Landslide Hazard Rating Matrix and Database

Vol. 1 of 2

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16. Abstract

The Office of Geotechnical Engineering (OGE) of the Ohio Department of Transportation (ODOT) recognizes the need to develop a strategy to provide timely preventive maintenance to avoid on-set of large or catastrophic slope failures. Furthermore, with limited financial resources, the OGE is forced to make rational decisions on the priority of various landslide (slope failure) maintenance and remediation needs. To address these issues, this research project was undertaken with the following objectives: (a) Develop a field validated landslide geological hazard rating matrix, (b) Develop field reconnaissance forms in paper format and electronic format (window plus ArcPad), (c) Develop and deploy a web enabled, GIS based landslide database, and (d) Develop a user's manual and training materials for the landslide geological hazard database. Based on synthesis of literature review of existing practices, ODOT in-house expert opinions, and knowledge of prevalent Ohio geological formations in landslide prone areas, the principal investigator developed the ODOT specific landslide hazard rating system, together with the field site reconnaissance form. A pilot database containing 39 landslide sites was compiled and statistically analyzed to ascertain the reasonableness of the hazard rating outcome. A web accessible landslide database in a GIS platform was developed, pilot tested, and deployed. In addition, a user's manual was developed to assist training of the future users of the system. The benefits from full implementation of the landslide database and landslide hazard rating matrix include: (a) elimination of excessive paper work, (b) near real-time monitoring and data management, (c) centralized information, (d) uniform data collection and reporting, (e) enhanced data sharing. Furthermore, the Ohio Department of Transportation can reap the benefits of cost saving due to early stage detection of landslide and taking pro-active remediation measures.

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CHAPTER I

INTRODUCTION

1.1 STATEMENT OF THE PROBLEM

Landslides or embankment/slope failures occur on highways due to a variety of reasons. For example, the man-made embankment may deteriorate overtime due to causes such as improper compaction of fill or non-durable fill, use of materials that are prone to deterioration. Other causes, such as heavy rainfalls, groundwater, overloading, and erosion at the toe of a slope may trigger landslide. The failures of the highway embankments can exert an adverse impact on other highway structures, such as pavement and bridges. As a result of landslides, pavement surface may become undulated, developing cracks and dips, which could cause loss of driving control leading to car accident, fatalities and property loss. Similarly, a bridge structure may become unstable due to slope failure of the abutment slope. 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 in the affected area. 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.

The highway agencies need to develop a strategy to provide timely preventive maintenance to avoid the on-set of large or catastrophic slope failures. Furthermore, with limited financial resources, the highway agencies are forced to make a rational decision on the priority of different landslide (slope failure) maintenance and remediation needs. The decision-making and prioritizing the limited financial resources to address these identified landslide remediation/prevention needs can be executed objectively only if a framework of landslide hazard rating system is available and a well developed inventory of existing landslide sites is in existence.

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 funds to repair unstable slopes. The Office of Geotechnical Engineering (OGE) within ODOT is in charge of developing a comprehensive Geological Hazard Management System (GHMS) to better manage data and activities related to planning, design, construction, and maintenance of both existing and new highway infrastructures that maybe affected by the known geological hazards in Ohio, including landslides, rockfalls, abandoned underground mines, karst, and shoreline erosion.

The OGE has developed the guiding requirements of the GHMS as follows: (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. Based on these guiding principles, a research effort was undertaken to develop the necessary tools for addressing the landslide specific geohazard. The specific objectives of this research effort are enumerated below.

1.2 OBJECTIVES OF THE STUDY

PHASE I:

1. Development of a user-friendly form as part of site reconnaissance for collecting pertinent landslide site information. The landslide site information to be collected includes 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 other potential future study. The collection of site information is conducted by using either a portable PC or a hand-held GPS unit, or both.

2. 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.

3. 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 an extensive statistical analysis of a pilot data set of 37 landslide sites in Ohio.

PHASE II:

1. Implementation of the GIS based landslide inventory/ rating database in a new scalable web enabled application.

2. Connecting of the GIS landslide inventory database, landslide hazard rating system, and landslide remedial cost database into the ODOT Geotechnical Database Management System.

1.3 ORGANIZATION OF THE REPORT

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 report is also outlined in this chapter.

Chapter II provides a literature review of the 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. Detailed instructions on how to conduct a landslide site reconnaissance and to fill in the information in the form are provided in the User's Manual.

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.

Finally, Chapter VI 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 REVIEW

2.1 OVERVIEW

This chapter provides pertinent information and a review of literature that relates to the development of landslide hazard rating systems for prioritizing the slope remediation plans. The landslide types and their corresponding features are discussed. The principles of landslide management as well as the relevant landslide hazard rating systems are discussed in the chapter.

2.2 LANDSLIDE MITIGATION NEEDS

For Ohio DOT, the term landslide is generally used to describe the phenomenon of "the movement of a mass of soil, debris, or earth down a slope". In this report, landslide and slope failure are used interchangeably without making any distinction among them. The slope failure can be triggered by a number of external stimuli, such as earthquake shaking, intense rainfall, storm waves, stream erosion, construction, etc. These activities can cause an increase in driving shear stress or decrease in resisting shear strength of slope-forming materials. Often factors, such as vegetation cover, drainage conditions, climate and weathering 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 landslides 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 sectors, private sectors and local administrations with full involvements of Geoscientists, Engineers, Geologists and Researchers in the development of the system that can be implemented for the reduction of losses caused by landslides. On behalf of the large multisector, multiagency stakeholder group involved in landslide hazard mitigation, 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.

National Landslide Hazard Mitigation strategy, developed by USGS in response to the rising costs resulting form landslide hazards in the United States, includes two essential steps: 1) developing new partnerships among government at all levels, academia and the private sectors, and 2) expanding landslide research, such as mapping, assessment, real-time monitoring, forecasting, information management and dissemination, mitigation tools, emergency preparedness. In particular, USGS adopts a strategy to promote the use of new technological advances and to provide incentives for the adoption of loss reduction measures nationwide.

The implementation of effective landslide planning and management systems could reduce both social and economic losses from landslide (Dai, et al. 2002). For example, in the state of California, by implementing approaches that included 1) restriction of development in landslide-prone areas, 2) use of excavation, grading, landscaping, and construction codes, 3) use of physical measures to prevent landslides, and 4) development of warning systems, the losses due to landslides were reduced by 10%. More importantly, California is a state advocating the need to figure out and prioritize landslide-prone areas based on severity, elements at risk, and loss that may occur. Based on the developed list of priority landslide areas, financial resources could be judiciously used to remedy these landslide-prone areas.

2.3 FACTORS 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 causing instability of a slope can be understood by categorizing causes into slow changing and fast changing processes. The following literature review emphasizes the importance of recognizing the factors that govern the slope stability transition from stable to unstable state.

2.3.1 STABILITY OF SLOPES

Factor of safety of a slope 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 variations 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 several external and internal causal factors. Based on its stability, slopes can be 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 are marginally stable slopes. Finally, when the destabilizing forces produce continuous movement, the slope is considered an actively unstable slope. Physically, slopes exist in any one of the three states.

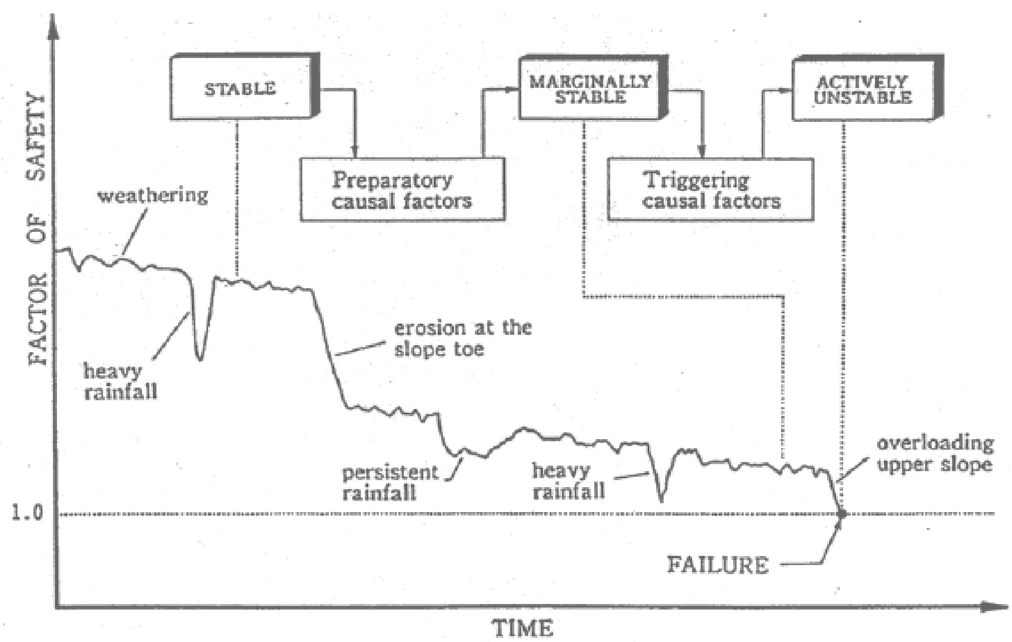


Figure 2.1 Changes of the factor of safety with time (Popescu, 1994)

2.3.2 LANDSLIDE CAUSAL FACTORS

Various types of slope movements reflect the wide range of factors responsible for shifting a slope from a stable state to an unstable state. Proper recognition of conditions that made the slope unstable is of primary importance as it helps figuring out the most appropriate remediation option. According to Popescu (1994) and Dai, et al. (2002), the framework for understanding the various causal factors of landslides based on the three stability stages can be divided into two groups: 1) Preparatory variables and 2) Triggering variables. Preparatory variables are causal factors which make the slope susceptible to failure but without actually initiating it, and thereby tend 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 that would initiate the slope movement by shifting the slope from a marginally stable state to an unstable state. These types of variables are very difficult to estimate as it may change in a very short time span.

Although slow changes due to preparatory causes contribute to the process of reduction of slope stability, the causes that provoke the greatest rate of slope movement in a short span of time should be examined. These causes involve sudden triggering mechanisms that lead to the slope failure. A brief list of landslide causal factors is provided in Table 2.1, which is arranged in four 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. GEOMORPHOLOGICAL 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. A landslide can be classified and described by two nouns. The first describes the material and the second describes the type of movement, as shown in Table 2.2. The definitions of terms used in Table 2.2 are further explained in Table 2.3. The movements are divided into five categories: *falls, topples, slides, spreads, and flows*. The sixth type originally proposed by Varnes (1978) has been substituted by a complex movement as a combination of the five types of landslide. The five kinematically distinct types of landslide movement are described by Cruden and Varnes (1996) as shown in Figure 2.2. The readers should be cautioned that although Table 2.2 and Table 2.3 contain the rock as one of material types, they are listed in the table to follow truthfully Varnes (1978, 1996) work. Since ODOT has a separate rockfall hazard rating system (ODOT 2002), the readers should use that particular rating system if the rockfall hazards are involved.

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

<table>
<tr><td colspan="2" rowspan="3">Types of movements</td><td colspan="3">Types of materials</td></tr>
<tr><td rowspan="2">Bedrock</td><td colspan="2">Engineering slope</td></tr>
<tr><td>Predominantly coarse</td><td>Predominantly fine</td></tr>
<tr><td colspan="2">Fall</td><td>Rock fall</td><td>Debris fall</td><td>Earth fall</td></tr>
<tr><td colspan="2">Topples</td><td>Rock topple</td><td>Debris topple</td><td>Earth topple</td></tr>
<tr><td colspan="2">Spread</td><td>Rock spread</td><td>Debris spread</td><td>Earth spread</td></tr>
<tr><td colspan="2">Flow</td><td>Rock flow</td><td>Debris flow</td><td>Earth flow</td></tr>
<tr><td rowspan="3">Slides</td><td>Rotational slide</td><td>Rock slump</td><td>Debris slump</td><td>Earth slump</td></tr>
<tr><td rowspan="2">Translation slide/ Wedge</td><td>Rock block slide</td><td>Debris block slide</td><td>Earth block slide</td></tr>
<tr><td>Rock slide</td><td>Debris slide</td><td>Earth slide</td></tr>
<tr><td colspan="2">Complex</td><td colspan="3">Combination of two or more principal types of movement</td></tr>
</table>

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 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 from a steep slope along a surface, on which little or no shear displacement takes place. The soil 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 at the toe of 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 about a point or axis below the center of gravity of the displaced mass. Toppling is sometimes driven by gravity exert by 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 mass occurring dominantly on surfaces of rupture or on a 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. Varnes (1978) emphasized that the distinction between rotational and translational slides is 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 soil mass is displaced along a planar or undulating surface of rupture, sliding out and over the original ground surface. Translational slides are usually shallower than rotational slides. Therefore, the ratio of depth to length of a translational slide 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 slides often follow discontinuities such as fault, joints, or bedding surfaces, or the contact between rock and residual or transported soils.

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 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) has made a distinction between spread of rock, which could be extended without forming identifiable surface of rupture, and movement of 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 situations that the concept of spread is worth recognizing as a separate type of movement.

2.4.5 FLOW

Flow is a spatially continuous movement, in which surfaces of shear are short-lived, closely spaced and usually not preserved. The distribution of velocities in the displacing soil 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."

2.4.6 CREEP

Creep is the imperceptibly slow, steady, downward movement of slope-forming soil. 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. 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).

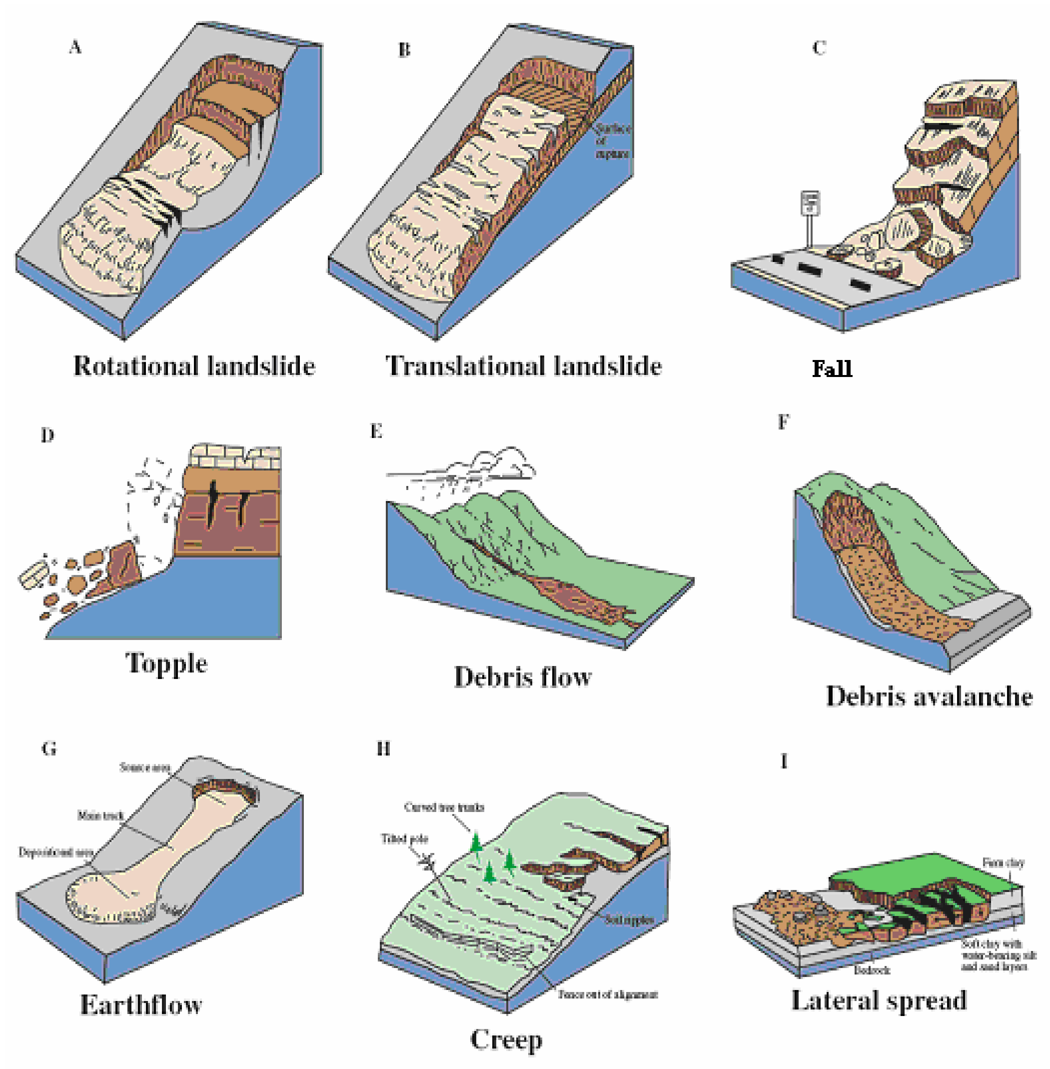


Figure 2.2 Types of landslides (USGS Fact Sheet 2004-3072)

2.5 LANDSLIDE PRONE LOCATIONS

The typical landslide prone areas and the typical signs 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 features where landslides are more prone to occur.

2.5.1 GROUND WATER OCCURRING (Figure 2.3A)

Spring 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.

2.5.2 SIDE-HILL CUT-AND-FILL SECTIONS (Figures 2.3B, 2.3C and 2.3D)

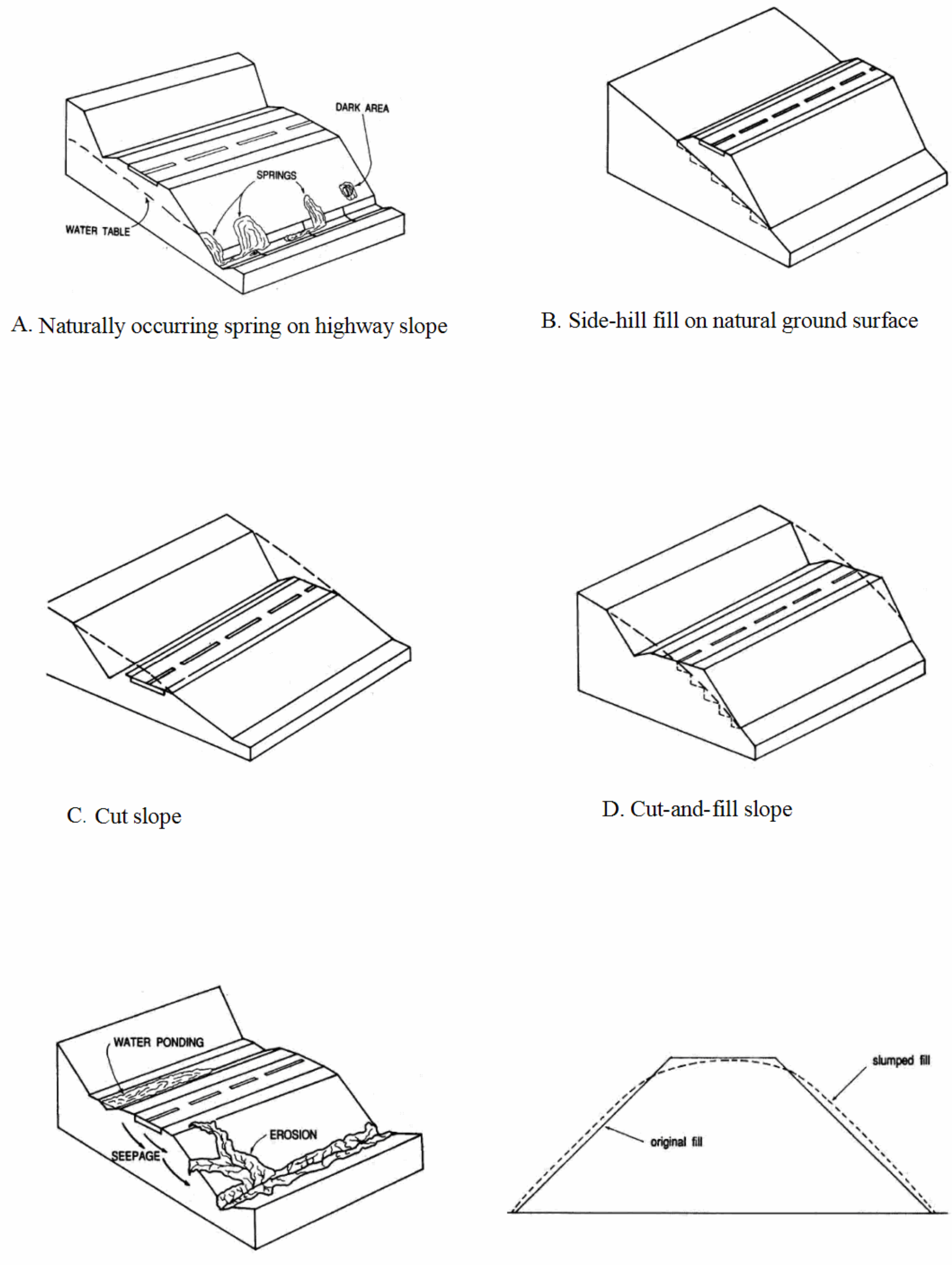
Side-hill cut and cut-and-fill sections are particularly prone to landslides. The toe of the cut slope on the uphill side is subject to erosion and loss of toe support (undercutting). The side-hill fill portion of a cut-and-fill section may be weakened by ground water saturation. Also, if the interface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

2.5.3 POORLY DRAINED LOCATION (Figure 2.3E)

Drainage is one of the most important factors involving landslides. Ground 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.

2.5.4 VERY HIGH FILL (Figure 2.3F)

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”.



A. Naturally occurring spring on highway slope
B. Side-hill fill on natural ground surface
C. Cut slope
D. Cut-and-fill slope
E. Poorly drained highway embankment
F. Settlement of very high highway fills

Figure 2.3 Vulnerable 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 an early stage, 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 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 existence of an unstable slope above the roadway. The presence of debris could be the forerunner of massive 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 will have bulge at the toe of the slide where the sliding mass has accumulated and piled up. This bulge indicates that 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 an embankment. 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 highway 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 color may indicate distinct differences in the amount of water content from one area of the slope to another. The area containing the greater amounts 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 lead to undercut near 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 cause 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)

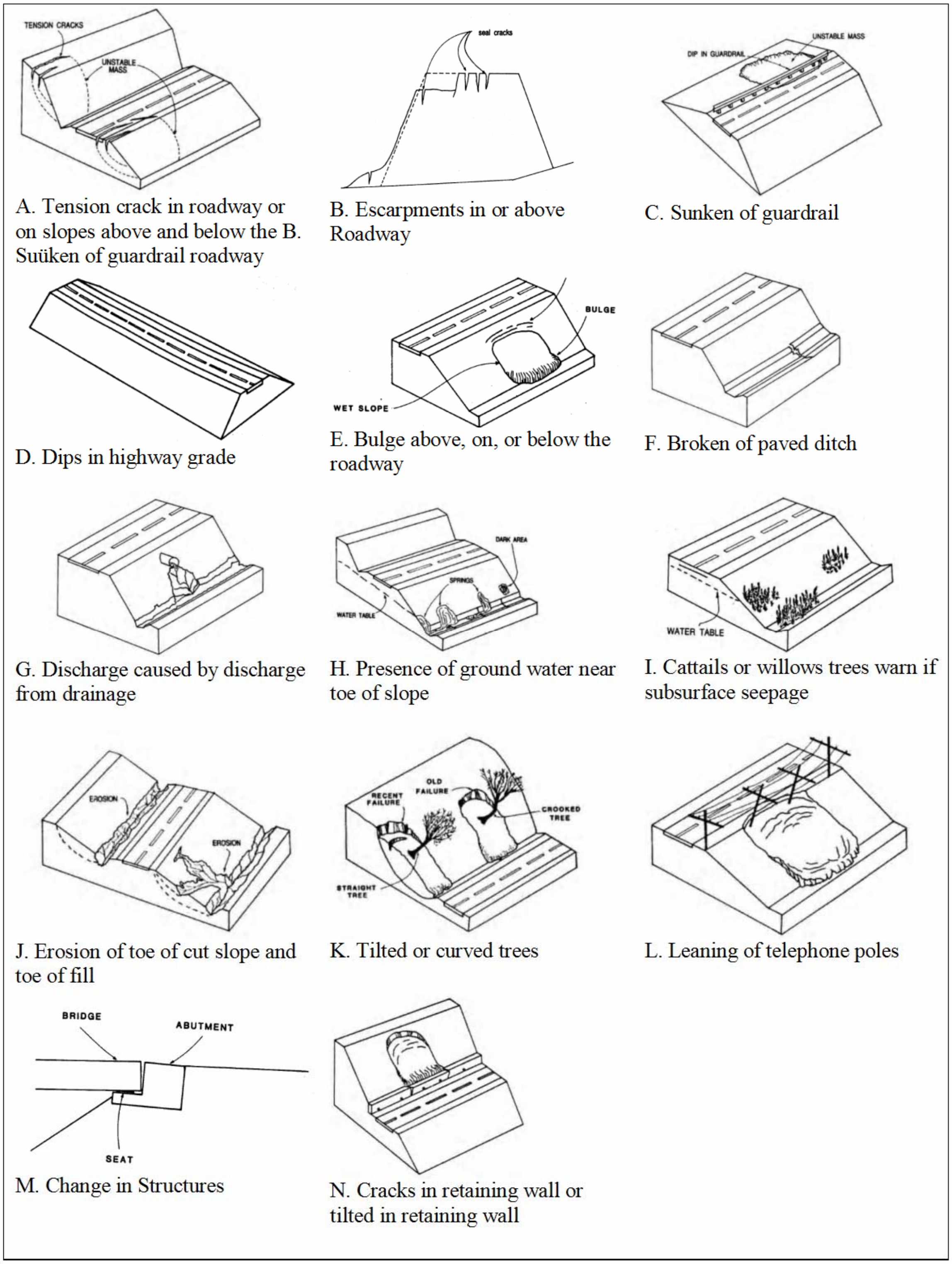
More subtle signs of earth movements could be trees that are tilted from vertical. Tilted trees at the toe of a slope that are now growing vertically indicate an old landslide that had moved many years ago. However, the movement has stopped and the tree is now growing vertically again. A tree growing in a continuous gentle curve may indicate a very gradual and slow creeping slope movement. Telephone poles and fence that have sunken or tilted 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 caused by 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: 1) 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, 2) 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: 1) risk analysis, 2) risk assessment, and 3) risk management. The risk analysis can be practiced in many levels ranging from qualitative to quantitative evaluations (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 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): 1) accepting risk, 2) avoiding risk, 3) reducing the likelihood, 4) reducing consequences, 5) monitoring and warning system, 6) transferring the risk, and 7) 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 effectively managing the geological hazard mitigation. The integration of database and GIS is possible because GIS software is developed considering several user-friendly features needed for 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.

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 of 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 cataloguing, 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, including 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 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.

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. Furthermore, databases are used for effective storage and retrieval of time-related data, which can be used for qualitative modeling of magnitude –frequency relationships as well as for 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. They emphasize 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 the application of GIS is an essential tool in the data analysis and the subsequent hazard assessment. Making use of GIS techniques, three methodological approaches were 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 mapping of the 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 person who developed the systems may be influenced by their 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 the selected criteria and weighting values. Most of applications were intended to provide a 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 systems are reviewed.

2.9.1 LANDSLIDE MANAGEMENT IN HONG KONG

Hong Kong has developed a numerical rating system since 1988 for landslide hazard. Slope failure problems in Hong Kong are severe because more than 60% of land is steeper than 15 degree and about 40% of land is greater than 30 degree. Hong Kong is also very extensive in urbanization. Thus, potential risk of loss of property, life, and economy due to a landslide is very high. Hong Kong used three systems to classify slopes: ranking system, squatter area, and classification of the undeveloped land. More detailed information about these three systems can be found in Tables B.1, B.2, and B.3 in Appendix B.

2.9.1.1 RANKING SYSTEMS FOR CUT AND FILL SLOPES

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

Ranking system for fill slopes in Hong Kong takes two aspects of slopes into consideration: 1) the fill slopes with insufficient compaction and 2) the fill slopes without enough protection system against infiltration of rainfall, groundwater, leakage of drainage pipe, etc. The ranking score for fill slopes in Hong Kong is called “x” score.

Some of the limitations of Hong Kong’s ranking system can be summarized as follows. In high rank slopes, the consequence score may be high but instability score may be low. Furthermore, the ranking system may not be suitable for other areas that urbanization is not as extensive as in Hong Kong. The data used to calculate the score are subjective, which were adjusted when individual assigns different weightings. The ranking system accounts for the proximity of a building to the slope and its intended use. However, the type of building structures 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 might be less prone to damage if it was supported on deep foundations instead of shallow foundations.

2.9.1.2 CLASSIFICATION OF SQUATTER AREA

The classification of squatter area is for the 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 residents who can only afford low cost housing, and usually they are in areas with slopes steeper than 30 degrees.

2.9.1.3 CLASSIFICATION OF UNDEVELOPED LAND

Hong Kong Government has also developed a program to classify its terrain. A Geotechnical Land Use Maps (GLUM) at the scale of 1:20,000 was created, which categorized the terrain into four classes depending on the slope angle, slope forming materials, hydrology, and evidence of past instability. The terrain with the past instability is classified as Class IV (dangerous). The area that the development can be made is classified as Class I and Class II. Class III is the terrain that cannot be classified as dangerous.

2.9.2 OREGON

Oregon Department of Transportation (ODOT) has initially developed a rockfall hazard rating system in early 1980's. Rockfall locations are inventoried. The system consists of six steps as follows: 1) slope inventory, 2) preliminary rating, 3) detailed rating, 4) preliminary design and cost estimate, 5) project identification and development, and 6) annual review and update. Preliminary rating and detail rating are used during rating process.

Preliminary rating

The *preliminary rating* considers classification criteria as follows.

- *A-Rating* is for rock fall activity that must be obvious.
- *B-Rating* is for rock fall that is deemed possible, but the frequency is low enough or the roadside is large enough.
- *C-Rating* is used for rockfall that is unlikely to reach a roadway.

Detail rating

The detail rating involves the use of 12 different factors, including 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 score system was used for assigning numerical rating scores (3, 9, 27, and 81). The total score of 12 factors represents the risk of a rockfall location. The exponential score system can rapidly distinguish the more hazardous sites from others.

Oregon DOT released the latest version in 2001, which is intended for applications to both landslide and rockfall. The objectives of the new development are as follows: 1) develop scoring system for rating landslide and rockfall, 2) develop project selection process, 3) develop database of landslide and rockfall, and 4) develop GIS database for managing the problems related to unstable slopes. Oregon DOT rating system takes the historical information, benefit and cost ratio into consideration as well.

Some of key elements in the new Oregon DOT slope rating system are as follows.

- Assessment of hazard scores based on five categories: 1) Failure Hazard/ Speed of Failure, 2) Roadway impact, 3) Annual Maintenance Frequency, 4) Average Daily Traffic, 5) Accident History.
- Modification factors are used to take into account of highway classification factor based on the importance of highway classes, and maintenance benefit-cost factor.
- Other factors that may influence project selection, such as culvert impacts, environment impacts, repair cost, impact of adjacent structure, among others.

2.9.3 WASHINGTON STATE

The Washington State Department of Transportation (WSDOT) has developed the Unstable Slope Management System (USMS) since 1993, which can be used for both rockfalls and landslides. Both slope condition and economic assessment were incorporated in the strategy for managing slopes. The information used for assessing slope conditions included the location of slope, whether the slope is on left or right of centerline, type of instabilities and frequency of slope failure. Economic assessment includes the estimation of annual maintenance cost associated with mitigating the unstable slope.

Eleven factors are used in the scoring system to rate the slope. Based on the overall score, the unstable slopes were categorized into three categories: Category A (high potential), Category B (moderate potential) and Category C (low potential).

WSDOT used Microsoft Access® to maintain the database of landslide sites and also prioritized the remedial need by grouping the highways based on their functional class. Therefore, slopes at interstate facilities and principal arterials are to be remediated first, followed by those at the lower volume roads. Within the same highway functional class, the slopes are ranked in descending numerical order, so that the highest-risk slope within that class would be remedied first.

The WSDOT system used the cost associated with traffic delay and annual maintenance cost factored over the life of 20 years. The cost associated with traffic delay is the estimation of how many days that slope remains being failed. The other factor is the amount of roadway that would be impacted. This factor is one of factors in numerical rating system and it is used in reduction factor for calculation of traffic delay costs.

Life-cycle maintenance costs were determined on the basis of 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. These are used to develop a list of benefit-cost ratio of the sites. The unstable slope must have a cost benefit ratio greater than one to be considered for the unstable slope program.

However, the WSDOT system has some drawbacks. For example, in the lower functional highway with high catastrophic potential, the unstable slope site may have low traffic volume but it might be the only roadway in the area. This will cause problem in transportation when the road is closed.

2.9.4 INDIANA

Indiana Department of Transportation (INDOT) developed landslide remediation strategy using unconventional methods in 1999. The unconventional landslide remedial methods refer to the landslide remedial methods that are not common in the state of Indiana. The unconventional remedial method includes horizontal wick drains, driven recycle plastic pins, railroad rail piles, lime cement columns, biotechnical remediation, and gravity mass retaining systems. These methods are proposed because they have a cost benefit when applied to relatively small landslides. They provide a sufficient safety factor and a lower cost than conventional methods.

ArcView and Arc/Info (ESRI) GIS software is used in this study to provide a convenient means for the management, storage and manipulation of spatial information. With the application of ArcView, the themes of geographical referenced information is constructed and subsequently superimposed to enable correlation study. The landslide locations corresponding with their geologic and geographic information are entered into the developed database. With GIS application, the correlation of landslide occurrence with geographic and geologic information can be developed. Consequently, landslide occurrence can be linked to topography and bedrock geology. The recommended solution for landslide failure can be systematically determined.

2.9.5 TENNESSEE

Tennessee Department of Transportation (TDOT) developed a management system for landslide along Tennessee highway in 2000. The objectives can be explained as 1) development of a statewide spatiotemporal landslide database accessible to TDOT planners, engineers, and geologists and 2) production and visualization of landslide thematic map accessible via internet. The system is implemented on GIS database, which allows users to link attributes, temporal and spatial data in a spatiotemporal database for cataloguing, visualizing, and managing landslides along Tennessee highway. The spatiotemporal data includes attribute data such as landslide types, age, scale, bedrock, geology and some information from the administration office such as historical data, maintenance data. All reports, letters, memos, design sketches, drawings, and contract documents 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 string 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 for the day of the year. The Julian date is used as a reference for each update of information, and for keeping track of activity related to the project.

2.9.6 UTAH DEAPRTMENT OF TRANSPOTATION (UDOT)

Utah Department of Transportation (UDOT) developed the unstable slope inventory in summer 2001. This development started with the concern of future increases in traffic load and a variety of terrain that unstable activities are frequently found. The study plan of UDOT includes Phase I and Phase II.

In Phase I, the rockfall hazard rating system (RHRS) developed by Oregon Department of Transportation (Oregon DOT) is adopted. Rockfall locations were inspected and documented. The subjective preliminary specification of Oregon DOT is used to classify the slopes. An amount of 479 sites were classified as "A" class, 569 sites were B class, and 51 sites were rated as class C. The database inventory for this study was constructed for unstable slopes from class A and B and some from class C, which included some basic site descriptions, locations, and photographs.

The phase II study was to evaluate unstable slope hazard rating systems previously developed by NYSDOT, Oregon DOT (both 1992 and 2001 versions). The comparative study of the three rating systems helps to determine the suitable parameters to be used in the Utah database and future development of the rating system. The phase II development also included implementation of GIS database, linking the spatial data to the Utah highway grid. The GIS database was compatible with the ArcView GIS software developed by ESRI. The database for this project was compiled in a dBASE file format.

CHAPTER III

LANDSLIDE FIELD RECONNAISANCE FORM AND DATA COLLECTION PROCESS

3.1 OVERVIEW

The landslide field reconnaissance form and the process of landslide data collection are described in this chapter. The purpose of developing a form is to make sure that the field reconnaissance data is collected in a consistent and uniform manner. The form is developed based on syntheses of expert opinions of ODOT engineers, geologists, and existing practices by other state agencies.

According to the different ODOT personnel to fill in the information, the landslide field reconnaissance form is broken down into three parts including parts A, B and C. 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 data saved into a handheld GPS unit or a laptop computer through ArcPad® is called a shapefile. Once the landslide field reconnaissance form is digitally filled, the resulting shapefile can be uploaded into the database though the webpage. Once the data is successfully submitted to the database, 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 web pages are described in Chapter V of the User's Manual.

3.2 LANDSLIDE FIELD RECONNAISSANCE FORM AND LANDSLIDE RECONNAISSANCE PROCESS

The Landslide Field Reconnaissance Form is designed to consist of four parts: Landslide Observation Report and Parts A, B, and C. The complete form can be found in Appendix A.

3.2.1 LANDSLIDE OBSERVATION REPORT

Reporting of a potential landslide site is initiated by completing the Landslide Observation Report by a highway maintenance/construction worker or a crew member from a County Office. The report 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 adequate background knowledge in geology or geotechnical engineering, are often the first ones to observe changes along 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), among others. 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 FIELD RECONNAISSANCE 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 a landslide at all, there is no follow up activity. The Landslide Observation Report is kept in the folder for future reference. If he/she determines that it is indeed a landslide, then the Landslide Field Reconnaissance 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 form. 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 Part B, which requires a compilation of 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. The electronic files of sketches and photos need to be submitted to database and association between landslide site, photos, and sketches need to be established. The process of submitting and associating these electronic files with a landslide site is presented in Chapter V of the User's manual. 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 FIELD RECONNAISSANCE FORM PART C

Once DGE receives 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 information previously collected by CM/TM in Part A and Part B. If DGE finds inconsistent information in Part A and Part B, he/she can modify this information accordingly. DGE would then perform a detailed 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 submits Part C data 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. It should be noted that filling in Part C information by DGE is broken down into three tiers, as shown in Figure 3.1.

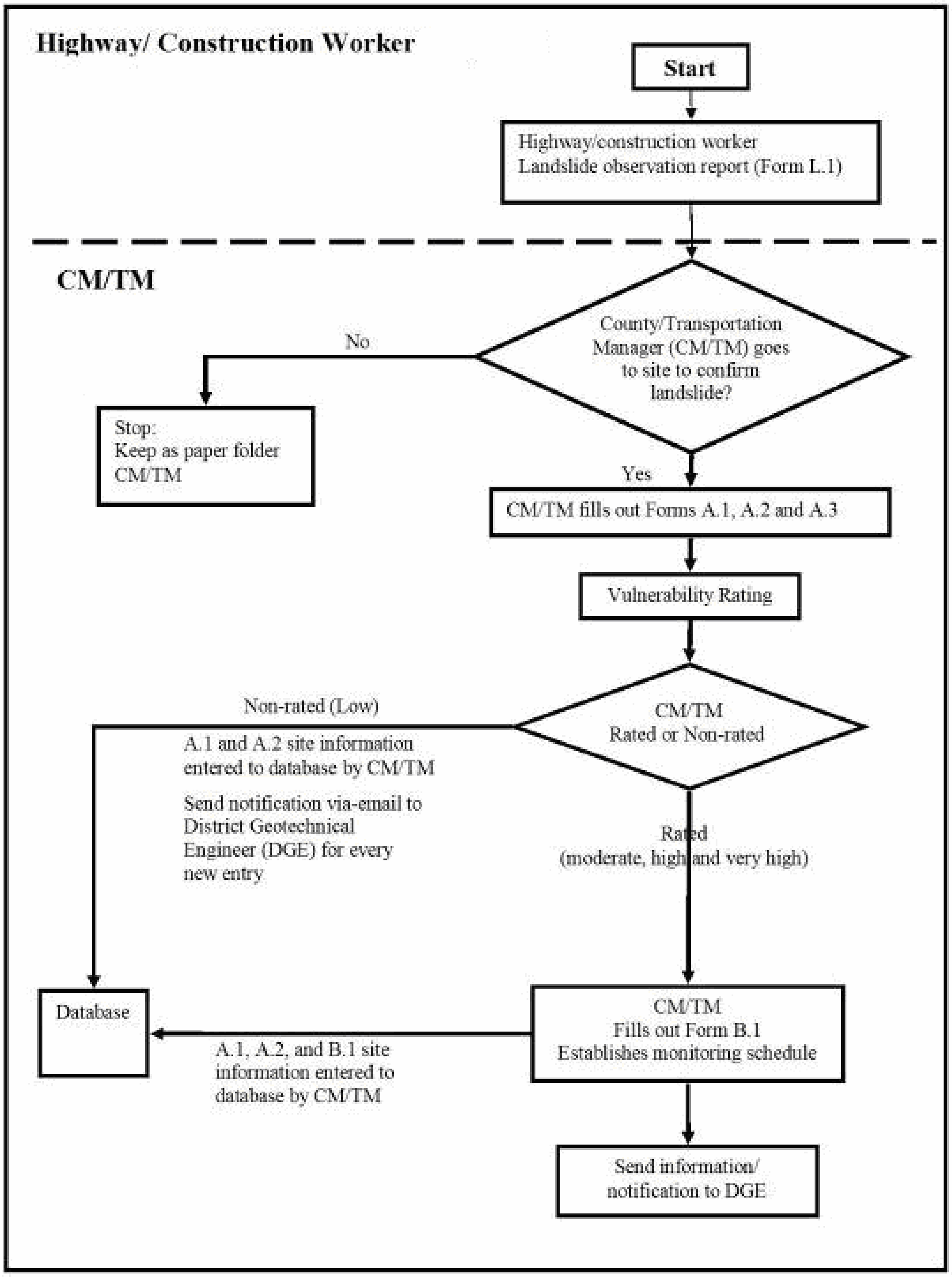


Figure 3.1 Landslide reconnaissance process

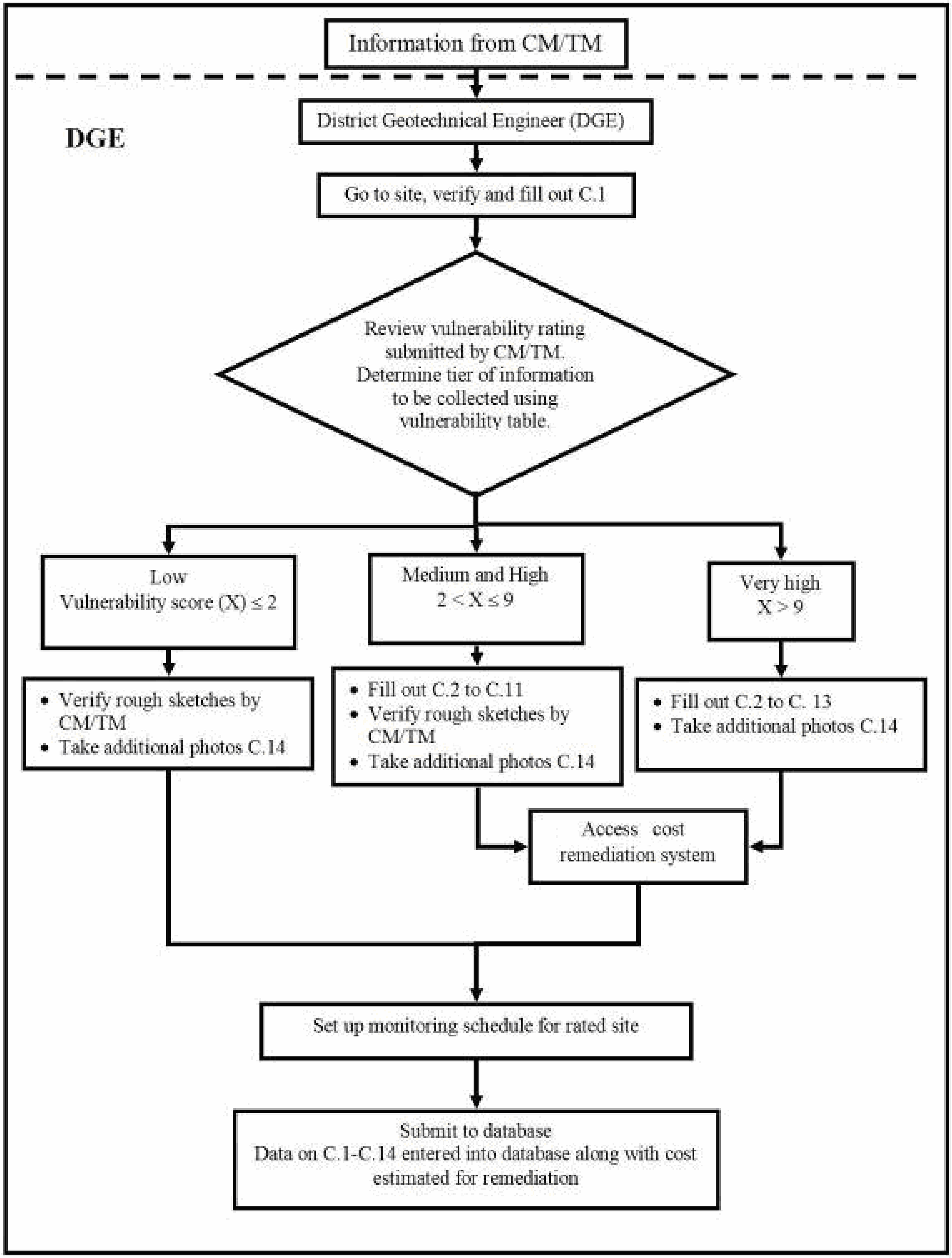


Figure 3.1 Landslide reconnaissance process (continued)

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 and geologists 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 office was 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 and geologists 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 Field 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.

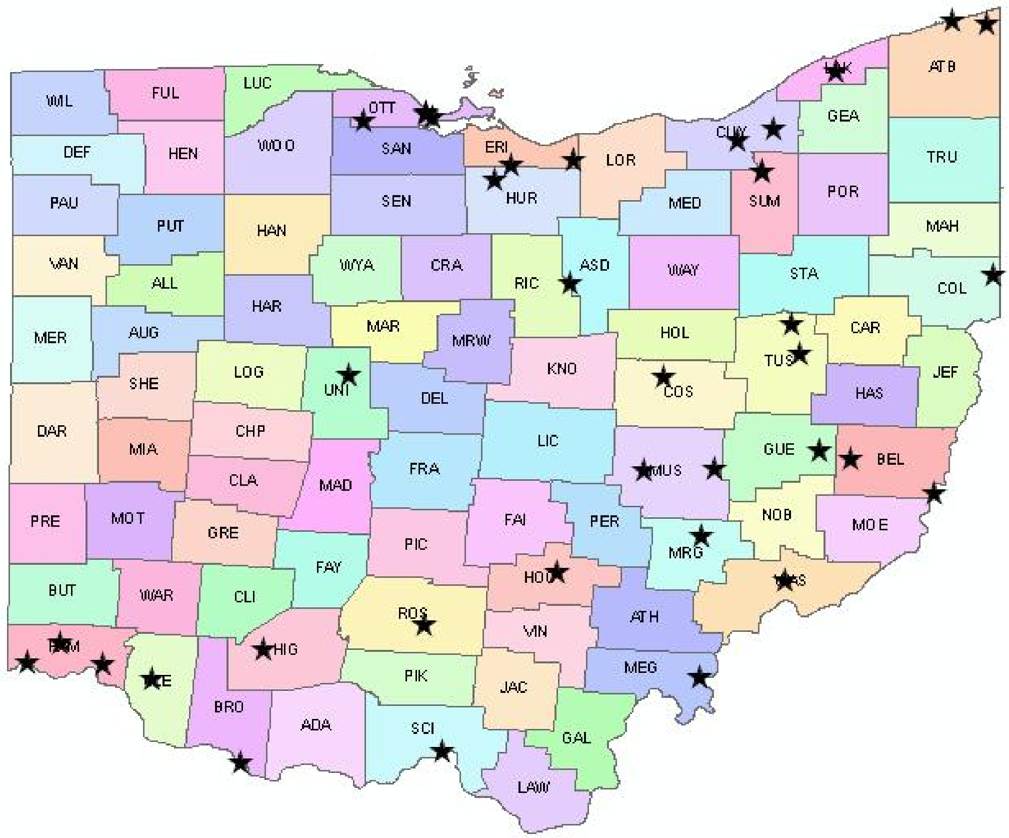


Figure 4.1 Locations of thirty seven landslide sites

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 Ohio DOT in-house expert opinions 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 four 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: 1) Movement location and impact on roadway, 2) Hazard to traveling public, 3) Decision sight distance, 4) Average daily traffic, 5) Accident history, and 6) 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
Oregon DOT Rockfall Hazard Rating System (RHRS)	Pierson and Vickle (1993)	Systematic method of prioritizing rockfall sites requiring maintenance or repair
Oregon DOT Landslide Rating System	Oregon DOT (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)	OregonDOT (2001)	WSDOT (1993)	Ohio DOT
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	Accident history			×	×	×
16	Benefit-cost ratio			×	×	×
17	Rate of movement					×
18	Known instability related to geology	×	×			
19	Occurrence of ground and water surface	×	×		×	
20	Impact to road structure and adjacent features	×		×	×	×
21	Vertical and horizontal of scarp of displacement			×	×	×
22	Traffic speed		×		×	×
23	Potential future impact	×			×	×
24	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: 1) classify landslides, 2) simplify characteristics of landslides, and 3) 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 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 4.5 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 because 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

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.

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 4.9, 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 4.10. The t values and significances are shown in Table 4.10. 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. 10 ANOVA tests 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			

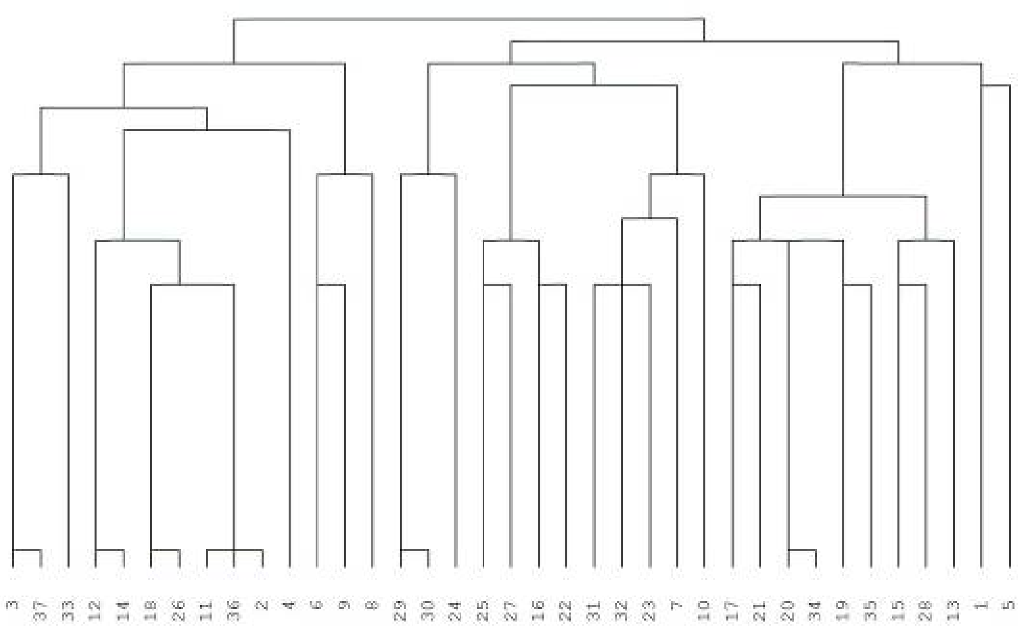
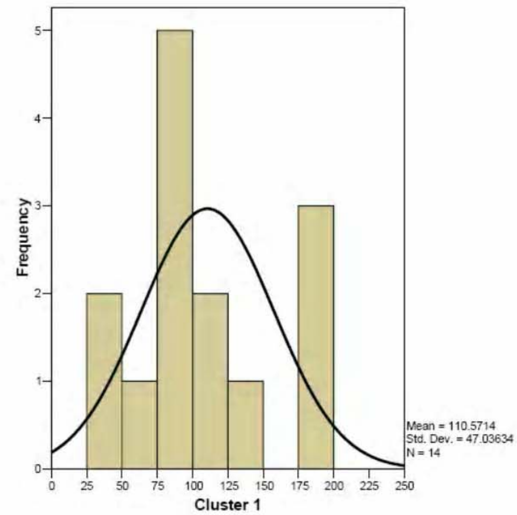
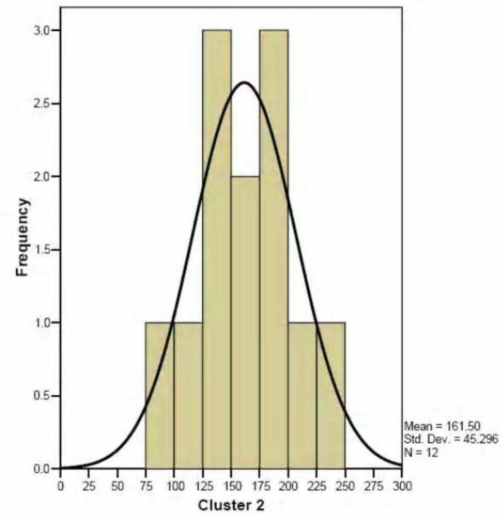


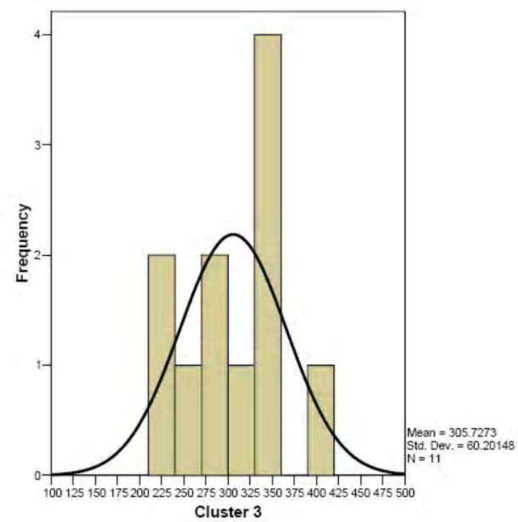
Figure 4.2 Tree diagram of 37 landslide sites



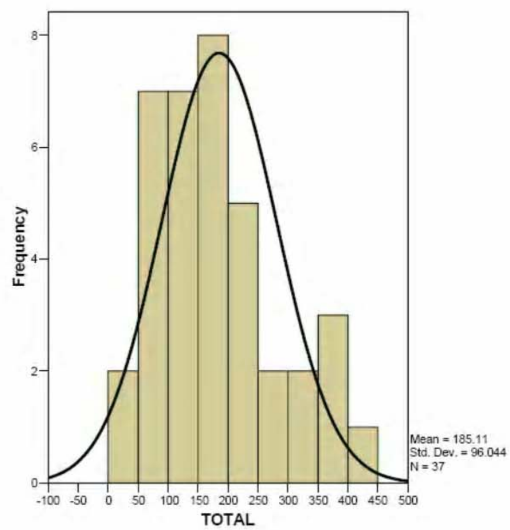
(a) A Histogram of cluster 1 (low hazard)



(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

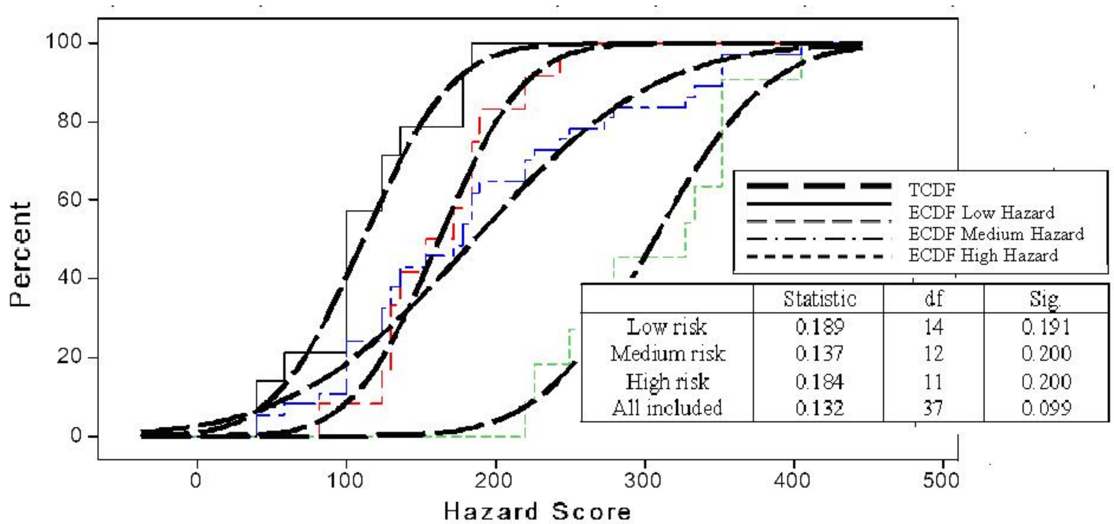


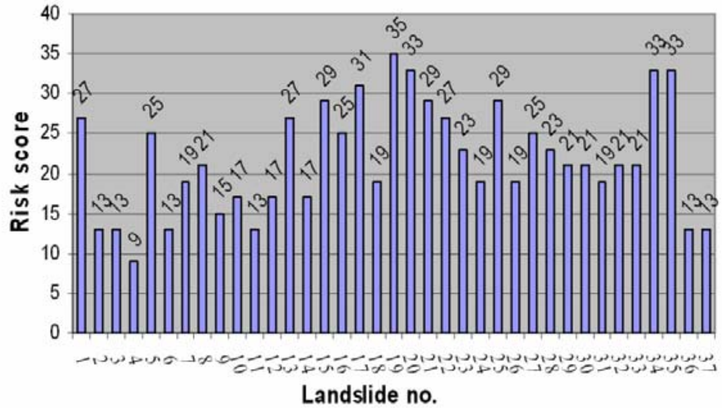
Figure 4.4 Normality test

Table 4.21 t-test of hazard scoring criteria

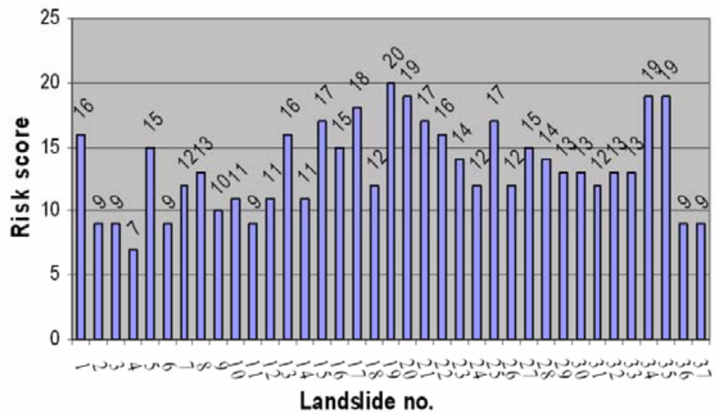
	Cluster1	Cluster 2		Cluster 3
Hypothesis testing α = 0.05	$H_0 : \mu \le \mu_0$ $H_1 : \mu > \mu_0$ $\mu_0 = 150$	$H_0 : \mu \ge \mu_0$ $H_1 : \mu < \mu_0$ $\mu_0 = 150$	$H_0 : \mu \le \mu_0$ $H_1 : \mu > \mu_0$ $\mu_0 = 250$	$H_0 : \mu \ge \mu_0$ $H_1 : \mu < \mu_0$ $\mu_0 = 250$
Mean	110.20	161.5	161.5	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)	$\frac{Sig.(2-tailed)}{2} < \alpha$ $and \quad t > 0$	$\frac{Sig.(2-tailed)}{2} < \alpha$ $and \quad t < 0$	$\frac{Sig.(2-tailed)}{2} < \alpha$ $and \quad t > 0$	$\frac{Sig.(2-tailed)}{2} < \alpha$ $and \quad t < 0$
Rejection of H_0	Failed to reject	Failed to reject	Failed to reject	Failed to reject

4.6 COMPARISONS OF DIFFERENT HAZARD SCORING SYSTEM

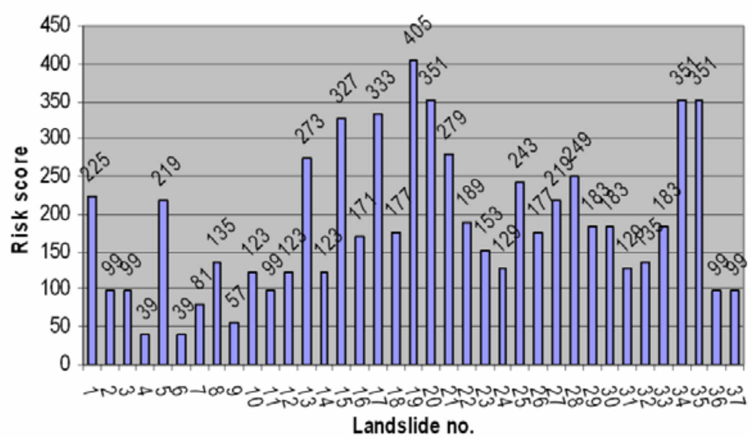
This section shows that the scoring technique of the exponential scoring system of 3, 9, 27 and 81 would give ODOT the most effective approach to assess and differentiate the risk among the pilot data set of 37 landslide sites. The exponential scoring system is compared with the arithmetic (1, 2, 3, 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 4.5. 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.



(a)



(b)



(c)

Figure 4.5 Comparisons of distributing of different numerical scoring system (a) odd number, (b) arithmetic, and (c) exponential scoring systems

CHAPTER V

DESIGN OF GIS-BASED WEB APPLICATION

5.1 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. Furthermore, the web based database allows for data searching, data query and data analysis. In addition, the system provides the capability for user management.

The main technologies used in the system include the following:

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

5.2 SYSTEM ARCHITECTURE

5.2.1 OVERALL SYSTEM

The system is composed of several sub components, as shown in Figure 5.1. 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 the functions such as GIS information processing, map services and the GIS associated data searching and data analysis. Also, it provides 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 show in Figure 5.2.

- 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 Shape 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.

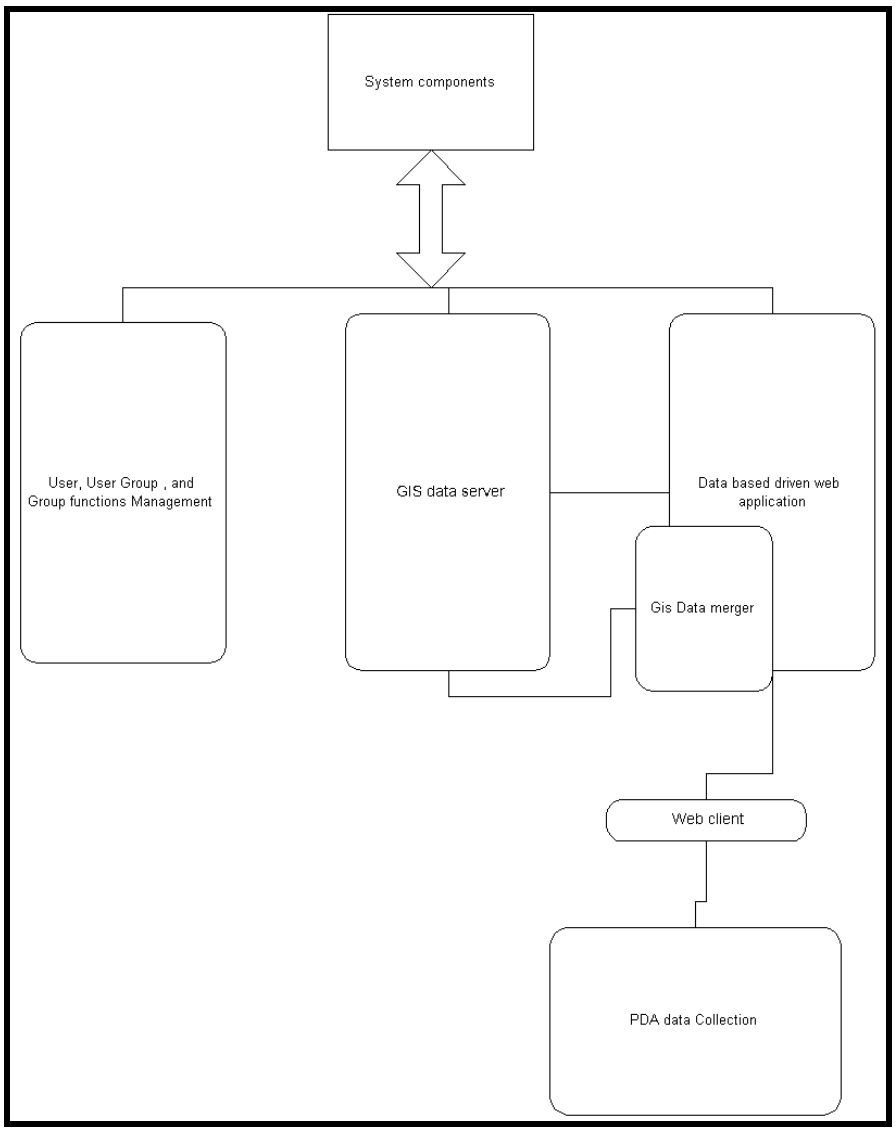


Figure 5.1 Overall system diagram of the system

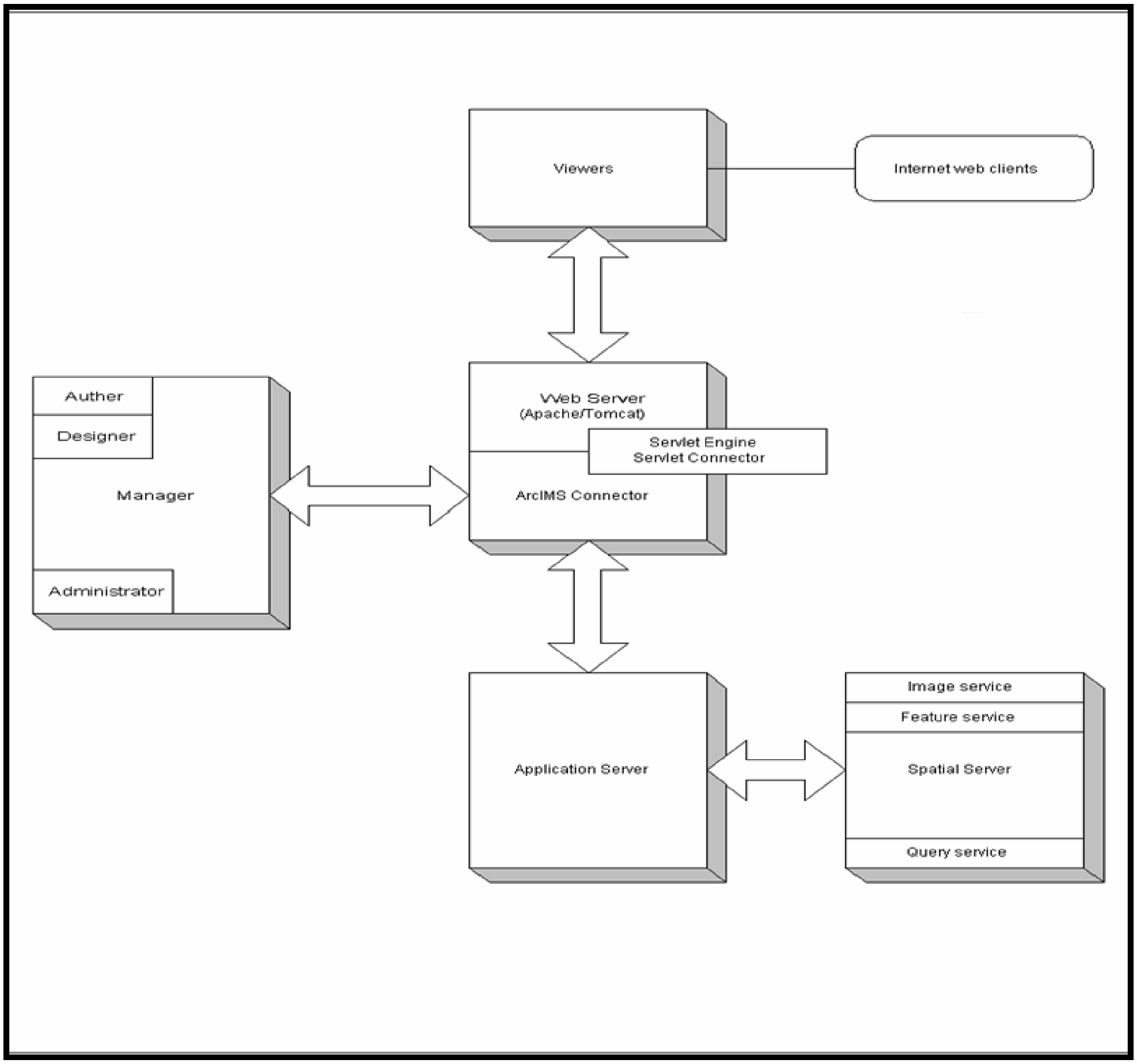


Figure 5.2 ArcIMS component connections

5.3 DATA FLOW

Several components are designed and implemented to meet the requirements of the data collection and data processing described in Chapter III. Meanwhile, the roles of the users involved in the system data processing are defined.

As shown in the Figure 5.3, 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. CM/TM performs initial site visit for the preliminary site evaluation. During the site visit, the Landslide Field Reconnaissance Form, Part A is complete. 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. The Landslide Field Reconnaissance Form, Part B is filled and uploaded to the database system.

These landslide sites are further evaluated by a District Geotechnical Engineer (DGE). The Landslide Field Reconnaissance Form, Part C is filled in three tiers based on Vulnerability Table.

Figure 5.4 depicts the data flow implemented in the system.

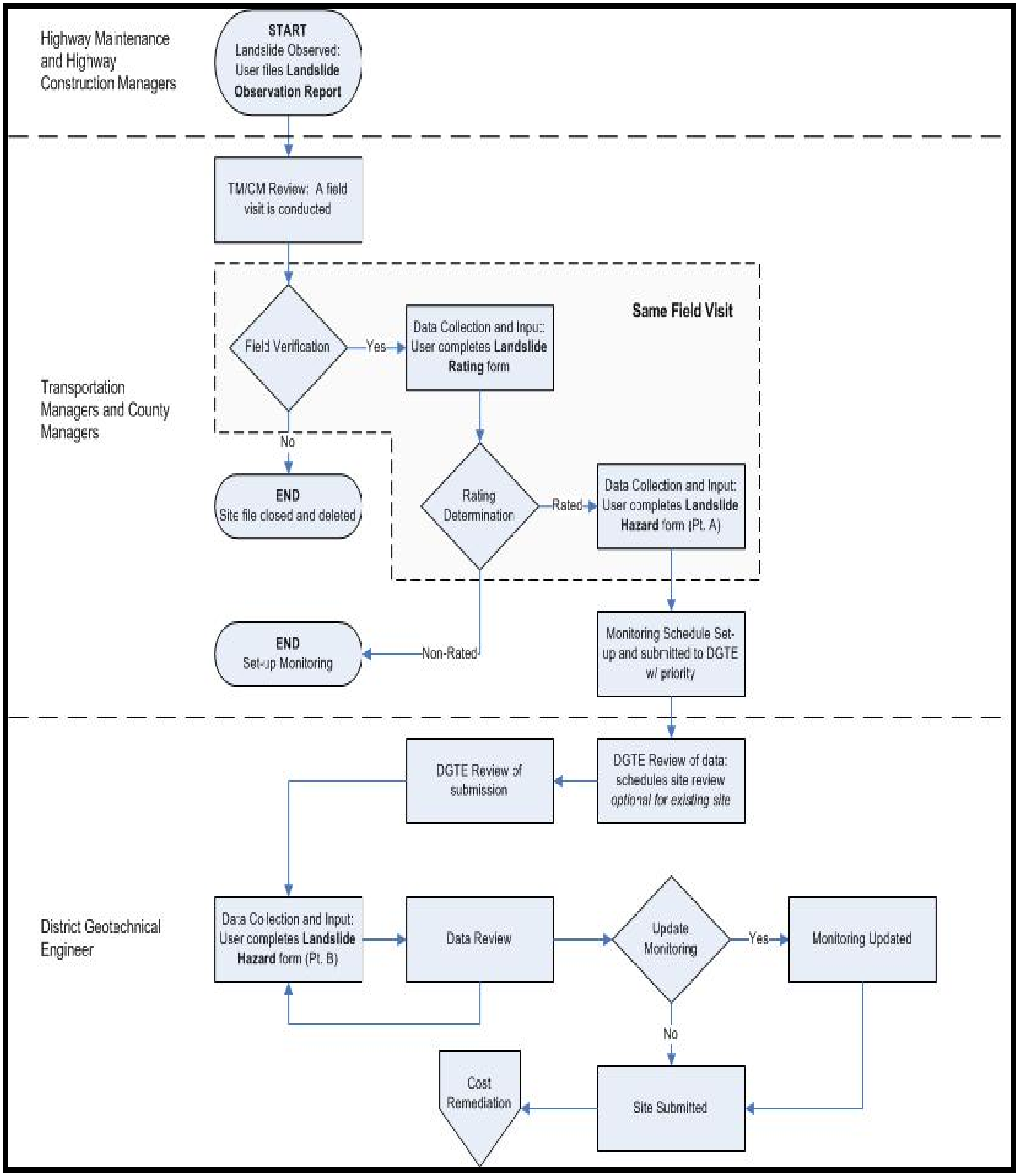


Figure 5.3 Data process steps.

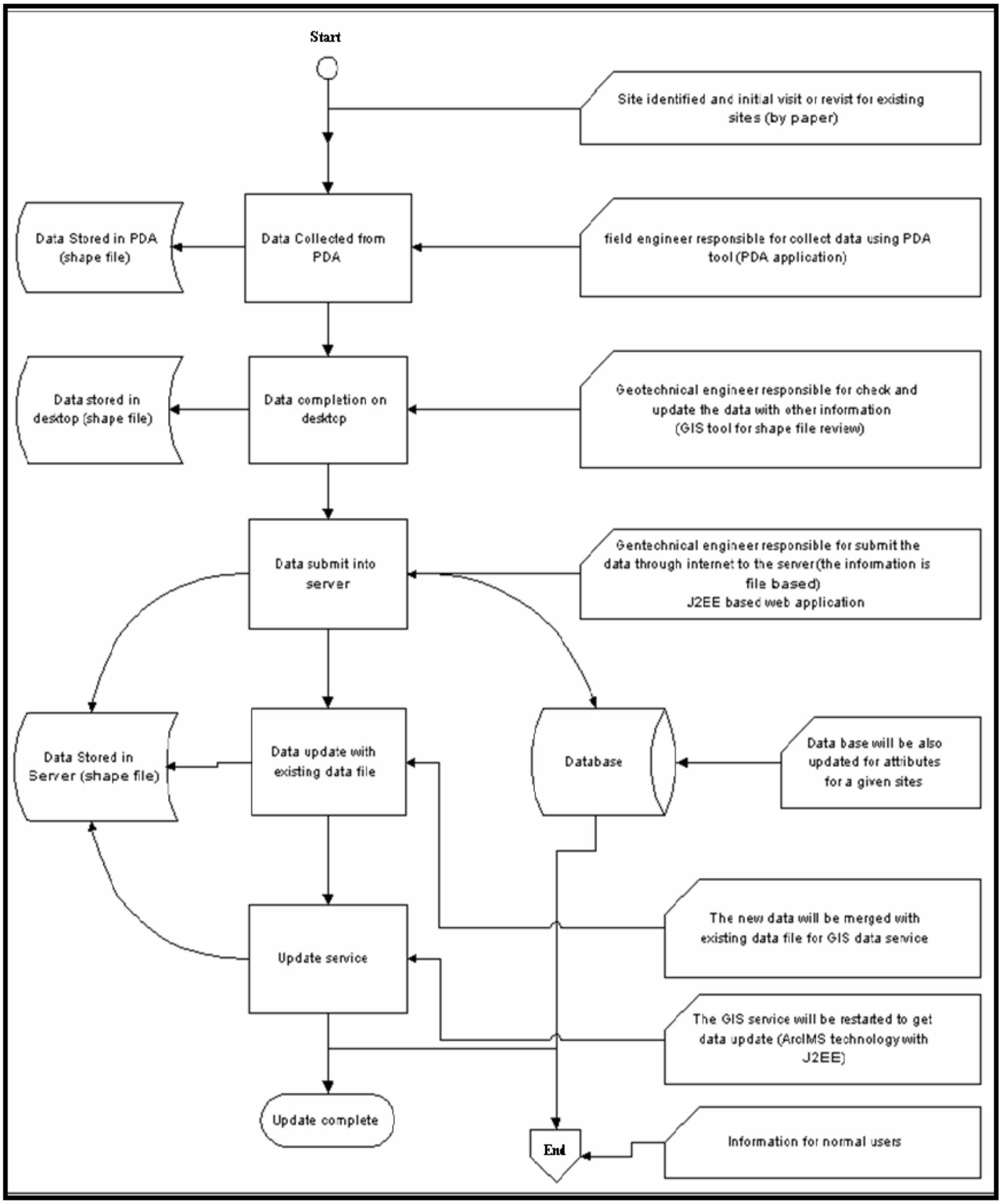


Figure 5.4 Data flow in the system

5.4 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. Certain users who belong to a certain group can have a set of pre-defined user privileges. The system is designed to be flexible so that a certain user group (for example, administrator) can dynamically setup a new user group with the prescribed privileges. These functions include adding new group, 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 5.5.

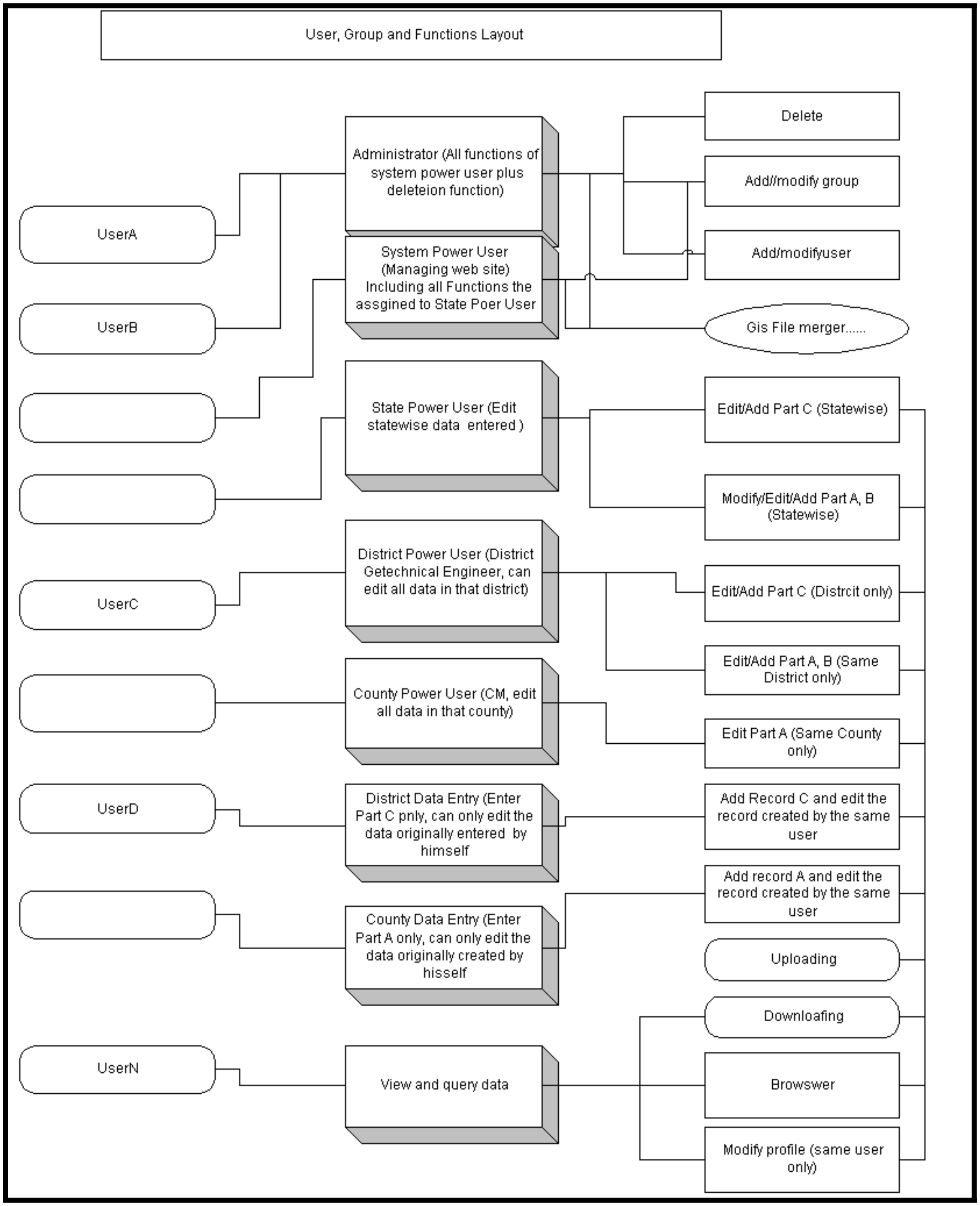


Figure 5.5 Typical users/user group and their functions

5.5 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 a 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 5.6.

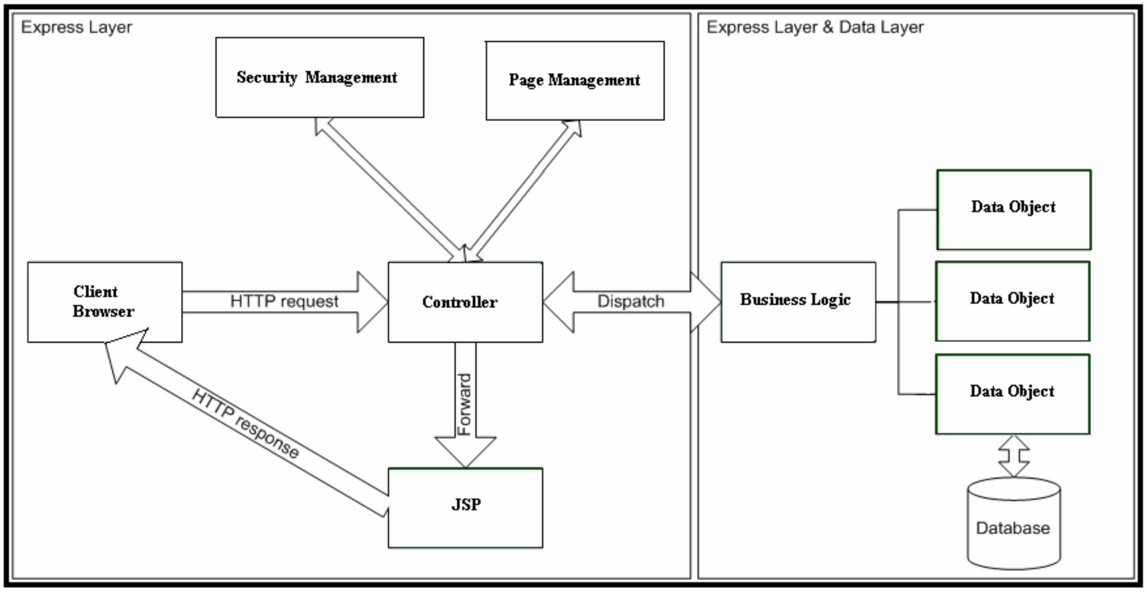


Figure 5.6 Web application architecture

5.6 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.

5.7 FILE MANAGEMENT

At present, the spatial data, pictures and sketches are maintained in the server 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

- ShpFile
- 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. 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.

"ShpFiles" folder stores the dbf file for file uploading process. When uploading is complete, Shape files will be automatically merged into database. Meanwhile, these files are kept for downloading purpose. As a result, levels of subfolders will be created based on the following convention:

- District name will be used as subfolder under c:\DataFile\ShpFiles
- County name will be used as subfolder under c:\DataFile\ShpFiles\District x (x: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12)
- User name plus date together will be used as the last 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 5.7.

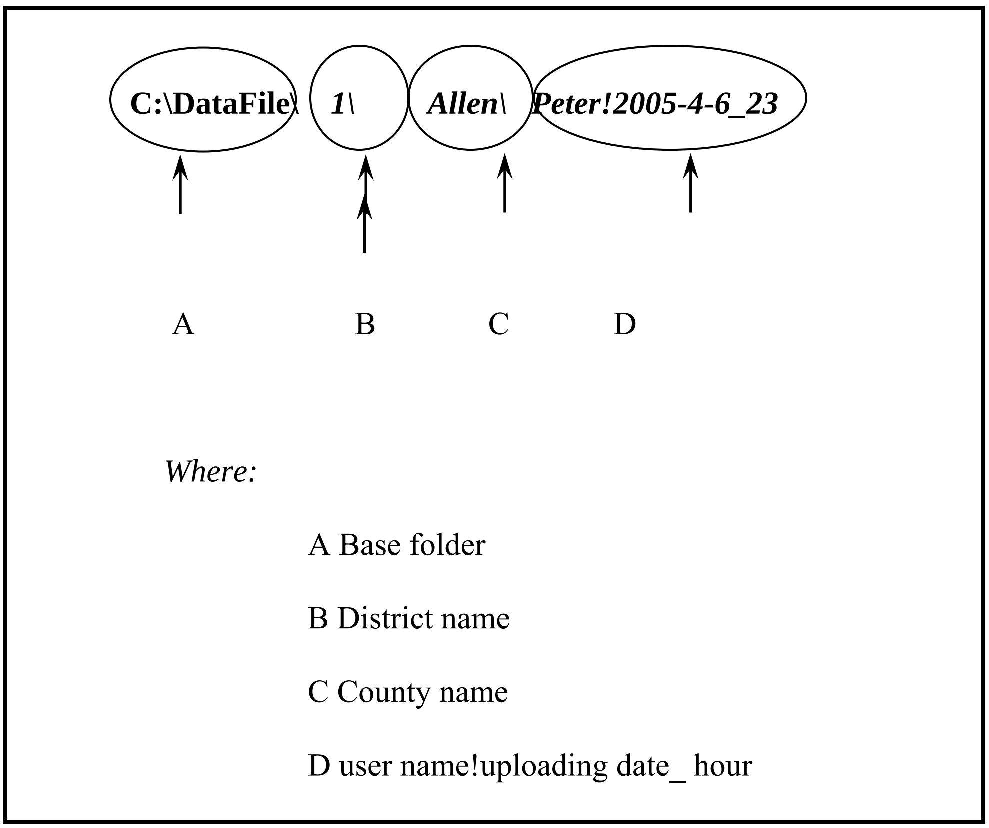


Figure 5.7 Folder structure for un-merged files

The "file" folder is used to store the pictures, sketches about Part A and Part C. The sub-folder is created by the date when the picture is uploaded. The link is stored into database. It is not recommend that the users browse the picture here.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY OF IMPORTANT RESEARCH RESULTS

A landslide hazard rating matrix and landslide inventory database are developed for landslide risk/hazard management for ODOT. The landslide rating matrix is developed based on syntheses of expert knowledge, in-house experiences of ODOT engineers, geologists, 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 statistical methods are used to verify the validity of the developed landslide hazard rating system to ensure that the system yields a rationally prioritized ranking of 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, however, relies on both experts' opinions and cluster analysis.

Based on the analysis results of 37 landslide sites collected as a pilot database, the landslide numerical rating system gives reasonable ranking of landslide hazards. The cluster analysis technique is used to classify the 37 landslide sites and the results show that the rating system can distinguish landslide hazard into three 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, 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 decisions on landslide repair priorities among all inventoried landslide sites. 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 heighten the differences and maximize the effectiveness of the numerical risk/hazard scores for the 37 pilot landslide data.

The development and deployment of the Ohio landslide database system provides ODOT a systematic approach to manage landslides and slope failures along its highways. The Landslide Field 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 in counties and districts. The daunting tasks of collecting, managing data pertaining to numerous landslides becomes manageable due to the development and deployment 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 provides ODOT a near real-time management capability. Because the landslide data are centrally stored, they can be accessed readily by different constituents. The landslide inventory data is uniform, consistent, comprehensive, and intelligent. The ODOT personnel can quickly manipulate, sort, group, and report pertinent landslide data sets in an effective way. The time for gathering and analyzing landslide data is shorter. 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 application of the developed landslide hazard rating 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 probability of catastrophic failure for a site. It can not be used as a prediction tool to predict when or which slope among all inventoried landslide sites will fail catastrophically first.

- The application of the landslide hazard rating system is developed based on both subjective and objective data. For determining the subjective rating, personal experience and judgment are often involved, to ensure uniform scoring approach, it is recommended that training sessions be held for all personnel involved.
- The landslide hazard rating system is developed using a limited amount of data information. For example, information pertaining to maintenance history and accident history was not always available for the landslide sites in the pilot database. In the future research, the landslide field reconnaissance forms should be filled as complete as possible. As the database is grown and the data sets become more complete, the landslide hazard rating matrix needs to be reevaluated. This requires adjustment of the scoring criteria as well as additional statistical analyses.

REFERENCES:

1. Aleotti, P., and Chowdhury, R., "Landslide Hazard Assessment: Summary Review and New Perspectives" Bulletin of Engineering Geology Environment, 58, pp. 21-44, 1999.
2. Everitt, B., Cluster Analysis, John Wiley & Sons, New York, 1993
3. Cruden, David M., and Varnes, David J., "Landslide Types and Processes", Landslides Investigation and Mitigation, National Research Council, Transportation Research Board, Special Report 247, pp. 36-75, 1996.
4. Dai, F. C., and Lee, C. F., "Landslide Characteristics and Slope Instability modeling using GIS, Lantau Island, Hong Kong" Geomorphology, 42, pp. 213-228, 2002.
5. Dai, F. C., Lee, C. F., and Ngai, Y. Y., "Landslide Risk Assessment and Management: An Overview" Engineering Geology, 64, pp. 65-87, 2002.
6. Dikau, R. Cavallin, A., and Jager, S., "Databases and GIS for landslide research in Europe", Geomorphology, 15, 227-239, 1996
7. Federal Highway Administration (FHWA), "Highway Slope Maintenance and Slide Restoration Workshop", Participant Manual, U.S. Department of Transportation, Report No. FHWA-RT-88-040, December, 1988.
8. Fell, R., and Hartfort, D., Landslide Risk Management, in "Landslide Risk Assessment", Cruden and Fell (eds.), Balkema, Rotterdam, pp. 51-110, 1997
9. Hadjin, D.J., "NYSDOT Rock Slope Rating Procedure and Rockfall Assessment Internal Report", New York State Department of Transportation, Albany, New York, 2001

10. Holt, G.D., “Applying Cluster Analysis to Construction Contractor Classification”, Building and Environment, 31(6), pp. 558-568, 1996.

11. Koirala, N.P. and Watkins, A.T., “Bulk appraisal of slopes in Hong Kong”. In Landslides, Proc. Of the Fifth Int. Symp. on Landslide, Lausanne, Switzerland. A.A. Balkema, Rotterdam, The Netherlands, 2, pp. 1181-1186. 1988

12. Lange, C.B., and Deschamps, R.J., “Landslide Remediation Using Unconvential Methods”, FHWA/IN/JTRP-99/6, September 1999

13. Lakrod, K., Chaisrisook, C., Youngsmith, B., and Skinner, D.Z., “RAPD analysis of genetic variation within collection of Monascus spp”. Isolated form red rice (ang-kak) and sofu, Mycol. Res. 104 (4), pp. 403-408, April, 2000

14. Lawrence A. Pierson, “Rockfall Hazard Rating System”, Transportation Research Record No 1343, National Academy Press, D.C. 1992

15. Lowell, S. and Morin, P., “Unstable Slope Management”, TR News 207, March-April, 2000, pp. 11-15, 2000

16. ODOT, “ODOT Landslide & Rockfall Pilot Study (Final Report)” ODOT Geo-Hydro Section, HQ Geo-Hydro Unit, 2002

17. Popescu, M. E., “A Suggested Method for Reporting Landslide Causes”, Bulletin of the International Association of Engineering Geology, 50, pp. 71-74, 1994

18. Pierson, L.A. “Rockfall Hazard Rating System”, Transportation Research Record No 1343, National Academy Press, D.C. pp. 6-13, 1992.

19. Pack, R.T., “Utah rockfall hazard inventory phase I”, Utah Department of Transportation Research Division, April 2002

20. Ross, B., La Rosa, A., Mauldon, M., Ralston, B., Drumm, Eric., “GIS Landslide Inventory Along Tennessee Highway”, Transportation Research Board, 80th Annual Meeting, Washington D.C. TRB Identification Number: 01-0236, 2000

21. Terzaghi, K., and Peck, R.B., “Soil Mechanics in Engineering Practice”. John Wiley & Sons, New York, 1948

22. Varnes, David J., “Slope Movement Types and Processes”, Landslides: Analysis and Control, National Research Council, Transportation Research Board, Special Report 176, pp. 11-33, 1978.

23. Woodard, J.M., “Development of Rockfall Hazard Rating Matrix for the State of Ohio”, Doctoral Dissertation, Kent State University, 2003

APPENDIX A

LANDSLIDE FIELD RECONNAISSANCE FORM

OHIO LANDSLIDE HAZARD RATING SYSTEM

Landslide Inventory Number

☐-☐☐☐☐☐☐

Landslide Observation Report filled 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	

OHIO LANDSLIDE HAZARD RATING SYSTEM

Landslide Inventory Number
☐-☐☐☐☐☐☐

Part A filled by Transportation/County Manager

Evaluator's name	
Date of observation	

Site Location

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 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: ______________ft
State coordinates (Mid-point) (Auto generation)	Zone: ______________ Northing: ______________ Easting: ______________
USGS Quad (Auto generation)	Name: ______________ Number: ______________

Landslide Inventory Number

☐-☐☐☐☐☐☐

<u>OHIO LANDSLIDE HAZARD RATING SYSTEM</u>

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______________

OHIO LANDSLIDE HAZARD RATING SYSTEM

Landslide Inventory Number
☐-☐☐☐☐☐☐

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.

OHIO LANDSLIDE HAZARD RATING SYSTEM

Landslide Inventory Number
□-□□□□□□

Part B filled 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

Landslide Inventory Number

□-□□□□□□

OHIO LANDSLIDE HAZARD RATING SYSTEM

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

OHIO LANDSLIDE HAZARD RATING SYSTEM

Landslide Inventory Number
☐-☐☐☐☐☐☐

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: ______

Landslide Inventory Number
☐-☐☐☐☐☐☐

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

OHIO LANDSLIDE HAZARD RATING SYSTEM

Landslide Inventory Number
□-□□□□□□

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

OHIO LANDSLIDE HAZARD RATING SYSTEM

Landslide Inventory Number
☐-☐☐☐☐☐☐

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________________________

Landslide Inventory Number
□-□□□□□□

Part C (continued)

Preliminary Determination of Causes of Landslide

Human activities	__Excavation/under cutting __Deforestation __ Defective maintenance __Water leakage from pipes __Loose waste dumping __Groundwater pumping __Loading __Failure of drainage __Artificial vibrations __ 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

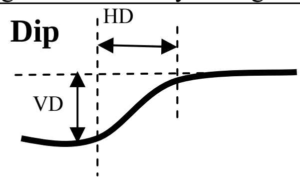
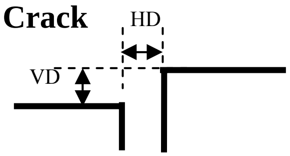
OHIO LANDSLIDE HAZARD RATING SYSTEM

Landslide Inventory Number

□-□□□□□□

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)________ Horizontal displacement (HD) (inch)______	**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____

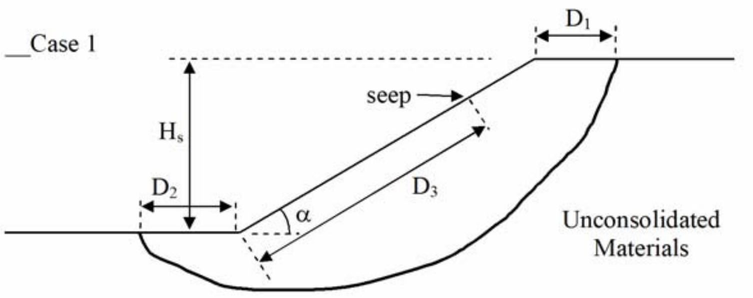
OHIO LANDSLIDE HAZARD RATING SYSTEM

Landslide Inventory Number
□-□□□□□□

Part C (continued)

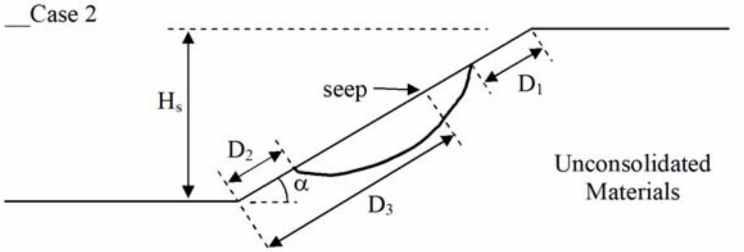
Information for estimation of landslide repair cost

__Case 1



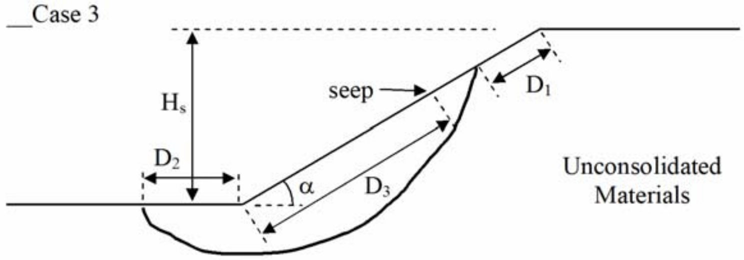
1. Average slope angle, α,_________
2. Height of slope, H_s (ft)__________
3. Length of slope repair, L, parallel to highway (ft)______________
4. Distance from crest of slope to failure surface, D_1(ft)____________
5. Distance from toe of slope to failure surface, D_2 (ft)________________
6. Distance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

__Case 2



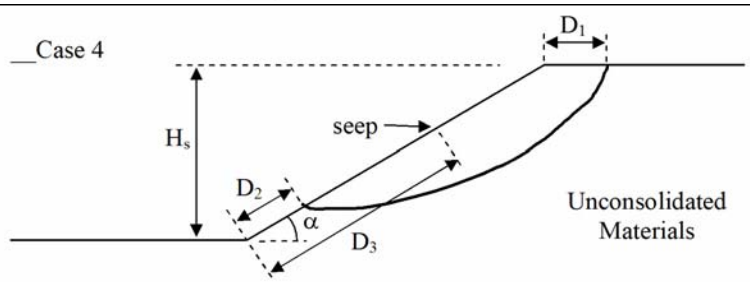
1. α,____________________
2. H_s (ft)__________________
3. L(ft)___________________
4. D_1(ft)__________________
5. D_2(ft)___________________
6. D_3(ft)___________________

__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,____________________
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

Landslide Inventory Number

□-□□□□□□

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________________

Landslide Inventory Number

☐-☐☐☐☐☐☐

OHIO LANDSLIDE HAZARD RATING SYSTEM

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____

OHIO LANDSLIDE HAZARD RATING SYSTEM

Landslide Inventory Number
□-□□□□□□

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	

Landslide Inventory Number
□-□□□□□□

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	

Landslide Inventory Number

□-□□□□□□

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:

Landslide Inventory Number

□-□□□□□□

Part C (continued)

Cross-section:

Landslide Inventory Number

□-□□□□□□

Part C (continued)

Additional Pictures

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

APPENDIX B

SLOPE RATING SYSTEMS BY OTHER AGENCIES

HONG KONG (1988)

Table B.1 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 B.1 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 B.2 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 B.3 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 B. 4 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.

OREGON DOT (1993)

Table B.5 Preliminary rating system

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

Table B.6 Oregon Dot's Rockfall Hazard rating System (1993)

Category			Rating Criteria and Score			
			Points 3	Points 9	Points 27	Points 81
Slope Height			25 Feet	50 Feet	75 Feet	100 Feet
Ditch Effectiveness			Good Catchment	Moderate Catchment	Limited Catchment	No Catchment
Average Vehicle Risk			25% of the Time	50% of the Time	75% of the Time	100% of the Time
Percent of Decision Sight Distance			Adequate sight distance, 100% of low design value	Moderate sight distance, 80% of low design value	Limited sight distance, 60% of low design value	Very limited sight distance, 40% of low design value
Roadway with Including Paved Shoulders			44 feet	36 feet	28 feet	20 feet
Geologic Character	Case 1	Structural Condition	Discontinuous joints, favorable orientation	Discontinuous joint random orientation	Discontinuous joints adverse orientation	Continuous joints adverse orientation
		Rock Friction	Rough irregular	undulation	planar	Clay infilling or slickenside
	Case 2	Structural Condition	Few differential erosion features	Occasional differential erosion features	Many differential erosion features	Major differential erosion feature
		Different in Erosion Rates	Small difference	Moderate difference	Large difference	Extreme difference
Block Size ------------------------------ Volume of Rockfall/Event			1 Foot ---------------- 3 cubic yards	2 Feet ----------------- 6 cubic yards	3 Feet ----------------- 9 cubic yards	4 Feet ------------- 12 cubic yards
Climate and Presence of Water on Slope			Low to moderate precipitation no freezing period; no water on slope	Moderate precipitation or short freezing period or intermittent water on slope	High precipitation or long freezing period or continual water on slope	High precipitation and long freezing periods or continual water on slope and long freezing periods
Rockfall History			Few falls	Occasional fall	Many fall	Constant fall

OREGON DOT (2001)

Table B.7 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)

<table>
<tr><td rowspan="2" colspan="2"></td><td rowspan="2">Low hazard receive 0 point</td><td colspan="20"></td></tr>
<tr><td colspan="12">Medium hazard receive maximum of 54 points</td><td colspan="8">High hazard can receive full point range</td></tr>
<tr><td rowspan="3">2. Roadway impact (pick one)</td><td>Landslides:</td><td>All low hazard slide above (0 point)</td><td colspan="3">Would only affect shoulder during major failure (3 points)</td><td colspan="3">Two-way traffic would remain after major failure (9 points)</td><td colspan="3">One way traffic would remain after major failure(27 points)</td><td colspan="3">Total closer in the vent of major failure 0-3 miles detour(54 points)</td><td colspan="3">Total closure in the event of major failure; 3-10 mile detour (70 points)</td><td colspan="3">Total closure in the event of major failure; 10 -60 mile detour (85 point)</td><td colspan="2">Total closure in the event of major failure > 60 mile detour (100 points)</td></tr>
<tr><td colspan="22">or</td></tr>
<tr><td colspan="2">Rockfalls:</td><td colspan="4">Rockfall are completely contained in ditch (3 points)</td><td colspan="4">Rocks fall into shoulder only (9 points)</td><td colspan="4">Rock are enter roadway (27 points)</td><td colspan="4">No ditch, all falling rocks enter roadway (81 points)</td><td colspan="4">Rock occasionally fill part or all of a lane (100 points)</td></tr>
</table>

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 B.8 Highway Classification Factors

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

Table B.9 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

WASHINGTON STATE DOT (1993)

Table B.100 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