'Dishansh 2005' - A Java Based Software Application to Plot and Analyze Structural Data for Seismological and Geotechnical Interpretations

सिप्रक्तु माता मही रसा नः

Naveenchandra N. Srivastava*,
Rita U. Thakor**,
Sejal V. Patel**,
Sejal G. Viroja**,
Urvi S. Chetta**,
Hirenkumar B. Naik**
&
Shashikant A. Sharma**

**Institute of Seismological Research,*
Directorate of Economics and Statistics Campus,
Sector 18, Gandhinagar – 382018, India
E-mail: dg-isr@gujarat.gov.in

***Bhaskaracharya Institute for Space Applications*
and Geo-informatics, Indulal Yagnik Marg,
Gandhinagar – 382 007, India

ABSTRACT

Spatial relations in the geosciences are commonly represented by projecting the orientation of planes and lines on a horizontal surface. 'Dishansh 2005' plots planer and linear structural features, for seismological and geotechnical interpretations. Equal area and equal angle projections provided by this software can be used to present and analyze geometrical and angular relationships between lines and planes. Stereographic projections provide easy solutions of the problems dealing with the angular relationships between lines and planes in space. Joints, bedding planes and faults are represented by lines or points on the projection of a reference sphere. Design and development process of 'Dishansh 2005' strictly followed the concept of software engineering. For proper planning, scheduling and control of activities of this software development project, PERT (Program Evaluation Review Technique) has been implemented. It is an interactive multi purpose tool to meet various requirement of user. It allows the user to analyze and visualize structural data following the same techniques used in manual stereonets.

Keywords: Focal mechanism solution, stereonet, projection, PERT

1. INTRODUCTION

Direction and degree play significant role in plotting and analyzing structural data for seismological and geotechnical analysis. Hence, the software is named as Dishansh {Disha (Direction) + Ansh (Degree)} in Gujarati language (Patel, 2005).

The orientation of planar features (strike and dip of bedding, foliation, joints) and linear features (trend and plunge of lineations of all kinds) are the primary field data of structural geologists. Stereographic projections provide the means to aggregate these data to help interpret the overall structure of a field area. Structural data presented in this manner emphasize the angles between lines and planes rather than the relative positions of lines and planes in space (i.e. as an alternative to maps of structural data). The inclination and orientation of the plane can also be defined by the pole of the plane. The pole is the point at which the surface of the sphere is pierced by the radial line, which is normal to the plane.

Several types of stereonet can be used to represent the geological data. The widely used projections are Equal Area projection and Equal Angle projection. The intersection of the line(s) of projection with the horizontal "primitive circle" represents the orientation of the structure. Thus, the number of dimensions are reduced by one, and planes in three-dimensional rock structures are represented by lines (great circles), lineations are represented by points (piercing the primitive circle), and planes may also be represented by the lines normal to their surface (poles) that are then represented by points on a stereonet. Stereonets are a convenient way to graphically represent structural data collected in the field without having to deal with complexities of topography. Spatial relations are lost, but geometric relations are preserved.

"Equal angle" stereonets preserve the angular relations of three-dimensional structures, and are commonly used in crystallography to show the spatial relations of crystallographic axes, symmetry elements (e.g. rotation axes, mirrors, center of symmetry), poles to crystal faces (lines normal to the faces), and zone axes. Geoscientists can "view" geologic structures or crystallographic forms via the abstract representations of stereonets.

Joints, bedding planes and fault are represented by lines or points on the projection of a reference sphere. A unit area on the projected area represents the same fraction of the total area of the reference sphere. This feature of Equal Area is advantageous in statistical investigations (Samadhiya,1993).

Geologic processes such as types of folding and faulting commonly give rise to bedding orientation that cannot be restored to their original state by translational movement alone. Stereographic or equal-area projections provide a means by which rotation of structural data may be easily and accurately accomplished. Although it is possible to determine directions and angles by the use of this projection, it is not possible to determine distances and area. On the other hand, use of the equal-area projection and descriptive geometry may be combined effectively.

Solutions of the problems dealing with the angular relationships between lines and planes in space may be obtained much more easily by stereographic projection. For certain problems, however, use of the stereonet is essential, namely, in the study of the three-dimensional geometry of the rock masses, especially if structurally complex (Ragan, 1968). Start up screen of software has been kept simple, so that user can navigate through various available options. It is shown in Fig.1.

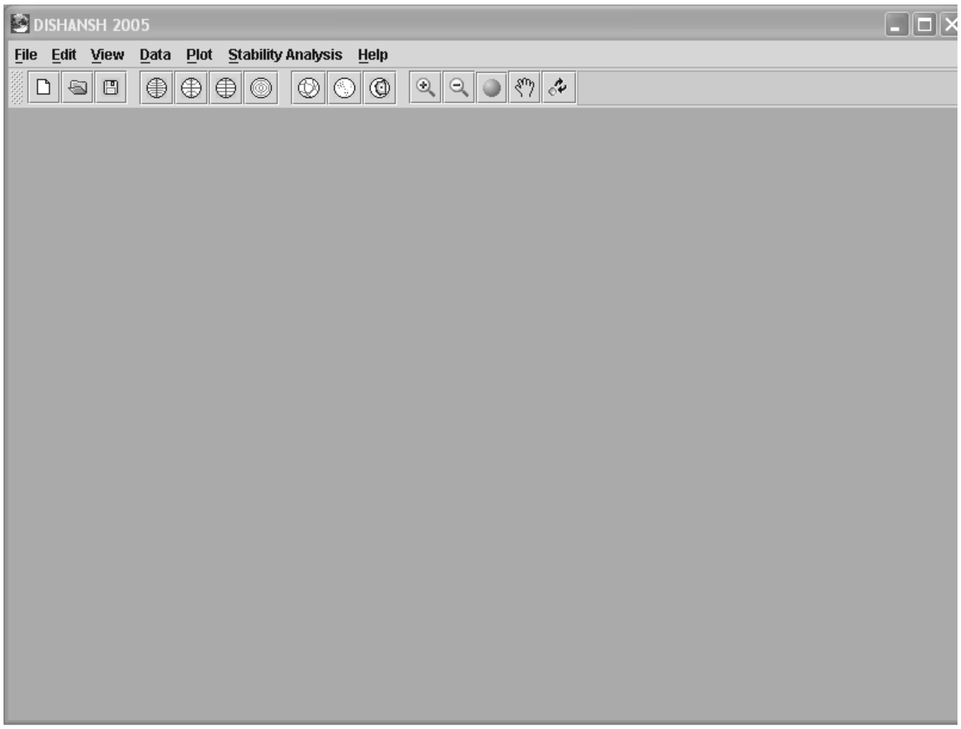

Fig. 1 - Initial screen of 'Dishansh 2005'

2. OBJECTIVES

- To display planer and linear structural feature.
- To generate beachball diagram for various focal mechanism.
- To display the slope instability mechanisms and to calculate Factor of safety.
- To utilize strong programming capabilities of Java to generate interactive GUI (Graphical User Interface).

3. 'BEACHBALL DIAGRAM' FOR SEISMOLOGICAL INTERPRETATION

This work presents construction of beachball diagram using Java based software application 'Dishansh 2005'. Beachball diagram represents graphic depiction of Focal mechanism solution (FMS). It represents graphically the geometry of a moment tensor derived by seismologists using sophisticated wave-form analysis.

Earthquakes occur when stresses in the earth reach a level greater than the strength of the rock, causing the rocks on opposite sides of the fault to suddenly and violently slip past one another. Beachball diagrams show how seismic waves and the earthquake creates vary in different directions as they leave the hypocenter. Focal mechanism is the description of the orientation of the fault plane and the direction of first motion in that plane, derived from studies of the wave patterns radiated from the focus (Vere-Jones, 1995). The focal mechanism of thousands of earthquakes has now been studied. Thus much new and valuable information is being obtained on the present tectonic activity of the crust (Billings, 1987).

During an earthquake the accumulated elastic energy is released suddenly by physical displacement of the ground, as heat and as seismic waves that travel outwards from the focus. By studying the first motions, the focal mechanism of the earthquake can be inferred and the motion on the fault plane interpreted. The orientations of P- and T-axes and of the fault plane and auxiliary plane can be obtained even for distant earthquakes by analyzing the directions of first motions recorded in seismograms of the events. The analysis is called a fault plane solution, or focal mechanism solution (Lowrie, 2002). The technique represents a very powerful method of analyzing movements of the lithosphere, in particular those associated with plate tectonics (Kearey and Vine, 1990). Beachball diagram for thrust focal mechanism is shown in Fig. 2. Data source for beachball diagram is reported by Koper (2001).

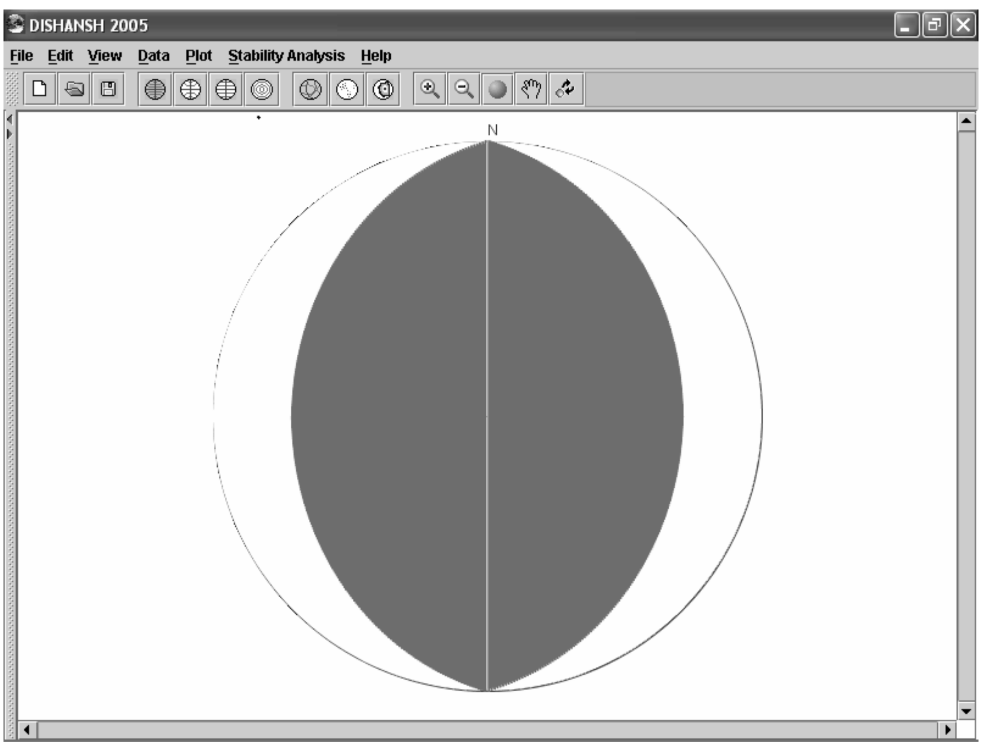

Fig. 2 - Beachball diagram for thrust focal mechanism

4. DISPLAY AND ANALYSIS OF GEOTECHNICAL DATA

Rock mass is a discontinuous medium. It is characterized by faults, joints and bedding planes. These structural features control mainly the behaviour or response of the mass during excavation or loading stage. Hence, it is important to understand the influence of these features. Spherical projection of the geologic data is used to understand the overall impact of structural features using Lambert or Equal Area Projection (or Schmidt Net) and Equal Angle Projection (Wulff Net).

The dominant role of geological discontinuities in behavior of rock slope has been emphasized for a long. Certain combinations of geological discontinuities, slope geometry and groundwater conditions result in slopes in which the risk of failure is high. The stability of slopes is of great importance to civil, geotechnical and mining engineers worldwide. Stability analyses are required for a wide variety of engineering projects, such as:

- open pit mines
- road cuts
- dams
- embankments
- natural slope stabilization

The stability of a slope is controlled by local geological, structural and groundwater conditions. One of the most important aspects of rock slope analysis is the systematic collection and presentation of geological data in such a way that it can easily be evaluated and incorporated into stability analysis. Spherical projection provides a convenient means for the presentation of geological data. The Lambert equal area projection is a system used to represent the spherical shape of the earth on a flat surface. In adapting this projection to structural geology, the traces of planes on the surface of a reference sphere are used to define the dips and dip directions of the planes. In engineering applications, the lower reference hemisphere is used for the presentation of data.

Different types of slope failure are associated with different geological structures. Hence, it is important to recognize the potential stability problems during the early stages of a project. One of the most important aspects of rock slope analysis is the systematic collection and presentation of geological data in such a way that it can easily be evaluated and incorporated into stability analyses. Experience has shown that spherical projections provide a convenient means for the presentation of geological data (Hoek and Bray, 1977).

Failure mechanisms for rock slopes are conveniently assessed by means of stereographic projections of the structural data and the slope geometry. Methods are available for planar and wedge failure described by Hoek & Bray (1977). For plane and wedge failure, different constructions of failure mechanisms are required. Markland’s test is designed to establish the possibility of a wedge failure in which sliding takes place along the line of intersection of two discontinuities. Plane failure is also covered by this test.

(i) Plane Failure

Plane failure occurs when a geological discontinuity, such as a bedding plane, strikes parallel to the slope face and dips into the excavation at an angle greater than the angle of friction. Markland test plot for plane failure is shown in Fig. 3. Slope face, friction circle and critical zone for sliding failure are indicated. Data source for plane failure analysis is reported by Sahoo (1999).

General conditions for plane failure

- The plane on which sliding occurs must strike parallel or nearly parallel (within approximately $\pm 20^0$) to the slope face.
- The failure plane must "daylight" in the slope face.
- The dip of the failure plane must be greater than the angle of friction.

(ii) Wedge Failure

When two discontinuities strike obliquely across the slope face, the wedge of rock resting on these discontinuities will slide down the line of intersection, provided that the inclination of this line is significantly greater than the angle of friction. The calculation of the factor of safety is more complicated than that for plane failure (Hoek and Bray, 1977). Markland test plot for wedge failure is shown in Fig. 4. Data source for wedge failure analysis is reported by Sahoo (1999).

General conditions for wedge failure

As in the case of plane failure, condition of sliding is $\psi_f > \psi_i > Ø$, where ψ_f is the inclination of the slope face, ψ_i is the dip of the line of intersection and Ø is the angle of friction.

The Factor of Safety can be defined as the ratio of the total force available to resist sliding to the total force tending to induce sliding. When the slope is on the point of failure, a condition of limiting equilibrium exists in which resisting and disturbing forces are equal and the factor of safety F = 1. When the slope is stable, the resisting forces are greater than the disturbing forces and value of the factor of safety will be greater than unity. A slope will fail if the factor of safety falls below unity. Computation of factor of safety for potential plane and wedge failures are shown in Figs. 5 and 6.

5. SOFTWARE FUNCTIONALITY

User can perform large range of operations with this interactive software:

- This software provides multiple database connectivity. It allows user to enter data manually, to create new ASCII file and to retrieve data from MS Access, MS Excel and ASCII files.

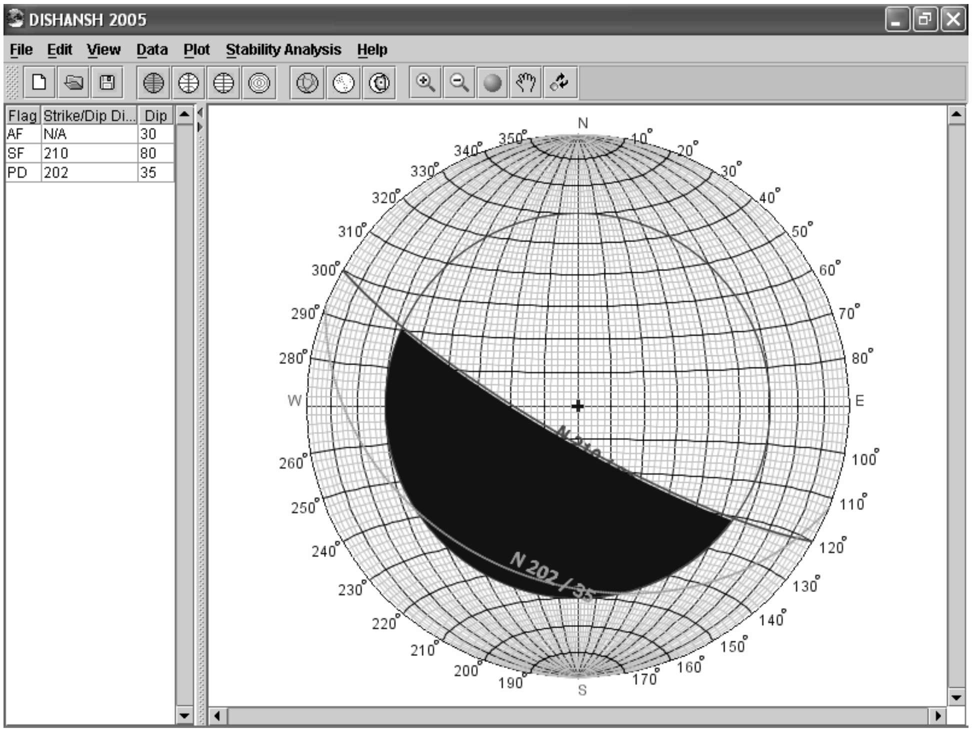

Fig. 3 - Markland test plot for plane sliding

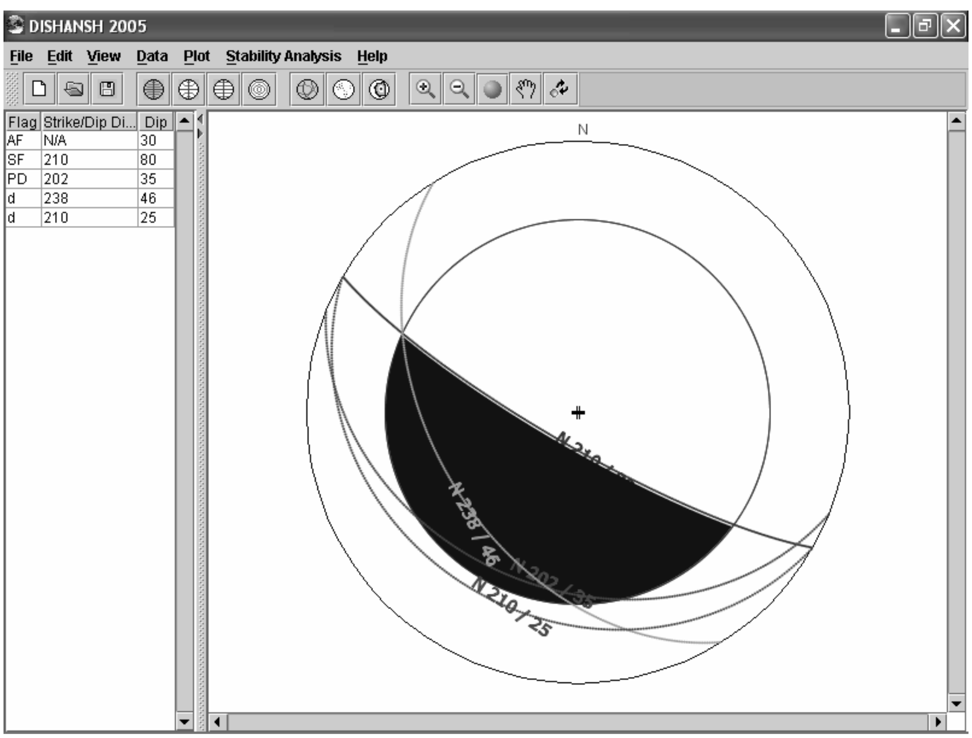

Fig. 4 - Markland test plot for wedge sliding

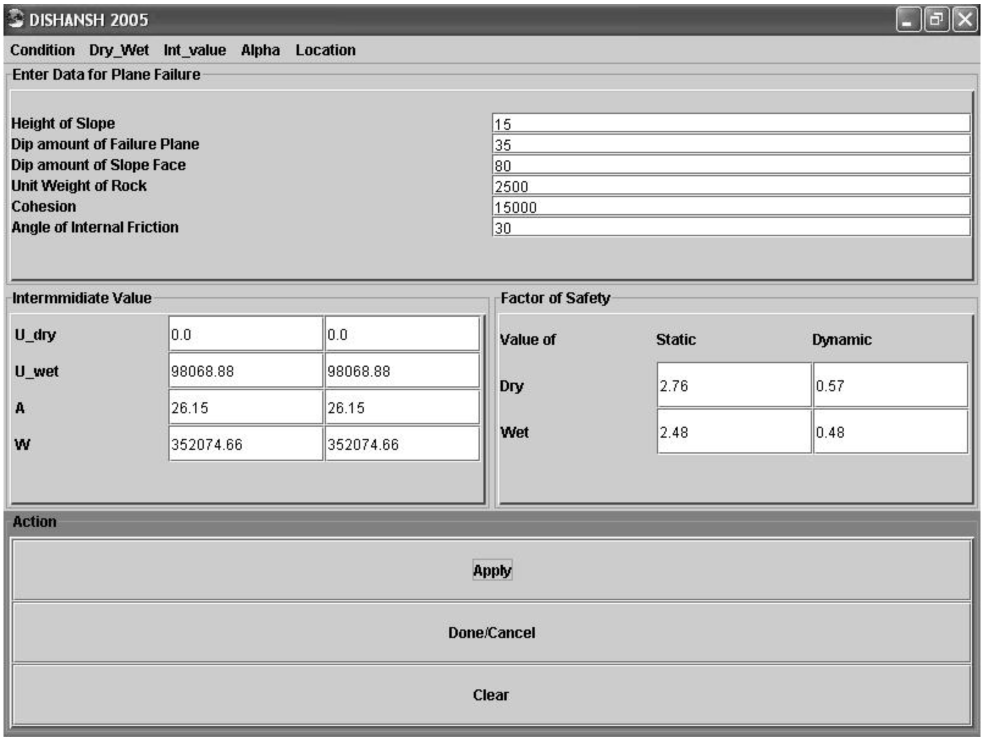

Fig. 5 - Computation of 'Factor of Safety' for planer sliding

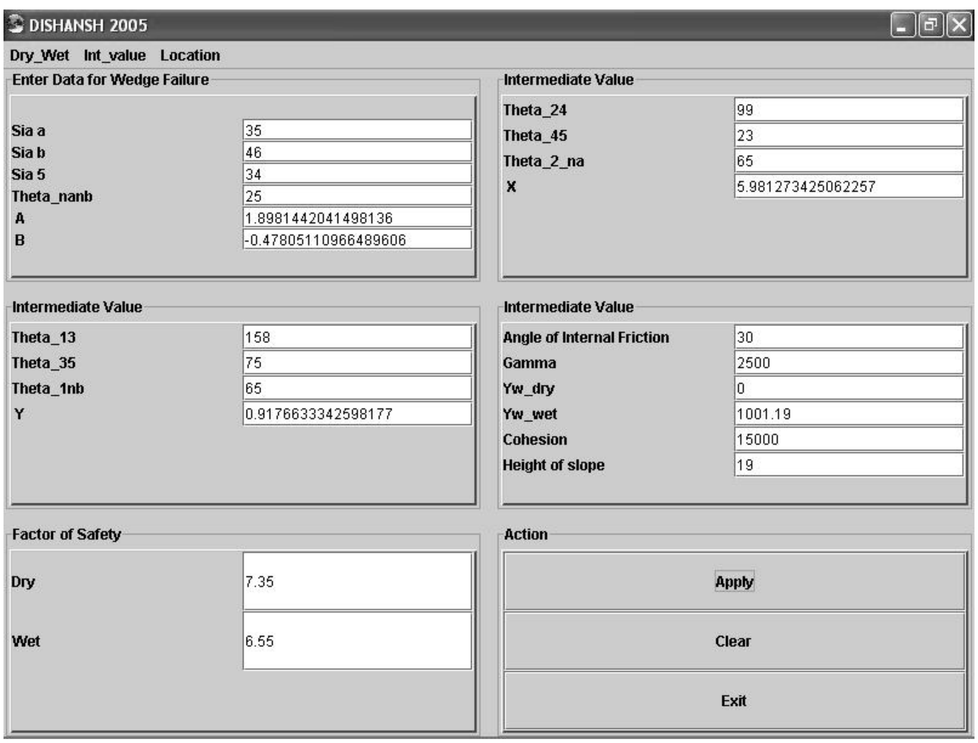

Fig. 6 - Computation of 'Factor of Safety' for wedge sliding

- ‘Dishansh 2005’ provides equal area, equal angle and orthographic projections for the display and analysis of structural data for seismological and geotechnical studies.
- ‘Dishansh 2005’ plots planes and poles according to the input data.
- Angle between two poles can be displayed using this software.
- It also performs other important functionalities like generation of beachball diagram and slope stability analysis.
- To find out density of poles, software provides Kalsbeek net.
- Various utility functions are provided like zoom in, zoom out, pan, print, save the plotted image, display of necessary details etc.
- User can plot, delete, edit the data pertaining to plane or pole repetitively.
- Tool tip can display the details of pole.
- User can view the output in his own customized way using interactive GUI of ‘Dishansh 2005’.

6. TOOLS AND TECHNOLOGY

Development of ‘Dishansh 2005’ has strictly followed SDLC (Software Development Life Cycle). The fundamental reason that necessitated the utilization of core Java for the development of software is that in Java, GUI (Graphical User Interface) provides excellent interactivity with user. Besides this, Java is an object oriented programming language (Palmer, 2001). It is simple, secure, portable, robust, multithreaded, architecture neutral, high performance, interpreted, distributed and dynamic programming language. Like the successful computer languages that came before, Java is a blend of the best elements of its rich heritage combined with the innovative concepts required by its unique environment (Schildt, 2001). Today, Java is used not only for web programming, but also to develop standalone applications (Liang, 1998).

Software testing is the critical element of the software quality assurance and represents the ultimate review of specification, design and code generation. Once the source code has been generated, software must be tested to uncover as many errors as possible before delivery to the users. Software has been successfully implemented in the client’s environment. Developers have tested ‘Dishansh 2005’ using various software techniques like structural testing, condition testing, interface testing etc. (Thakor et al., 2005).

Swing is a new set of user interface components that is much more complete, flexible and portable. It is a major part of Java Foundation Classes. It provides user more control of how application looks. User can choose between several pre-built “look-and-feels”, or he can also create of his own. Look-and-feels have become an important issue in GUI development over the past few years. One of the most exciting aspects of the Swing classes is the ability to dictate the look-and-feel of each component, even resetting the look-and-feel at runtime (Eckstein, 2001). Swing components can have tool tips placed over them. Functioning of ‘Dishansh 2005’ requires Windows operating system (95/98/2000/XP) and Microsoft Office. Hardware requirement consists of 200 MB free space on hard disk and 32 MB RAM. It is supported on i586 intel and 100 per cent compatible platforms running Microsoft windows.

7. ADVANTAGES AND LIMITATIONS OF ‘DISHANSH 2005’

‘Dishansh 2005’ is an easy to use and reliable software. It satisfies user’s various requirements – accuracy of results, an easy to use and interactive interface which allows the user to assess the results, and generate professional looking output, for inclusion in reports, papers and presentations. All of this and more is delivered by ‘Dishansh 2005’. With the help of this software it is possible to estimate mode of failure on the stereonet. Based on various stability parameters, the possibility of planer sliding and wedge sliding can all be quickly evaluated. This software is very easy to learn and use. It satisfies various seismological and geotechnical requirement from initial problem exploration, to the generation of high quality output for professional reports and presentations. It is client side application i.e. it works on standalone PC. It can not be deployed in client – server environment. JVM (Java Virtual Machine) needs to be installed on computer.

8. APPLICATION OF PERT FOR THE DEVELOPMENT OF ‘DISHANSH 2005’

PERT is an acronym for Program Evaluation Review Technique. It is eminently suitable for research and development programmes, aerospace projects, and other projects involving new technology. In such projects the time required for completing various jobs or activities can be highly variable. Hence the orientation of PERT is ‘probabilistic’. PERT in a way supercedes the older technique known as the Gantt chart. Contrary to Gantt chart in PERT every individual item of work can be accommodated and displayed in the logical sequence (Arogyaswamy, 1988). Variability of project duration in PERT analysis is measured by variance or its square root and standard deviation (Chandra, 2005). PERT has been found quite useful for proper planning, scheduling and control of project related activities. If the project has to be finished at its earliest, then completion of some activities can not be delayed. These activities are called critical activities. The path obtained by joining the critical activities is called the critical path of the project. Critical path for ‘Dishansh 2005’ is shown in Figure 7.

Procedure adopted in applying PERT is given below.

a. Key activities and their sequence are identified.
b. Activities are listed in logical sequence (Table 1).
c. For every activity three time estimates are considered for computation of expected duration (Table 2).
d. Expected duration for each activity is considered for the construction of network diagram.
e. Standard deviation of duration is computed for each activity.

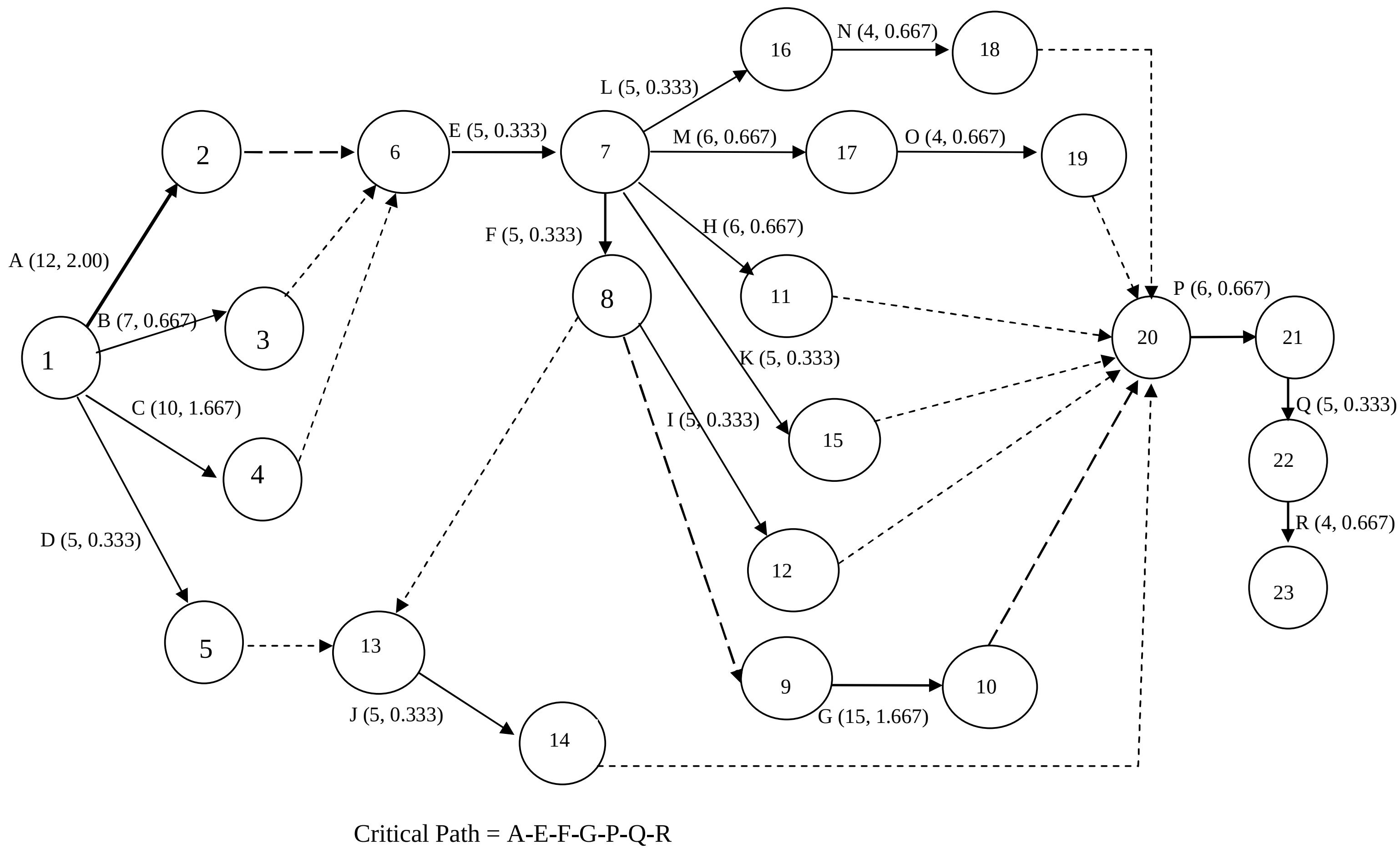

Fig. 7 - Network diagram of 'Dishansh 2005'

f. Network diagram is constructed (Fig. 7).
g. Critical path is identified.

Table 1 - Details of activities

Activity	Description	Predecessor Activity
A	Draw equal area net	-
B	Draw equal angle net	-
C	Draw orthographic net	-
D	Kalsbeek net	-
E	Plotting Planes	A, B, C
F	Plotting Poles	E
G	Multiple database connectivity	E, F
H	Plotting Beta Diagram	E
I	Angle between two poles	F
J	Finding Density of Poles for contouring	D, F
K	Generation of Beachball Diagram	E
L	Markland test for plane failure	E
M	Markland test for wedge failure	E
N	Computation of Factor of Safety for plane failure	L
O	Computation of Factor of Safety for wedge failure	M
P	Variuos Utility options	E, F
Q	GUI for all functionality	P
R	Softaware Testing	Q

Table 2 - Three time estimates of different activities

Activity	Optimistic Time (a)	Most Likely Time (m)	Pessimistic Time (b)	Expected Duration (t_e) $t_e = (a + 4.m + b)/6$	Standard Deviation of Duration (σ)
A	6	12	18	12	2.000
B	5	7	9	7	0.667
C	7	9	17	10	1.667
D	4	5	6	5	0.333
E	4	5	6	5	0.333
F	4	5	6	5	0.333
G	10	15	20	15	1.667
H	4	6	8	6	0.667
I	4	5	6	5	0.333
J	4	5	6	5	0.333
K	4	5	6	5	0.333
L	4	5	6	5	0.333

M	4	6	8	6	0.667
N	2	4	6	4	0.667
O	2	4	6	4	0.667
P	4	6	8	6	0.667
Q	4	5	6	5	0.333
R	3	3.5	7	4	0.667

Probability of completion of project by a specified time viz. within 60 days

Here, $\sigma = (b - a) / 6$
The expected duration of the critical path $\mu = 12 + 5 + 5 + 15 + 6 + 5 + 4 = 52$ days

$$\sigma^2 = (2.00)^2 + (0.333)^2 + (0.333)^2 + (1.667)^2 + (0.667)^2 + (0.333)^2 + (0.667)^2$$
$$= 4 + 0.111 + 0.111 + 2.779 + 0.445 + 0.111 + 0.445$$
$$= 8.002$$

Probability $\Pr[t <= 60] = \Pr[(t - \mu) / \sigma]$
$= \Pr[(60 – 52) / \text{sqrt}(8.002)]$

$= \Pr[8 / 2.83]$

$= \Pr[Z <= 2.83]$

$= 0.9977$

So, it can be said that the probability of completion of project in 60 days is 99.77 %.

9. SUMMARY

‘Dishansh 2005’ has been developed using Java programming language to plot and analyze data pertaining to structural discontinuities. User convenient interface has been designed to ease the user with software. This is a tool capable of many different applications and is designed both for the novice or occasional user, and for the accomplished user of stereographic projection who wishes to utilize more advanced tools in the analysis of structural data. Probability of completion of project by a specified date has been computed with the help of mean and standard deviation of different time estimates. Multiple database connectivity and various utility options are characteristic of this software. Beachball diagram for various focal mechanisms can be constructed using ‘Dishansh 2005’. It is an application of interest for structural geologist / seismologist / geotechnical engineers etc.

Acknowledgement

The authors express gratitude to Shri Rajkumar, I.A.S., Secretary, Department of Science and Technology, Government of Gujarat for his encouragement and keen interest. Thanks are also due to Shri T. P. Singh, Director General, Institute of Seismological Research, Gandhinagar for providing necessary guidance and permission to publish this work. They acknowledge Bhaskaracharya Institute for

Space Applications and Geo-informatics, Gandhinagar for facilitating necessary support for the development of 'Dishansh 2005'.

References

Arogyaswamy, R. N. P. (1988). Courses in Mining Geology, Oxford and IBH Publishing Co. Pvt. Ltd. , New Delhi, pp 443.

Billings, M.P. (1987). Structural Geology, Prentice- Hall of India Private Limited, New Delhi, pp 489.

Chandra, P. (2005). 'Projects : Planning, Analysis, Financing, Implementation and Review', Tata Mc Graw – Hill Publishing Company Limited, New Delhi, 647.

Eckstein, R., Loy, M. and Wood, D. (2001). Java Swing, Shroff Publishers and Distributors Pvt. Ltd., Mumbai, pp 7.

Hoek, E. and Bray, J. (1977). Rock Slope Engineering, The Institution of Mining and Mettallurgy, London, pp 29.

Kearey, P. and Vine, F. J. (1990). Global Tectonics, Blackwell Scientific Publications, Oxford, pp 9.

Koper, K. D. (2001). Help with Focal Mechanisms, http://mnw.eas.slu.edu/People/KKoper/Teaching/EASA-193/2002/foc_mec/

Liang, Y.D. (1988). An Introduction to Java Programming, Prentice Hall of India Private Limited, New Delhi, pp 3.

Lowrie, W. (2002). Fundamentals of Geophyics, Cambridge University Press, pp 116.

Palmer, G. (2001). Java Programmer's Reference, Wrox Press Ltd., Birmingham, UK, pp 2.

Patel, A. J. (2005). Real Dictionary: English- English – Gujarati, Akshara Prakashan, Ahmedabad, pp 240 & 260.

Ragan, D. M. (1968). Strucutral Geology – An Introduction to Geometrical Techniques, John Wiley & Sons, New York, pp 77.

Sahoo A.K. (1999). Evaluation of Remedial Measures of Some Hillslopes based on Failure Rock Mechanism Pertaining to Tehri Dam Reservoir, M.Sc. Thesis, Unpublished, Department of Earth Sciences, University of Roorkee, pp 12 & 13.

Samadhiya, N. (1993). Graphical Presentation of Geologic Data, Short course on Landslide Analysis and Control, Department of Civil Engineering and Earth Sciences, University of Roorkee, pp 20.

Schildt, H. (2001). Java 2 Complete reference, Fourth Edition, Tata Mc Graw – Hill Publishing Company Limited, New Delhi, pp 9.

Thakor, R. U., Patel, S.V., Viroja, S. G. and Chetta, U. S. (2005). Dishansh, B.E. Dissertaion thesis, Unpublished, Bhaskaracharya Institute for Space Applications and Geo-informatics, Gandhinagar, Gujarat, pp 96.

Vere-Jones, D. (1995). Forecasting Earthquakes and Earthquake risk, International Journal of Forecasting 11, Elsevier, pp 503 – 538.