3D MODELLING IN GIS FOR LAND SLIDE STUDIES

A DISSERTATION

submitted in partial fulfilment of the requirements for the award of the degree

of

MASTER OF ENGINEERING

in

CIVIL ENGINEERING

(With Specialization In Remote Sensing and Photogrammetric Engineering)

By

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the dissertation entitled "**3D Modelling in GIS for Land Slide Studies**", in partial fulfillment of the requirements for the award of the degree of **Master of Engineering in Civil Engineering** with specialization in **Remote Sensing and Photogrammetric Engineering** submitted in the Department of Civil Engineering, University of Roorkee, Roorkee is an authentic record of my own work carried out from September 1998 to January 1999, under the guidance of supervisors **Dr. R.S. Tiwari**, Professor, Department of Civil Engineering and **Er. O.P. Dubey**, Lecturer, Department of Civil Engineering, University of Roorkee, Roorkee (U.P.) India.

The matter embodied in this dissertation has not been submitted by me for any other degree or diploma.

Dated : 1st February, 1999.

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This is to certify that the above statement made by the candidate is correct to the best of our knowledge and belief.

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ABSTRACT

Geographical Information System (GIS) is in use in many application areas since its advent. In the present date it has come upto solid (3D) modelling from planimetric (2D) modelling. Landslides, one of the major natural hazards, are generally studied in 2D perspective. 2D analysis involves many assumptions with which, it is difficult to satisfy the behaviour of practical landslide phenomena. It would be rather realistic if the landslides are studied in their 3D perspective using GIS provided required data is available.

Generally subsurface data of slide is not available. Therefore, in the present study a model was developed based on synthetic data. Many analysis tools like rendering, visualization, Boolean logics, characterization, sectioning were applied. Later same methodology was applied to Matli slide in Uttarkashi district on the Uttarkashi-Tehri road. On the developed model slope stability analysis was carried out. Then volume of different geological layers which are prone to slide were computed. For the management of the slide a rataining wall has been proposed and designed. Some of the design parameters were observed from the developed model.

The present study demonstrates the capability of 3D modelling in GIS. A landslide is a 3D phenomenon, 3D GIS has wide applications in studies related to landslides.

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 PREAMBLE

During the last decade use of Remote Sensing and Geographical Information System (GIS) in many studies pertaining to monitoring of the earth resources, and disasters mitigation has increased manifold. GIS, being capable to handle different types of data sets, is in wide use for resource management and disasters management, GIS has also been used for landslide hazard zonation. Further development in GIS have led to 3D-GIS which is also being used in many applications.

1.2 GEOGRAPHICAL INFORMATION SYSTEM

Geographical information system (GIS) is a blooming branch of science, which has gained globled popularity since last few years and is finding applications in almost is all branches of resource management, for example, transportation planning, urban and town planning, landuse planning, hazard management, business management, traffic control etc.

Among the various catastrophic natural hazards landslides are more hazardous and unpredictable because several factors are responsible for its occurrence. In Himalayan ranges landslides or rock slide occur frequently causing a lot of damage to human life and properties every year. These slides often block the major roads in hill areas causing transportation problem. Sometimes, river courses are also blocked causing floods on upstream side. It causes a great damage to flora and fona. Beside surfacial factors, there are a number of sub-surfacial factors which play vital role in activating these hazards. Till recently most of the landslide studies were carried out by conventional method of data analysis. Now a days, use of GIS for landslide studies is gaining momentum. Till now, a landslide study involves decision making using only surfacial factors. Land slide being a spatial phenomena it is expected that use of 3D modelling will go a long way in understanding and managing the landslides.

Following the considerable growth in GIS to meet the needs of digital mapping and of spatial data base development, attention is now focusing on the design and implementation of 3D-GIS in a range of geoscientific application areas. According to Turner (1995) "Three Dimensional (3D) visualization and interpretation of the wealth of multidimensional data available to geoscientific community have become increasingly practical with the rapidly expanding power of computers, coupled with their declining costs. Continuation of these trends appears likely, so much greater use of 3D visualization/modelling to geoscientists can be expected".

1.2.1 GIS : Historical Background

The origin of GIS may be traced to the concept of some geographers who thought of storing the maps in computers. GIS originated in near operational mode in 1962 with the sponsoring of Canadian Geographical Information System (CGIS) by Federal Govt. It, however, got a tremendous boost in 1980, with the availability of personal computers to common people. The launching of the Landsat series of satellites by USA, in 1972, catalyzed the spread of GIS technology since repetitive spatial information of earth resources, which otherwise had been difficult, was now available as an important input into GIS system. (Mishra, 1996).

Thus, GIS is a modern decision making tool in the hands of managers and planners.

1.3 UTILITY OF 3D GIS

When reference is made about GIS, generally it is meant a two dimensional (2D) GIS, but GIS has stepped to 3D via 2.5D. According to Raper and Kelk (1991) a 2D visualization is a graph or raster where the z value defining surface is projected on to 2D plan; a 2.5D visualization, is isometric model where the attribute associated with an x,y location is projected onto an x,y,z coordinate reference system and all the three axes are displayed. This operation transforms the map of z attributes for an x,y position, so that each z attribute defines a position on the z axis, creating a surface with no thickness visualized within 3D space. A 3D visualization, however, is a full 3D solid model where many x,y,z observations are structured into a solid structure and visualized in perspective view, complete with multiple occurance of z.

While switching from 2D to 3D requirements of the hardware and software increase manifolds. Flynn (1990) estimated that the computational requirements for fully realistic 3D graphic animation is $2x10^5$ times more demanding compared to 3D static graphics, which in turn increases the requirement of the processing speed. Other hardware developments may require additional device buffers to allow refreshment of the buffer because the next screen is built as the first screen clears fastly. Also 3D data structure being its complex system requires a deep understanding.

Besides many initial hurdles, 3D GIS come into useful application since 1989. Youngmann (1989) used 3D GIS for enhancement of oil exploration programme, Bak and Mill (1989) used it for mining project planning while Turner (1989) used it for hydrogeological applications, Smith and Pradis (1989) took advantage of 3D GIS for environmental monitoring while Batten (1989) used if for landscape architecture. Others, who have reported use of 3D GIS are, Slingerland and Keen (1990) for meteorology, Petrie and Kennie (1990), Bogdan and Rosingh (1993) in Civil Engineering, Kelk (1991) in geological modelling and Buter (1995) for modelling the sand deposits in reservoir.

Use of 3D GIS is not limited to above mentioned applications only. It is just starting point and it can be used in many engineering and earth sciences applications.

1.4 STATEMENT OF THE PROBLEM

From the above it is clear that 3D GIS has been used by the researchers to solve a variety of problems.It has been found a reliable and effective tool for carrying out the analysis of data pertaining to resource management, including renewable and non renewable resources for sustainable development, study of various types of disasters, their prevention and mitigation, urban and rural development etc. Its further development and application in newer fields form an active area of research. To this end an attempt has been made in this study to demonstrate the usefulness of 3D GIS in studies related to landslides. The present study has been carried out with the following objective :

* to generate a 3D model and study its capabilities,
* to manage a landslide through 3D modelling in GIS.

1.5 SCOPE OF THE PRESENT STUDY

The recent advancements in microcomputer based GIS have lead to extensive modelling capabilities. Using these capabilities, in the present study a macro programme has been developed for generation of 3D model from a 3D data file for a chosen study area. Boolean logics (union, intersection, difference), animation techniques (hidden surfaces, smooth etc.), measurements (depth, area, volume etc.) sections have been applied to the developed model for estimating surface area, volume, mass and center of gravity of the area prone to slide. Finally using these parameters a retaining wall has been designed for controlling the landslide.

For the present study it is proposed to generate data file for the hill sections of the study area and a model is created, slide mass then can be separated using slip surface with the help of Boolean intersection. Subsequently the volume, centre of mass of the sliding mass and other another data are calculated for thrust calculation and analysis of the landslides.

1.6 ORGANISATION OF THESIS

The present work has been compiled into six chapters. Chapter 2 deals with the basic concept of modelling in GIS. Chapter 3 gives a brief description related to the landslides and related parameters. Chapter 4 deals with the details pertaining to study area and the GIS components used in the present study. Chapter 5 deals with the methodology. The conclusions and recommendations for the future work are described in the chapter 6.

CHAPTER 2
MODELLING IN GIS

2.1 PREFACE

"GIS is an Organized collection of computer hardware, software, geographic data and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information." (Understanding GIS, 1994).

GIS for commercial uses were developed in the 1980's with the advent of powerful and relatively low-cost computers which also made possible greater access to previously specialized software and data from large mainframe computers. The present trend is towards the use of 'Desktop-GIS' similar to other business/professional software for a unity of applications (wwwesri.com) .

This has also paved way for GIS modelling which involves symbolic representation of locational properties (where), as well as thematic and temporal attributes describing characteristics and conditions of space and line.

2.2 COMPONENTS OF GIS

A GIS has mainly there components, shown schematically in Fig.2.1

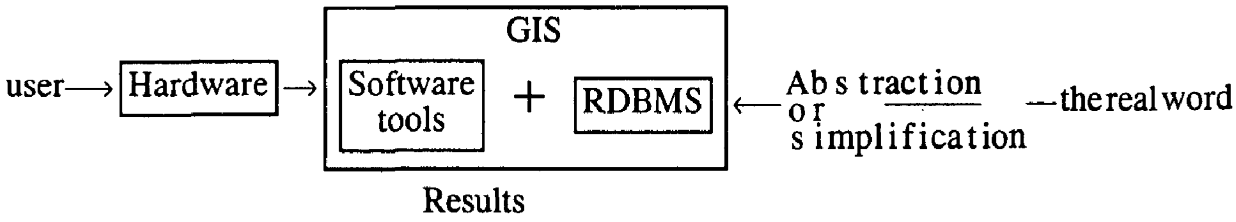


Fig. 2.1 Components of GIS (Source: Understanding GIS, 1994)

2.2.1 Hardware Components

The major hardware components are :

(a) Plateform for a GIS range from low end PCs to high end workstations.

(b) A spatial data entry system : Digitizer, scanner etc.

(c) A graphical display system : VGA monitors, the X-terms etc.

(d) Secondary storage devices : Hard disk, CD-ROM etc.

(e) A plotter or printer for taking cartographic quality outputs in spatial format.

2.2.2 Software Components (Modules)

Software modules can be classified is to three categories namely.

(a) Data entry, editing and management module

(b) Data analysis and modelling module

(c) Data display and output module

These module combined altogether works for input, storing and managing geographically referenced information.

2.2.3 Database Management System

Once data is stored in hard disk or magnetic disk, then there should be a system which can respond to the user's queries with desirable speed and efficiency and this is the point where data base management system (DBSM) comes into picture. DBMS were designed to facilitate storage and retrieval of large data collections. They include facilities to pocket and secure data, inforce consistency to the data stored and take the data available to different users, which form necessary services to GIS.

2.3 GIS FUNCTIONALITY

GIS has four major functions viz data input, data management, data manipulation and analysis and data output. These are being discussed in brief in following articles.

2.3.1 Data Input

GIS has two types of data spatial and non spatial, out of these two, major problem is with spatial data as special data comes in different formates, different scales and different projection systems. GIS has capability to combine all these type of spatial datas on a single platform. Data to GIS can be input with the help of digitizer, scanner etc. or by manual entry.

2.3.2 Data Management

These are the functions performed by GIS to store and retrieve data from the database. This capability is similar to that provided by database management software. Data is entered into a predefined structure which may or may not be inter related.

2.3.3 Data Manipulation and Analysis

These functions may very from one GIS software to another but can be broadly subdivided into spatial v/s nonspatial analysis. These functions are helpful for carrying out query on the spatial and non spatial data. Data analysis and modelling part are being discussed in detail in coming articles.

2.3.4 Data Output

After data analysis and getting results, it is desirable to represent that results in a form suitable to the user using output function of GIS. Output may be in the form of maps, tables texts etc. either as softcopy (on screen or electronic file) or as a hard copy (paper or photograph etc.). Generally vector based system gives better output than that of rester based system.

2.4 GIS SOFTWARES

These days there is a boom of GIS software packages, G. Mendicino (1996) has given a comprehensive list of these packages. Out of available packages Arc/Info and MGE (Moduler GIS Environment) are powerful and are being used worldwide. Both are used here for the present study.

Arc/Info version 3.4.2(b) on DOS O/S, which includes the following modules namely Arc digitizing system (ADS), Arc edit, Arc plot, ArcCogo, Tables, Tin etc. has been used for spatial data entry, editing of spatial data, map outputs and data conversion respectively. MGE version 06.00 on windows NT 4.0 O/S has been used for creation of model and analysing it ie for modelling. MGE works on Microstation 95 platform, so capabilities of Microstation95 were also used in the study. A brief description of these softwares is as follows :

a) **Arc/Info**

Arc/Info was designed by ESRI, Redlands, California, as a vector based GIS, and is composed of two primarily components. ARC was written by ESRI to store coordinate data and perform all operations on that type of data. INFO is a relational database management system (RDBMS) developed by Henco Corp., California. INFO is used under license from Henco to store and perform operations on attributes, i.e. descriptive non-coordinative data. Over the last decade ARC/INFO has been a substantial amount of technical evolution. In addition, linked internal modules for the reanalysis of terrain data (TIN) and for address matching, route selection and allocation of demand to service point (NET work) etc.

Capabilities of different Arc/Info systems subsystems are summarized as follows :

* Data conversion for loading data into and out of Arc/Info (e.g. Autocad format, i.e. DXF files).
* Map coverage digitization and editing
* Error detection and verification for map data automation
* Coordinate projection and transformation used to convert data from one projection system to another.
* Management and manipulation of feature attributes.
* Analytical operations including feature buffering, map overlays nearest neighbour analysis, and reporting of summary statistics

One of the major capabilities of Arc/Info is that it can customize the analysis using macro language called 'Simple Macro Language' (SML). SML is a fourth generation programming language with facilities to use named variables, perform logical branching, and loops, manipulate character strings and text, perform arithmetic operations and perform selected GIS operations.

(b) MGE

MGE was designed by Intergraph corporation. It is also a vector based GIS software. MGE works on a platform software called Microstation. Microstation version 95 is deigned by Benteley corporation and is used with license from Benteley. Microstation is a CAD package having many advanced tools. The capabilities of Microstation may be categorized into four categories viz. 2D drafting aids, advanced 2D drafting aids, 3D drafting aids and Miscellaneous. Appendix-A gives an idea about the capabilities of Microstation 95. First column of the table shows the category as defined above second represents the tool box under that category and third highlights the ability of that tool box. The table is compiled from the manual of Microstation 95 'Users Guide'.

Like wise Arc/Info, MGE or Microstation can also be customized using macros. The macro of Microstation contains two parts, the first part is visual basic and second part is microstation basic extension (MBE). MBE(s) are nothing but subroutines written in basic. In the present study Macro is exclusively used for creation and presentation of 3D model.

2.5 MODELLING IN GIS

The word modelling can mean different things to different people. A model is a representation of a reality and then analyzing that representation is called modelling.

Modelling in GIS can be divided into planer geometry in GIS ie. 2D modelling and solid geometry in GIS i.e. 3D modelling. Planer geometry in GIS is popular these days due to facilities of automated mapping (AM) and facility management (FM), overlays, buffer etc.

2.5.1 Planer Geometry in GIS

Planer geometry in GIS is for representation of two dimensional or planimetric details on map and making query on that. In general sense, planer geometry can be thought as the process of combining a set of input maps with a function to produce output map.

$$\text{Output map} = f(\text{Two or more input maps})$$

The function 'f' may take any user defined form. It may be either a set operator union, intersection or difference; or Boolean operator OR, XOR, AND, NOT or something else representing combination of above two.

Other planimetric modelling includes to answer the questions related to geographical locations eg. what is at this particular location?

Planer geometry in GIS uses raster and vector data formats in two dimensions. All the analysis are restricted to planimetric details only.

2.5.2 Solid Geometry in GIS

As mentioned earlier, 3D modelling involve representation of planimetric position as well as variation in the numerical value of an attribute along the depth or height. Therefore a 3D GIS modelling may be visualized as multilayer modelling.

Conversion from plane to solid ie. 2D to 3D adds storage and computational overhead to GIS software. Thus it is not surprising that, until very recently, developers and vendors of GIS Software have not perceived the 3D GIS market. This situation is now beginning to change, due largely to the application of 3D graphics systems in engineering and resource management and development of affordable hardware that can support the rapid generation of 3D graphical display and analysis.

Data table in 3D GIS are almost similar to that of 2D, except that it contain two attribute table instead of one. First attribute table contains elevations at particular location and the second contains information regarding variation of an attribute along depth or height at a particular location e.g. variation in soil characteristic with elevation. The first attribute table fulfil the need to generate DEM (Digital Elevation Model) or DTM (Digital Terrain Model) of the area, whereas the second attribute table is for modelling in the third dimension. Once a 3D model is available it can be used suitably.

2.6 DATA STRUCTURE FOR 3D MODELLING

Like 2D, 3D modelling also has two type of data structure namely, raster based system and vector system. In raster based system, the smallest volume element is called VOXEL (Raper, 1989), Where as in the vector based system the seeding element is a point represented by 3D vector. The data structure, being an important aspect of a modelling, is being described in the following articles.

2.6.1. Raster Data Structure

In raster based system the feature space is divided into suitable number of voxels. If a voxel is filled with the feature of interest, it is classified as filled and known as "on" and assigned 1 otherwise the voxel is classified as hollow and known as "off" and assigned 0. Fig. 2.2 shows the "on" "off" voxels. (Raper, 1989).

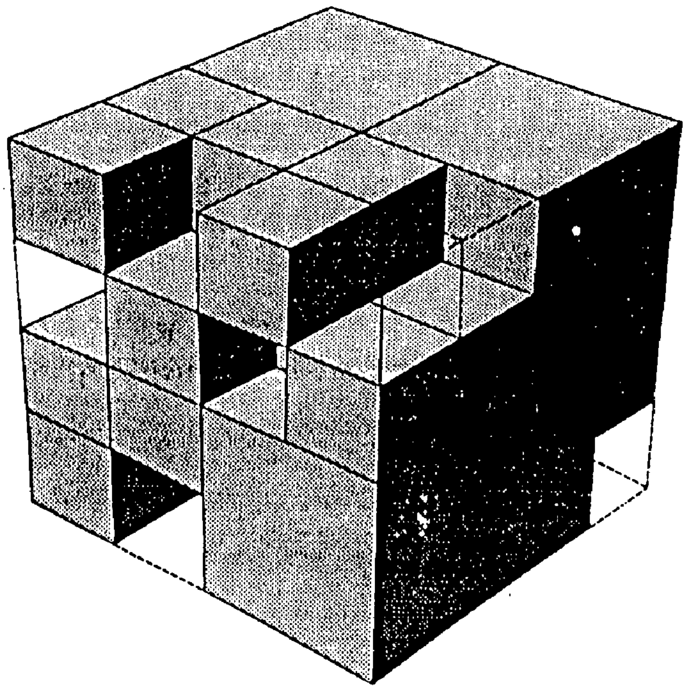


Fig : 2.2 Raster Data Presentation.

Representation of a complex feature requires spatial indexing systems to eliminate redundant storage. This will help in optimizing the data storage. Different indexing systems are 3D-layer-and-row-order raster, octree, polytree etc.

2.6.2. Vector Data Structure

The vector data structure is based on basic element "node", a point feature is represented as node, arc feature with two node (start & end). A polygon feature is represented with a set of arcs, i.e. many nodes in two principle planes, and a solid feature is represented with spatial polygons, ie. many nodes in three principle planes. This structure may be represented as shown in fig. 2.3 (Gupta, 1998).

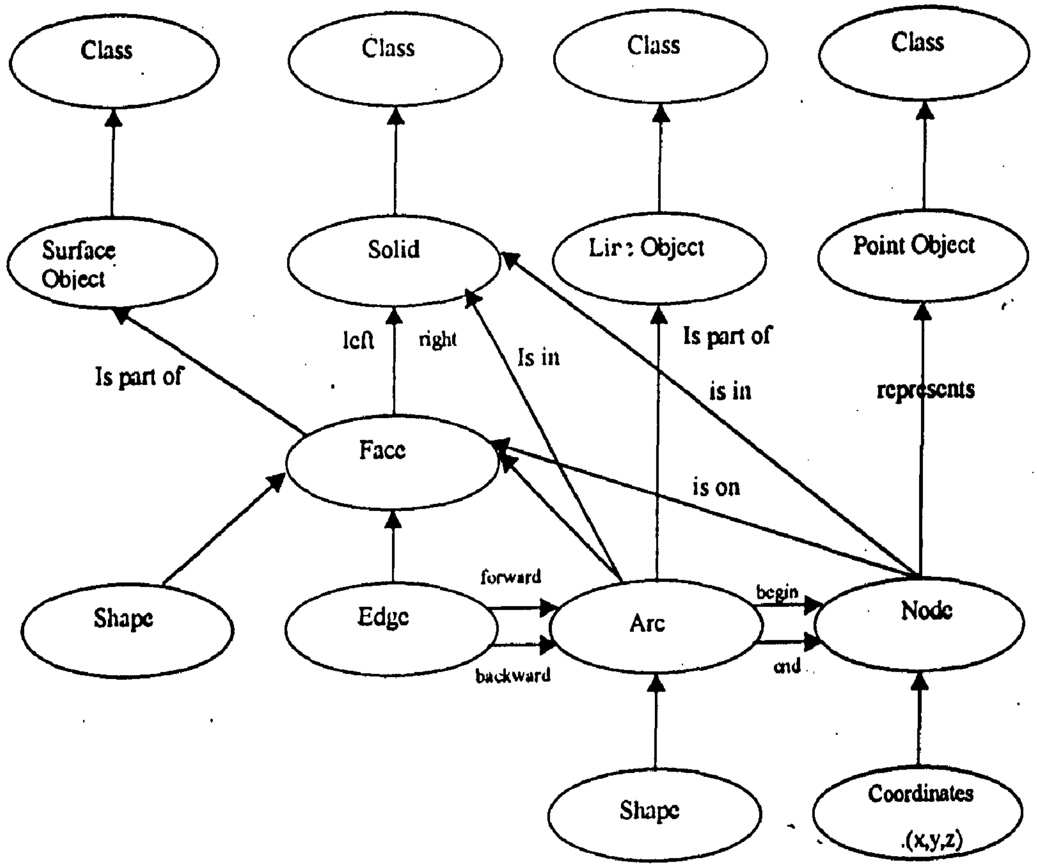


Fig: 2.3 : Vector Data Structure (Source : Gupta, 1998).

2.6.3. Merits/Demerits of Raster and Vector

The raster based system of data structure is simple, fast and efficient for carrying out many operations as compared to vector data structure, but this system requires huge storage capacity. Quadtree and polytree may be the substitute, but they have their own advantages and disadvantages.

So far as vector based system is concerned it has advantage to bring together spatial and non-spatial components of a data in object oriented form and data base can be for any complex configuration. The main disadvantage of vector based system is that it requires a complex database operation to set up each new data description and bind it to the database.

2.7 DATA ANALYSIS

Once a 3D model, either in raster or vector format, is created it may be suitably used in a specific area of application. Retrieval, updating and analysis of the data may be carried out in the same manner as in 2D modelling.

Some of the commonly used functions are tabulated in table 2.1 (Comparison is based on execution time of the operation).

Table 2.1 Comparison of 3D Spatial Modelling functions

(Compiled from : Raper & Kelk, 1991)

Spatial function	Data format		
	Raster	Vector	Fig. No.
Visualization			
Translate	slow	fast	2.4(a)
Scale	slow	fast	2.4(b)
Rotate	slow	fast	2.4(c)
Transformation			
Shear	slow	fast	2.4(d)
Selection			
AND	fast	slow	2.4(e)
OR	fast	slow	2.4(e)
XOR	fast	slow	2.4(e)
NOT	fast	slow	2.4(e)
Inter Relationship			
Metric	fast	fast	2.4(f)
Topology	fast	fast	2.4(g)
Modelling			
Build	fast	slow	2.4(h)
Characterization			
Volume	fast	slow	2.4(i)
Centre of mass	fast	slow	2.4(j)
Surface area	fast	fast	2.4(k)
Orientation	slow	fast	2.4(l)

Fig.2.4 depicts some of the functions, which are simply enhancement of their 2D equivalents. These functions include the basic Boolean operators, the transformation, rotation, scaling and adjacency etc. However, in addition to above there are also functions, which specifically concerns solids, eg. sectioning.

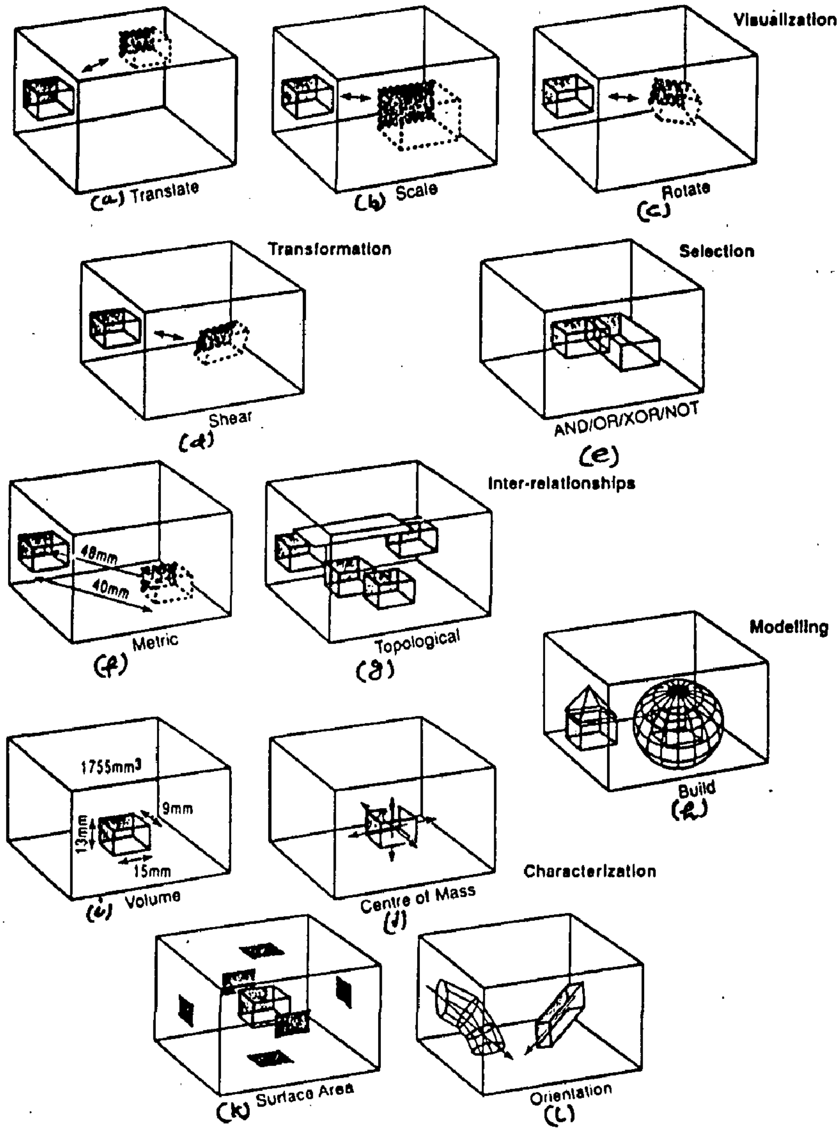


Fig. 2.4 : 3D Spatial functions: (a) Translate, (b) Scale, (c) Rotate, (d) Shear, (e) Selection, (f) Metric, (g) Topological, (h) Build, (i) Volume, (j) Center of Mass, (k) Surface Area, (l) Orientation.

(Source: Raper and Kelk, 1991)

It is clear from the above discussion that GIS is a powerful tool for managing the geographically referenced data and modelling the same for efficient and user defined outputs. Furthermore, a 3D GIS gives added capabilities to analyse and manage phenomena related to sub/super surface.

CHAPTER 3

LANDSLIDES : A BRIEF STUDY

3.1 INTRODUCTION

The process of movement of large masses of earth material from one place to another, under gravity, is generally called 'Mass Washing'. The term 'Landslide' is defined as a process of downward and outward movement of slope forming materials composed of rocks, soils, artificial fills or a combination of all these as well as anything else that may fall in the way of the movement such as houses, roads etc. along surface of separation by falling, sliding and flowing at a faster rate. Landslides may occur as an attempt of earthquake or floods due to heavy rains causing damages and devastation, sometimes of unprecedented nature.

3.2 LANDSLIDES : HUMAN INTERACTION

Many categories of people are related to landslides slope stability, directly or indirectly, as shown in flow diagram below :

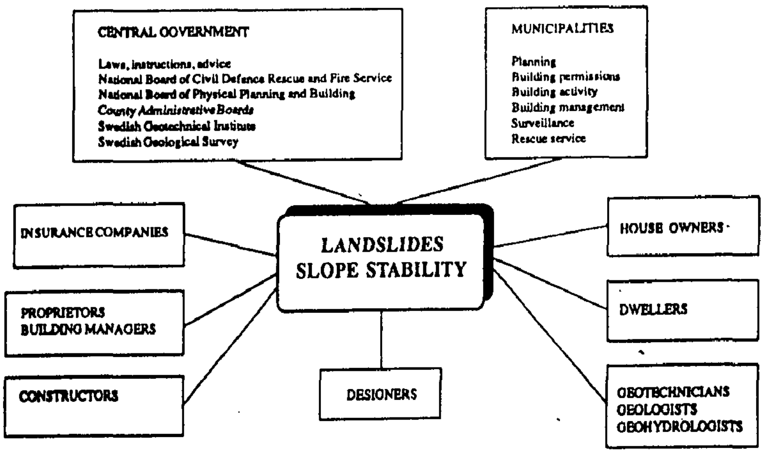


Fig. 3.1: Flow Chart of Human Interaction to Landslides.
(Source: Ottosson, 1991)

3.3 CAUSES OF LANDSLIDE

The factors which are responsible for landslide may be categories into two subheads as discussed below. (Anbalagan, 1991)

3.3.1 Natural Factors

* High relief or steep slopes.
* Undercutting of banks by deeply incised rivers and streams.
* Extensive development of weak rocks such as Phyllites, slates and schists, presence of calcareous inter-layers in these rocks which lead to high porosity and void formation due to preaching and dissolution.
* Heavily fractured rocks because of intense folding and faulting. As many as four systematic sets of fracture plus other random and stress relief joints are very common in mountains region.
* High weathering of rocks.
* Seismic activity.

3.3.2 Anthropogenic Factors

* Deforestation : Intensive deforestation is one of the major causes of landslide in lower Himalayas.
* Improper Landuse : Factors like agriculture on steep slopes, irrigation on steep slopes, ever grazing, quarrying (for construction material) without considering the conditions of terrain etc. are also responsible for landslides.
* Developmental Activities : Improper & unplanned development of infrastructure e.g.. houses on steep slope, unlined canal near the toe of a unstable slope.

3.4 CLASSIFICATION OF LANDSLIDES

There are many criteria for classifying a landslide, e.g.. based on slope movement, state of activity etc. A classification system is implemented using a criteria based on the form of sliding surfaces, the types of materials involved, rate of movements etc.

The land slide classification system proposed by Varnes (1978) which is adopted by Highway Research Board's committee on land slide in 1980 is in wide use. The system is based on the type of movement and type of the material involved (Table 3.1).

Table 3.1: Abbreviated Classification of Slope Movement (Varnes, 1978)

Type of Movement	**Type of Material**		
	Bed Rock	**Engineering Soils**	
		Predominantly Coarse	**Prominently Fine**
FALLS	Rock fall	Debris Fall	Earth Fall
TOPPLES	Rock topple	Debris topple	Earth topple
ROTATIONAL FEW UNITS	Rock slump & Rock Block slid e	Debris slump Debris Block Slide	Earth slump Earth Block Slide
TRANSLATION MANY UNITS	Rock slide	Debris slide	Earth slide
LATERAL SPREADS	Rock spread	Debris spread	Earth speed
FLOWS	Rock flow (deep creep)	Debris flow	Earth flow (soil creep)
COMPLEX	Combination of two or more principal types of movements		

CHAPTER 4

PLANNING FOR THE INVESTIGATION

4.1 PROPOSED INVESTIGATION

For the sake of better understanding of sub surface intermingling of different layers, it was decided to first generate some hypothetical data and model from data. After creation of model analysis is to be carried out on the model. Later a model is to be prepared from real world data and analysis is to be carried out keeping landslides in view. Details pertaining to real world data is given in the following articles.

4.2 DETAILS OF STUDY AREA

Due to geologic factors added by topographic features and influenced by anthopogenic factors, the entire Himalaya is prone to land slide. Some of the major landslides are Nirgad slide, Shivpuri slide, Bewan slide, Nakurchi slide at 5.0, 11.5, 23.8 and 28.0 km respectively from Rishikesh. Also Badethi slide, Sigum slide, Margoon slide at 4.4, 13.6, 16.9 Km respectively from study area.

The present study is carried out in the Uttarkashi district, Uttar Pradesh, India around 140 km from Rishikesh on Tehri - Uttarkashi road. Latitude and longitude of the slide is $30^{O}44'29''$ [illegible] and $78^{O}21'54''$ [illegible] The area is closed to a sharp bend on the right bank of the river Bhagirathi, near village Matli. The height of the slide area is approximately 1150 meters above mean sea level. The area has an annual rainfall of about 150 cm., with heavy intensity of rainfall usually occurring continuously for a week or so in rainy season. The region in moderately forested with cultivation of paddy and other crops is some fields. Map 1 shows the location map of the study area.

4.3 HISTORY OF THE LANDSLIDE

The first landslide in this area occurred in 1984 when a large portion of hill slided down towards the road side. As per local people the slide has possibly occurred after the installation of an electrical pole on the hill slope, which resulted in the formation of a depression on the slope where water got accumulated and caused the slope to slide downward. Since then it has become a regular phenomenon in every monsoon season.

Since, 1984, the landslide has increased in dimension and at present it has become very dangerous. A retaining wall was constructed some years back but it was found ineffective to check the heavy flow of debris, particularly during monsoon, which causes blockage of road and disruption of traffic.

4.4 GEOLOGY OF THE STUDY AREA

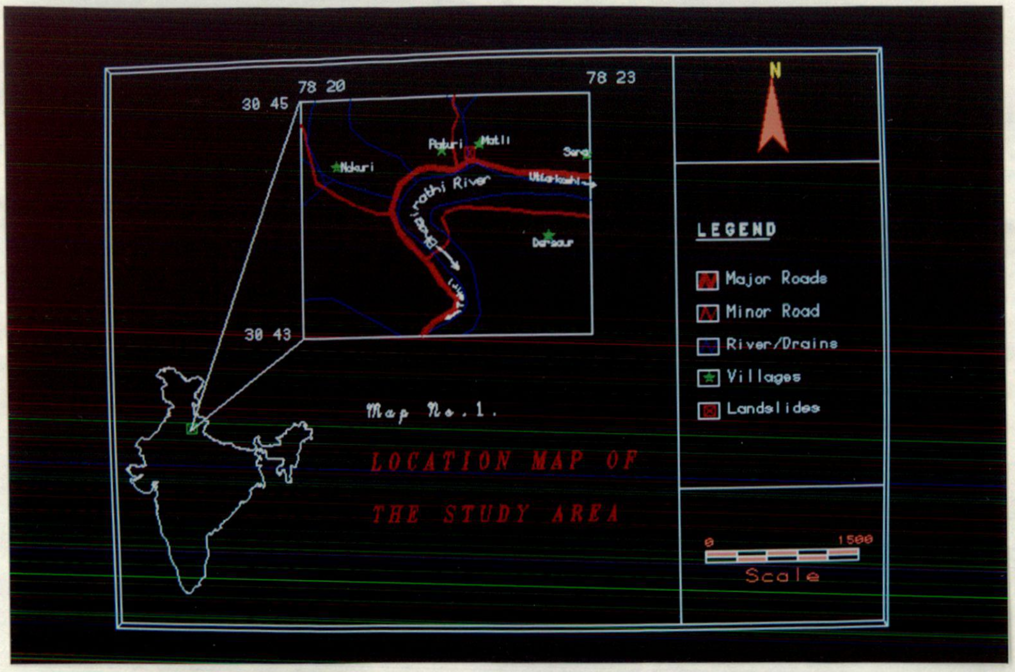
Geologically, the rocks in and around the slide area belong to Chail formation of Pre-Cambrian age. The main rock types are Phyllites, Schists and Metabasiccs. The lower horizons of the slide zone have been found to consist of hard and compact rocks whereas the rock exposures in the central region have been found to consist of moderate to highly weathered Phyllites and Schists with comparatively less weathered Metabasics rock. The central zone otherwise is generally covered with coluvium and slide debris having moderate to highly weathered rock pieces. The Metabasics are commonly massive, highly jointed, fractured and slight to moderately weathered in nature. The beds generally dip towards south with an amount ranging from 25^0 - 65^0. In addition two sets of joints are also present in the rocks of the lower horizons. The joints are generally closed whereas in the upper horizon, however, the joints in the lower horizon are open. The variation in the attitudes of the beds in general, indicate the presence of fold.

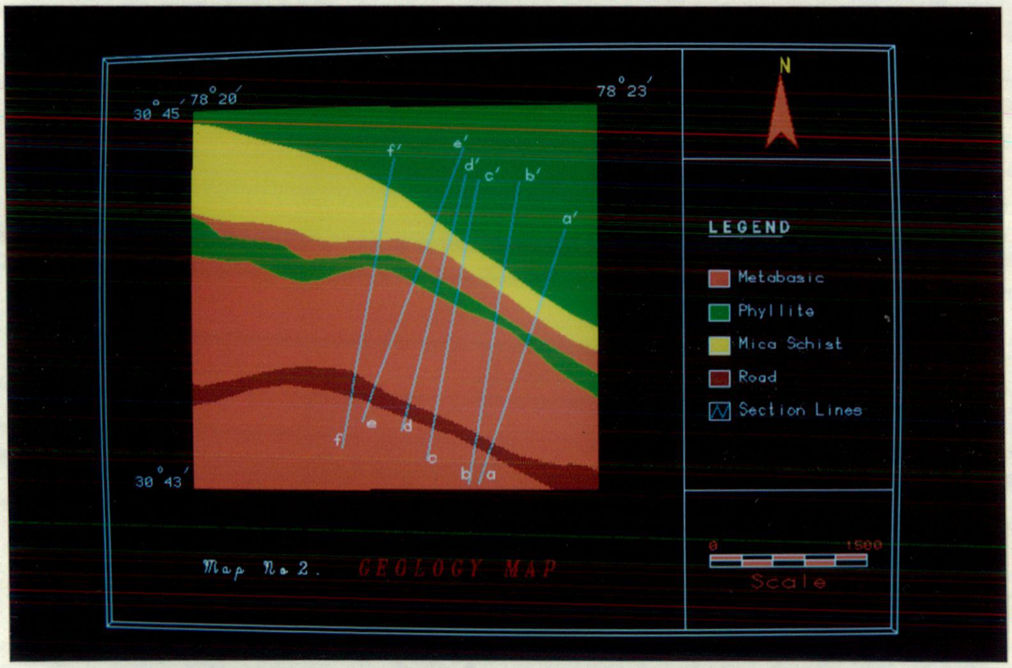
The middle and upper horizons show the presence of highly weathered and fractured rocks overlain by moderate to highly plastic clay soil yellowish in appearance. The phyllites are inter bedded with Mica Schists which are generally deformed and weathered.

The geological succession in the slide area is as follows:

Upper horizon	Highly weathered phyllites
Middle horizon	Moderately weathered mica schists.
Middle horizon	Moderately weathered phyllites
Lower horizon	Slightly to moderately weathered metabasics.

The cracks are generally present above the crown of the slide and towards eastern boundary of the slide. The dimensions in terms of width, length and depth as well as the attitudes of all the cracks have shown significant changes indicating the instability of the slope in this region. Map 2 shows the geology map of the study area.


30 45
78 20
78 23
30 43
N
LEGEND
Major Roads
Minor Road
River/Drains
Villages
Landslides
0
1500
Scale
Map No. 1.
LOCATION MAP OF
THE STUDY AREA


30°45
78°20′
78°23′
30°43′
N
LEGEND
Metabasic
Phyllite
Mica Schist
Road
Section Lines
0
1500
Scale
Map No 2.
GEOLOGY MAP


30°45
78°20′
78°23′
30°43′
N
LEGEND
Thick Forest
Moderate Forest
Sparse Forest
River/Water Bodies
Agricultural Land
Barren Land
0
1500
Scale
Map No 3.
LANDUSE MAP

4.5 LANDUSE OF THE STUDY AREA

In the study area there are basically three landuse categories viz. forest, agriculture in barren land. Forest class is further subdivided into thick forest, moderately thick forest and sparse forest. Map 3 gives the landuse of the study spot and surroundings.

4.6 SELECTED PERAMETERS FOR STUDY

As present study on landslides is proposed to be carried out in 3D GIS environment, therefore, subsurface information pertaining to lithology becomes the dominent factor. Lithology of the area was used to create a 3D model.

4.7 PROCUREMENT OF DATA

Geological and other data of the area is taken from a project of Central Building Research Institute, Roorkee; entitled "Environmental Development of Garhwal Himalaya with Particular Reference to Landslide Hazard Zonation and Efficiency on Innovative Control Measures", investigated by Mahrotra, et al., in 1993. Study area of the present report is named as Matli Slide in the aforesaid project.

CHAPTER 5
METHODOLOGY

5.1 PREAMBLE

In developing countries, authentic subsurface information is not easily available what to say of digital data. Infact, nearly 80% of the efforts, while using a GIS based analysis, goes to data generation. The present study is in no way an exception. For the proposed study area, since detailed subsurface information was not available, it was thought proper to generate subsurface synthetic data and demonstrate the capacities of the 3D GIS modelling using the same. After developing the general concept the same was used for the available data for the study area. The time lag between the above mentioned two events was utilized to collect the relevant data for the study area. Details of the study are being described below.

5.2 CREATION OF 3D SYNTHETIC MODEL

The creation of a synthetic 3D model involves basic steps viz data extraction, display of the model and analysis i.e. 3D modelling as described below :

5.2.1 Data Extraction

As discussed earlier, 3D modelling requires parametric location alongwith numerical value of the variation in the attribute in the third dimension. For the generation of subsurface synthetic data bore holes were assumed in a regular grid pattern terrain as shown in the figure 5.1. A total 25 bore holes were located at intersection of 20m x 20m in x and y direction.

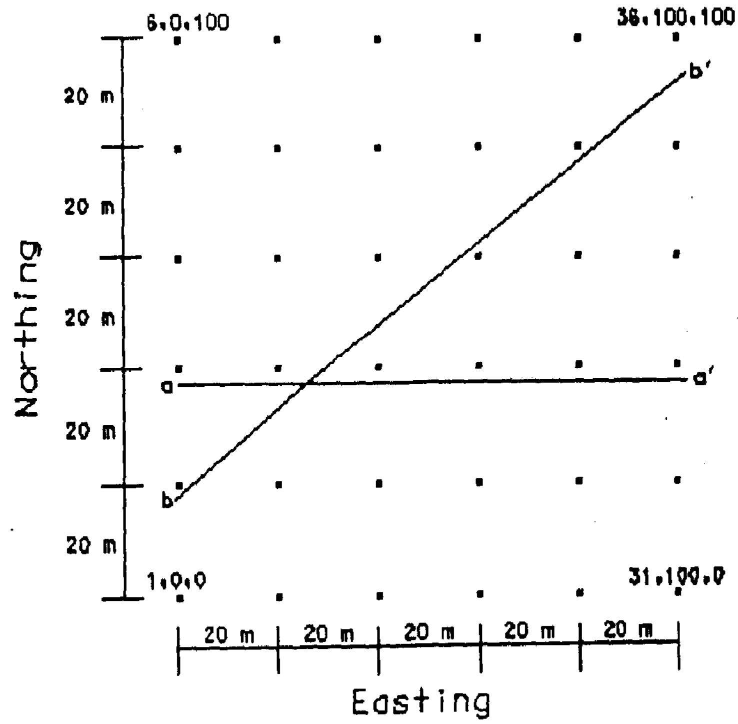


Fig. 5.1 Layout of Bore Holes

Location of the first bore hole was assumed to be origin, with its co-ordinates easting and northing as (0,0). Attribute data, subsurface information were arranged in a tabular form as shown in table 5.1. The first column of the table depicts the bore hole identification number, followed by parametric location i.e. E and N, the fourth column contains the elevation and subsurface attribute with layer IDs tabulated in the fifth column.

Table 5.1 Part of Data Extraction Table

Bore Hole ID	Easting	Northing	Height	Attribute
1	0.00	0.00	100.00	1
1	0.00	0.00	90.00	1
1	0.00	0.00	90.00	2
1	0.00	0.00	89.00	2
1	0.00	0.00	84.00	2
1	0.00	0.00	70.00	2
1	0.00	0.00	89.00	3
1	0.00	0.00	84.00	3
2	0.00	20.00	99.60	1
2	0.00	20.00	89.60	1
2	0.00	20.00	89.60	2
2	0.00	20.00	88.60	2
2	0.00	20.00	83.60	2
2	0.00	20.00	70.00	2
2	0.00	20.00	88.60	3
2	0.00	20.00	83.60	3

The generated data table is captured in the computer, with the help of text editor, notepad. In this way, for each attribute a file is created, containing location of different points in that layer. These files have *.dat extension.

5.2.2 Display of the model

3D display of data is important for visualization and analysis of data. It is estimated that about fifty percent of the brain neurons are involved in vision, 3D display lights up more neurons and thus involves a larger portion of brain in understanding and solving a particular problem (Driel, 1989). For 3D display a macro was written in visual basic using MBE capabilities. Details of the macro are given in appendix B.

The developed macro can be executed in command window of the microstation application. The macro first of all demands an input data file with extension *.dat. After selection of the input file it reads data from the file and creates a B-spline surface from the data. Macro was utilized to create surfaces for each attribute. Each generated surface is stored in a separate layer and with different color code, so that a single attribute can be analysed, as and when required as well as all the attributes are also analysed and displayed simultaneously.

Plate I shows the 3D model created from the synthetic data, where subsurface lithological variation is shown in different color. Class 1 is given green color, class 2 red and class 3, which is intermingling with class 2, is assigned yellow color.

5.2.3 3D Modelling

Modelling is carried out for better understanding of the role of a feature or features present in the model. To carry out modelling many modelling tools are available as described below.

*** Rendering :**

Rendering is carried out for enhancing the visual impact of the created model. Rendering is achieved by converting the line structure in to either smooth, filled hidden lines or hidden lines, which imparts a better visualization. In the present study hidden lines have been used for rendering. Plate II shows the rendered image of plate I.

*** Visualization :**

Visualization is achieved through translation, scaling, rotation (Table 2.1). These three functions were applied one by one on the developed 3D model. In translation one layer (class 1) was translated little above to get a better idea about the joining surface of class 1 and class 2. Similarly class 3 was translated below its holding layer i.e. class 2. This translation is shown in plate III. Zoom in and zoom out are the capabilities of system which help in achieving the scale effect. Different rotation about x, y and z directions were applied to get a view of the model in different situations. All this helps in feature understanding in the model.

*** Characterization :**

Characterization is carried out for extracting information about volume, center of mass, surface area etc. of a feature. Characterization is attempted on the model and output are summarized in table 5.2

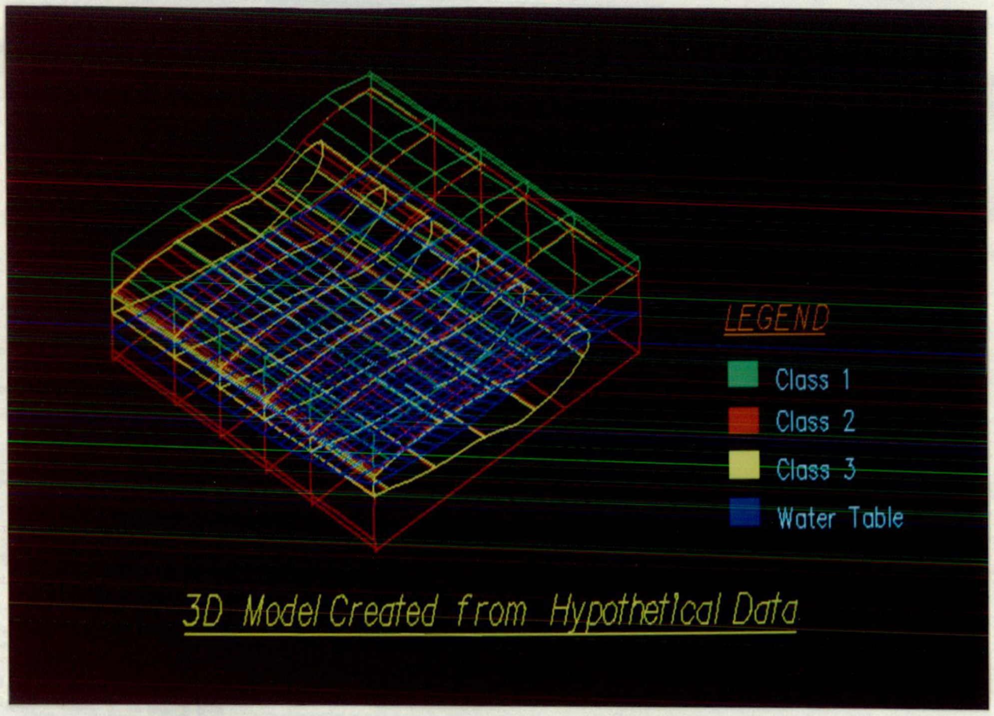


Plate 1 : 3D Model Created from Hypothetical Data

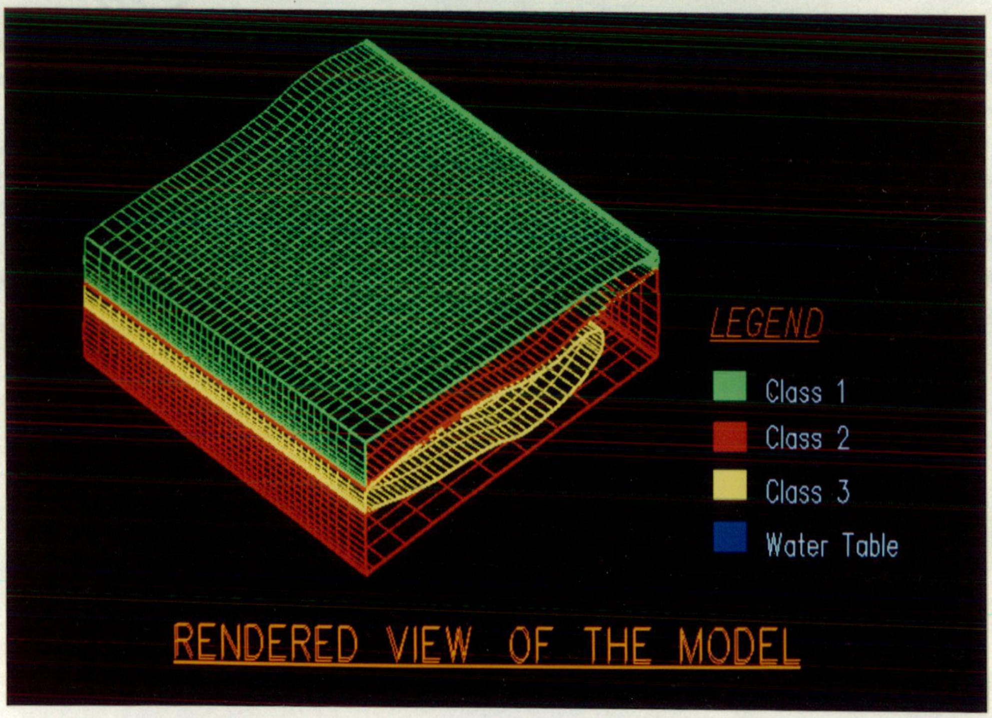


Plate 2 : Rendered View of the Model

Table 5.2 Model Characterization (Synthetic Data)

Attribute Class ID	Volume (m^3)	Surface Area (m^2)	Center of mass (m) (x)	(y)	(z)
1	50866.312	21541.763	44.722	50.004	92.618
2	11732.116	39123.219	44.193	51.271	86.818
3	52818.189	17493.216	42.096	49.803	82.057

*** Boolean Logics :**

Logic gates in terms of union, intersection etc. are useful tool for modelling. They are used for feature understanding and decision making. So far as landslide is concerned, Boolean logic gates are very useful in slip surface and related studies. As determination of slip surface involves geotechnical investigations, an imaginary slip surface was assumed in the present study, and the same was superimposed on the 3D model generated from the synthetic data, and cut with the help of Boolean difference. Plate IV shows the result.

*** Sections :**

In any analysis one of the major task is to draw sections at defined locations and orientation. In order to implement this, two sections at aa' and bb' were drawn by using generate section tool and these sections are shown in fig 5.2.

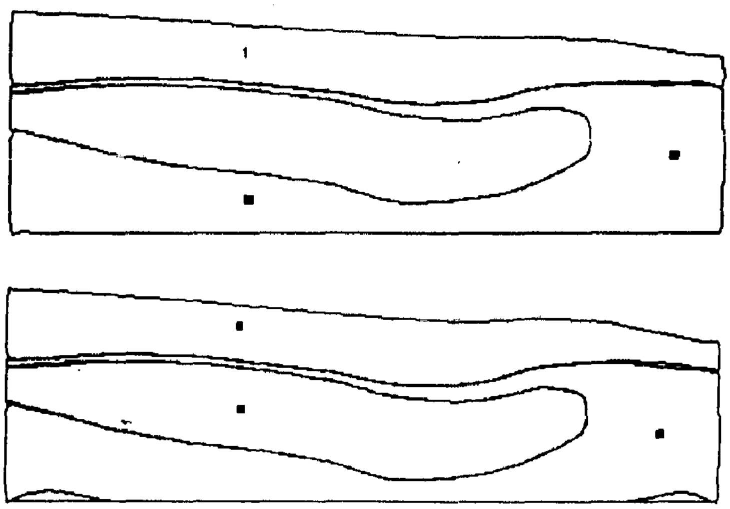


Fig 5.2 Sections through Model at(i) aa' and (ii) bb'

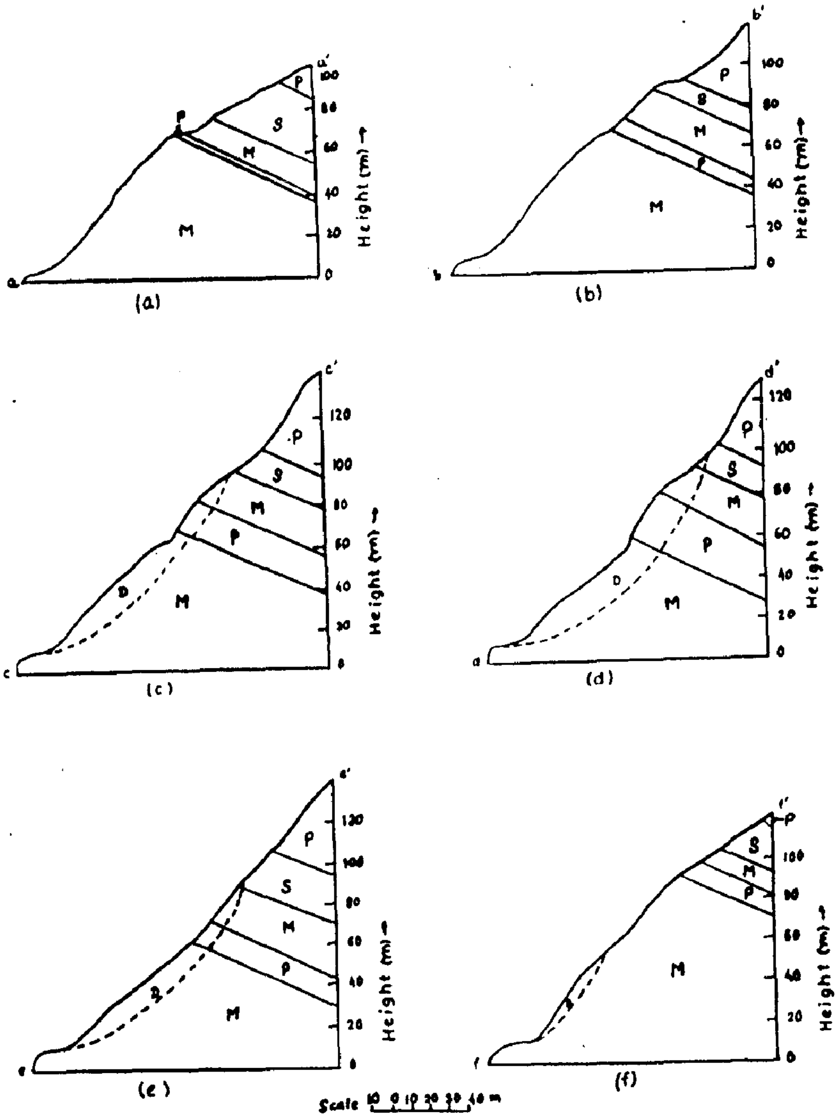


Fig. 5.3.: Geological Sections of the study area through (a) aa', (b) bb', (c) cc', (d) dd', (e) ee'and (f) ff'.
In the fig. M-Metabasic, P-Phyllite, S-Mica Schist
(Source : Mahrotra, 1993)

5.3 3D Modelling of Matli land slide

A 3D model of the landslide at about 140 Km from the Rishikesh on Tehri - Uttarkashi Road (Map 1) was prepared. For this slide bore hole data were not available but only some geological sections (fig 5.3) were available. Utilizing the surface elevation, geological map (Map 2) a 3D model of the area was generated. The steps followed in generating 3D model were the same as described in article 5.2. Subsurface information was captured layerwise. The bottom most Metabasic layer was assigned an identification number (id no.) 11, laying above it, the Phyllite layer, was assigned id no. 21. The third layer from bottom, which is Metabasic again, has been assigned an id no. 12 and layer above it, Mica Schist, was assigned id no. 31. The topmost layer, which is Phyllite, has been assigned id no. as 22. Once the data is captured, using the developed macro (appendix B), a 3D model of the slide has been developed (Plate V). In the Model various geological layers are shown in different color. The developed model was interpreted visually and analytically.

5.3.1. Visual Interpretation of Model

The visual study of the developed model (Plate V) reveals that the model can depict various units clearly, which helps in information extraction. Visual interpretation showed that the major portion of the slide is occurring in metabasic type of rock. Although this type of rock is generally hard, but since it is exposed to sun and rainfall, it is prone to weathering and as a result its top surface gets converted into debris. The deforestation activities on the slope acted as a catalytic agent. To manage this slide either rock anchors or a retaining wall may be required. In the present study a retaining wall has been designed.

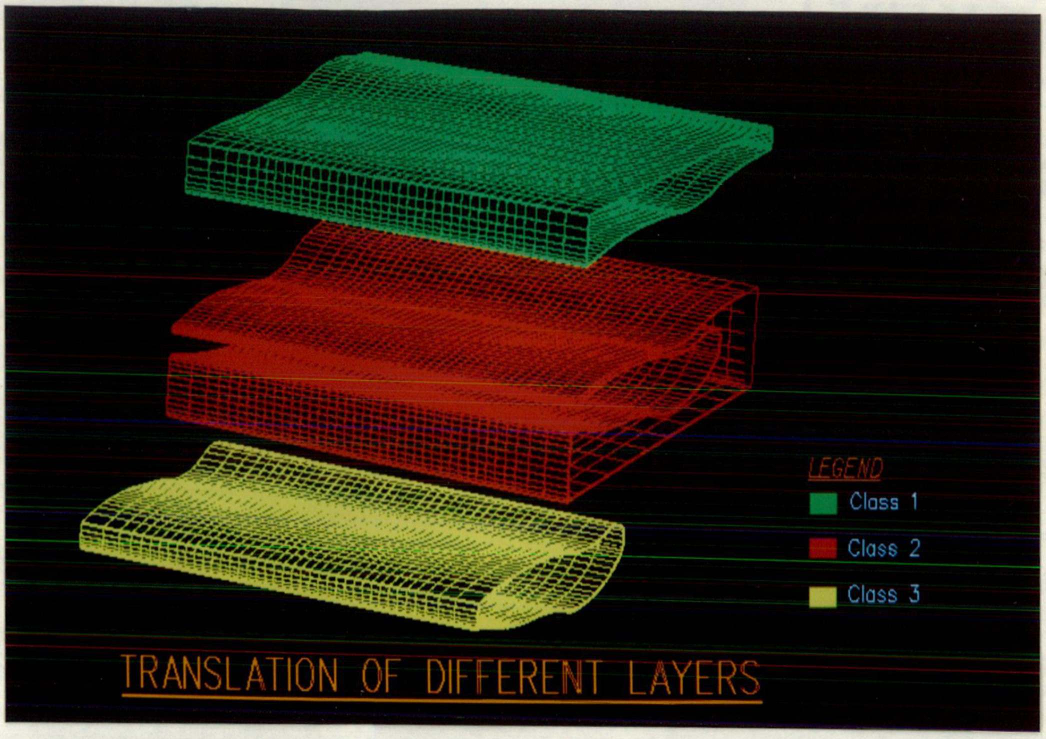


Plate 3. Translation of Different Layers

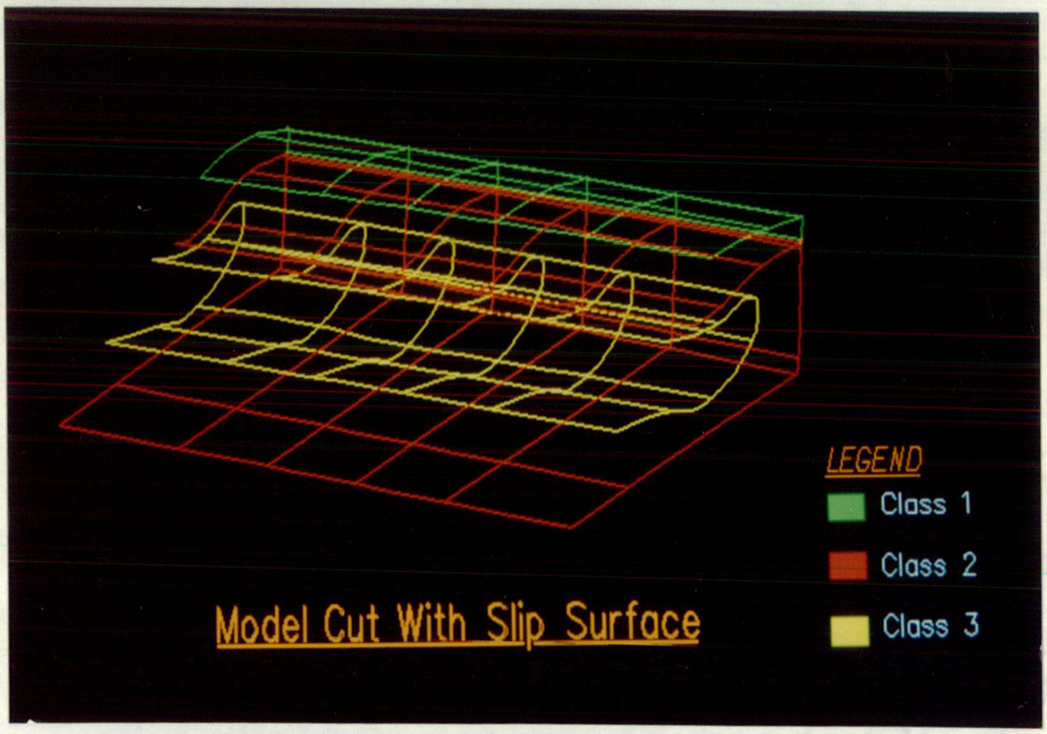


Plate 4. Model Cut with Slip Surface

5.3.2 Analytical Interpretation of Model

For analytical interpretation, the Boolean difference between slip surface and model was carried out, thus separating out sliding mass. Plate VI depicts the sliding mass translated from original model. After the separation of sliding mass, characterization of the same was carried out, and results are summarized in table 5.3 giving volume, mass and centre of mass of individual layerwise debris. Based on characterization in table 5.3 a RCC counter fort retaining wall was designed.

Table 5.3 Characterization of Debris

Layer ID	Volume (m^3)	Unit weight (KN/m^3)	Mass (KN)
11	3440.42	23.30	80161.79
12	1226.92	23.30	28589.24
21	930.16	22.47	20900.70
22	0.00	22.47	0.00
31	218.44	25.37	5541.82
Total	5815.94		135191.54

Different lithological units exert different amount of pressure on retaining structure, based on total mass of their sliding unit. This gives rise to need of chracterization of different sliding units so as to calculate total thrust on retaining structure. In the present model retaining wall is coming in metabasic layer only, so sliding debris was consider as a uniform mass. Design of retaining wall is given in appendix C. Reinforcement details are shown in fig 5.4.

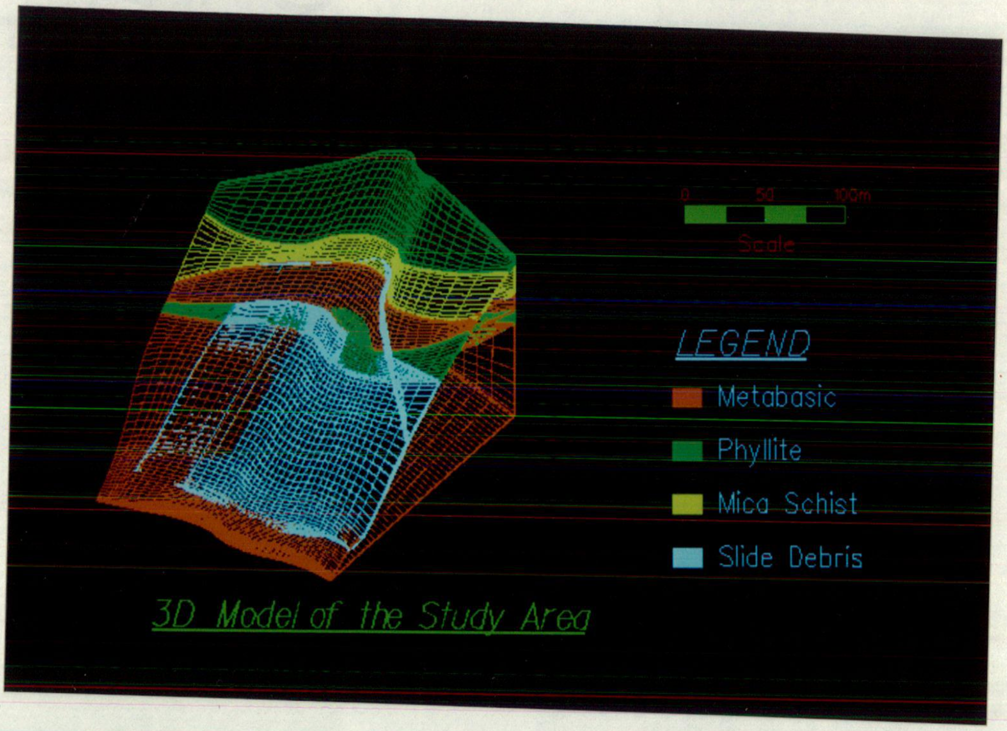


Plate 5. Model of the Real Data

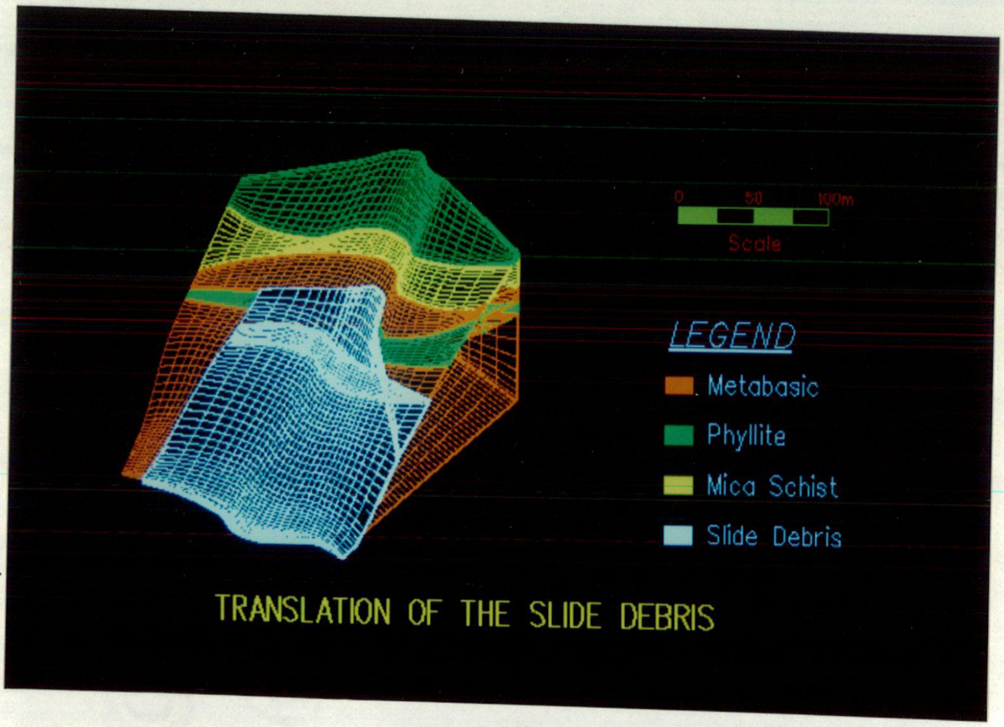


Plate 6. Translation of the Slide Debris

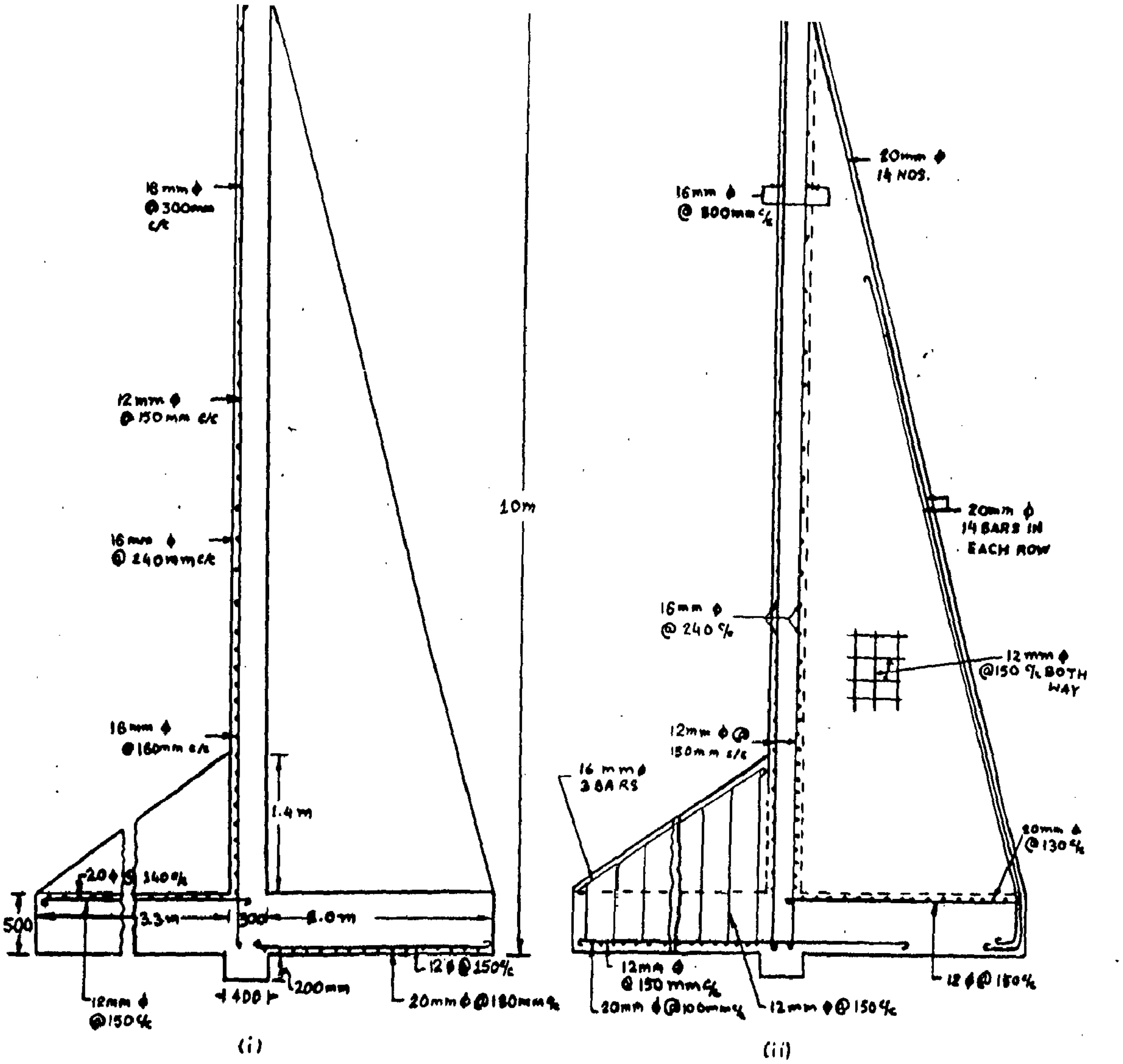


Fig. 5.4 : Sections of Retaining wall (i) at midway between counter fort, (ii) through counter fort.

5.4 CONCLUDING REMARKS

From the above discussions it is clear that 3D modelling helps in feature understanding and simulating a phenomena close to reality. In the present study on landslide, the 3D modelling has helped in carrying out the slope stability analysis considering the spatial distribution of earth parameters, such as variation in the lithological features, landcover etc. The developed model has been further used to suggest measures for managing the present slide which, as mentioned earlier, is posing a severe hazard to road traffic to Uttarkashi.

CHAPTER - 6

CONCLUSIONS AND FUTURE RECOMMENDATIONS

Many earth phenomena are space dynamic. For the sake of simplicity these phenomena are generally studied as a 2D phenomena. This often leads to erroneous or incomplete results. With the advancement in computing facilities it is now possible to carry out such studies in 3D. From the present study it is concluded that 3D GIS is powerful tool which can give clear and quantitative perception by integration of discretely varying 3D data. Further section and Boolean logics make it robustic for better understanding the interior of the solid objects. On the other hand requirements of fast processors and large storage capacity are retarding its fast development.

Landslides are catastrophic spatial phenomena which are influenced by above the surface, on the surface and below the surface activities. If this phenomenon is studied in 2D, it will have to be based on several assumptions and therefore, in such a case a 3D modelling is more appropriate. From the present study it was observed that 3D modelling in GIS, for landslides, is helpful in

* feature understanding through visualization,
* slope stability analysis including slip circle analysis (using Boolean Logics)
* characterization of features, which helps in landslide management or assessment of river blockage problem.

Thus, a safe and desirable conclusion is that 3D modelling in GIS is very useful and essential for studying the landslide dynamics and risk intensity assessment.

3D modelling in GIS is a developing field and has extensive applications in many application areas. So studies related to use of 3D GIS in different fields needs to be carried out. Also a study on river blockage due to landslide and its prevention can be carried out in 3D GIS environment.

APPENDIX - A

CAPABILITIES OF MICROSTATION 95

Category	Tool Box	Capabilities
2D drafting aids	Placing elements	Can set element attributes Can place elements ie. linear, ellipse, polygon, points and area
	Drafting aid	Can place element with precision Can place temporary grid in background
	Measurements	Can measure distance, radius, angle between lines, length, area and volume.
	Manipulation and modifying element	Can place a polygon to select the elements with case Can copy, move,scale, rotate, mirror and construct array of element (s).
	Change attribute	Can change attribute like colour, level, symbology of the elemet(s)
	Modify	Can extend or shorter a line Can trim the element (s) Can construct a chamfer between two lines.
Advanced 2D Drafting aids	Fillets	Can construct circular or parabolic fillets Can construct chamfer b/w two lines.

Category	Tool Box	Capabilities
	Group	Can join elements altogether so as to work as a single element Can drop or add a single element to a particular group Can create is two lines with some offset from centre line Can construct joints between multilines joint may be a too joint or corner joint Can delete multiline partially
	Isometric drawings	Can place isometric block or circle
	Placing curves	Can place B-Spline, composite, conic, spiral, helix areas
	Auxiliary coordinate system	Can define auxiliary coordinate system for the drawing.
3D drafting aids	3D view control	Can set view perspective, display depth, activedepth, view rotation and canera Can render the view
	3D Primitives	Can place slab, sphere, cylinder, cone, torus or wedge.
	3D free form surface	Can place surface or solid of projection, free form surface ie. B-Splive surface. Can construct surface edge, tubular surface, offset surface etc.

Category	Tool Box	Capabilities
	Modify 3D surface	Can trim, punch, stitch, split tubular surface(s) Can change surface normals
	Boolean logic	Can do union, intersection, or difference between two elements
	Fillet surface	Can construct fillet, chamfer between surface Can blend surfaced
	Extract wire frames	Can extract surface sale lines or trim boudrics
Miscellaneous	Cells	Can place cells, cell matrix and modify or replace cell (s).
	Pattern	Can hatch an area, make pattern in area or delete pattern
	Annotation	Can place tent, note, edit text, change, text attribute etc.

APPENDIX B

MACROS FOR 3D MODELLING

```
'Macro to place a 3D b-spline surface

Sub main

Dim point As MbePoint

suggest$     = " "
filter$      = "*.dat"
directory$   = "c:\users\skm\final\dgn\data\"
title$       = "Select an input file for data"
filename$    = " "

status  = MbeFileOpen (filename$, suggest$, filter$, directory$, title$)
  If status = MBE_success Then
     button = MbeMessageBox (" Selected filename is ( " + filename$ + ")
     .")
     Open filename$ for input As #1
     MbeSendCommand "PLACE SURFACE"
     MbeSetAppVariable "3DTOOLS", "ms3DToolSettings.surface.type", 0&
     MbeSendCommand "ACTIVE WEIGHT 0"
'        MbeMessageBox (" Give number of points in U-direction.")
          Input #1, maxu%
'        MbeMessageBox (" Give number of points in V-direction.")
            Input #1, maxv%
print maxu;maxv
     For numx% = 0 To maxu Step 1
          For numy% = 0 To maxv Step 1
               If Eof(1) = True Then
                    Exit For
               Else
                    Input #1, point.x, point.y, point.z
                    point.x = point.x * 1.5
                    point.y = point.y * 2.0
                    MbeSendDataPoint point, 1%
               End If
               If numy = maxv And numx = 0  Then
                    MbeSendReset
               End If
          Next numy
     Next numx
     Close
     MbeSendReset
  Else
     MbeMessageBox "File is not selected."
  End If
End Sub
```

```
'Macro for rendering the image
Sub main
    Dim startPoint As MbePoint
    Dim point As MbePoint, point2 As MbePoint

'   Start a command
    MbeSendCommand "WINDOW AREA EXTENDED 2"

'   Coordinates are in master units
    startPoint.x = 20.660290#
    startPoint.y = 121.527960#
    startPoint.z = 125.839810#


    MbeSendCommand "PLACE FENCE ICON "

    point.x = startPoint.x + 1.918600#
    point.y = startPoint.y - 4.534410#
    point.z = startPoint.z - 2.615800#
    MbeSendDataPoint point, 2%

    point.x = startPoint.x + 76.610650#
    point.y = startPoint.y - 164.916370#
    point.z = startPoint.z - 88.305710#
    MbeSendDataPoint point, 2%

    MbeSendCommand "RENDER VIEW HIDDEN "

    MbeSendCommand "RENDER ICON "

'   Set a variable associated with a dialog box
    MbeSetAppVariable "", "msToolSettings.renderView.target", 1&

    MbeSendCommand "RENDER ICON "

End Sub
```

APPENDIX C

DESIGN OF RETAINING WALL

Retaining wall is designed taking total volume and weight of debris from table 5.3. Details of the design are given below :

Unit weights of debris $w = \frac{1135191.54}{5815.98} = 23.20 \text{ kN/m}^3$

Bearing capacity of soil = 20 kN/m^2

Cohesion of soil = 125 kN/m^2

Angle of internal friction = 30°

Coefficient of friction between soil and conc. = 0.5

Using M15 concrete and mild steel reinforcement.

So $c = 5 \text{ N/mm}^2$, $t = 140 \text{ N/mm}^2$, $m = 19$

$k = 0.404$, $j = 0.865$, $R = 0.874$

For the soil angle of internal friction = 30°

So $K_a = \frac{1\text{-}\sin 30}{1+\sin 30} = \frac{1}{3}$

$$K_p = \frac{1}{K_a} = 3$$

The ratio of length of toe slab (DE) to the base of width b may be found by the expression :

$$\alpha = 1 - \frac{q}{2.260 + 1} = 1 - \frac{200}{2.2 \times 22.3 \times 10} = 0.5923$$

$$b = 0.95\ H \sqrt{\frac{K_a}{(1-\alpha)\ (1+3\alpha)}}$$

$$= 0.95 \times 10 \sqrt{\frac{1}{3(1-0.5923)(1+3\times0.5923)}} = 0.5426 \simeq 0.55$$

However range of b is between 0.5 H to 0.6H

so keeping b = 0.55H = 0.55 x 10 = 5.5 m   Say 4.6 m

length of toe slab = αxb = 3.257 ≃ 3.3 m

Taking uniform thickness of stem = 0.3m

Length of head slab = 5.6 - (3.3 + 0.3) = 2.0 m

Assuming thickness of base slab = 0.3 m

Clear spacing of counter forts is

$$l = 3.5 \left(\frac{H}{\omega}\right)^{1/4} = 3.5\left(\frac{10}{22.3}\right)^{1/4} = 2.86\ m$$

keeping them 3m apart.

Counterforts is also provided over toe slab at same clear spacing

Stability of Wall

Moment due to self load (about toe):

Designation	Force (kN)	L Area (m)	Moment (about toe kNm)
Weight of steam	0.3x(10-0.3)x1x25 = 72.75	3.3+0.15 = 3.45	2.50.98
Weight of base	0.3 x 5.6 x 1 x 25= 42.0	2.8	117.60
Weight of soil on heel	2x(10-0.3)x1x22.3 =432.6	4.6	
	ΣW = 547.35	Total	2358.64

∴ Resisting moment = 2358.64 kNm

Horizontal Earth pressure $P_H = K_{a\omega} \frac{H^2}{2} = \frac{1}{3} \times \frac{1}{2} \times 22.3 \times 10^2 = 371.67$ KN

Overtunning moment $= M_o = P_H \frac{H}{3} = 371.67 \times \frac{60}{3} = 1238.89$ kNm

F.S. again ovetraning $= \frac{MR}{M_o} = \frac{2358.64}{1238.89} = 1.9 < 2$ hence safe

F.S. against sliding $= \frac{\mu \Sigma w}{pH} = \frac{0.5x5.47.35}{371.67} = 0.74 < 1$

So wall is unsafe in sliding, so a shear key is to be provided.

Pressure Distribution

Net moment $= M_R - M_o = 2358.4 - 1238.89 = 1119.75$ kNm

Distance $\bar{x}$ from toe, point of application of resultant force

$$\bar{x} = \frac{\Sigma M}{\Sigma w} = \frac{1119.75}{547.35} = 2.05\text{m}$$

Eccentricity $= e = \frac{b}{2} - \bar{x} = \frac{5.6}{2} - 2.05 = 0.75$ m

It is less then $\frac{b}{2}$ i.e. 0.93 so no tension will develop.

Pressure under toe D $= p_1 = \frac{\Sigma\omega}{b}\left(1 + \frac{6e}{b}\right) = \frac{547.35}{5.6}\left(1 + \frac{6x0.75}{5.6}\right)$

$= 176.30$ kN/m^2 $<$ 200 kN/m hence safe.

Pressure under heel C $= p_2 = \frac{\Sigma\omega}{b}\left(1 + \frac{6e}{b}\right) = \frac{547.35}{5.6}\left(1 - \frac{6x0.75}{5.6}\right)$

$= 19.20$ kN/m^2

Pressure Intensity under E $= p_1' = 176.30 - \frac{176.30-19.20}{5.6} \times 3.3 = 83.72$ kN/m^2

Pressure Intensity under B $= p_2' = 176.30 - \frac{176.30-19.20}{5.6} \times 3.6 = 75.31$ kN/m^2

Design of Heel slab

Considering strip of 1m near edge.

Net downward pressure = 9.7x22.3 + 0.3x25 - 19.2 = 193.46 kN/m^2

Maximum negative moment $= \frac{pl^2}{12} = 193.46 \times \frac{(3)^2}{12} = 145.10$ kNm

$d = \sqrt{\frac{145.10 \times 10^6}{1000 \times 0.874}} = 407.45$ mm > 300 mm So unsafe

Keeping depth of heel as 0.5 m

d = 0.5 - 0.06 = 0.440 mm i.e. 440 mm

Now downward pressure = 9.7x22.3 + 0.5x25 - 19.2 = 209.61 kN/m^2

moment 209.61 x $\frac{(3)^2}{12}$ = 157.21 kNm

d = $\sqrt{\frac{157.21 \times 10^6}{1000 \times 0.874}}$ = 42.4.12 mm < 460 mm So unsafe

shear force = V = 209.61 x $\frac{3}{2}$ = 314.42 kN.

$\Sigma = \frac{314.42 \times 1000}{1000 \times 440}$ 0.71 N/mm^2 < C_c hence shear reinforcement is not required

Steel

at supports

$$A_{st0} = \frac{157.21 \times 10^6}{140 \times 0.865 \times 440} = 2950.42 \text{ mm}^2$$

Providing 20 mm dia bars @ 100 mm c/c (3141.6 mm^2)

Maximum positive BM = $\frac{pl^2}{16} = \frac{3}{4} M_1$ = 117.91 kNm

Area of bottom steel = $A_{st2} = \frac{117.91 \times 1000,000}{140 \times 0.865 \times 440}$ = 2212.81 mm^2

20 mm dia bars @ 140 mm % (2244 mm^2)

Reinforcement near B

Considering 1 m strip near B

net downward pressure = 9.7x22.5 + 0.4x25 - 75.31 = 155.44 kN/m^2

This is about $\frac{55.44}{209.61}$ = 0.74 of load intensity at C

Hence spacing of bars = $\frac{107.6}{0.74} \simeq 145$ mm say 140 mm c/c at top face

near support = $\frac{140}{0.74} = 189.19$ say 180 mm c/c at bottam face

Distribution steel

$A_{st} = \frac{0.15}{100}$ (1000 x 500) = 750 mm^2

Using 12mm diabers @ 150 mm o/c (754 mm^2)

Design of Toe Slab :

A coonnterfort is provided so to slab will behave like comtinons slab.

Taking depth of foe slab equl of hed slab i.e. 500 mm d=500-60=400 mm

Net pressure at D = 0.5X25-176.30=-163.80 KN/m^2 i.e. 163.80 KN/m^2 upward

Similarly net presone at E= 0.5x25-83.72=71.22 KN/m^2 (upword)

Considering 1m strip at D

Maximum negative BM = $\frac{wl^2}{--}$ = 163.80 x $\frac{(3)^2}{12}$ = 122.85 KNm

d = $\sqrt{\frac{122.85 \text{ x}}{1000 \text{ x } 0}}$ 440 mm sefe

shear force V =

Steel at D

at supports (top) $A_{st1} = \frac{122.85 \times 10^6}{140 \times 0.865 \times 440} = 2305.57 \text{ mm}^2$

Providing 20 ϕ bars @ 130 mm c/c (2416.6 mm^2)

(Bottom) $A_{st} = \frac{3}{4} A_{st1} = 1729.18 \text{ mm}^2$

(Providing 20 ϕ bar @ 180 mm c/c)

Steel at E

upward pressure is $\frac{71.22}{163.80}$ 0.43 times then that at D

So, spacing of top steel $= \frac{136.3}{0.43} = 313.47$ mm

Providing 20 mm @ 260 mm c/c at top

Spacing of bottom steel $= \frac{181.68}{0.43} = 422.52$ mm

Providing 20 ϕ bars @ 360 mm c/c

Distribution steel = 12 ϕ bars @ 150 mm c/c

Design of Stem (Vertical Slab)

Stem acts as vertical slab

Comsidering unit width at B

Intensity of earth pressure $= p_e = K_a w H_1 = \frac{1}{3} \times 22.3 \times 9.5 = 63.18 \text{ kN/m}^2$

Negative BM near support $= M_1 = \frac{p_e l^2}{12} = 63.18 \times \frac{(3)^2}{12} = 47.39$ kNm

$$d = \sqrt{\frac{47.39 \times 10^6}{1000 \times 0.874}} = 232.85 \text{ mm} < 240 \text{ mm} \quad \text{safe}$$

$$\text{shear force} = V\ 63.18 \times \frac{3}{2} = 94.77 \text{ kN.}$$

Steel

$$\text{Near counterforts } A_{st1} = \frac{47.39 \times 10^6}{140 \times 0.865 \times 240} = 1630.54 \text{ mm}^2$$

Providing 16ϕ bars @ 120 mm c/c (1675.52 mm^2)

$$\text{Maximum positive benidng moment} = \frac{3}{4} M_1 = 35.54 \text{ KNm}$$

$$\text{Steel} = \frac{3}{4} A_{st1} = 1222.90 \text{ mm}^2$$

Design of main counterfort

Taking thickness of counterfort 0.5 m earth pressure at any section at h m below $= \frac{1}{3} \times 22.3 \times h \times 3.5 = 26\ h$.

Similarly net downward pressure on heel at C = 9.7 x 22.5 + 0.5 x 25 - 19.2

= 205.3 kN/m^2

at B = 9.7 x 22.5 + 0.5 x 25 - 75.31 = 149 kN/m^2

Reaction transfered to each counterfort ⇒ 205.3 x 3.5 = 718.55 kN/m at C

⇒ 149.2 x 3.5 = 522.17 kN/m at B

Critical section for counterfort is at F i.e. earth surface

Pressure intensity at F(b = 9m) = 26x9 = 234 kN/m shear force $V = \frac{1}{2} \times 234 \times 9 = 1053$ kN/m

$$M = 1053 \times \frac{1}{3} = 3159 \text{ KNm}$$

$$d = \sqrt{\frac{3159 \times 10^6}{500 \times 0.874}} = 2087.2 \text{ mm}$$

Total depth = 2087.2 + 60 = 2147 mm

Angle θ of face AC = $\tan^{-1}\left(\frac{2}{9.5}\right) = 11.888 = 11°53'19''$

$\sin\theta = 0.206$ and $\cos\theta = 0.9785$

Depth $F_1C_1 = AF_1 \sin\theta = 9 \times 0.206 = 1.854 = 1854$ mm

Depth FG = 1854 + 300 = 2154mm > 2147mm (safe)

Steel

Steel is provided in two layers

d = 2150 - 50 - 20 = 2080 mm (50mm clear cover, 20mm dia bar)

$$A_{st} = \frac{3159 \times 10^6}{140 \times 0.9 \times 2080} = 4205.36 \text{ mm}^2$$

providing 20 ϕ bars 14 Nos. in two layers.

Design of shear key

Shear key is required as wall is unsafe under sliding

Let depth of key = a

$p_p = K_p p = 3x83.72 = 251.16 \text{ kN/m}^2$

Total passive pressure = p_px a = 251.16 a

Sliding force at level $D_1C_1 = \frac{1}{3} \times \frac{22.3}{2} (10+a)^2$

Weight of soil between bottom of base and D_1C_1

= 5.6 x a x 22.3 = 124.88 a kN

$\Sigma w = 547.35 + 124.88 a$

(547.34 kN = Σw; from stability of wall)

Hence ability of wall against sliding with FOS = 1.5

$$1.5 = \frac{\mu \Sigma w + P_p}{P_H} = \frac{0.5(547.35 + 124.88a) + 251.16 a}{3(10+a)^2}$$

or

$$90 a + 4.5 a^2 + 450 = 273.68 + 313.60 a$$

or

$$4.5 a^2 - 223.60 a + 176.32 = 0$$

from above equation a = 0.138 m

Keeping a = 0.2m and width of key 0.4

Actual force resited by key = $1.5\ P_H - \mu\Sigma W$

$= 1.5 \times 3(10 + 0.2)^2 - 0.5 \times (547.35 - 124.88 \times 0.2)$

$= 206.99$ kN

Shear stress = $\frac{206.99 \times 1000}{500 \times 1000}$ = 0.41 mm safe

Binding stress = $\frac{206.99 \times 1000 \times 200}{1/6 \times 1000 \times (500)^2}$ = 0.99 mm safe

Detailed section of the retaining wall is shown w fig. 5.4.

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