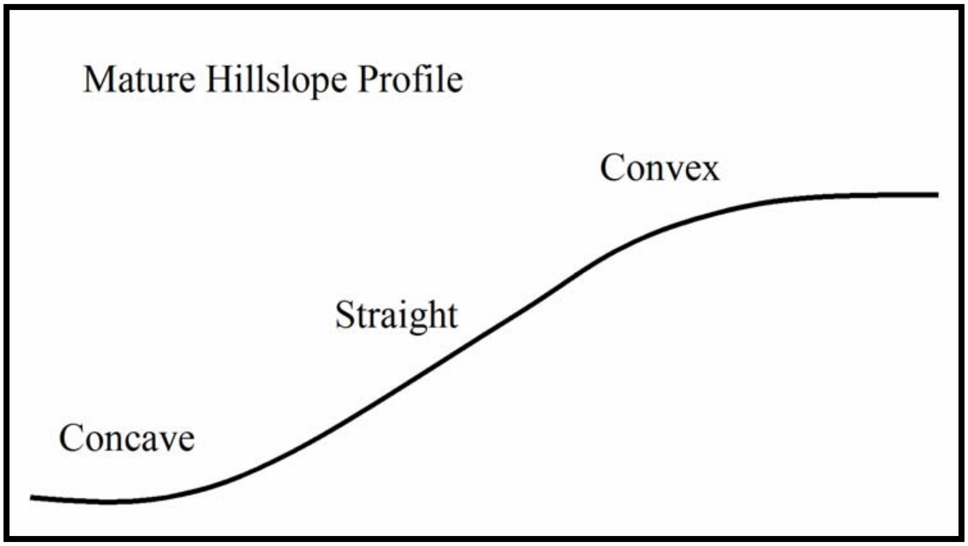


Figure C.8 Ideal mature hillslope profile,
presented by William Morris Davis 1907 (Abramson, 1996)

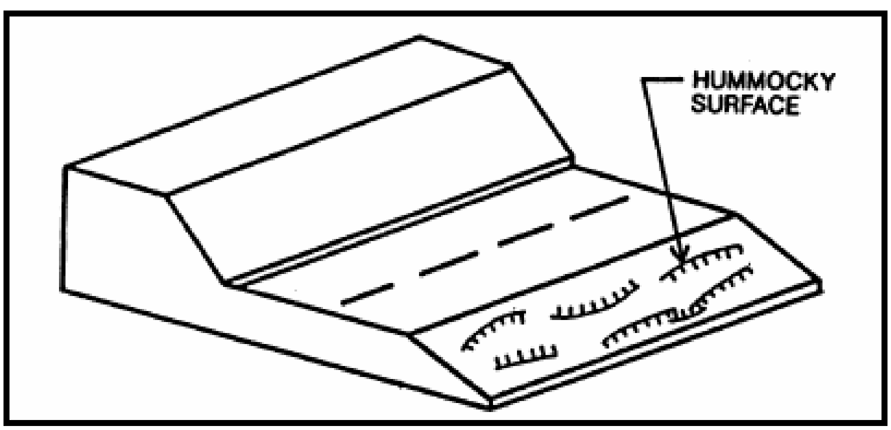


Figure C.9 Hummocky (FHWA, 1988)

5. Vegetation: Plants grows along the slope.

Density — Sparse: Vegetation is grown in widely spaced intervals.

Moderate: Average quantity or extent of vegetation is found.

Dense: The slope has relatively high density of vegetation.

6. Soil Origin:

Colluvium is poorly sorted mixture of angular rock fragments and fine-grained materials deposited by rain, or slow continuous down slope creep. It is usually found at the hill side or gentle slope.

Alluvium is sediment deposit transported by running water and settled down when the speed of water flow is not sufficient to carry them. The deposits are generally of relatively narrow particle size range regardless of consisting f cobble and gravel in rushing water or sand from moderately moving rivers or clay from sluggish river.

Till is unsorted, unstratified, unconsolidated, heterogeneous material deposited directly from the ice and generally consist of clay, silt, sand-gravel, and boulder interbedded in varying proportion. Till is usually dense to very dense and high strength and low compressibility.

Residual soil is formed in place by mechanical and chemical weathering of their parental bedrocks.

Weathered rock is involved in two types of weathering, which are chemical and mechanical weathering. Chemical weathering is the breakdown of minerals into new compounds by action of chemical agents. Mechanical weathering is the process by which rock is broken down into smaller fragment as a result of energy developed by physical force such as freeze and thaw cycles and temperature change.

Unweathered rock is the rock mass without or insignificant disintegration by either chemical or mechanical weathering.

Fill composes of varieties of materials. The size of materials may be ranged from very fine particle to large cobbles.

7. Soil Type:

Boulders are particles of rock that will not pass a 12-inch square opening.

Cobles are particles of rock that will pass a 12-inch square opening and be retained on a 3-inch sieve.

Gravel: Very large particle sizes, all or nearly all of which are large rock fragments clearly visible to the eye.

Sand: Much smaller particle sizes, but still clearly visible to the eye. The particles will not stick together but will pour loosely when dry. The particle size up to 2 mm is referred to as sand and the particle larger than 2 mm to 200 mm will be called gravel.

Silt: Particle sizes are much smaller than sand. The particles are visible to the eye only with difficulty. The soil feels slightly gritty. A small lump will crush easily between the fingers.

Clay: Particles cannot be seen with the naked eye. Soil fell sticky when wet and can be easily molded between the fingers. When dry. A small lump can be crushed between the finger with great difficultly.

Clayey Silt is earth material with high percentage of silt and low percentage of clay.

Silty Clay is earth material having high percentage of clay and low percentage of silt.

Combination: the soil is mixed with many types of soils.

Rock Fragments are particles of rock that has the size bigger than boulders.

Organics are formed basically in situ, either growth or subsequently decay of dead plants such as by accumulation of the fragment of inorganic skeletons or shells of organism.

8. Rock Type:

Shale is sedimentary rock mainly composed of silt-size and clay size particles. Most shales are laminated and display fissility; the rock has a tendency to split along relatively smooth and flat surfaces parallel to the bedding.

Mudstone /Clay stone is pretty much the same as shale except that it is not fissility.

Siltstone is fine-grained rock of consolidated silt.

Sandstone is a rock made of sand more or less firmly united. Common or siliceous sandstone consists mainly of quartz sand.

Limestone: A common sedimentary rock consisting mostly of calcium carbonate, $CaCO_3$.

Coal is A natural dark brown to black graphite like material used as a fuel, formed from fossilized plants and consisting of amorphous carbon with various organic and some inorganic compounds

Interbedded is a sedimentary rock with many types of multilayer rock.

Dolomite is a magnesia-rich sedimentary rock resembling limestone. It occurs in distinct crystals, often crystalline granular, either white or clouded. It includes much of the common white marble.

9. Landslide Characteristics

Type of Movement (note: rockfall is not included):

Slide:

Rotational slides are the movement of rock or earth which has surface of rupture as curve or concave. In rotational slide in soil, the ratio of depth of surface of rupture and length of surface of rupture is in the range of 0.15 to 0.33. The head of the displaced material may move vertically downward, whereas the upper surface of the displaced material may tilt back ward toward the scarp. It may be observed that water may be ponding in the area of backward tilt.

Translational slides are the mass failure sliding along planar or undulating surface of rupture or the original ground surface. The translational slides are generally shallower than rotational slide. They have the ratio between depth and length of surface of rupture typically less than 0.1. Translational slides in rock masses have been called block slides or planar slide.

Debris slides are failure of unconsolidated material that break up into smaller parts. They occur in much steeper slope and failure surface, which have rather high velocity and have complicated run out phenomena. The geometry of the failure area is characterized by a low depth to the length ratio of less than 0.05 and high length to breadth ratio about 5 to 10 or more.

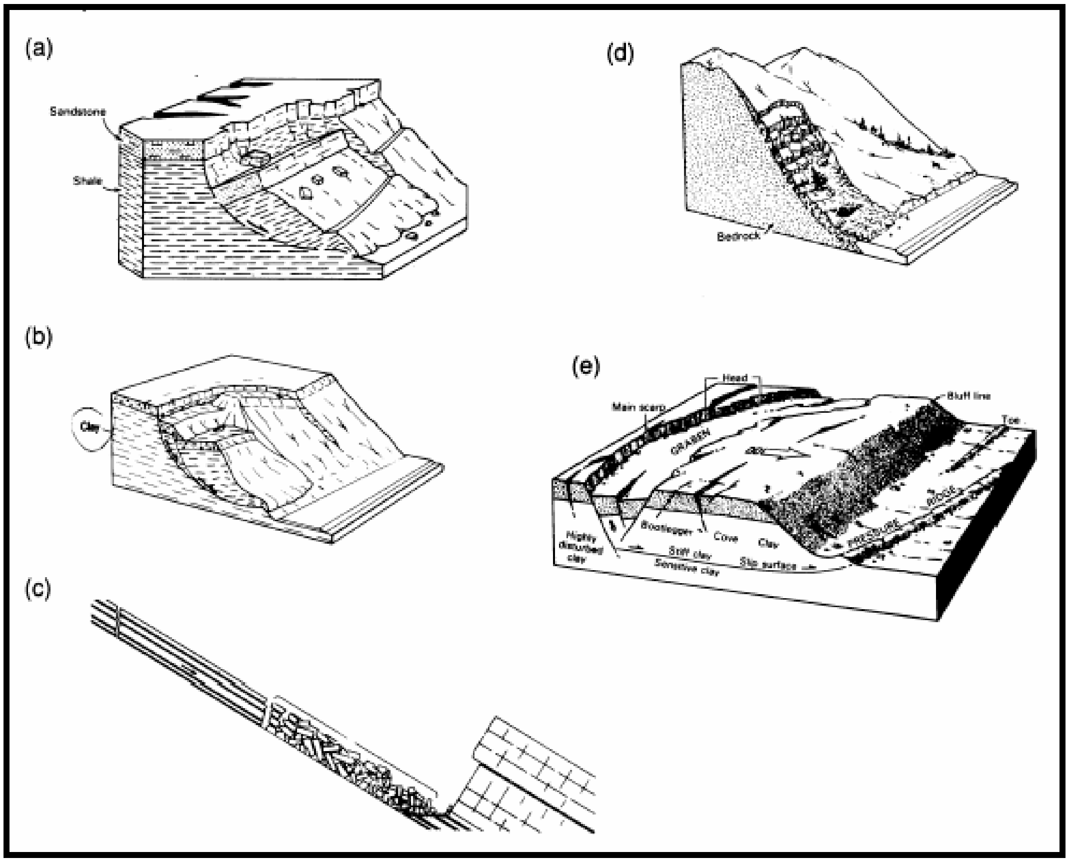


Figure C.10 Example of rotational and translational slides: (a) rotational rock slide, (b) rotational earth slide, (c) translation rock slide, (d) debris slide, (e) translation earth blockslide (Cruden and Varnes, 1996)

Flow:

Flow is a spatially continuous movement in which surfaces of shear are short-lived, closely spaces, and usually not preserved. The distribution of velocities in the displacing mass resembles that in a viscous liquid.

Slow earth flow is somewhat drier and slower earth flow having clay or weathered clay-bearing rocks, moderate slope and adequate moisture.

Loess flow is a type of flow that occurs in the loess material. Loess is the material that is deposited by wind. The materials usually consist of silt and/or fine sand and some clay binder. Loess is easy to erode when flood or rained on.

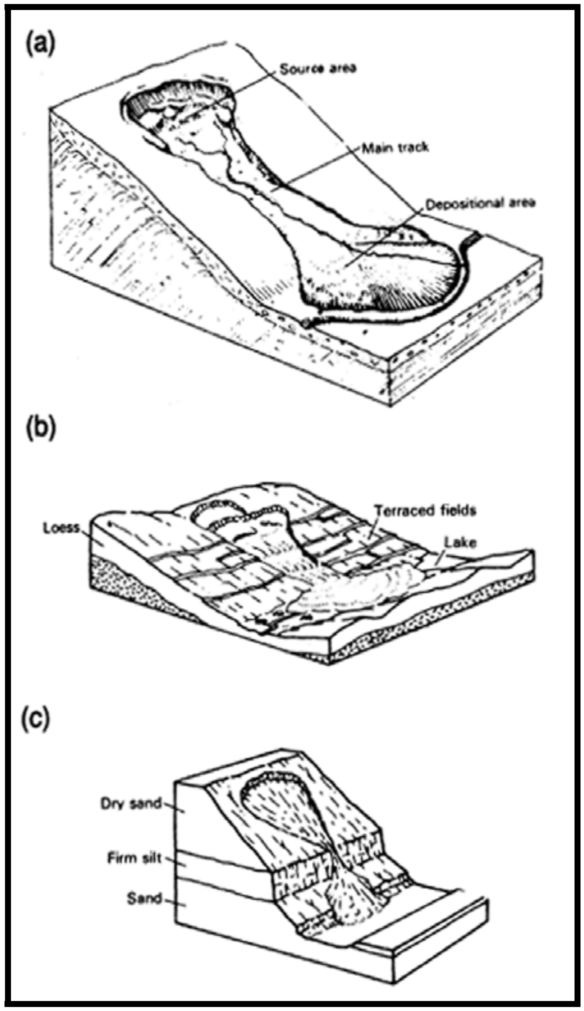


Figure C. 11 Example of flows (a) slow earth flow, (2) loess flow, and (3) dry sand flow (Cruden and Varnes, 1996)

Debris flow can be distinguished from other types of flow by the basis of particle size. The debris flow contains a relatively high percentage of coarse fragments.

Debris avalanche is used to term the debris flow that move extremely rapid.

Block stream is tongues of rocky debris on steep slope moving extremely slow and often fed by talus cone at the head.

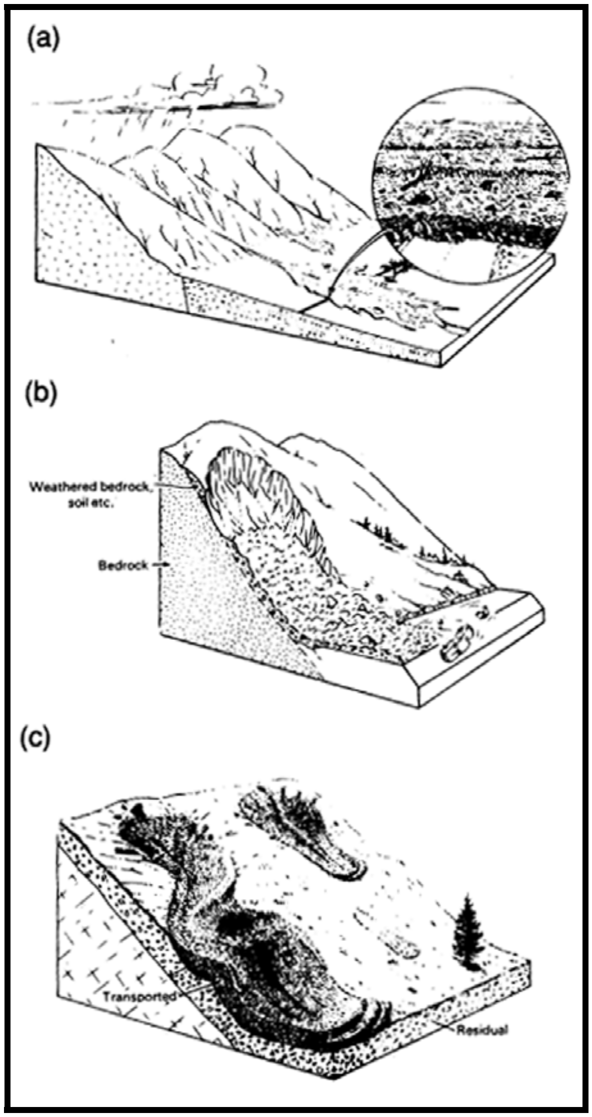


Figure C.12 Chanalized debris flows: (a) debris flow, (b) debris avalanche, and (c) block stream (Cruden and Varnes, 1996)

<u>Spread</u>

Spread is defined as an extension of a cohesive soil or rock mass combined with a general subsidence of the fracture mass of cohesive material into softer underling material. Spread may result from liquefaction, which is triggered from a rapid ground motion such as earthquake or artificial induced.

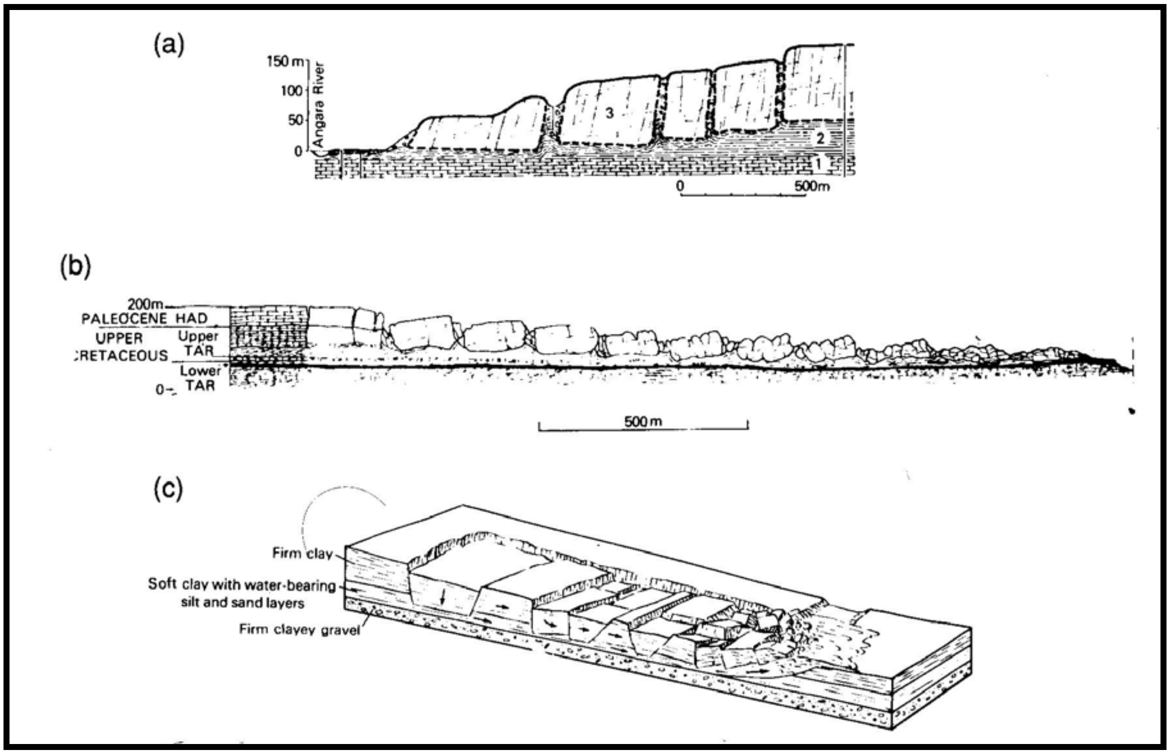


Figure C. 13 Typical rock and earth spreads: (a), (b) rock spreads that have experienced lateral extension without well-defined basal shear surface or zone of plastic flow. (c) Earth spread resulting from liquefaction or plastic flow of subjacent material (Cruden and Varnes, 1996)

10. <u>State of Landslide Activity:</u>

Active landslides are those currently moving.

Inactive landslides are those that last moved more than one annual cycle of season ago. The detailed differences of active and inactive are show in the table below.

Stabilized landslides can be described as for example the toe of slope has been protected by some types of remediation and those methods have stopped the movement. It is called as stabilized.

Table C.1 Features indicating Active and Inactive Landslides (Abramson et al 1996)

Active	Inactive
Scarp, terraces, and crevices with sharp edges	Scarp, terraces, and crevices with round edges
Crevices and depressions without secondary infilling	Crevices and depressions infilled with secondary deposit
Secondary mass movement on scarp face	No secondary mass movement on scarp faces
Surface of rupture and marginal shear plane show fresh slickenside and striations	Surface of rupture and marginal shear plane show old or no slickenside and striations
Fresh fracture surfaces on blocks	Weathering on fractured surfaces of blocks
Disarranged drainage system; many ponds and undrained depressions	Integrated drainage system
Pressure ridge in contact with side margin	Marginal fissure and abandoned levees
No soil development on exposed surface of rupture	Soil development on exposed suface of rupture
Presence of fast growing vegetation	Presence of slow growing vegetation
Distinct vegetation differences on and off slide	No distinction between vegetation on and off slide
Tilted tree with no vertical growth	Tilted tree with new vertical growth above inclined trunk
No new supportive, secondary tissue on trunks	New supportive, secondary tissue on trunks

APPENDIX D

ADDITIONAL EXAMPLES OF

LANDSLIDE HAZARD ASSESSMENT

(Only parameters based on judgment are discussed)

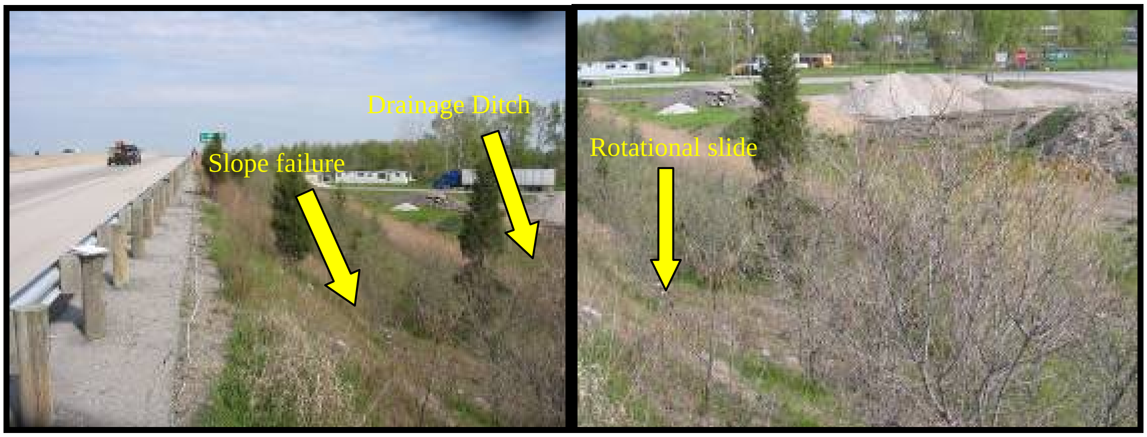
1. Picture set no. 1

Comment on picture set no.1

It was reported that the embankment was excavated by some utility companies many times (interviewing a local resident). Surface erosions were observed on the failed slope. A pond is located near the toe of the embankment but it does not affect the stability of slope. Longitudinal and alligator cracks are found on the roadway but they are not result of the slope instability.

- **Movement location/impact:** low potential to affect the shoulder/ 3 points
- **Hazard to traveling public:** visible crack or dip no visible drop/ 3 points
- **Maintenance response:** requires observation with periodic maintenance/ 9 points

2. <u>Picture set no. 2</u>



<u>Comment on picture set 2</u>

Several failure locations were found on the slope. The failures were shallow, which were relatively old and inactive. There was a drainage ditch at the toe of slope with present water. There was no evidence of failure on the roadway surface. This failed slope needs some periodic obdervations because the failures exist and they may be reactivated after rainfall.

- **Movement location/impact:** low potential to affect the shoulder/ 3 points
- **Hazard to traveling public:** visible crack or dip no visible drop/ 3 points
- **Maintenance response:** requires observation with periodic maintenance/ 9 points

3. Picture set no. 3

Comment on picture set no. 3

The portion of roadway seems to continue sliding into a running parallel river. A recent road work (asphalt patching) was observed. The new embankment along the roadway edge was up to 4 feet in thickness. There was no evidence of crack on the roadway surface but the roadway humps still existed as seen in the pictures. The settlement looks severe, which might generate serious damage to the roadway in the future.

Note: For this site, the maintenance history is important to use along with the decision. The newly paved roadway surface might hide the current failure situation from the investigator.

- **Movement location/impact:** On roadway, or on slope with high potential to affect roadway or structure/ 81 points
- **Hazard to traveling public:** > 3 inches of displacement/ 81 points
- **Maintenance response:** Requires routine maintenance/ 27 points

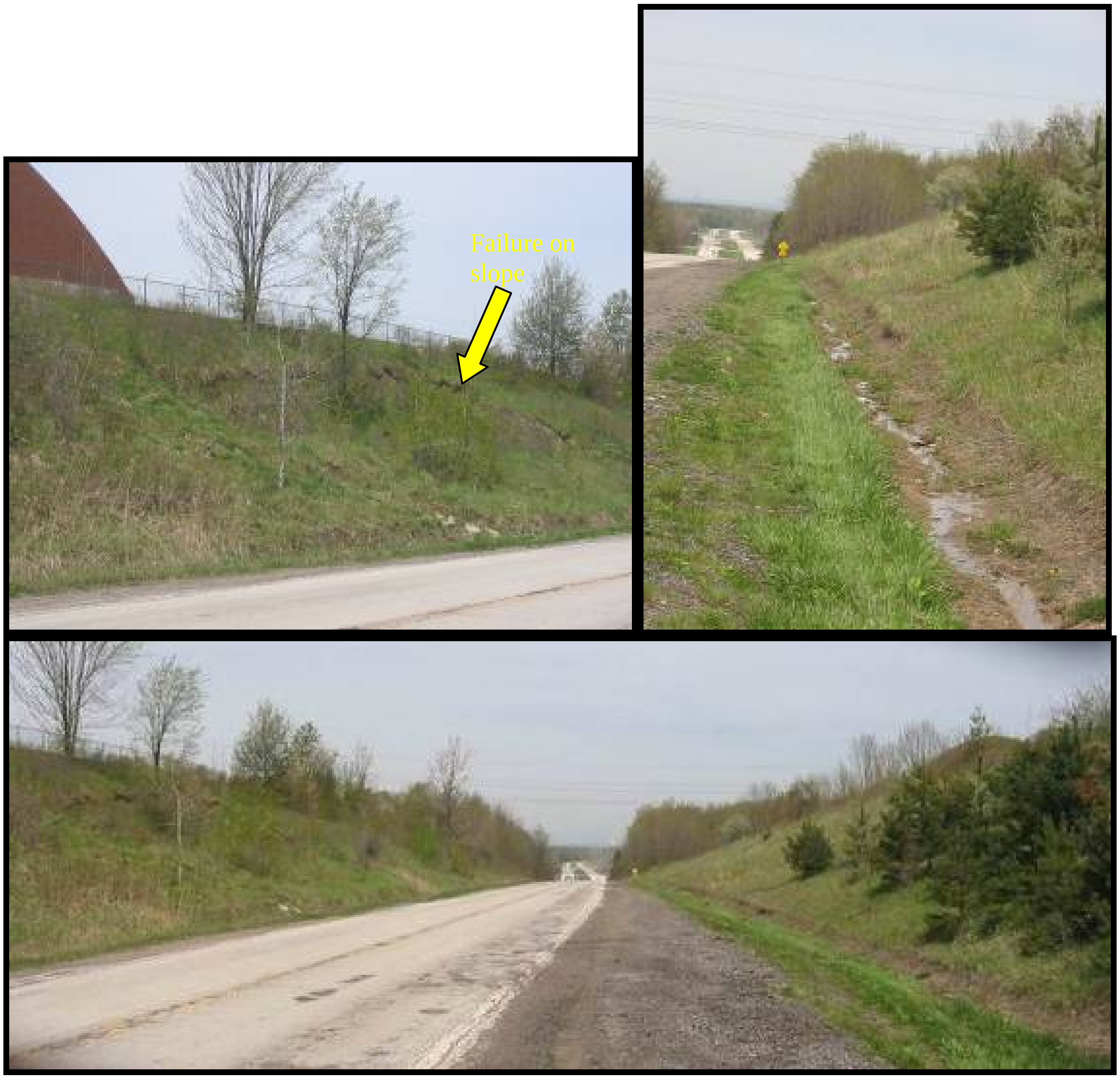
4. <u>Picture set no. 4</u>

<u>Comment on picture set no. 4</u>

There were significant dips that can be seen from long distance. The evidence of the failed slope can be noticed from misalignment of the guardrail. The longitudinal cracks paralleled to the fogline. It was not clear evidence that these cracks were related to the slope movement. The river below was suspected to cause erosion at the toe of slope. At the tilted guardrail (affected area), a concrete pipe was found. This pipe is connected to the farm opposite to the failed site, which may be another cause of erosion.

- **Movement location/impact:** On slope with high potential to affect roadway/ 81 points
- **Hazard to traveling public:** 1-3 inches of displacement/ 81 points
- **Maintenance response:** Requires observation with periodic maintenance/ 9 points

5. <u>Picture set no. 5</u>

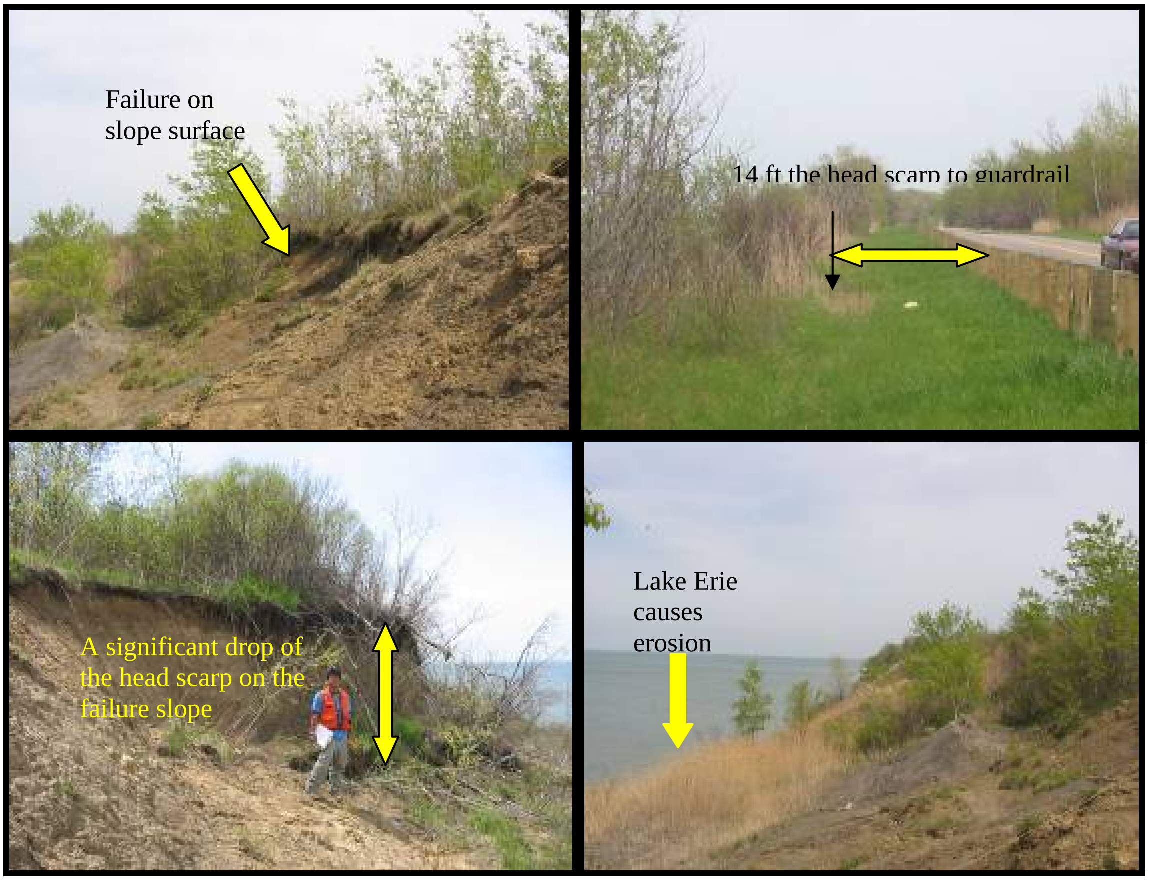


<u>Comment on picture set no. 5</u>

The failed slopes were observed on both sides of the cut though slope as seen in the pictures. There existed the evidence of groundwater. The area above the cut was wet and has standing water in many places. The ditches at the toe of both sides of slopes were filled with water. There was no evidence of rainfall prior to the day of the site visit. The water may come from the groundwater seepage. The slope on the southbound lane has a catch basin and concrete pipe connected from the building above the slope and daylights at the flank and drain water to the toe of slope. This was suspected to be another cause of instability. There were longitudinal cracks on the road but they were not influenced by the slope failure.

- **Movement location/impact:** On slope with high potential to affect structure beyond right of way/ 81 points
- **Hazard to traveling public:** no failure/ 3 points
- **Maintenance response:** Requires observation with periodic maintenance/ 9 points

6. Picture set no. 6



Comment on picture set no. 6

The wave induced by Lake Erie generated severe erosion at the toe of this failed slope. Some evidences showed that the roadway had been shifted form the original position several times. The closest head scarp was 14 ft from the guardrail. There was no crack found on the pavement surface but the erosion may affect the roadway structure any time. The closest distance between Lake Erie and the roadway at the failed slope location is approximately 200 ft. The roadway surface is approximately 80 ft above the lake. The failed slope area consisted of a series of collapsing failures. The maximum vertical displacement of the average head scarp was more than 8 ft.

- **Movement location/impact:** On slope with high potential to affect the roadway/ 81 points
- **Hazard to traveling public:** no failure/ 3 points
- **Maintenance response:** Requires observation with periodic maintenance/ 9 points

7. **<u>Picture set no. 7</u>**

Comment on picture set no. 7

There was no evidence of failure on the roadway surface. The failure type of the failed slope appeared to be the creep failure. Many areas on the slope surface were saturated with water. The soil type that is found on the slope is soft to medium stiff brown silty clay mixed with gravels. The failed slope is suspected to be a construction related failure.

- **Movement location/impact:** Failure only found on the slope/ 3 points
- **Hazard to traveling public:** no failure evidence on road/ 3 points
- **Maintenance response:** Requires observation with periodic maintenance/ 9 points

8. **<u>Picture set no. 8</u>**

Comment on picture set no. 8

This failed slope is a big ancient landslide. The most active part was located at the toe of slope because it is adjacent to the river. The failed slope was found to be very active. There were many vertical displacements on the uphill slope, which was approximately 50 to 70 feet above the roadway. No crack was found on the road surface. The toe of the failed slope is cut out in some parts. It is suspected that the displaced mass may have failed onto the roadway because the roadway ditch was found to be recently cleaned.

The slope surface is hummocky with numerous cracks along the surface. Numerous tension cracks were found in the area between the roadway and the river as well. Springs and hydro-plants were found in many places on the area upslope. Material found on slope composes of dense brown clayey sand with numerous sandstone and rock fragments of gravel to boulder size

- **Movement location/impact:** On slope with high potential to affect the roadway/ 81 points
- **Hazard to traveling public:** no evidence of failure on road/ 3 points
- **Maintenance response:** Requires immediate response/ 81 points

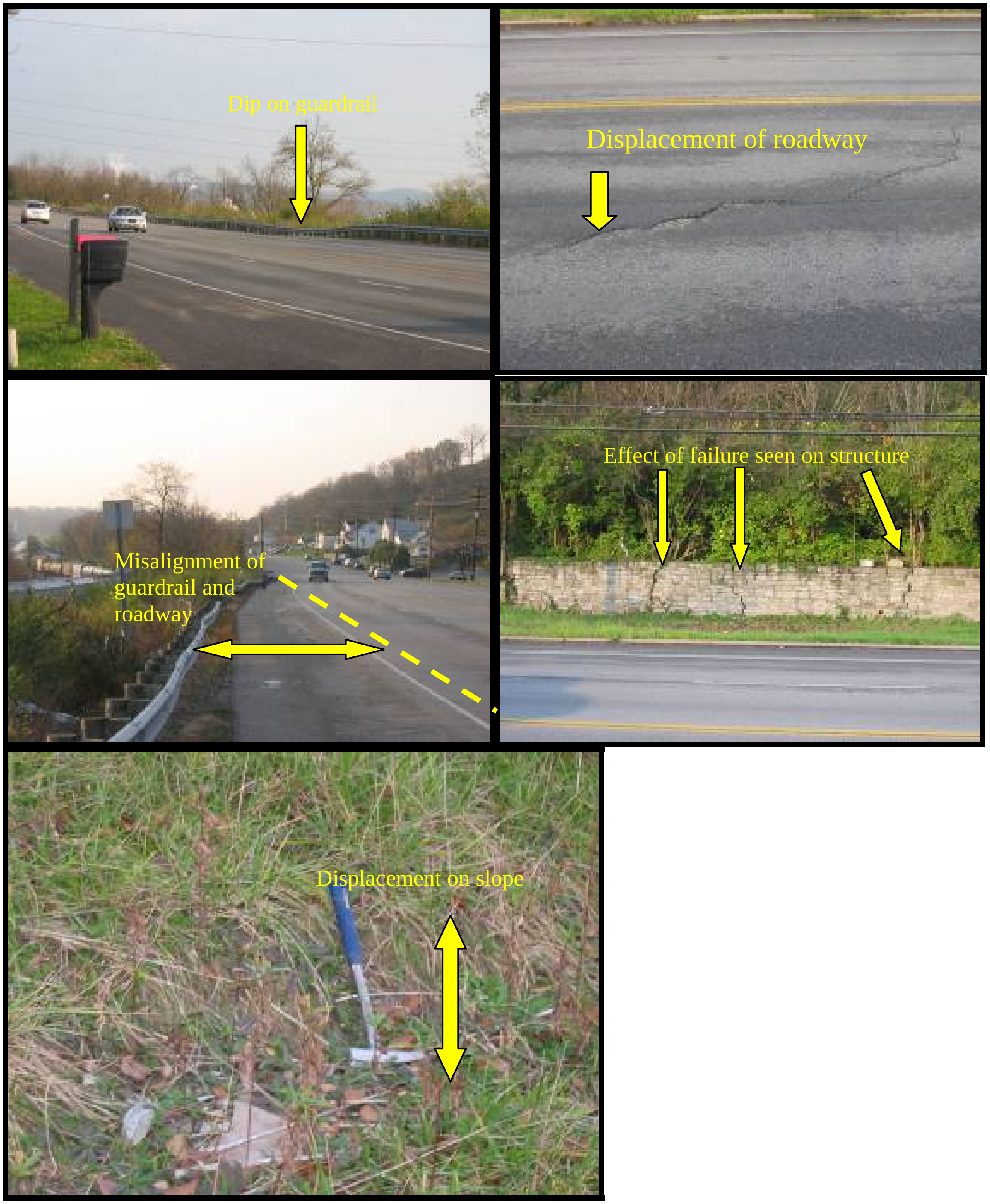
9. Picture set no. 9

Comment on picture set no. 9

Vertical displacements in roadway were noticeable in both directions. These might cause accident to the traveling public. Ponding water was found in the roadway median between two traffic directions. The problems might be generated from this standing water. There was no evidence of slope failure on slope. The roadway dip may be generated from creeping of materials in the slope and may trigger the larger slope failure in the future.

- **Movement location/impact:** On slope with high potential to affect the roadway/ 81 points
- **Hazard to traveling public:** more than 3 inches/ 81 points
- **Maintenance response:** Requires immediate response/ 81 points

10. Picture set no. 10



Comment on picture set no. 10

The roadway and the guardrail have moved downslope for several feet. A railroad is located at the toe of the failure slope. Numerous cracks and vertical displacements (drops) were found on the surface of road. The vertical displacements were approximately greater than 3”. The failed slope was suspected to be a deep seat landslide. The roadway is found to be located in the middle of landslide. The head scarp of this failed slope might be located beyond the white brick wall above the roadway. The evidence of failure can be seen on the wall behind the roadway as well.

- **Movement location/impact:** On slope with high potential to affect the roadway/ 81 points
- **Hazard to traveling public:** more than 3 inches/ 81 points
- **Maintenance response:** Requires immediate response/ 81 points

## 11.	Picture set no. 11

Comment on picture set no. 11

The failed slope was located on the side of embankment above the culvert. The failure was found to be a shallow rotational landslide. The failure appeared to have a minor effect to the roadway. The hair line cracks were found on the surface of roadway, which paralleled to fogline and shoulder. The displacements of these hairline cracks were up to 1”. The materials found in the embankment were a combination of silt, weathered shale and clay (medium to stiff). It was speculated that the problem might start from the running water in the creek at the toe of the failed slope, which are weakening the soil strength and washing away the materials at the toe of the slope.

- **Movement location/impact:** On slope and low potential to affect shoulder/ 3 points
- **Hazard to traveling public:** more than 1”/ 9 points
- **Maintenance response:** Requires observation and periodic maintenance / 9 points

12. <u>Picture set no. 12</u>

Comment on picture set no. 12

The failed slope was located at an embankment approach of a bridge-crossing railroad. The failure can be clearly seen on the roadway shoulder. The vertical and horizontal displacements were up to 7”. The displacement was also found on the retaining wall downslope, which had approximately 2 to 3”. A railroad is located next to the retaining wall. The standing water was found behind the retaining wall, which exerted the additional pressure acting on the wall. The materials on the embankment are composed of very highly to highly silt stone / shale.

- **Movement location/impact:** On slope with high potential to affect roadway/ 81 points
- **Hazard to traveling public:** more than 3”/ 81 points
- **Maintenance response:** Response immediately / 81points

13. <u>Picture set no. 13</u>

<u>Comment on picture set no. 13</u>

The slope failure was located on the highway embankment along the river. It was a recent paved roadway but the displacements were noticeable. It was suspected that this failed slope may have a high rate of movement and have been frequently maintained. The thickness of pavement was up to 1.5 ft in some locations. The vertical and horizontal displacements on roadway surface were varied from the hairline cracks up to 4”. The undulations of roadway and guardrail were noticeable. The causes of this failed slope were suspected to be related to the material degradation and the construction technique. Another cause of failure may be generated from toe erosion by the river.

- **Movement location/impact:** Failure is on the roadway and have high potential to cause hazard/ 81 points
- **Hazard to traveling public:** more than 3”/ 81 points
- **Maintenance response:** Response immediately / 81points

14. <u>Picture set no. 14</u>

<u>Comment on picture set no. 14</u>

A creek was located at the toe of the failed slope. The old rip-rap was found at the toe for the erosion protection. A culvert was found on the other side of the roadway. There was the standing water where the culvert daylights. The water was also found at the roadway median. Springs and seeps were found flowing out of the slope at the failed slope location. The slope surface was hummocky. Material found on slope was very soft to medium stiff clay. Cracks were present on the pavement and shoulder with the displacements up to 1.5”. It was suspected that the failed slope may be the result of malfunction of the drainage system and the effect of the running water in the creek.

- **Movement location/impact:** Failure is on the shoulder with the moderate potential to cause hazard/ 27 points
- **Hazard to traveling public:** less than 3 inches/ 27 points
- **Maintenance response:** Require routine maintenance response/ 81points

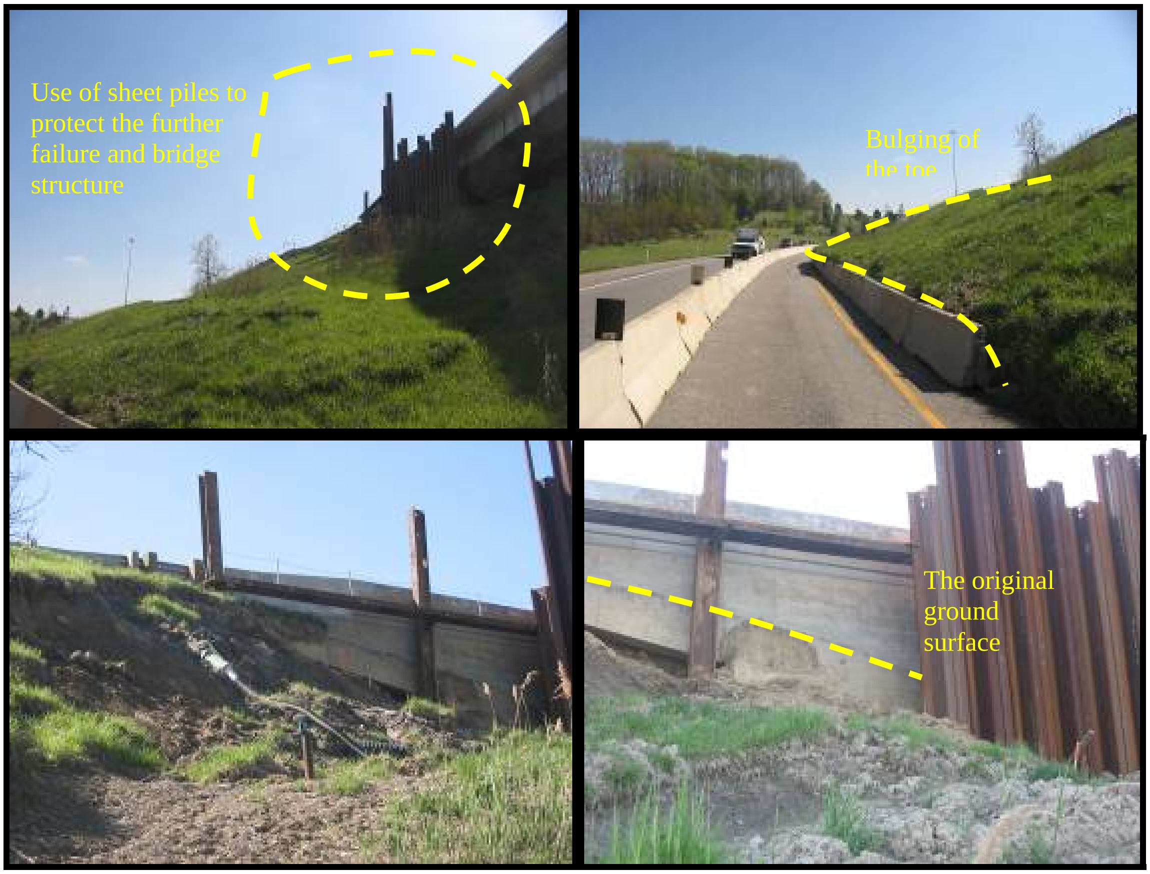
15. <u>Picture set no. 15</u>

Comment of picture set no. 15

The failure was located on the slope above the highway. Groundwater seepage was found throughout the failed slope. There were a small road and a drainage ditch on the top of the slope. The cause of the failed slope was suspected to be the malfunction of the drainage ditch on the top slope, which may release water to the slope surface. There was no failure found on the roadway.

- **Movement location/impact:** Failure has no effect to the roadway/ 3 points
- **Hazard to traveling public:** No displacement on road/ 3 points
- **Maintenance response:** Require observation and periodic maintenance / 9 points.

16. Picture set no. 16

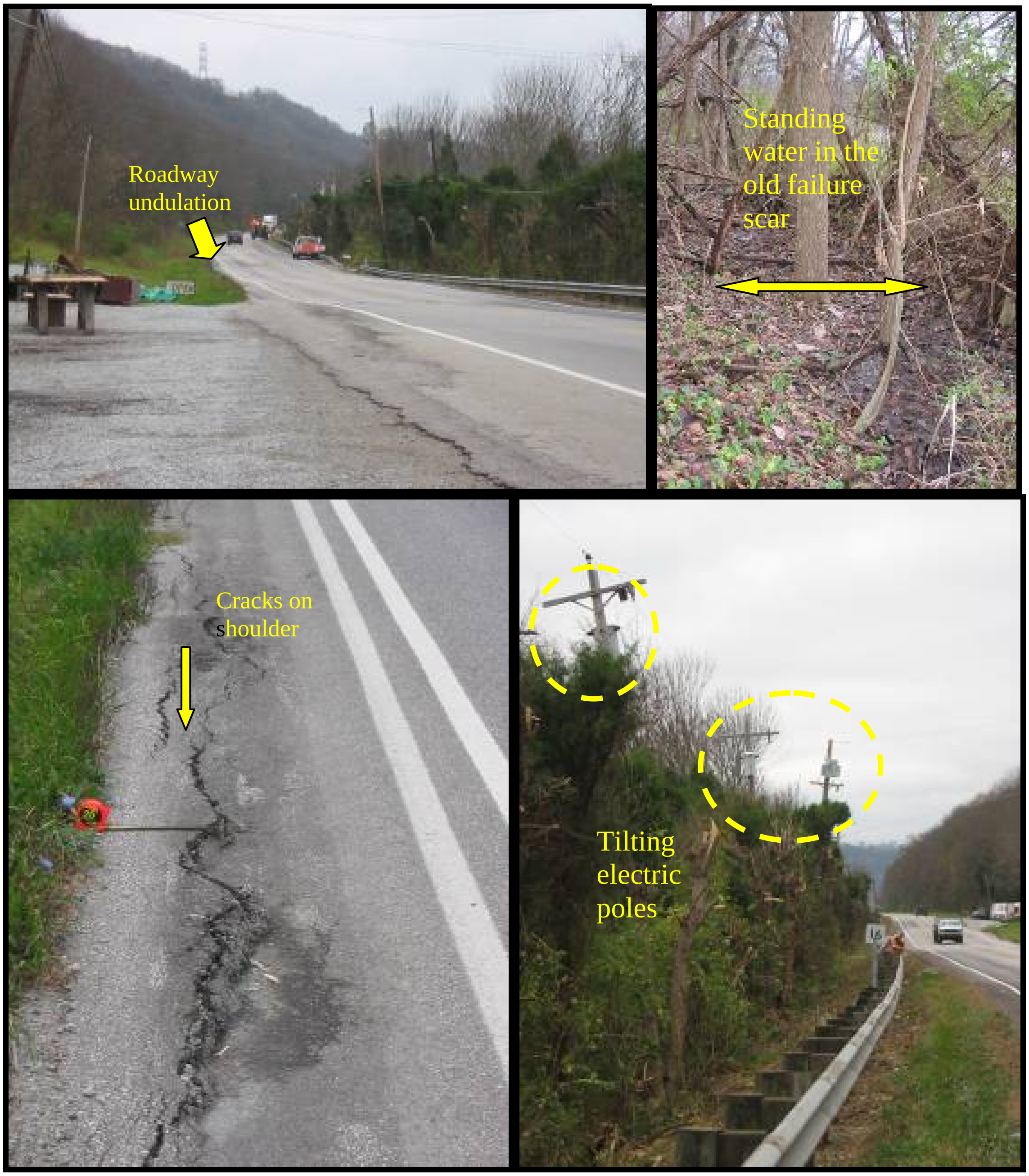


Comment on picture set no. 16

The failed slope was located at a busy four-lane highway intersection. The concrete barriers were placed at the toe of slope to protect the displaced material from reaching the moving traffic. The sheet piles were driven to protect the slope from the progressive failure. The vertical displacements of the failed slope were large, which can be seen at the exposed bridge structure.

- **Movement location/impact:** Failure affects the highways above and below the slope. It also affect the stability of bridge structure/ 81 points
- **Hazard to traveling public:** Displacement is on the road/ 81 points
- **Maintenance response:** Require immediate response for safety of traveling public and the stability of the bridge structure/ 81 points.

17. Picture set no. 17



<u>Comment on picture set no. 17</u>

The failed slope location is located on a large active rotational landslide. The fluctuation of the Ohio River was suspected to aggravate the instability of the failed slope. The failure evidence can easily be seen from the tilting of telephone pole and the misalignment of the guardrail. The vertical and horizontal displacements on roadway such as cracks and roadway undulations were noticeable. There were the wet old and still active minor scarps with the depth and width approximately 2-4 feet. The effect of the failed slope may also affect the houses that locate at the toe of slope.

- **Movement location/impact:** Failure found on the roadway with high potential to affect roadway and structures/ 81 points
- **Hazard to traveling public:** displacement less than 3 inches / 27 points
- **Maintenance response:** Require routine maintenance response / 27 points.

APPENDIX E

THE COLLECTED DATA AND SITE SKETCHES OF EXERCISE EXAMPLES PROVIDED IN CHAPTER IV

LANDSLIDE INFORMATION OF EXAMPLE1

Landslide Observation Report filed by Highway/construction worker

Name of reporter		Brent Black
Affiliation (District)		11
Date		5/11/2004
Site Location	**County**	Belmont
	Route	S.R. 7
	Mile marker (county basis)	2.31

Description (Visual Inspection)

Landslide material(s)	√ Soil _Rock _Both
Number of lanes (one direction)	√ 1 _2 _3 _4 _5 _6
Posted speed limit (miles/hr)	_15 _20 _25 _30 _35 _40 _45 _50 √ 55 _60 _65 _70
Location of landslide relative to roadway	_Above roadway √ Below roadway _both
Position of impact on roadway	Position of cracks/dips: √ Pavement √ Shoulder _Ditch _None Position of earth debris: _ Pavement _Shoulder _Ditch √ None
Impact to adjacent structures or properties	_Roads _Railroads _Residential _Buildings _Commercial √ Bridge _Utilities _Others_______
Vegetation	Barren_% Grass _% Shrub_% Tree 100% Other_______
Presence of surface water	√ Yes _No
Presence of groundwater	√ Yes _No _Unknown
Previous site works (Based on observation at the site)	_Temporary _Failed temporary _Permanent _Failed permanent √ Patching of asphalt _Guardrail work _Other
Recent precipitation	_Heavy _Moderate √ Light
Duration	_24-hr _3-d √ 7-d _15-d
Date identifying first evidence of instability	Unknown
Name of verifier (CM/TM)	-
Date of verification	-
Signature	-

Part A filed by Transportation/County Manager

Evaluator's name	Brent Black
Date of observation	5/13/2004

Site Location

Jurisdiction	_County _Turnpike _Municipal √ State _Township _Federal _Private
County	Belmont
District	11
Route system	_**IR**-interstate _**US**-United States route √ **SR**-state route _**CR**-county road _**TR**-township road _**MR**-municipal road _**RA**-ramp _**PA**-park roads _**BK**-bike route
Route number	7
Mile marker (county basis)	Beginning: 2.31 Ending: 2.37
Network linear feature (NLF) (auto generation)	SBELSR007**C
Number of Lanes (one direction)	√ 1 _2 _3 _4 _5 _6
Location of landslide relative to roadway	_Above roadway √ Below roadway _Both

Centroid of Affected Highway (GPS Information)

GPS coordinates	Centroid: Latitude: 80° 47' 46.44 W Longitude: 39° 52' 28.29 N Elevation: 174.95 ft
	Beginning point: Latitude: N.A. Longitude: N.A. Elevation: N.A.
	Ending point: Latitude: N.A. Longitude: N.A. Elevation: N.A.
State coordinates (Mid-point) (Auto generation)	Zone: South Northing: 209476.250530 Easting: 745744.490229
USGS Quad (Auto generation)	Name: PAWHATAN POINT Number: 3908067

A.1/3

Landslide vulnerability table

Probability of additional movement	Probability of significant impacts to the roadway, structures, adjacent property or features			
	Very High	*High*	*Moderate*	*Low*
Very High	Very High	Very High	High	Moderate
High	Very High	High	High	Moderate
Moderate	High	High	Moderate	Low
Low	Moderate	Moderate	Low	Low

Remark: A landslide site having "low" vulnerability is non-rated.

General information

General dimensions (Rough estimate)	Length (ft): 250 Width (ft): 350 Estimated maximum depth of sliding surface (ft) ~40-50ft
Preliminary rating (Use landslide vulnerability table)	√ Rated _Non-rated
Inspection frequency	_Hourly _Daily √ Weekly _Biweekly _Monthly _Quarterly _Yearly _Others____

A.2/3

Part B filed by Transportation/County Manager

Evaluator's name	Brent Black
Date of observation	5/13/2004

Site Location

Jurisdiction	_County _Turnpike _Municipal √ State _Township _Federal _Private
County	Belmont
District	11
Route system	_**IR**-interstate _**US**-United States route √ **SR**-state route _**CR**-county road _**TR**-township road _**MR**-municipal road _**RA**-ramp _**PA**-park roads _**BK**-bike route
Route number	7
Mile marker (county basis)	Beginning: 2.31 Ending: 2.37
Network linear feature (NLF) (auto generation)	SBELSR007**C
Number of lanes (one direction)	√ 1 _2 _3 _4 _5 _6
Location of landslide relative to roadway	_Above roadway √ Below roadway _Both

Site History

Date of original construction (m/d/y)	___/___/___
Date of alignment modifications (m/d/y)	___/___/___
Date of remedial activities (m/d/y)	___/___/___
Past remedial activities	_Drainage _Bio-stabilization _Slope geometry correction _Retaining structures _Internal slope reinforcement _Erosion control _Chemical stabilization _Others unknown
Existing remediation	_Drainage _Bio-stabilization _Slope geometry correction _Retaining structures _Internal slope reinforcement _Erosion control _Chemical stabilization _Others unknown
Annual maintenance frequency (times/year)	unknown
Annual maintenance cost (Average Over the Past 5 to 10 Years) (dollars/year)	unknown
Maintenance response (Based on judgment)	_No response _Require observation with periodic maintenance _Require routine maintenance response to preserve roadway √Require immediate response for safe travel or to protect adjacent structure

B.1/2

Traffic Data

Average daily traffic (ADT)	Total traffic: 6410 vehicles/day Passenger traffic: unknown vehicles/day Trucks traffic: unknown vehicles/day
Accident history in past 10 years (Number of occurrence)	Number of accident in past 10 years____ Number of accident without loss____ Number of accident with vehicle and property damage____ Number of accident with injury 1 Number of accident with fatality__
Estimated detour route length (miles)	unknown miles
Posted speed limit (miles/hr)	_15 _20 _25 _30 _35 _40 _45 _50 √ 55 _60 _65 _70
Estimated traveling time of detour (hr)	Truck unknown hr Passenger unknown hr

Part C (District Geotechnical Engineer)

Evaluator's name	Brent Black
Date of observation	5/13/2004

Site Location verified by DGTE (provide O.K. click button)

Jurisdiction	_County _Turnpike _Municipal √ State _Township _Federal _Private
County	
District	
Route system	_**IR**-interstate _**US**-United States route √ **SR**-state route _**CR**-county road _**TR**-township road _**MR**-municipal street _**RA**-ramp _**PA**-park roads _**BK**-bike route
Route number	7
Mile marker (county basis)	Beginning: 2.31 Ending: 2.37
Network linear feature (NLF) (auto generation)	SBELSR007**C
Number of lanes (one direction)	√ 1 _2 _3 _4 _5 _6
Location of landslide relative to roadway	_Above roadway √ Below roadway _Both

Centroid of Affected Highway (GPS Information) verified by DGTE (provide O.K. click button)

GPS coordinates	Centroid: Latitude: 80° 47' 46.44 W Longitude: 39° 52' 28.29 N Elevation: 174.95 ft Beginning point: Latitude: N.A. Longitude: N.A. Elevation: N.A. Ending point: Latitude: N.A. Longitude: N.A. Elevation: N.A.
State coordinates (Mid-point) (Auto generation)	Zone: South Northing: 209476.250530 Easting: 745744.490229
USGS Quad (Auto generation)	Name: PAWHATAN POINT Number: 3908067

Part C (continued)

Required information for data collection (use landslide vulnerability table)

Low (0< X ≤ 2 points)	Moderate and High (2< X ≤ 9 points)	Very high (X > 9 points)
• Verify and fill out C.1 • Very rough sketches by CM/TM • Take additional photos C.14	• Verify and fill out C.1 • Fill out C.2 to C.11 • Verify rough sketches by CM/TM • Take additional pictures C.14	• Verify and fill out C.1 • Fill out C.2 to C.13 • Take additional photos C.14

Landslide vulnerability table

Probability of additional movement (A)	Probability of significant impacts to the roadway, structures, adjacent property or features (B)			
	Very High(4)	*High(3)*	*Moderate(2)*	*Low(1)*
Very High(4)	Very High (16)	Very High (12)	High (8)	Moderate (4)
High(3)	Very High (12)	High (9)	High (6)	Moderate (3)
Moderate(2)	High (8)	High (6)	Moderate (4)	Low (2)
Low(1)	Moderate (4)	Moderate (3)	Low (2)	Low (1)

Vulnerability score (X) = A× B

Inspection schedule

Inspection frequency	__Hourly __Biweekly __Yearly	__Daily __Monthly __Others__________	√ Weekly __Quarterly

C.2/14

Part C (continued)

Slope Characteristics

Slope type		__Natural __Cut __Fill √ Cut and fill
Average slope angle (α_{ave}°)		$\alpha_{ave} = \frac{\alpha_1 \cdot l_1 + \alpha_2 \cdot l_2 + ... \alpha_n \cdot l_n}{L} = 25^{\circ}$
Slope surface appearance		__Straight __Concave __Convex √ Hummocky __Terraced __Complex
Vegetation cover		__Grass__% __Shrub__% __Cultivated land__% __Reforestation__% √ Woodland 100% __Other______________
Vegetation density		__Sparse __Moderate √ Dense
Hydrogeology	**Surface water**	**Types of water sources** __Reservoir __Lake __River √ Creek __Pond __Surface drainage __Others__________ __None **Location of water sources that may affect landslide** __Above √ Below __Both
	Groundwater (use visual inspection)	**Groundwater flow** __Into landslide __Off landslide __Both √ Unknown __None **Groundwater condition** __Spring __Seep __Both √ Unknown __None **Location of ground water:** __Above __Below __Middle __None **Presence of monitoring or water well** __Artesian __Flowing artesian __Pooled √ None observed
Erosion area		√ Head __Toe __Flank __Body __None
Possible cause of failure		√ Erosion of the toe __Precipitation __Failure of drainage __Drainage outlet __Surface water √ Weathering of materials __Deforestation __Change of water level
Orientation of slope (Azimuth; The clockwise angle from the north)		N.A. degree
Direction of landslide (Azimuth; The clockwise angle from the north)		N.A. degree

C.3/14

Part C (continued)

Slope Materials (by Visual Inspection and Judgment)

Soil origin	√ Colluvium √ Weather rock Others √ Alluvium _Unweathered rock _Till √ Fill _Residual soil _Combination
Soil type	_Boulders/cobbles _Fine sand _Clayey sand √ Combination √ Others Local called "red dog", Slake _Stone fragments _Silty gravel _Silty soil √ Gravel _Silty sand √ Clayey soil _Sand _Clayey gravel _Organic
Rock type	√ Shale _Limestone _Combination _Others _Mudstone /claystone _Coal _Siltstone _Interbedded _Sandstone _Dolomite

Landslide Characteristics

Type of Movement (Rockfall is not included.)	**Slide**	_Rotational rock slide _Rotational earth slide _Debris slide _Translational rock slide √ Translational earth block slide _Complex
	Flow	_Slow earth flow _Dry sand flow _Debris flow _Complex _Loess flow _Debris avalanche _Block stream
	Spread	_Rock spread _Complex spread _Earth spread
Rate of movement		______ inches/year √ unknown
State of landslide activity		√ Active _Inactive _Mitigated

Observed Remediation

Past remedial activities	_Drainage _Slope geometry correction _Internal slope reinforcement _Chemical stabilization _Others unknown _Bio-stabilization _Retaining structures _Erosion control
Existing remediation	_Drainage _Slope geometry correction _Internal slope reinforcement _Chemical stabilization _Others None observed _Bio-stabilization _Retaining structures _Erosion control

Part C (continued)

Preliminary Determination of Causes of Landslide

Human activities	_Excavation/under cutting _Deforestation _Defective maintenance _Water leakage from pipes _Loose waste dumping _Others _Groundwater pumping _Loading _Failure of drainage _Artificial vibrations √ Construction related
Natural activities	√ Rainfall _Earthquake _Loss of vegetation √ Inadequate long term strength _Surface water level change/rapid drawdown √ Degradation of construction material _Others _Snowmelt _Ground water _Toe erosion
Comment (limit no more than 50 words)	

Observed Traffic Information

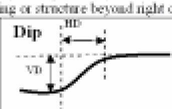
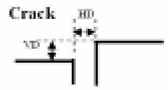
Actual sight distance (ASD) (ft.)	300 ft
Percent decision sight distance (%DSD) %DSD=(ASD/DSD)*100	34 %

Decision sight distance (DSD)

Posted speed limit (mph)	Decision sight distance (ft)
25	375
30	450
35	525
40	600
45	675
50	750
55	875
60	1000
65	1050
70	1100

Part C (continued)

Impact assessment on roadway and beyond right of way

Current and potential impact of landslide on roadway	__On slope with a low potential to affect shoulder __On slope with a low potential to affect roadway __On shoulder or on slope with a moderate potential to affect roadway √ On roadway, or on slope with a high potential to affect roadway or structure	
Current and potential impact of landslide on the area beyond right of way	__On slope with a low potential to impact area beyond right of way __On slope with a moderate potential to impact area beyond right of way __On slope with a high potential to impact area beyond right of way __On slope with a high potential to impact building or structure beyond right of way	
Evidence of impact on roadway	**Dip** √ Yes __No **Maximum displacement of dip** Vertical displacement (VD) (inch) ≥3 Horizontal displacement (HD) (inch) ≥3	**Dip** 
	Crack √ Yes __No **Maximum displacement of crack** Vertical displacement (VD) (inch) ≥3 Horizontal displacement (HD) (inch) ≥3	**Crack** 
	Earth debris on roadway __Yes √ No Estimated volume (Yd^3)______	

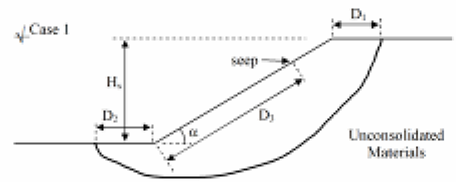
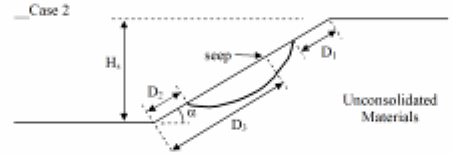
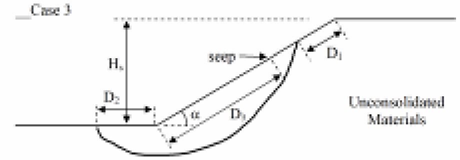
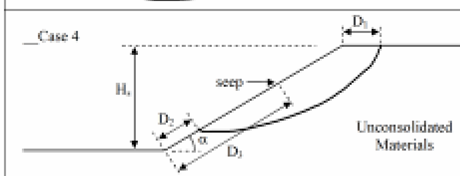
Adjacent Structures and Areas

Adjacent structures	__Roads __Railroads __Residential __Buildings √ Bridge __Utilities __Others______
Surrounding area	√ Forest __Agriculture √ Rural __Urban __Housing development __Others______

C.6/14

Part C (continued)

Information for estimation of landslide repair cost

√ Case 1 	1. Average slope angle, α, 25° 2. Height of slope, H_s (ft) 55 3. Length of slope repair, L, parallel to highway (ft) 250 4. Distance from crest of slope to failure surface, D_1(ft) 40 5. Distance from toe of slope to failure surface, D_2 (ft) 50 6. Distance along slope (measured from toe) to groundwater seeps, D_3, and approximate quantities of groundwater (ft) unknown
__Case 2 	1. α______ 2. H_s (ft)______ 3. L(ft)______ 4. D_1(ft)______ 5. D_2(ft)______ 6. D_3(ft)______
__Case 3 	1. α______ 2. H_s (ft)______ 3. L(ft)______ 4. D_1(ft)______ 5. D_2(ft)______ 6. D_3(ft)______
__Case 4 	1. α______ 2. H_s (ft)______ 3. L(ft)______ 4. D_1(ft)______ 5. D_2(ft)______ 6. D_3(ft)______

Cost Estimate

Repair cost	unknown
Benefit cost ratio	unknown
Estimated time required for remediation (days)	unknown days

C.7/14

Part C (continued)

Suggested Remediation Measure

√__Benching & regarding
√__Counter berm & regrading
__Flattening Slope
__Soil Drainage
__Bedrock Drainage
__Retaining Walls
__Light Weight Fills
__Dynamic Compaction
__Bio-engineering
__Geofabrics
__Sheet Piling
__H Piling
__Drilled Piling
__Soil Nailing
__Tieback Walls
__Remove & Replace
__Shear Key
__Chemical Treatment
__Relocation
__Bridge
__Change Line or Grade
__Other______________

C.8/14

Part C (continued)

Sources of Supplemental Information

__Aerial photos	√_Field visit
__Satellite imaginary	__Local people
__County-ODOT	__Dist-ODOT
√_State-ODOT	__City and county engineer
__Soil/Rock/Water samples	__GPS features
__Folder/ File location	__Academia with engineering or geology program
__USGS publications and files	__USGS Quadrangles

__USGS open file map series #78-1057 "Landslide related features"
__Division of geological survey (ODNR)
__Division of mineral resource management (ODNR)
__Division of soil and water (ODNR)
__Others____________________________________

C.9/14

Part C (continued)

Landslide hazard rating matrix

CATEGORY		RATING CRITERIA and SCORE Points 3	Points 9	Points 27	Points 81	Total Item Scores
Movement location/ impact (select higher score)	Current and potential impact of landslide on roadway	On slope with a low potential to affect shoulder	On slope with a low potential to affect roadway	On shoulder, or on slope with a moderate potential to affect roadway	On roadway, or On slope with a high potential to affect roadway or structure	81
	Current and potential impact of landslide on area beyond right of way	On slope with a low potential to impact area beyond right of way	On slope with moderate potential to impact area beyond right of way	On slope with high potential to impact area beyond right of way	On slope with high potential to impact structure beyond right of way	
Hazard to traveling public (Select higher score)	Rate of displacement in roadway if known	<1-inch/year	1 to 3-inches/year No single event ≥1-inch	3 to 6-inches/year No single event ≥3-inches	>6-inches/year Single event ≥3-inches	81
	Evidence of displacement in roadway	Visible crack or dip no vertical drop	≤1-inch of displacement	1 to 3-inches of displacement	≥ 3-inches of displacement	
Maintenance (Select higher score)	Maintenance frequency	None to rare	Annually (one time/year)	Seasonal (1 to 3 times/ year)	Continuous throughout year (> 3 times/year)	81
	Maintenance response	No response	Requires observation with periodic maintenance	Requires routine maintenance response to preserve roadway	Requires immediate response for safe travel or to protect adjacent structure	
%Decision Sight Distance (%DSD)		≥ 90	89 -50	49-35	< 34	81
ADT		<2000	2001-5000	5001-15000	>15001	27
Accident history (Related to landslide)		No accident	Vehicle or property damage	Injury	Fatality	27
					Total Score	378

C.10/14

Part C (continued)

Hazard calculation sheet

Hazard category	Explanation	Item Scores
1. Movement Location/ Impact	The impact of slope failure is observed on both traffic lanes. Dips and cracks are noticeable on both traffic directions. Significant drops and separation between the fill material and bridge structure are noticeable as well as misalignment of guardrail.	81
2. Hazard to Traveling Public	The rate of movement is not available at the time that the investigation is conducted. The displacement observed on road is used. It is about a foot separation between bridge structure and fill material. Due to the recent pave roadway surface, the displacement on road is not visible.	81
3. Maintenance	The maintenance history is also not available. However, some cracks on the bridge substructure and separation between the fill material and the bridge are observed. The response for maintenance is judged to be high, which requires the immediate response.	81
4. %DSD	The speed limit at the site location is 55 miles/hr. The actual sight distance is approximately 300 ft. The calculated DSD is about 34%.	81
5. ADT	10,110 cars/ day	27
6. Accident history (Related to landslide)	Injury	27
	Total score	378

C.11/14

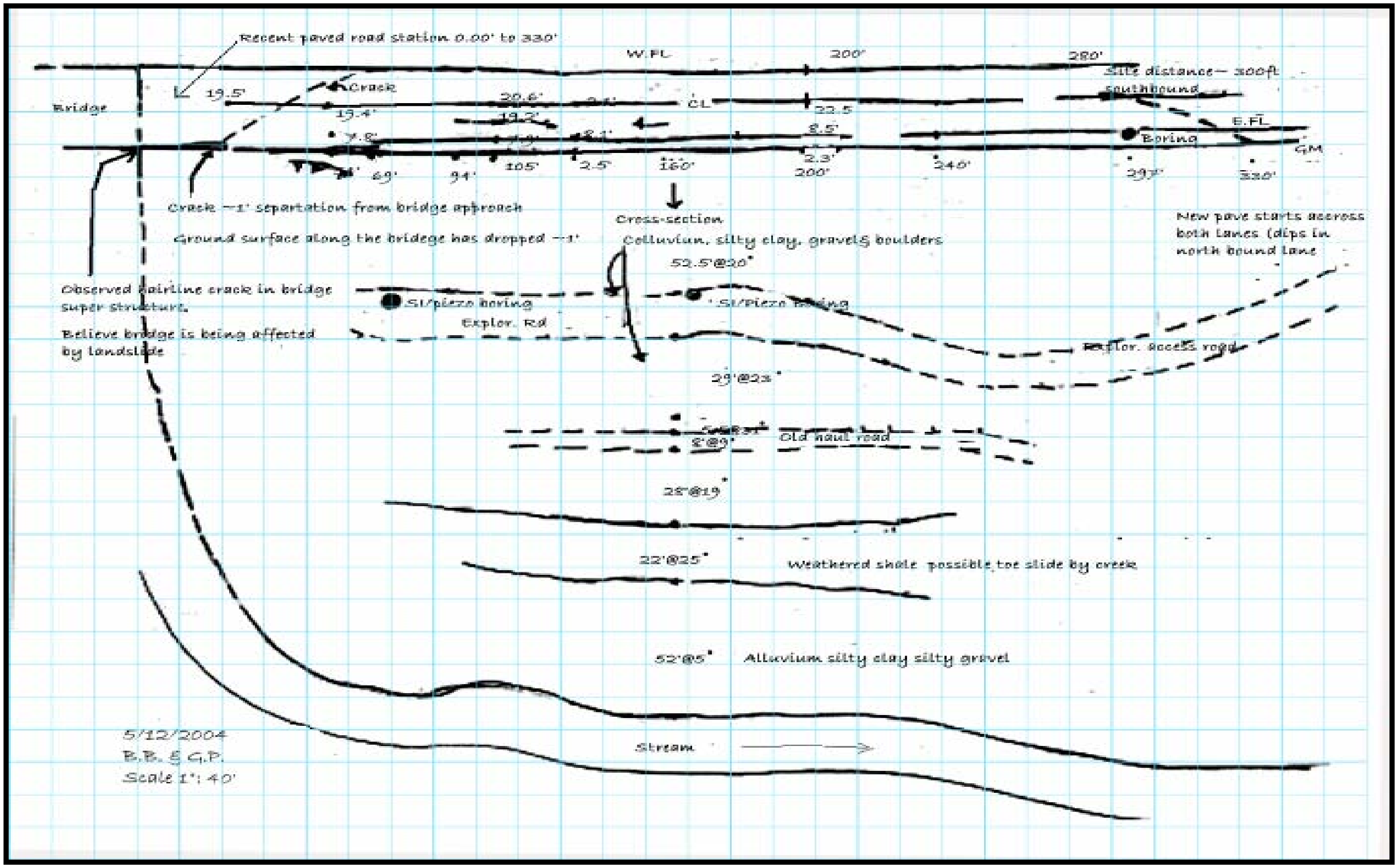


Figure E.1 A plan sketch of Example 1

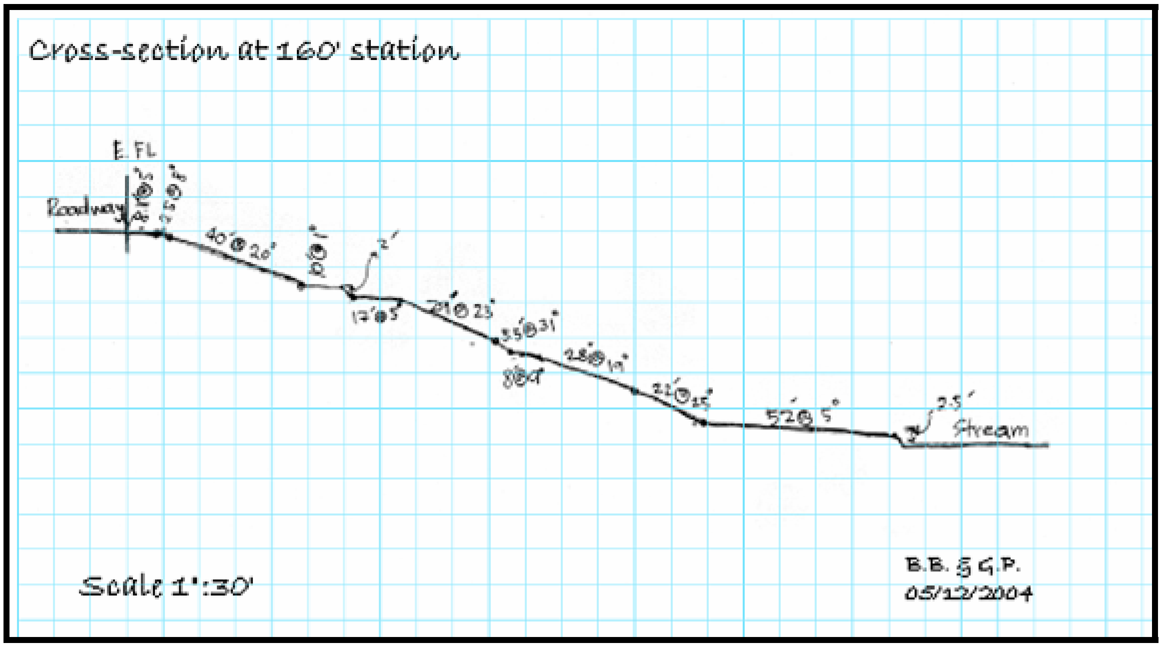


Figure E.2 A cross-section sketch of Example 1

LANDSLIDE INFORMATION OF EXAMPLE 2

Landslide Observation Report filed by Highway/construction worker

Name of reporter		Brent Black
Affiliation (District)		2
Date		5/04/2004
Site Location	**County**	Ottawa
	Route	S.R. 2
	Mile marker (county basis)	17.71

Description (Visual Inspection)

Landslide material(s)	√ Soil _Rock _Both
Number of lanes (one direction)	_1 √2 _3 _4 _5 _6
Posted speed limit (miles/hr)	_15 _20 _25 _30 _35 _40 _45 _50 _55 _60 √ 65 _70
Location of landslide relative to roadway	_Above roadway √Below roadway _both
Position of impact on roadway	Position of cracks/dips: _Pavement √Shoulder _Ditch _None Position of earth debris: _ Pavement _Shoulder _Ditch √None
Impact to adjacent structures or properties	_Roads _Railroads _Residential _Buildings _Commercial _Bridge _Utilities _Others no adjacent structure
Vegetation	Barren _% Grass 100% Shrub _% Tree __% Other________________
Presence of surface water	√ Yes _No
Presence of groundwater	√ Yes _No _Unknown
Previous site works (Based on observation at the site)	_Temporary _Failed temporary _Permanent _Failed permanent √ Patching of asphalt _Guardrail work _Other
Recent precipitation	_Heavy _Moderate √ Light
Duration	_24-hr _3-d √ 7-d _15-d
Date identifying first evidence of instability	Unknown
Name of verifier (CM/TM)	-
Date of verification	-
Signature	-

L.1/1

Part A filed by Transportation/County Manager

Evaluator's name	Brent Black
Date of observation	5/03/2004

Site Location

Jurisdiction	_County _Turnpike _Municipal √State _Township _Federal _Private
County	S.R.
District	2
Route system	_**IR**-interstate _**US**-United States route √ **SR**-state route _**CR**-county road _**TR**-township road _**MR**-municipal road _**RA**-ramp _**PA**-park roads _**BK**-bike route
Route number	2
Mile marker (county basis)	Beginning: 17.71 Ending: 17.72
Network linear feature (NLF) (auto generation)	SOTTSR00002**C
Number of Lanes (one direction)	_1 √2 _3 _4 _5 _6
Location of landslide relative to roadway	_Above roadway √Below roadway _Both

Centroid of Affected Highway (GPS Information)

GPS coordinates	Centroid: Latitude: 83° 0' 10.56 W Longitude: 41° 31' 13.2 N Elevation: 142.97 ft
	Beginning point: Latitude: N.A. Longitude: N.A. Elevation: N.A.
	Ending point: Latitude: N.A. Longitude: N.A. Elevation: N.A.
State coordinates (Mid-point) (Auto generation)	Zone: North Northing: 391024.863750 Easting: 557993.661026
USGS Quad (Auto generation)	Name: LACARNE Number: 41083E1

A.1/3

Landslide vulnerability table

Probability of additional movement	Probability of significant impacts to the roadway, structures, adjacent property or features			
	Very High	*High*	*Moderate*	*Low*
Very High	Very High	Very High	High	Moderate
High	Very High	High	High	Moderate
Moderate	High	High	Moderate	Low
Low	Moderate	Moderate	Low	Low

Remark: A landslide site having "low" vulnerability is non-rated.

General information

General dimensions (Rough estimate)	Length (ft): 80 Width (ft): ~148 Estimated maximum depth of sliding surface (ft) ~15-20ft
Preliminary rating (Use landslide vulnerability table)	√ Rated _Non-rated
Inspection frequency	_Hourly _Daily _Weekly √Biweekly _Monthly _Quarterly _Yearly _Others____

Part B filed by Transportation/County Manager

Evaluator's name	Brent Black
Date of observation	5/03/2004

Site Location

Jurisdiction	_County _Township _Turnpike _Federal _Municipal _Private √State
County	S.R.
District	2
Route system	_**IR**-interstate _**CR**-county road _**RA**-ramp _**US**-United States route _**TR**-township road _**PA**-park roads √ **SR**-state route _**MR**-municipal road _**BK**-bike route
Route number	2
Mile marker (county basis)	Beginning: 17.71 Ending: 17.72
Network linear feature (NLF) (auto generation)	SOTTSR00002**C
Number of lanes (one direction)	_1 √2 _3 _4 _5 _6
Location of landslide relative to roadway	_Above roadway √Below roadway _Both

Site History

Date of original construction (m/d/y)	___/___/___
Date of alignment modifications (m/d/y)	___/___/___
Date of remedial activities (m/d/y)	___/___/___
Past remedial activities	_Drainage _Slope geometry correction _Internal slope reinforcement _Chemical stabilization _Others unknown _Bio-stabilization _Retaining structures _Erosion control
Existing remediation	_Drainage _Slope geometry correction _Internal slope reinforcement _Chemical stabilization _Others unknown _Bio-stabilization _Retaining structures _Erosion control
Annual maintenance frequency (times/year)	unknown
Annual maintenance cost (Average Over the Past 5 to 10 Years) (dollars/year)	unknown
Maintenance response (Based on judgment)	_No response _Require observation with periodic maintenance _Require routine maintenance response to preserve roadway √Require immediate response for safe travel or to protect adjacent structure

Traffic Data

Average daily traffic (ADT)	Total traffic: 16330 vehicles/day Passenger traffic: unknown vehicles/day Trucks traffic: unknown vehicles/day
Accident history in past 10 years (Number of occurrence)	Number of accident in past 10 years_____ Number of accident without loss_____ Number of accident with vehicle and property damage_____ Number of accident with injury __ Number of accident with fatality__
Estimated detour route length (miles)	unknown miles
Posted speed limit (miles/hr)	_15 _20 _25 _30 _35 _40 _45 _50 _55 _60 √ 65 _70
Estimated traveling time of detour (hr)	Truck unknown hr Passenger unknown hr

Part C (District Geotechnical Engineer)

Evaluator's name	Brent Black
Date of observation	5/03/2004

Site Location verified by DGTE

Jurisdiction	_County _Turnpike _Municipal √State _Township _Federal _Private
County	S.R.
District	2
Route system	_**IR**-interstate _**US**-United States route √ **SR**-state route _**CR**-county road _**TR**-township road _**MR**-municipal road _**RA**-ramp _**PA**-park roads _**BK**-bike route
Route number	2
Mile marker (county basis)	Beginning: 17.71 Ending: 17.72
Network linear feature (NLF) (auto generation)	SOTTSR00002**C
Number of lanes (one direction)	_1 √2 _3 _4 _5 _6
Location of landslide relative to roadway	_Above roadway √Below roadway _Both

Centroid of Affected Highway (GPS Information) verified by DGTE (provide O.K. click button)

GPS coordinates	Centroid: Latitude: 83' 0'10.56 W Longitude: 41' 31'13.2 N Elevation: 142.97 ft
	Beginning point: Latitude: N.A. Longitude: N.A. Elevation: N.A.
	Ending point: Latitude: N.A. Longitude: N.A. Elevation: N.A.
State coordinates (Mid-point) (Auto generation)	Zone: North Northing: 391024.863750 Easting: 557993.661026
USGS Quad (Auto generation)	Name: LACARNE Number: 41083E1

Part C (continued)

Required information for data collection (use landslide vulnerability table)

Low (0< X ≤ 2 points)	Moderate and High (2< X ≤ 9 points)	Very high (X > 9 points)
• Verify and fill out C.1 • Very rough sketches by CM/TM • Take additional photos C.14	• Verify and fill out C.1 • Fill out C.2 to C.11 • Verify rough sketches by CM/TM • Take additional pictures C.14	• Verify and fill out C.1 • Fill out C.2 to C.13 • Take additional photos C.14

Landslide vulnerability table

Probability of additional movement (A)	Probability of significant impacts to the roadway, structures, adjacent property or features (B)			
	Very High(4)	*High(3)*	*Moderate(2)*	*Low(1)*
Very High(4)	Very High (16)	Very High (12)	High (8)	Moderate (4)
High(3)	Very High (12)	High (9)	High (6)	Moderate (3)
Moderate(2)	High (8)	High (6)	Moderate (4)	Low (2)
Low(1)	Moderate (4)	Moderate (3)	Low (2)	Low (1)

Vulnerability score (X) = A× B

Inspection schedule

Inspection frequency	__Hourly √ Biweekly __Yearly	__Daily __Monthly __Others________	__Weekly __Quarterly

Part C (continued)

Slope Characteristics

Slope type		__Natural __Cut √ Fill __Cut and fill
Average slope angle (α_{ave}°)		$\alpha_{ave} = \frac{\alpha_1 \cdot l_1 + \alpha_2 \cdot l_2 + ... \alpha_n \cdot l_n}{L} = \underline{25}^{\circ}$
Slope surface appearance		√ Straight __Concave __Convex __ Hummocky __Terraced __Complex
Vegetation cover		√ Grass 100% __Shrub__% __Cultivated land__% __Reforestation__% __Woodland__% __Other____________
Vegetation density		__Sparse __Moderate √ Dense
Hydrogeology	**Surface water**	**Types of water sources** __Reservoir √ Lake __River __Creek __Pond __Surface drainage __Others________ __None **Location of water sources that may affect landslide** __Above √ Below __Both
	Groundwater (use visual inspection)	**Groundwater flow** __Into landslide __Off landslide __Both √ Unknown __None **Groundwater condition** __Spring __Seep __Both √ Unknown __None **Location of ground water:** __Above √ Below __Middle __None **Presence of monitoring or water well** __Artesian __Flowing artesian __Pooled √ None observed
Erosion area		√ Head __Toe __Flank __Body __None
Possible cause of failure		__Erosion of the toe __Precipitation √ Failure of drainage __Drainage outlet √ Surface water √ Weathering of materials __Deforestation √ Change of water level
Orientation of slope (Azimuth; The clockwise angle from the north)		N.A. degree
Direction of landslide (Azimuth; The clockwise angle from the north)		N.A. degree

Part C (continued)

Slope Materials (by Visual Inspection and Judgment)

Soil origin	_Colluvium _Alluvium _Till _Residual soil _Weather rock _Unweathered rock √ Fill _Combination _Others
Soil type	_Boulders/cobbles _Stone fragments √ Gravel _Sand _Fine sand _Silty gravel _Silty sand _Clayey gravel _Clayey sand _Silty soil √ Clayey soil _Organic √ Combination √ Others Silty clay with gravel
Rock type	_Shale _Mudstone /claystone _Siltstone _Sandstone _Limestone _Coal _Interbedded _Dolomite _Combination _Others N.A.

Landslide Characteristics

Type of Movement (Rockfall is not included.)	**Slide**	_Rotational rock slide _Translational rock slide √ Rotational earth slide _Translational earth block slide _Debris slide _Complex
	Flow	_Slow earth flow _Loess flow _Dry sand flow _Debris avalanche _Debris flow _Block stream _Complex
	Spread	_Rock spread _Earth spread _Complex spread
Rate of movement		_____ inches/year √ unknown
State of landslide activity		√ Active _Inactive _Mitigated

Observed Remediation

Past remedial activities	_Drainage _Bio-stabilization _Slope geometry correction _Retaining structures _Internal slope reinforcement _Erosion control _Chemical stabilization _Others unknown
Existing remediation	_Drainage _Bio-stabilization _Slope geometry correction _Retaining structures _Internal slope reinforcement _Erosion control _Chemical stabilization _Others None observed

Part C (continued)

Preliminary Determination of Causes of Landslide

Human activities	_Excavation/under cutting _Groundwater pumping _Deforestation _Loading _Defective maintenance √ Failure of drainage √ Water leakage from pipes _Artificial vibrations _Loose waste dumping √ Construction related _Others
Natural activities	√ Rainfall _Snowmelt _Earthquake √ Ground water _Loss of vegetation _Toe erosion √ Inadequate long term strength √ Surface water level change/rapid drawdown √ Degradation of construction material _Others
Comment (limit no more than 50 words)	

Observed Traffic Information

Actual sight distance (ASD) (ft.)	1,000 ft
Percent decision sight distance (%DSD) %DSD=(ASD/DSD)*100	100 %

Decision sight distance (DSD)

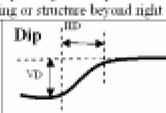
Posted speed limit (mph)	Decision sight distance (ft)
25	375
30	450
35	525
40	600
45	675
50	750
55	875
60	1000
65	1050
70	1100

Part C (continued)

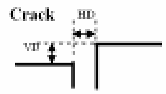
Impact assessment on roadway and beyond right of way

Current and potential impact of landslide on roadway	__On slope with a low potential to affect shoulder __On slope with a low potential to affect roadway √ On shoulder or on slope with a moderate potential to affect roadway __On roadway, or on slope with a high potential to affect roadway or structure
Current and potential impact of landslide on the area beyond right of way	__On slope with a low potential to impact area beyond right of way __On slope with a moderate potential to impact area beyond right of way __On slope with a high potential to impact area beyond right of way __On slope with a high potential to impact building or structure beyond right of way
Evidence of impact on roadway	**Dip** __Yes √ No **Maximum displacement of dip** Vertical displacement (VD) (inch) ≥3 Horizontal displacement (HD) (inch) ≥3
	Crack √ Yes __No **Maximum displacement of crack** Vertical displacement (VD) (inch) ≥3 Horizontal displacement (HD) (inch) ≥3
	Earth debris on roadway __Yes √ No Estimated volume (Yd^3)________

Dip



Crack



Adjacent Structures and Areas

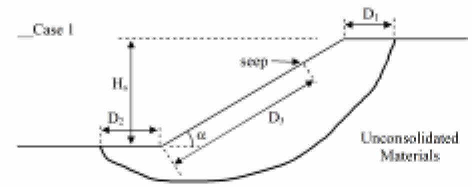
Adjacent structures	__Roads __Buildings __Others________	__Railroads √ Bridge	__Residential __Utilities
Surrounding area	__Forest __Urban __Others________	__Agriculture __Housing development	√ Rural

C.6/14

Part C (continued)

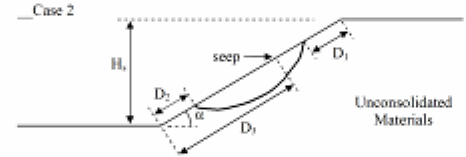
Information for estimation of landslide repair cost

__Case 1



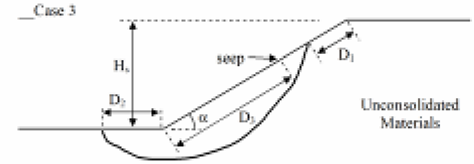
1. Average slope angle, α,______
2. Height of slope, H_s (ft) ______
3. Length of slope repair, L, parallel to highway (ft) ________
4. Distance from crest of slope to failure surface, D_1(ft) ______
5. Distance from toe of slope to failure surface, D_2 (ft) ________
6. Distance along slope (measured from toe) to groundwater seeps, D_3, and approximate quantities of groundwater (ft) ________

__Case 2



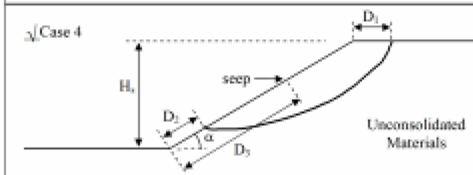
1. α,________
2. H_s (ft)________
3. L(ft)________
4. D_1(ft)________
5. D_2(ft)________
6. D_3(ft)________

__Case 3



1. α,________
2. H_s (ft)________
3. L(ft)________
4. D_1(ft)________
5. D_2(ft)________
6. D_3(ft)________

√Case 4



1. α,__25__
2. H_s (ft)__30__
3. L(ft)__150__
4. D_1(ft)__13__
5. D_2(ft)__0__
6. D_3(ft)__50__

Cost Estimate

Repair cost	unknown
Benefit cost ratio	unknown
Estimated time required for remediation (days)	unknown days

C.7/14

Part C (continued)

Suggested Remediation Measure

√ __Benching & regarding
√ __Counter berm & regrading
__Flattening Slope
__Soil Drainage
__Bedrock Drainage
__Retaining Walls
__Light Weight Fills
__Dynamic Compaction
__Bio-engineering
__Geofabrics
__Sheet Piling
__H Piling
__Drilled Piling
__Soil Nailing
__Tieback Walls
__Remove & Replace
__Shear Key
__Chemical Treatment
__Relocation
__Bridge
__Change Line or Grade
__Other________________

C.8/14

Part C (continued)

Sources of Supplemental Information

__Aerial photos
__Satellite imaginary
__County-ODOT
√ __State-ODOT
__Soil/Rock/Water samples
__Folder/ File location
__USGS publications and files
√ __Field visit
__Local people
__Dist-ODOT
__City and county engineer
__GPS features
__Academia with engineering or geology program
__USGS Quadrangles
__USGS open file map series #78-1057 "Landslide related features"
__Division of geological survey (ODNR)
__Division of mineral resource management (ODNR)
__Division of soil and water (ODNR)
__Others____

C.9/14

Part C (continued)

Landslide hazard rating matrix

CATEGORY		RATING CRITERIA and SCORE				Total Item Scores
		Points 3	Points 9	Points 27	Points 81	
Movement location/ impact (select higher score)	Current and potential impact of landslide on roadway	On slope with a low potential to affect shoulder	On slope with a low potential to affect roadway	On shoulder, or on slope with a moderate potential to affect roadway	On roadway, or On slope with a high potential to affect roadway or structure	27
	Current and potential impact of landslide on area beyond right of way	On slope with a low potential to impact area beyond right of way	On slope with moderate potential to impact area beyond right of way	On slope with high potential to impact area beyond right of way	On slope with high potential to impact structure beyond right of way	
Hazard to traveling public (Select higher score)	Rate of displacement in roadway if known	<1-inch/year	1 to 3-inches/year No single event ≥1-inch	3 to 6-inches/year No single event ≥3-inches	>6-inches/year Single event ≥3-inches	81
	Evidence of displacement in roadway	Visible crack or dip no vertical drop	≤1-inch of displacement	1 to 3-inches of displacement	≥ 3-inches of displacement	
Maintenance (Select higher score)	Maintenance frequency	None to rare	Annually (one time/year)	Seasonal (1 to 3 times/ year)	Continuous throughout year (> 3 times/year)	27
	Maintenance response	No response	Requires observation with periodic maintenance	Requires routine maintenance response to preserve roadway	Requires immediate response for safe travel or to protect adjacent structure	
%Decision Sight Distance (%DSD)		≥ 90	89 -50	49-35	< 34	3
ADT		<2000	2001-5000	5001-15000	>15001	81
Accident history (Related to landslide)		No accident	Vehicle or property damage	Injury	Fatality	3
					Total Score	222

C.10/14

OHIO LANDSLIDE HAZARD RATING SYSTEM

Part C (continued)

Hazard calculation sheet

Hazard category	Explanation	Item Scores
1. Movement Location/ Impact	The impact of slope failure is observed on the roadway shoulder.	27
2. Hazard to Traveling Public	The rate of movement is not available. The displacement observed on road is used. It is more than 3 inch displacement found on the roadway shoulder.	81
3. Maintenance	The maintenance for this site requires the routine maintenance response as the cracks were significant, and somewhat close to the traffic lane.	27
4. %DSD	The speed limit at the site location is 55 miles/hr. The actual sight distance is longer than 1000 ft. The calculated DSD is about 100%.	3
5. ADT	16,330 cars/ day	81
6. Accident history (Related to landslide)	None	3
	Total score	222

C.11/14

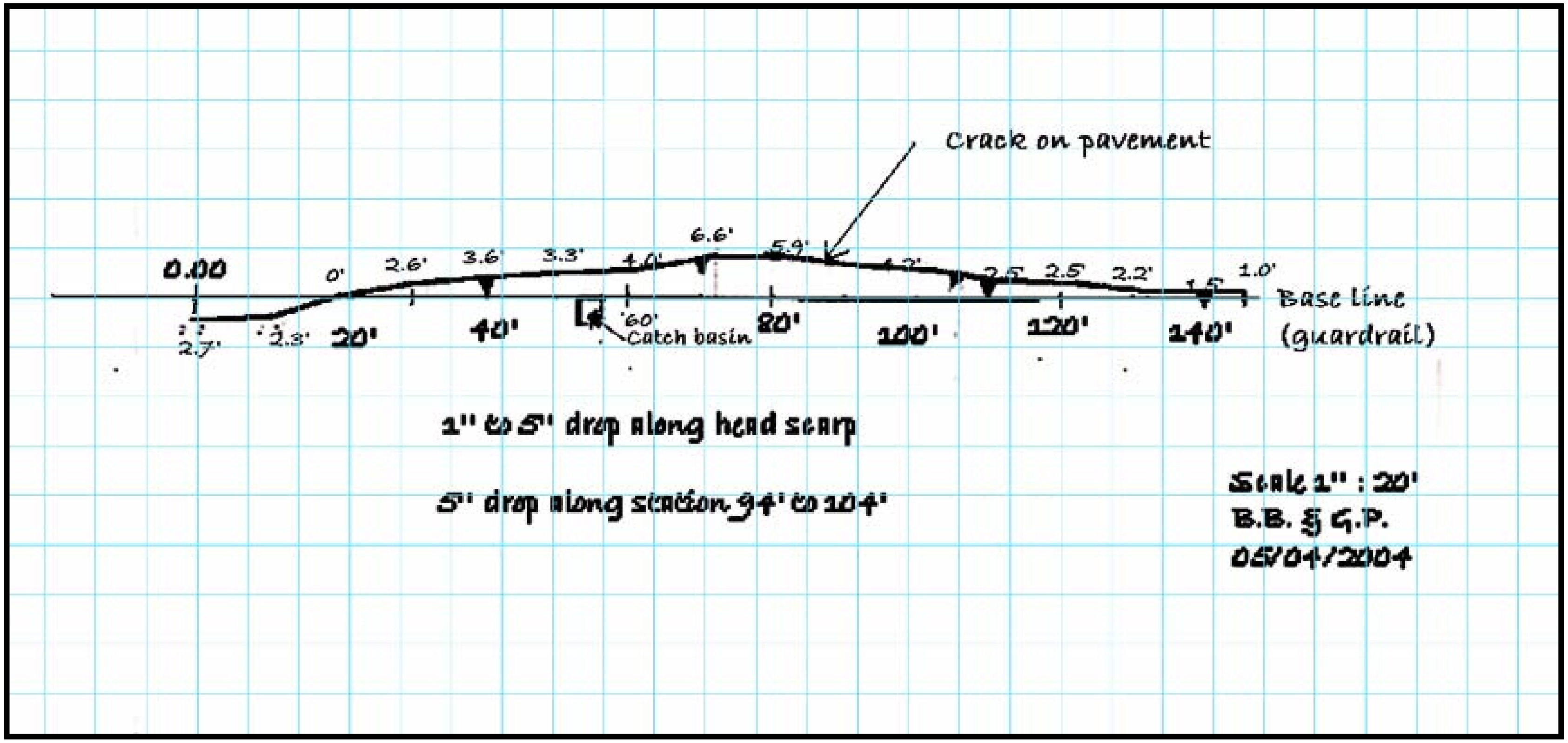


Figure E.3 A Plan Sketch of Example 2

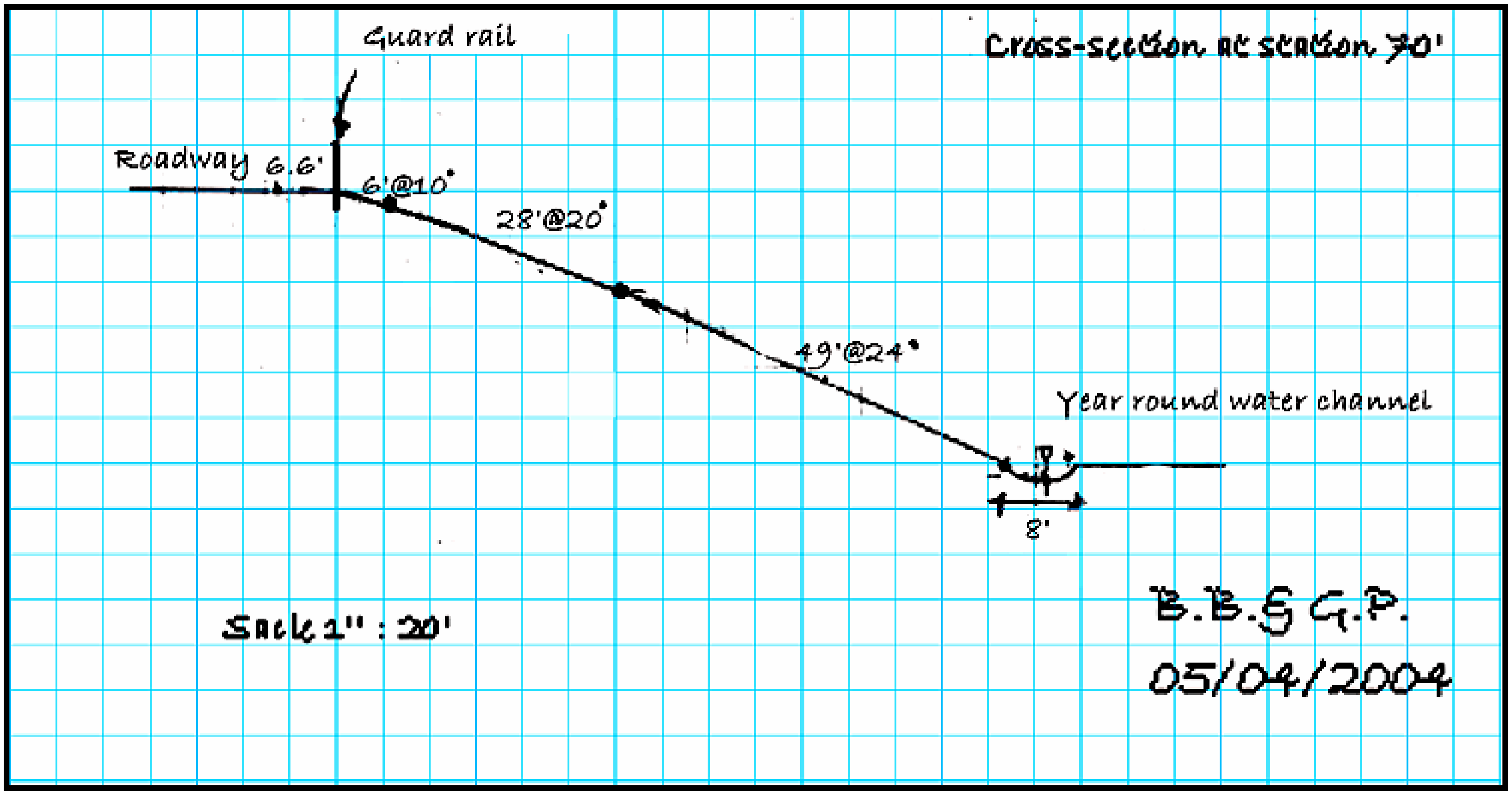


Figure E.4 A cross-section sketch of Example 2

LANDSLIDE INFORMATION OF EXAMPLE 3

Landslide Observation Report filed by Highway/construction worker

Name of reporter		Brent Black
Affiliation (District)		10
Date		5/11/2004
Site Location	**County**	Morgan
	Route	S.R. 78
	Mile marker (county basis)	23.00

Description (Visual Inspection)

Landslide material(s)	√ Soil _Rock _Both
Number of lanes (one direction)	_1 √2 _3 _4 _5 _6
Posted speed limit (miles/hr)	_15 _20 _25 _30 _35 _40 _45 _50 √55 _60 _65 _70
Location of landslide relative to roadway	_Above roadway √Below roadway _both
Position of impact on roadway	Position of cracks/dips: _Pavement √Shoulder _Ditch _None
	Position of earth debris: _Pavement _Shoulder _Ditch √None
Impact to adjacent structures or properties	_Roads _Railroads _Residential _Buildings _Commercial _Bridge _Utilities _Others no adjacent structure
Vegetation	Barren _% Grass 100% Shrub _% Tree _% Other_
Presence of surface water	√ Yes _No
Presence of groundwater	√ Yes _No _Unknown
Previous site works (Based on observation at the site)	_Temporary _Failed temporary _Permanent _Failed permanent √ Patching of asphalt _Guardrail work _Other
Recent precipitation	_Heavy _Moderate √ Light
Duration	_24-hr _3-d √ 7-d _15-d
Date identifying first evidence of instability	Unknown
Name of verifier (CM/TM)	-
Date of verification	-
Signature	-

L.1/1

Part A filed by Transportation/County Manager

Evaluator's name	Brent Black
Date of observation	5/11/2004

Site Location

Jurisdiction	_County _Turnpike _Municipal √State _Township _Federal _Private
County	S.R.
District	10
Route system	_**IR**-interstate _**US**-United States route √ **SR**-state route _**CR**-county road _**TR**-township road _**MR**-municipal road _**RA**-ramp _**PA**-park roads _**BK**-bike route
Route number	78
Mile marker (county basis)	Beginning: 23.00 Ending: 23.16
Network linear feature (NLF) (auto generation)	SMRGSR000078**C
Number of Lanes (one direction)	√ 1 _2 _3 _4 _5 _6
Location of landslide relative to roadway	_Above roadway √Below roadway _Both

Centroid of Affected Highway (GPS Information)

GPS coordinates	Centroid: Latitude: 81°48'25.09 W Longitude: 39°41'19.59N Elevation: 218.05 ft
	Beginning point: Latitude: N.A. Longitude: N.A. Elevation: N.A.
	Ending point: Latitude: N.A. Longitude: N.A. Elevation: N.A.
State coordinates (Mid-point) (Auto generation)	Zone: South Northing: 187709.351617 Easting: 659444.7770236
USGS Quad (Auto generation)	Name: MCCONNELSVILLE Number: 39081F7

A.1/3

Landslide vulnerability table

Probability of additional movement	Probability of significant impacts to the roadway, structures, adjacent property or features			
	Very High	*High*	*Moderate*	*Low*
Very High	Very High	Very High	High	Moderate
High	Very High	High	High	Moderate
Moderate	High	High	Moderate	Low
Low	Moderate	Moderate	Low	Low

Remark: A landslide site having "low" vulnerability is non-rated.

General information

General dimensions (Rough estimate)	Length (ft): 130 Width (ft): 850 Estimated maximum depth of sliding surface (ft) ~15-20ft
Preliminary rating (Use landslide vulnerability table)	√ Rated __Non-rated
Inspection frequency	__Hourly __Daily __Weekly __Biweekly √Monthly __Quarterly __Yearly __Others________

Part B filed by Transportation/County Manager

Evaluator's name	Brent Black
Date of observation	5/11/2004

Site Location

Jurisdiction	__County __Turnpike __Municipal √State __Township __Federal __Private
County	S.R.
District	10
Route system	__**IR**-interstate __**US**-United States route √**SR**-state route __**CR**-county road __**TR**-township road __**MR**-municipal road __**RA**-ramp __**PA**-park roads __**BK**-bike route
Route number	78
Mile marker (county basis)	Beginning: 23.00 Ending: 23.16
Network linear feature (NLF) (auto generation)	SMRGSR000078**C
Number of lanes (one direction)	√1 __2 __3 __4 __5 __6
Location of landslide relative to roadway	__Above roadway √Below roadway __Both

Site History

Date of original construction (m/d/y)	____/____/____
Date of alignment modifications (m/d/y)	____/____/____
Date of remedial activities (m/d/y)	____/____/____
Past remedial activities	__Drainage __Bio-stabilization __Slope geometry correction __Retaining structures __Internal slope reinforcement __Erosion control __Chemical stabilization __Others Unknown
Existing remediation	__Drainage __Bio-stabilization __Slope geometry correction __Retaining structures __Internal slope reinforcement __Erosion control __Chemical stabilization __Others Unknown
Annual maintenance frequency (times/year)	Unknown
Annual maintenance cost (Average Over the Past 5 to 10 Years) (dollars/year)	Unknown
Maintenance response (Based on judgment)	__No response __Require observation with periodic maintenance __Require routine maintenance response to preserve roadway √Require immediate response for safe travel or to protect adjacent structure

Traffic Data

Average daily traffic (ADT)	Total traffic: 1160 vehicles/day Passenger traffic: unknown vehicles/day Trucks traffic: unknown vehicles/day
Accident history in past 10 years (Number of occurrence)	Number of accident in past 10 years unknown Number of accident without loss____ Number of accident with vehicle and property damage____ Number of accident with injury __ Number of accident with fatality__
Estimated detour route length (miles)	unknown miles
Posted speed limit (miles/hr)	_15 _20 _25 _30 _35 _40 _45 _50 √ 55 _60 _65 _70
Estimated traveling time of detour (hr)	Truck unknown hr Passenger unknown hr

Part C (District Geotechnical Engineer)

Evaluator's name	Brent Black
Date of observation	5/11/2004

Site Location verified by DGTE

Jurisdiction	_County _Turnpike _Municipal √State _Township _Federal _Private
County	S.R.
District	10
Route system	_**IR**-interstate _**US**-United States route √**SR**-state route _**CR**-county road _**TR**-township road _**MR**-municipal road _**RA**-ramp _**PA**-park roads _**BK**-bike route
Route number	78
Mile marker (county basis)	Beginning: 23.00 Ending: 23.16
Network linear feature (NLF) (auto generation)	SMRGSR000078**C
Number of lanes (one direction)	√1 _2 _3 _4 _5 _6
Location of landslide relative to roadway	_Above roadway √Below roadway _Both

Centroid of Affected Highway (GPS Information) verified by DGTE (provide O.K. click button)

GPS coordinates	Centroid: Latitude: 81°48'25.09 W Longitude: 39°41'19.59N Elevation: 218.05 ft
	Beginning point: Latitude: N.A. Longitude: N.A. Elevation: N.A.
	Ending point: Latitude: N.A. Longitude: N.A. Elevation: N.A.
State coordinates (Mid-point) (Auto generation)	Zone: South Northing: 187709.351617 Easting: 659444.7770236
USGS Quad (Auto generation)	Name: MCCONNELSVILLE Number: 39081F7

Part C (continued)

Required information for data collection (use landslide vulnerability table)

Low (0< X ≤ 2 points)	Moderate and High (2< X ≤ 9 points)	Very high (X > 9 points)
• Verify and fill out C.1 • Very rough sketches by CM/TM • Take additional photos C.14	• Verify and fill out C.1 • Fill out C.2 to C.11 • Verify rough sketches by CM/TM • Take additional pictures C.14	• Verify and fill out C.1 • Fill out C.2 to C.13 • Take additional photos C.14

Landslide vulnerability table

Probability of additional movement (A)	Probability of significant impacts to the roadway, structures, adjacent property or features (B)			
	Very High(4)	*High(3)*	*Moderate(2)*	*Low(1)*
Very High(4)	Very High (16)	Very High (12)	High (8)	Moderate (4)
High(3)	Very High (12)	High (9)	High (6)	Moderate (3)
Moderate(2)	High (8)	High (6)	Moderate (4)	Low (2)
Low(1)	Moderate (4)	Moderate (3)	Low (2)	Low (1)

Vulnerability score (X) = A× B

Inspection schedule

Inspection frequency	__Hourly __Biweekly __Yearly	__Daily √ Monthly __Others__________	__Weekly __Quarterly

C.2/14

Part C (continued)

Slope Characteristics

Slope type		__Natural __Cut √ Fill √ Cut and fill
Average slope angle (α_{ave}°)		$\alpha_{ave} = \frac{\alpha_1 \cdot l_1 + \alpha_2 \cdot l_2 + ... \alpha_n \cdot l_n}{L} = 20°$
Slope surface appearance		__Straight __Concave __Convex √ Hummocky __Terraced __Complex
Vegetation cover		√ Grass 80% √ Shrub 20 % __Cultivated land__% __Reforestation__% __Woodland__% __Other ______________
Vegetation density		__Sparse √ Moderate √ Dense
Hydrogeology	**Surface water**	**Types of water sources** __Reservoir __Lake __River √ Creek __Pond __Surface drainage __Others__________ __None **Location of water sources that may affect landslide** __Above √ Below __Both
	Groundwater (use visual inspection)	**Groundwater flow** __Into landslide __Off landslide __Both √ Unknown __None **Groundwater condition** __Spring __Seep __Both √ Unknown __None **Location of ground water:** __Above √ Below __Middle __None **Presence of monitoring or water well** __Artesian __Flowing artesian __Pooled √ None observed
Erosion area		√ Head √ Toe __Flank __Body __None
Possible cause of failure		__Erosion of the toe __Precipitation __Failure of drainage __Drainage outlet √ Surface water √ Weathering of materials __Deforestation √ Change of water level
Orientation of slope (Azimuth; The clockwise angle from the north)		N.A. degree
Direction of landslide (Azimuth; The clockwise angle from the north)		N.A. degree

C.3/14

Part C (continued)

Slope Materials (by Visual Inspection and Judgment)

Soil origin	_Colluvium _Alluvium _Till _Residual soil _Weather rock _Unweathered rock √ Fill _Combination _Others
Soil type	_Boulders/cobbles _Stone fragments √ Gravel _Sand _Fine sand _Silty gravel _Silty sand _Clayey gravel _Clayey sand _Silty soil √ Clayey soil _Organic √ Combination _Others
Rock type	_Shale _Mudstone /claystone _Siltstone √ Sandstone _Limestone _Coal _Interbedded _Dolomite _Combination _Others Boulders in creek

Landslide Characteristics

Type of Movement (Rockfall is not included.)	**Slide**	_Rotational rock slide _Translational rock slide √ Rotational earth slide _Translational earth block slide _Debris slide _Complex
	Flow	_Slow earth flow _Loess flow _Dry sand flow _Debris avalanche _Debris flow _Block stream _Complex
	Spread	_Rock spread _Earth spread _Complex spread
Rate of movement		______ inches/year √ unknown
State of landslide activity		√ Active _Inactive _Mitigated

Observed Remediation

Past remedial activities	_Drainage _Bio-stabilization _Slope geometry correction _Retaining structures _Internal slope reinforcement _Erosion control _Chemical stabilization _Others unknown
Existing remediation	_Drainage _Bio-stabilization _Slope geometry correction _Retaining structures _Internal slope reinforcement _Erosion control _Chemical stabilization _Others None observed

Part C (continued)

Preliminary Determination of Causes of Landslide

Human activities	_Excavation/under cutting _Groundwater pumping _Deforestation _Loading _Defective maintenance _Failure of drainage _Water leakage from pipes _Artificial vibrations _Loose waste dumping √ Construction related _Others
Natural activities	√ Rainfall _Snowmelt _Earthquake √ Ground water _Loss of vegetation _Toe erosion √ Inadequate long term strength √ Surface water level change/rapid drawdown √ Degradation of construction material _Others
Comment (limit no more than 50 words)	

Observed Traffic Information

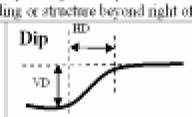
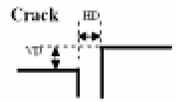
Actual sight distance (ASD) (ft.)	300 ft
Percent decision sight distance (%DSD) %DSD=(ASD/DSD)*100	34 %

Decision sight distance (DSD)

Posted speed limit (mph)	Decision sight distance (ft)
25	375
30	450
35	525
40	600
45	675
50	750
55	875
60	1000
65	1050
70	1100

Part C (continued)

Impact assessment on roadway and beyond right of way

Current and potential impact of landslide on roadway	__On slope with a low potential to affect shoulder __On slope with a low potential to affect roadway __On shoulder or on slope with a moderate potential to affect roadway √ On roadway, or on slope with a high potential to affect roadway or structure	
Current and potential impact of landslide on the area beyond right of way	__On slope with a low potential to impact area beyond right of way __On slope with a moderate potential to impact area beyond right of way __On slope with a high potential to impact area beyond right of way __On slope with a high potential to impact building or structure beyond right of way	
Evidence of impact on roadway	Dip __Yes √ No **Maximum displacement of dip** Vertical displacement (VD) (inch) ___ Horizontal displacement (HD) (inch) ___	**Dip** 
	Crack √ Yes __No **Maximum displacement of crack** Vertical displacement (VD) (inch) 0 Horizontal displacement (HD) (inch) 0	**Crack** 
	Earth debris on roadway __Yes √ No Estimated volume (Yd^3) ______	

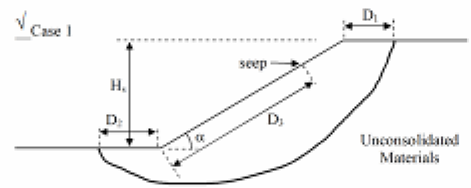
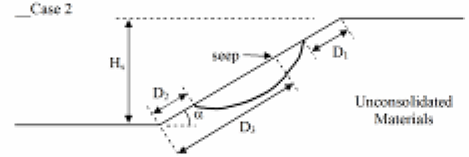
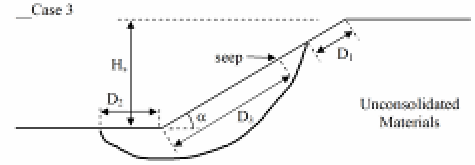
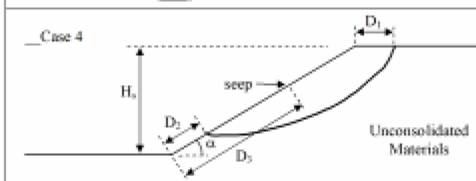
Adjacent Structures and Areas

Adjacent structures	__Roads __Railroads __Residential __Buildings __Bridge __Utilities __Others ______
Surrounding area	√ Forest __Agriculture √ Rural __Urban __Housing development __Others ______

C.6/14

Part C (continued)

Information for estimation of landslide repair cost

√ Case 1 	1. Average slope angle, α, 30° 2. Height of slope, H_s (ft) 25 3. Length of slope repair, L, parallel to highway (ft) 350 4. Distance from crest of slope to failure surface, D_1(ft) 15 5. Distance from toe of slope to failure surface, D_2 (ft) unknown 6. Distance along slope (measured from toe) to groundwater seeps, D_3, and approximate quantities of groundwater (ft) unknown
__Case 2 	1. α, ______ 2. H_s (ft) ______ 3. L(ft) ______ 4. D_1(ft) ______ 5. D_2(ft) ______ 6. D_3(ft) ______
__Case 3 	1. α, ______ 2. H_s (ft) ______ 3. L(ft) ______ 4. D_1(ft) ______ 5. D_2(ft) ______ 6. D_3(ft) ______
__Case 4 	1. α, ______ 2. H_s (ft) ______ 3. L(ft) ______ 4. D_1(ft) ______ 5. D_2(ft) ______ 6. D_3(ft) ______

Cost Estimate

Repair cost	unknown
Benefit cost ratio	unknown
Estimated time required for remediation (days)	unknown days

C.7/14

Part C (continued)

Suggested Remediation Measure

√__Benching & regarding
√_Counter berm & regrading
__Flattening Slope
__Soil Drainage
__Bedrock Drainage
__Retaining Walls
__Light Weight Fills
__Dynamic Compaction
__Bio-engineering
__Geofabrics
__Sheet Piling
__H Piling
__Drilled Piling
__Soil Nailing
__Tieback Walls
__Remove & Replace
__Shear Key
__Chemical Treatment
__Relocation
__Bridge
__Change Line or Grade
__Other__________________

C.8/14

Part C (continued)

Sources of Supplemental Information

__Aerial photos	√_Field visit
__Satellite imaginary	__Local people
__County-ODOT	__Dist-ODOT
√_State-ODOT	__City and county engineer
__Soil/Rock/Water samples	__GPS features
__Folder/ File location	__Academia with engineering or geology program
__USGS publications and files	__USGS Quadrangles

__USGS open file map series #78-1057 "Landslide related features"
__Division of geological survey (ODNR)
__Division of mineral resource management (ODNR)
__Division of soil and water (ODNR)
__Others____

C.9/14

Part C (continued)

Landslide hazard rating matrix

CATEGORY		RATING CRITERIA and SCORE: Points 3	Points 9	Points 27	Points 81	Total Item Scores
Movement location/ impact (select higher score)	Current and potential impact of landslide on roadway	On slope with a low potential to affect shoulder	On slope with a low potential to affect roadway	On shoulder, or on slope with a moderate potential to affect roadway	On roadway, or On slope with a high potential to affect roadway or structure	81
	Current and potential impact of landslide on area beyond right of way	On slope with a low potential to impact area beyond right of way	On slope with moderate potential to impact area beyond right of way	On slope with high potential to impact area beyond right of way	On slope with high potential to impact structure beyond right of way	
Hazard to traveling public (Select higher score)	Rate of displacement in roadway if known	<1-inch/year	1 to 3-inches/year No single event ≥1-inch	3 to 6-inches/year No single event ≥3-inches	>6-inches/year Single event ≥3-inches	3
	Evidence of displacement in roadway	Visible crack or dip no vertical drop	≤1-inch of displacement	1 to 3-inches of displacement	≥ 3-inches of displacement	
Maintenance (Select higher score)	Maintenance frequency	None to rare	Annually (one time/year)	Seasonal (1 to 3 times/ year)	Continuous throughout year (> 3 times/year)	9
	Maintenance response	No response	Requires observation with periodic maintenance	Requires routine maintenance response to preserve roadway	Requires immediate response for safe travel or to protect adjacent structure	
%Decision Sight Distance (%DSD)		≥ 90	89 -50	49-35	< 34	81
ADT		<2000	2001-5000	5001-15000	>15001	3
Accident history (Related to landslide)		No accident	Vehicle or property damage	Injury	Fatality	3
					Total Score	180

Part C (continued)

Hazard calculation sheet

Hazard category	Explanation	Item Scores
1. Movement Location/ Impact	The impact of slope failure is observed on traffic lanes.	81
2. Hazard to Traveling Public	The rate of movement is not available. Only hairline cracks are observed on roadway.	3
3. Maintenance	The maintenance for this site requires periodic observation.	9
4. %DSD	The speed limit at the site location is 55 miles/hr. The actual sight distance is approximately 300 ft. The calculated DSD is 34%.	81
5. ADT	1160 cars/ day	3
6. Accident history (Related to landslide)	None	3
	Total score	180

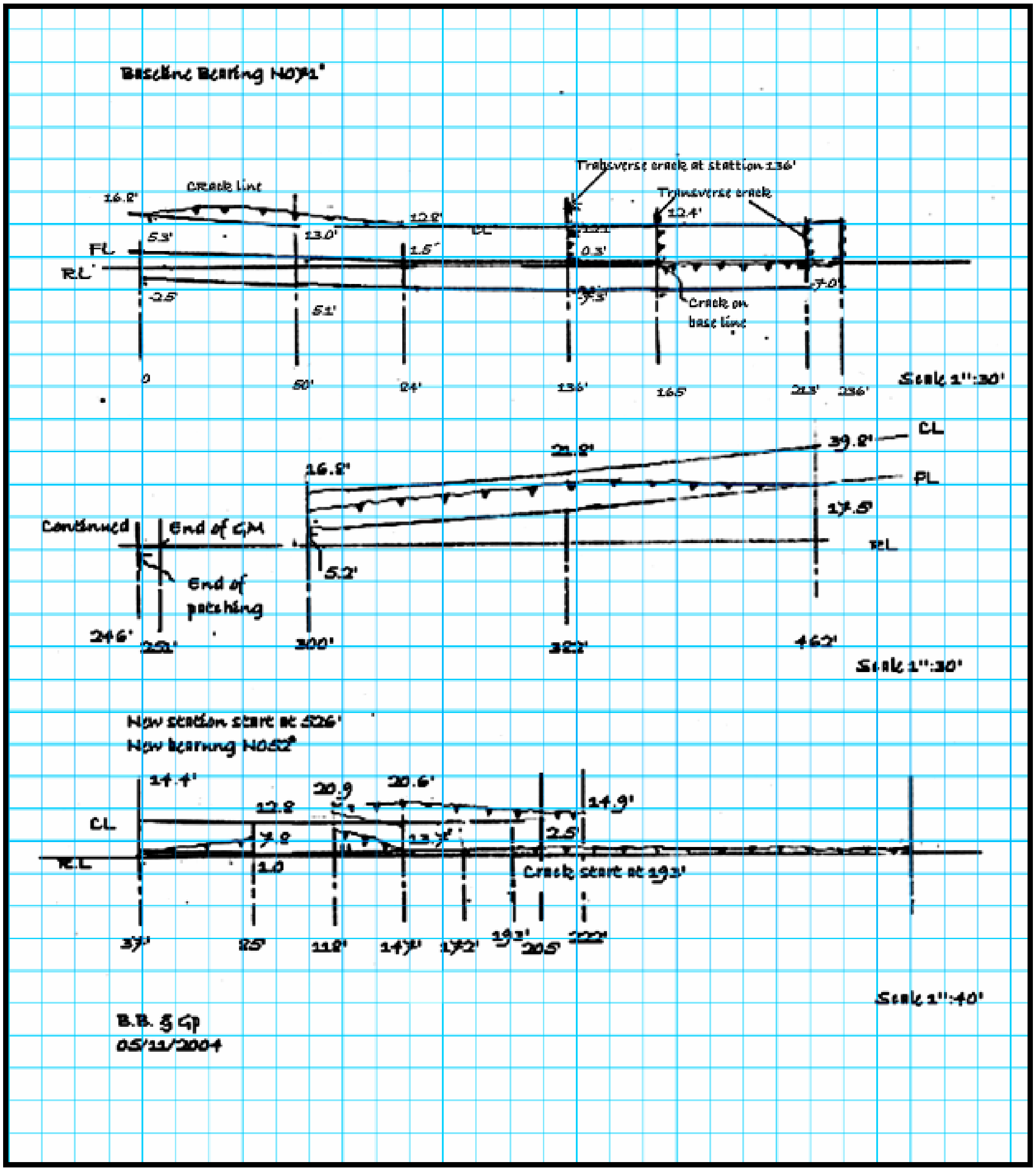


Figure E.5 A plan sketch of Example 3

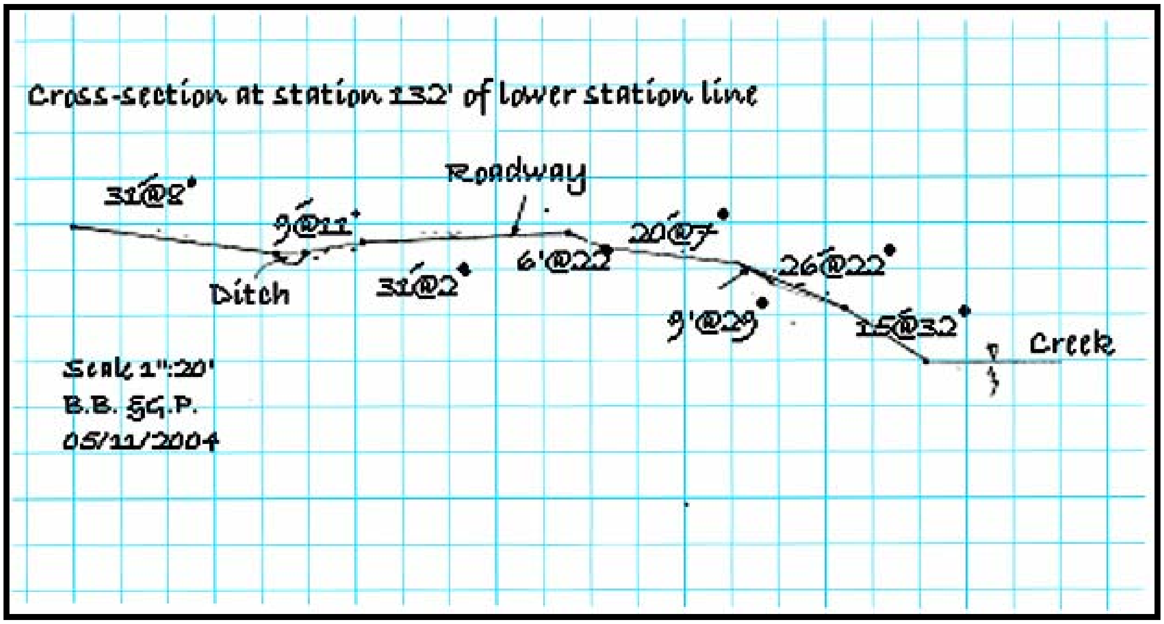


Figure E.6 A cross-section sketch of Example 3

APPENDIX F

CONTACTS

AND

SUPPLEMENTAL INFORMATION

Ohio Department of Transportation
Districts

District 1
1885 N. McCullough St.
Lima, OH 45801-0040
419-222-9055
fax: 419-222-0438

District 2
317 East Poe Rd.
Bowling Green, OH 43402-1330
419-353-8131
fax: 419-353-1468

District 3
906 North Clark St.
Ashland, OH 44805-1989
800-276-4188 or 419-281-0513
fax: 419-281-0874

District 4
2088 S. Arlington Rd.
Akron, OH 44306
800-603-1054 or 330-786-3100
fax: 330-786-2232

District 5
9600 Jacksontown Rd., S.E.
PO Box 306
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740-323-4400
fax: 740-323-3715

District 6
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800-372-7714 or 740-363-1251
fax: 740-369-7437

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SR 29 PO Box 969
Sidney, OH 45365-0969
937-492-1141
fax: 937-497-9734

District 8
505 South SR 741
Lebanon, OH 45036-9518
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fax: 513-932-7651

Central Office
1980 W. Broad Street
Columbus, OH 43223
614-466-7170
fax: 614-644-8662
ODOT Web Site:
http://www.dot.state.oh.us

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650 Eastern Ave. PO Box 467
Chillicothe, OH 45601
740-773-2691
fax: 740-775-4889

District 10
338 Muskingum Dr. PO Box 658
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800-845-0226 or 740-373-0212
fax: 740-373-7317

District 11
2201 Reiser Ave.
New Philadelphia, OH 44663
330-339-6633
fax: 330-308-3942

District 12
5500 Transportation Blvd.
Garfield Heights, OH 44125-5396
866-737-8112 or 216-581-2100
fax: 216-587-1730

LISTING OF COUNTY CODES AND DISTRICT

County	*Code*	*District*		*County*	*Code*	*District*
Adams	ADA	9		Licking	LIC	5
Allen	ALL	1		Logan	LOG	7
Ashland	ASD	3		Lorain	LOR	3
Ashtabula	ATB	4		Lucas	LUC	2
Athens	ATH	10		Madison	MAD	6
Auglaize	AUG	7		Mahoning	MAH	4
Belmont	BEL	11		Marion	MAR	6
Brown	BRO	9		Medina	MED	3
Butler	BUT	8		Meigs	MEG	10
Carroll	CAR	11		Mercer	MER	7
Champaign	CHP	7		Miami	MIA	7
Clark	CLA	7		Monroe	MOE	10
Clermont	CLE	8		Montgomery	MOT	7
Clinton	CLI	8		Morgan	MRG	10
Columbiana	COL	11		Morrow	MRW	6
Coshocton	COS	5		Muskingum	MUS	5
Crawford	CRA	3		Noble	NOB	10
Cuyahoga	CUY	12		Ottawa	OTT	2
Darke	DAR	7		Paulding	PAU	1
Defiance	DEF	1		Perry	PER	5
Delaware	DEL	6		Pickaway	PIC	6
Erie	ERI	3		Pike	PIK	9
Fairfield	FAI	5		Portage	POR	4
Fayette	FAY	6		Preble	PRE	8
Franklin	FRA	6		Putnam	PUT	1
Fulton	FUL	2		Richland	RIC	3
Gallia	GAL	10		Ross	ROS	9
Geauga	GEA	12		Sandusky	SAN	2
Greene	GRE	8		Scioto	SCI	9
Guernsey	GUE	5		Seneca	SEN	2
Hamilton	HAM	8		Shelby	SHE	7
Hancock	HAN	1		Stark	STA	4
Hardin	HAR	1		Summit	SUM	4
Harrison	HAS	11		Trumbull	TRU	4
Henry	HEN	2		Tuscarawas	TUS	11
Highland	HIG	9		Union	UNI	6
Hocking	HOC	10		Van Wert	VAN	1
Holms	HOL	11		Vinton	VIN	10
Huron	HUR	3		Warren	WAR	8
Jackson	JAC	9		Washington	WAS	10
Jefferson	JEF	11		Wayne	WAY	3
Knox	KNO	5		Williams	WIL	2
Lake	LAK	12		Wood	WOO	2
Lawrence	LAW	9		Wyandot	WAY	1

DISTRICT AND COUNTY CONTACT

District 1: 1885 N. McCullough St. Lima, OH 45801-0040, Tel: 419-222-9055, fax: 419-222-0438			
District Geotechnical Engineer: Russ Slonecker (419) 999-6882 Russ.Slonecker@dot.state.oh.us			
County	County Manager	Phone Number	e-mail address
Allen	Robert Gehr	419-228-6385	robert.gehr@dot.state.oh.us
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Hancock	Ron Kear	419-422-2451	ron.kear@dot.state.oh.us
Hardin	Tom Berning	419-673-4218	Tom.berning@dot.state.oh.us
Paulding	Doug Smalley	419-399-2746	doug.smalley@dot.state.oh.us
Putnam	Michael Pollock	419-523-3750	michael.pollock@dot.state.oh.us
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Williams	Lee Anderson	419-485-3505	Lee.Anderson@dot.state.oh.us
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District 3: 906 North Clark St., Ashland, OH 44805-1989, Tel: 800-276-4188 or 419-281-0513 Fax: 419-281-0874			
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Marion	Scott Kurz	740-382-0624	Scott.Kurz@dot.state.oh.us
Morrow	William Young	419-946-2921	William.Young@dot.state.oh.us
Pickaway	Jerry Reibel	740-477-3371	Jerry.Riebel@dot.state.oh.us
Union	Dan Wise	937-642-1986	Dan.Wise@dot.state.oh.us

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Lawrence	Cecil Townsend	740-532-1636	Cecil.Townsend@dot.state.oh.us
Pike	Steve Jenkins	740-289-2650	Steve.Jenkins@dot.state.oh.us
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Gallia	Jeff Phillips	740-446-1553	Jeff.Phillips@dot.state.oh.us
Hocking	John Pallo	740-385-2629	John.Pallo@dot.state.oh.us
Meigs	Brett Jones	740-992-2501	Brett.Jones@dot.state.oh.us
Monroe	Jeff Schenerlein	740-472-0921	Jeff.Schenerlein@dot.state.oh.us
Morgan	Pat Tornes	740-962-4665	Pat.Tornes@dot.state.oh.us
Noble	Jim Wharton	740-732-4504	Jim.Wharton@dot.state.oh.us
Vinton	Dana Peters	740-596-5532	Dana.Peters@dot.state.oh.us
Washington	Doug Clifton	740-373-0536	Doug.Clifton@dot.state.oh.us

District 11: 2201 Reiser Ave., New Philadelphia, OH 44663, Tel: 330-339-6633, Fax: 330-308-3942			
District Geotechnical Engineer: Jim Graham (330)308-3980 Jim.Graham@dot.state.oh.us			
County	County Manager	Phone Number	e-mail address
Belmont	Dave Schafer	740-782-1641	Dave.Schafer@dot.state.oh.us
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Columbiana	Barry Miner	330-424-7253	Barry.Miner@dot.state.oh.us
Harrison	Christopher Wood	740-942-4201	Christopher.Wood@dot.state.oh.us
Holmes	Randy Ramsey	330-674-1906	Randy.Ramsey@dot.state.oh.us
Jefferson	Thomas Corey	740-264-1722	Thomas.Corey@dot.state.oh.us
Tuscarawas	Jeff Bonomo	330-339-5050	Jeff.Bonomo@dot.state.oh.us

District 12: 5500 Transportation Blvd. Garfield Heights, OH 44125-5396, Tel: 866-737-8112 or 216-581-2100, Fax: 216-587-1730			
District Geotechnical Engineer: James Marszal (216)584-2128 James.Marszal@dot.state.oh.us			
County	County Manager	Phone Number	e-mail address
Cuyahoga			
Geauga			
Lake			

The ODOT District Locals and contact information can be obtained at:
http://www.dot.state.oh.us/dist.asp

Digital Photologs can be obtained at:
http://tscww012.dot.state.oh.us/OTS_Intranet/digilog/
OR
Contact Technical Services for ODOT Mainframe Access or DVD's at:
http://www.dot.state.oh.us/techservsite/Contact_Info.htm

Digital orthophoto quad sheets can be obtained at:
http://www.dot.state.oh.us/aerial/Glossary.asp?Item=Orthophotos
http://seamless.usgs.gov/
http://topomaps.usgs.gov/drg/

Aerial photographs including stereopairs can be obtained at:
http://www.dot.state.oh.us/aerial/

Roadway Type
http://www.dot.state.oh.us/planning/functional%20class/FunctionalClassmaps.htm

ADT, AVT, ATT
http://www.dot.state.oh.us/techservsite/availpro/Traffic_Survey/TSR_Report/default.htm

Roadway width, median
http://www.dot.state.oh.us/techservsite/availpro/Road_%20Infor/SLD/default.htm

AADT
http://www.dot.state.oh.us/techservsite/availpro/Traffic_Survey/Ann_Adj_Fctrs/Adj_Fctr04.PDF

Median Type and width, surface width
http://www.dot.state.oh.us/techservsite/availpro/Road_%20Infor/State_RI06/statemap.htm

General geological data can be contacted at:
http://www.dnr.state.oh.us/geosurvey/default.htm

Abandoned Mine Locator
http://www.dnr.state.oh.us/website/geosurvey/omsiua/viewer.htm

Active Mineral Industries
http://www.dnr.state.oh.us/geosurvey/oimimap/oimimap.htm

SLM for each state and interstate route can be obtained at:
http://www.dot.state.oh.us/techservsite/availpro/Road_%20Infor/SLD/default.htm.

Precipitation Data Information can be collected at the following sites:
ODNR:
http://www.dnr.ohio.gov/water/waterinv/precip_frequency.htm

NOAA:
http://www.ncdc.noaa.gov/oa/climate/climatedata.html