Chapter 23*

FEASIBILITY ASSESSMENTS

23.1 MINOR ROADS

The feasibility assessments for **minor roads** are the same as the prefeasibility assessments.

23.2 MEDIUM ROADS

In the case of **medium roads**, the feasibility assessments should be similar to the prefeasibility assessments except for the fact that the number of alternatives studied should be reduced to one or two and the level of rigors enhanced to bring the accuracy to ± 15 per cent.

Hazard assessment for the feasibility stage for medium roads is presented in Section 23.3. Risk assessment, based on these hazards, should be carried out in a way similar to the description given in Chapter 22 for medium roads. The traffic **count** should be carried out systematically at all nodal points and other important points.

The alignments selected by prefeasibility studies and approved for feasibility studies should be surveyed by the use of an Abney's Level, compass, ranging rods, altimeters, and distomats. Representative long sections and cross-sections should be taken in the field at about 100 metre intervals and at major dissections. Large-scale, existing topographical maps and aerial photos should be employed wherever possible.

The designs for road formation, cut slopes, retaining and breast walls, and drainage and erosion control should be based on hazard and terrain slope. Figures and Tables in Chapter 24 should be used for guidance. Also refer to the discussions on geometric standards in Section 22.4 for the design of horizontal and vertical profiles.

Quantity estimation should be based on the cross-sections, long sections, and field data on drainages and erosion controls. The formats for summarising estimations for construction quantities should be the same as those used in the prefeasibility stage.

The amount of resealing, every 4 to 5 years, for surface-dressed pavements, the amount of overlaying for improvements because of the staged-design of pavements, the amount of damage restoration made necessary by the monsoons or other hazards, and the amount of rehabilitation or restoration made necessary by major damages in hazardous areas, based upon assessed risk, should be properly assessed and included in the assessment of maintenance costs. Rate analysis for each item for construction and maintenance work should be carried out and the cost of each alternative alignment calculated, based on these rates.

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* Tables and Figures without credit lines in this Chapter are compiled by the author.

Economic analysis should be carried out using the cash flow method with detailed assessments of both direct and indirect benefits. The selection process should be similar to that of the prefeasibility stage. The feasibility stage environmental impact assessment for medium roads is presented in Section 23.4.

23.3 FEASIBILITY STAGE HAZARD ASSESSMENT AND MAPPING

The prefeasibility study will have established one or more feasible routes and will have roughly placed the alternative alignments on 1:50,000 scale topographic maps, positioning the alternative alignments as closely as possible to the apparent position of the centre line and selecting the best alignment out of the several alternatives. The following activities are necessary for data collection and map preparation during the feasibility stage.

23.3.1 *Discussion, Literature Search, and Preparatory Work*

The results from the prefeasibility study should be discussed with the project authorities and obligatory points on the route, such as villages, towns, saddles, passes, airports, tourist sites, and other areas of critical concern for fixing the road alignment, must be decided upon tentatively before going to the field.

The available literature collected for prefeasibility studies should be used together with the large-scale geological, geomorphological, land use, and other maps. Air photos or satellite images, and topographic maps on scales from 1:50,000 to 1:20,000 are necessary at this stage. If air photos are not available, an aerial photographic survey and a stereographic photo helicopter flight should be performed for major roads. For medium roads, a stereographic photo helicopter flight, at least, is needed. Apart from the above maps, hydrological, groundwater, meteorological, and seismicity data are also required for this stage of study.

23.3.2 *Office Work Prior to Fieldwork*

Two copies of topographic maps on a 1:25,000 scale, covering the alternative alignments from the prefeasibility stage studies are needed. These maps will be used in the field. It is also desirable, whenever possible, to prepare 1:25,000 scale, or even better 1:10000 scale, **orthotopomaps** prepared from 1:25,000 scale airphotos, or photo mosaics. If the topographic maps on a scale of 1:25,000 or 10,000 are not available, the 1:50,000 scale map should be enlarged to 1:25,000 scale and the alternative alignments should be fixed on the maps. At the same time, the geological, land use, and similar maps should also be enlarged to 1:25,000 scale for field use.

A first **photointerpretation** of the 1:25,000 set and of the **helicopter photos** should be carried out also during office work. These interpretations should then be corrected in accordance with field survey findings.

Slope maps (see Chapter 22) should be prepared on a scale of 1:25,000 from the topographic maps along the alternative alignment strips for at least 1 km up and 1 km down the alignment. If two alternative routes are running at a distance of less than 5 km, the slope map should include the entire area between them (Fig. 23.1) (see Annex 3).

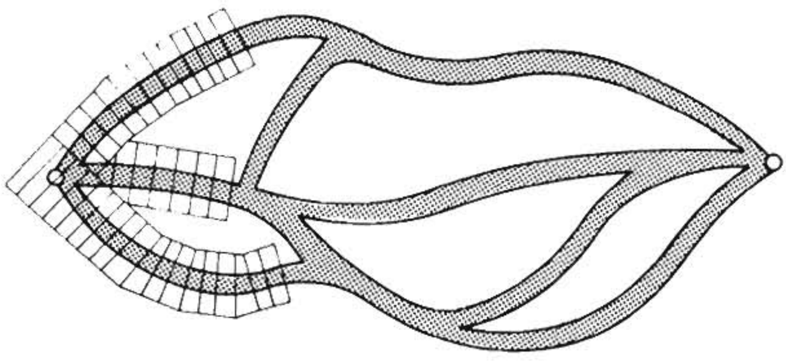


Fig. 23.1 Illustration of slope map covering three alignments

In the process of preparation for the field, arrangements must also be made for geological equipment which should include a geologic compass, geologic hammer, 10 per cent hydrochloric acid solution, distance measuring tape (at least 30m long) or similar equipment, e.g., a topofil or hipchain, a pocket calculator, an altimeter, a camera with films, camp equipment, and stationery.

The field work should be performed by a team consisting of an engineering geologist, geotechnical engineer, road locator engineer, and preferably also an economist and an environmentalist.

23.3.3 *Field Work Procedures for Engineering Geologists*

The field work is done mainly for the following three purposes: i) preparation of base field maps along the alternative alignment strips; ii) data collection for the state of nature, types and extent of danger, and information on past triggers; and iii) subjective judgement in the field on the probability of danger occurring.

a) *Field Mapping Techniques*

The topographic maps and air photos on a scale of 1:25,000 are marked carefully with all the observation points in the field. On the same map is also fixed the proposed road alignment. Prior to fixing the alignment, land forms such as nearby spurs, ridges, valleys, gullies, and terraces should be carefully studied. It is also recommended that any other possible short alternatives be shown. The map must include the extent and types of danger (i.e., slides, slumps, falls, flows, gullies, etc), as discussed in Chapter 12, the state of nature (i.e., rock and soil types, seepage, springs, land use, folds, faults, etc which are described in Chapters 3,4,5,9 and 10), and triggers (river undercutting, flood levels, deep gully incisions, past cloud burst effected areas, seismically active zones, etc.). Rock outcrops should be delimited from soil areas on the topographic maps.

The areas with thin soil cover (less than 1 m) should be classified as rocky areas. Major scarps, faults, folds, and crushed zones should also be marked on the map. Recent landforms such as alluvial terraces, point bars, alluvial and debris fans, talus and debris cones, talus slopes, faults, scarps, cliffs, moraines (tills), and other features or materials should be identified and shown on the map. As some of them are related directly to the mass movement process, they should be studied in connection with the danger types. River and stream courses should be corrected on the old maps, alluvial fans and terraces should be identified, and missing cliffs should be drawn. The observation points should be fixed between lithologic contacts. Bedding or foliation dips as well as strikes should also be marked on the map.

The above information should be duplicated in the record copy of the topographic map in the camp, and the data should be cross-checked for consistency with the "Data Sheet for State of Danger" described below.

b) *Data Collection Sheet*

For the sake of clarity and uniformity, it is recommended that the field observation data are recorded on the data sheet shown in Table 23.1. The procedure for data collection is discussed below.

c) *Location of the Station*

To locate the observation point accurately on the topographic map, geomorphic features such as the confluence of guillies, rivers, or creeks; their sharp bends, ridge crests, saddles, and peaks should be identified and the observation point should be fixed with the help of the above landmarks. If necessary, back bearings from two or more nearby landmarks can be plotted on the map and the intersection can be taken as the location (see Chapter 6). The elevation of the station should also be taken with an accurate altimeter (pressure changes caused by weather fluctuations should also be taken into account. Altimeter readings should be taken at reliable reference points for control). A brief description of location should be given together with the section type; this refers to whether the route is passing through the ridge (ridge section), the climb section, or the valley section (which may be a gorge, a flat river terrace, or a colluvial deposit).

d) *Slope Attributes*

Though the slope maps will have been prepared in the office from the 1:25,000 scale topographic maps, a common observation in the field is that the slope angles vary considerably, especially on flatter and steeper slopes. Owing to the fact that topographic maps are not very accurate (especially the 1:50,000 maps), and sometimes several decades old, the topography may have changed, and it is therefore necessary to measure the slope angle up and down the route and the length of the slope should be marked whenever there is any change in slope. If there is an abrupt break in the slope up or down the alignment, the slope length and angle should be assessed approximately.

e) *Drainage Characteristics and Groundwater*

A classification of the drainage pattern into such types as dendritic, parallel, trellis, rectangular, etc (see also Chapter 2) will have been performed while executing the air photo survey in the office. During the field work, the intensity of gullying has to be observed because it is the foremost important indicator of instability. Depending upon the material (rock/soil) and gradient, as well as the discharge, gullies should be classified according to the depth, width, channel morphology, sinuosity (straight, wavy, or irregular), and gradient. At the same time, the catchment area of the gully should be delimited on the topographical map. The area of influence of a gully, i.e., the area where it may trigger failures and erosion should also be estimated.

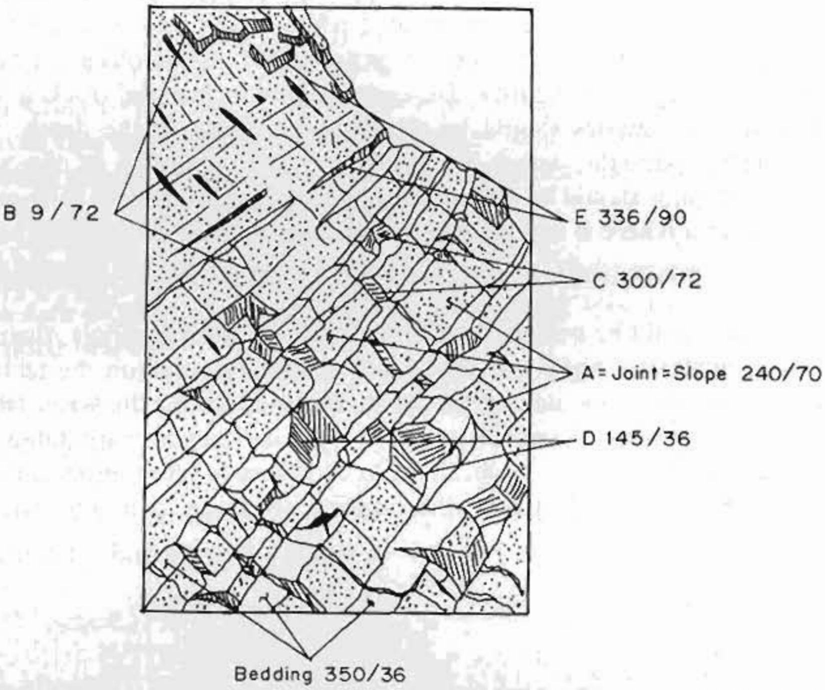
All springs and seeps should be marked on the map and, by using symbols, their discharge rate (as very low, low, moderate, high, and very high) should be noted on the table. The relative elevation of springs and seeps should also be noted, as these indicate the water table level on the slope. The seasonality (perennial/seasonal) and their types indicate the water table variation. Note also that springs and seeps may also be localised in certain rock types, especially in interbedded and fractured ones. Springs are also formed in massive limestone, dolomite, and quartzite.

f) *Rock Type*

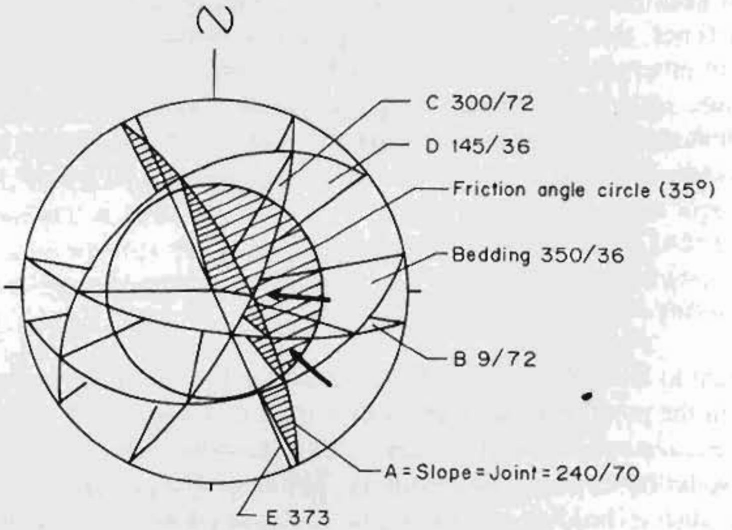
Rock outcrops should be studied in terms of texture (mostly grain size), structure, composition, colour, and thickness of layers (see Chapter 3). Special attention should be paid to changes in the lithology of sedimentary and metamorphic rock with more than one interbedded or alternating layer. Sometimes, thin, incompetent partings and joint infillings and seams could be responsible for failure in otherwise massive and sound rock. Sedimentary structures such as ripple marks, load and flute casts, and channels may increase the friction coefficient whereas cleavage and fissility planes may be prone to sliding. If the rock is covered by thin (about 1m) colluvium, or other soil types, the properties of both the bedrock and soil should be noted.

g) *Rock Weathering*

It is important to know the degree of weathering (and, if possible, its depth) for various reasons. Firstly, from the point of view of excavation quantities and cost, highly weathered rock is much cheaper to excavate than sound resistant rock. Secondly, complex weathering profiles can lead to perched water tables and slope instability. Thirdly, relict geological structures preserved during weathering, such as bedding, foliation, joints, etc, also have a strong influence on slope stability (Deere and Patton 1971). Weathering can also drastically reduce the rock strength and lead to weak foundations. Weathering grades of rocks can be determined from Figure 2.2. Chapter 2.



a. A rock outcrop with discontinuity sets



b. Schmidt upper hemispherical projection of discontinuities.

Source: Krähenbühl and Wagner 1983

Fig. 23.2 Measurement and plotting of structural geological features

h) *Rock Structure*

Measurement of rock structure should include determination of attitude (direction and dip angle) of the following discontinuities (see Chapters 4 and 6):

- o bedding plane,
- o joint,
- o foliation,
- o cleavage, and
- o fault.

It is also necessary to identify strongly-folded areas (small-scale folds). In those areas the bedding/foliation measurements should be excluded since they are irrelevant.

It is important to know the relationship of the discontinuity with the slope. For this purpose, the discontinuities are plotted on a stereonet as described in Chapter 7. Figure 23.2 shows various structural features in an outcrop and how these are plotted on a Schmidt Net by projecting on the upper hemisphere. Joint and bedding planes are studied for spacing, persistence, width, waviness, and infilling material as discussed in Chapter 10. Wherever possible, structural areas should be distinguished in the field. For each structural area, a pole contoured Schmidt Net should be constructed in order to obtain the preferred orientations of discontinuities. For the feasibility stage, it is necessary to perform at least 15 measurements from each set of joints and bedding/foliation in one outcrop of rock. In critical areas, the measurements may reach up to 200 and more.

i) *Major Folds, Faults and Sheer Zones*

Such faults as the Main Boundary Thrust, Main Central Thrust, and the like have a wide zone of crushing and/or sheering. The adjacent rocks are generally very fractured. Occasionally, small-scale folds are associated with the faults. Sometimes, a major vertical fault or an imbricate fault zone may be present. Careful study of the geological map and air photos to identify such faults and fault zones in the field and plot their extension on the map is recommended . The cores of large-scale folds contain fractured rocks. Generally the antiformal core is more fractured than the synformal core.

j) *Soil Type*

The following parameters and information should be obtained from a soil survey.

<u>Soil type</u> (i.e., alluvium, colluvium, eluvium (or residual soil), moraine, etc), its tentative depth, and engineering properties. Soil is discussed in Chapter 2, 7, and 9 and in the Annex. Alluvium consists of rounded, well-sorted, occasionally well-graded fragments deposited by a stream or river. Colluvium is made of angular, poorly-sorted, cohesionless deposits on the sides or bottoms of slopes or cliffs and brought there by gravity. Eluvium or residual soil is a soil formed from the *in situ* weathering of rock. Moraine is a material deposited by a glacier and composed chiefly of a silty-clay or clay matrix with subangular and sometimes striated cobbles and boulders.

Table 23.1 Data sheet for state of nature and dangers sketch

Study: Alignment No Date

1. Station No...........to .... Azimuth/slope Distance
   section type
   location
   altitude

2. Slope: up the road slope
   down the slope

3. River/gully dissection
   Spring, seepage, catchment
   activity

4. Groundwater
   Moist, wet, dripping, flowing

5. Rock type

6. Weathering grade refer to Chapter 2

7. Orientation of discontinuity
   Bedding/Foliation/Joint

8. Morphology of discontinuity
   Infilling, waviness ! =

9. Soil type
   Genetic, USCS,
   C, ϕ, refer to Chapters 9 and 10

10. Minimum soil depth estimate (to be observed in the gullies)

11. Type of danger:
    Rock/soil fall, slide, slump, debris flow, ...etc.
    length, width, tension cracks, tilted trees, huge boulders in the river, in gully

12. Major geologic structure (fault, fold)

13. Land use

14. Remarks

Soil depth can be eventually estimated from the origin of soil. Proximity to rock outcrops, and the number of rock outcrops in a given area, are good indicators of rather thin soil. Surveys performed in nearby gullies provide an indication of soil thickness when rock is exposed in the river bed or of minimum thickness when it is not. Generally, alluvium has a constant thickness, colluvium is thicker at the foot of the slope. The thickness of alluvium depends upon lithology, joint spacing and orientation, and climate. In tropical and subtropical areas, it can reach great thickness. Moraine is very thick in the Higher Himalayan Range, and possibly also in the catchment areas of the Northern Himalayan foothills. Within the catchment areas of the Northern Himalayan foothills, very thick soils (up to 200m) are often deposited in the lowermost zones of the valleys. These thick deposits are possibly the result of washoff of a general moraine and/or colluvium cover from the upper zones. These deposits, which can be classified as colluvium or re-deposited moraine, are very often highly unstable, mostly when the toe is undercut by streams and rivers (see Annex 1).

Engineering parameters of the soil are presented in Chapters 9 and 10. An approximate estimation of soil strength parameters, such as unit weight, friction angle, cohesion, moisture content, and depth of water table, is necessary for feasibility study. The position of the water table may be accounted for in surveying the moist and wet areas, the seeps, and the springs. These indicate a water table close to the surface of the ground. Dry material areas indicate that the water table may be deep, generally when no creek is present. Seasonal creeks or gullies may also indicate that the water table is rather deep.

The parameters can be estimated in the field. The estimated values of these parameters should account for the worst conditions during the life of a proposed road or structure. Chapter 9 discusses the background material on engineering soil classification and quick test methods.

k) *Types of Danger*

The main purpose of studying various types of danger is to assess the past, presently active, and dormant instabilities. The danger types related to the mountain terrain could be mass movements (such as landslides, debris flow, landslide-dams, and the action of glacial lake outburst floods). It is recommended that Varne's slope movement classification, as given in Chapter 12, be followed. Along with the classification of various dangers, it is also necessary to study the material (rock or soil) involved in the danger event, slope angle of the talus and slick head, as well as slope angle of the flow, rate and direction of movement, and possible cause and remedial measures. At the same time the possibility of recurrence and the interval of recurrence should also be enquired about and mentioned. The probability of the occurrence of specific dangers or a combination of dangers should be assessed as accurately as possible.

l) *Land Use*

The conditions of forest cover (sparse, dense, decaying, and dry) cultivated land, paddy ground, pasture land, irrigation features, and other human activities have to be surveyed during the field survey on the basis of air photos and/or helicopter photos.

m) *General Remarks*

While studying alternative routes, it is necessary to focus on the selection of bridge sites. At least two tentative bridge sites should be studied in the field and marked on the map. Both river banks of the bridge site should be studied for proximity to faults, rock and soil types, existing and potential landslides, the channel width, height of the banks, their nature (cut bank and depositional bank), the size of riverbed boulders, possible direction of river channel shifting, and scouring. The maximum flood level of the previous 20 years should be estimated also.

If it is proposed to place the road alignment along a cliff, its length should be noted on the map and information be given in Report 1 so that necessary trace cutting is done before the detailed survey.

The areas with debris or alluvial fans, high hazard gullying zones, rock and debris slides, debris and mudflows, or slumping should be studied and discussed separately.

23.3.4 *Office Work After the Field*

Office work after the field survey involves preparation of engineering geological, hydrogeological, morphostructural, and hazard maps. Risk assessment and comparison of various alternatives, based on the feasibility studies, are also carried out.

a) *Base Map Preparation*

The base map should include all the gullies, streams, rivers, spurs, ridges, cliffs, river terraces, major point bars, major talus, debris cones, and fans, as well as existing and past rockslides and landslides. The base map is prepared from the 1:25,000 scale topographic map modified from the field observations and from the air photo survey. The route and alternative routes and major sites of interest, such as proposed bridge sites, villages, airports, etc, should also be incorporated into this map.

b) *Observation Points Map*

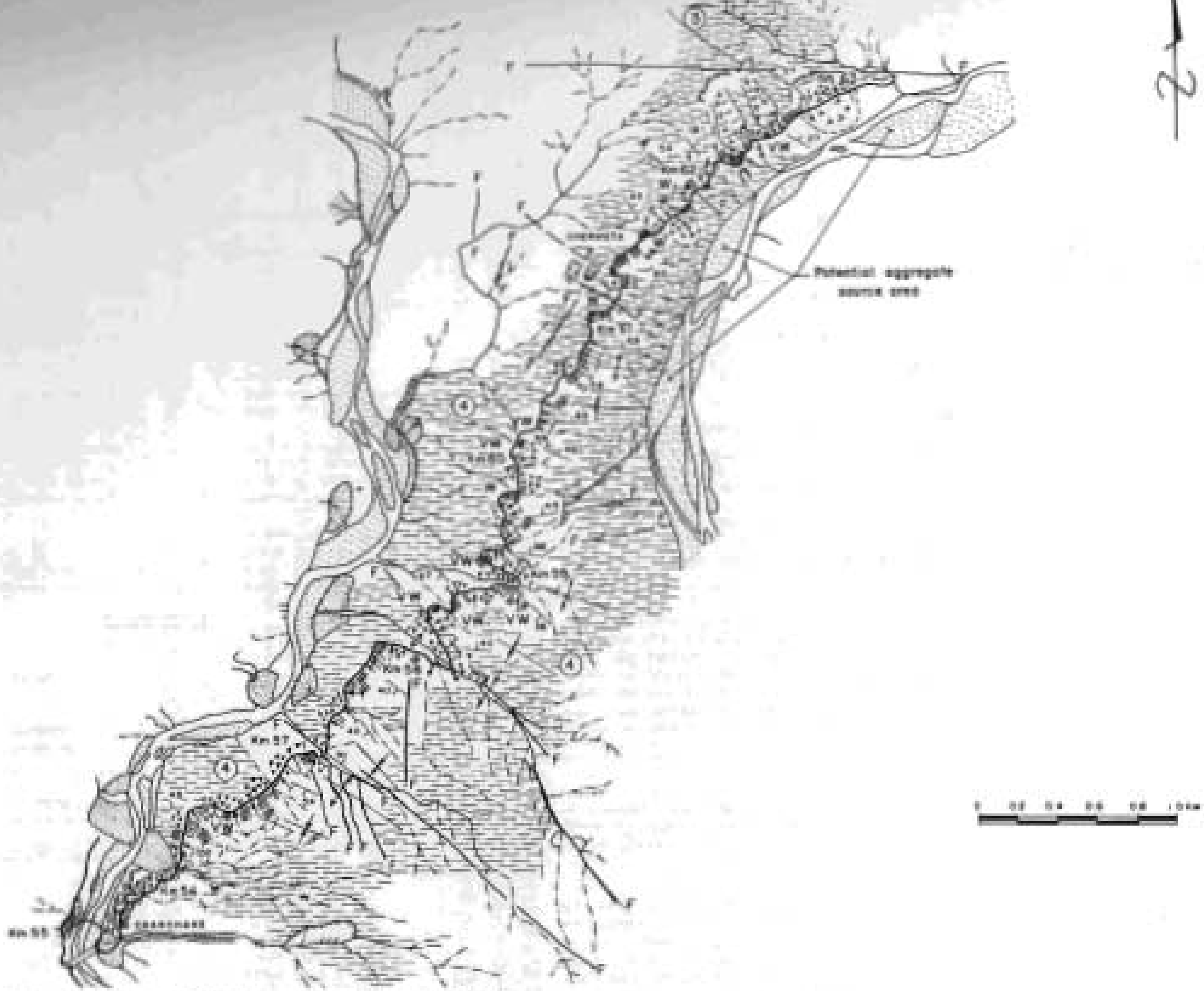
A first map will include the observation points drawn from the field topomap.

c) *Slope Map Modification*

The previously prepared slope map should be corrected and modified from the field data and re-drawn on the base map. If modification is impracticable, the field data should be incorporated on the morphostructural map.

d) *Engineering Geological Map*

The engineering geological map (Figs. 23.3a and 23.3b) is prepared on the base map by plotting the field data and studying the field map. It depicts the information on rock and soil, attitude of bedding, foliation and fault planes, axial traces of folds, fault extension with crushed zones, and such information as bank scouring, depth of cracks, and degree of weathering of rocks. Thick and thin soil covers should also be mapped with their genetic origins (colluvial, alluvial, eluvial, morainic glaciofluviatile, etc).



Source: Louis Berger Int'l. Inc., Rapti Roads, 1985

Fig. 23.3(a) Engineering geological map

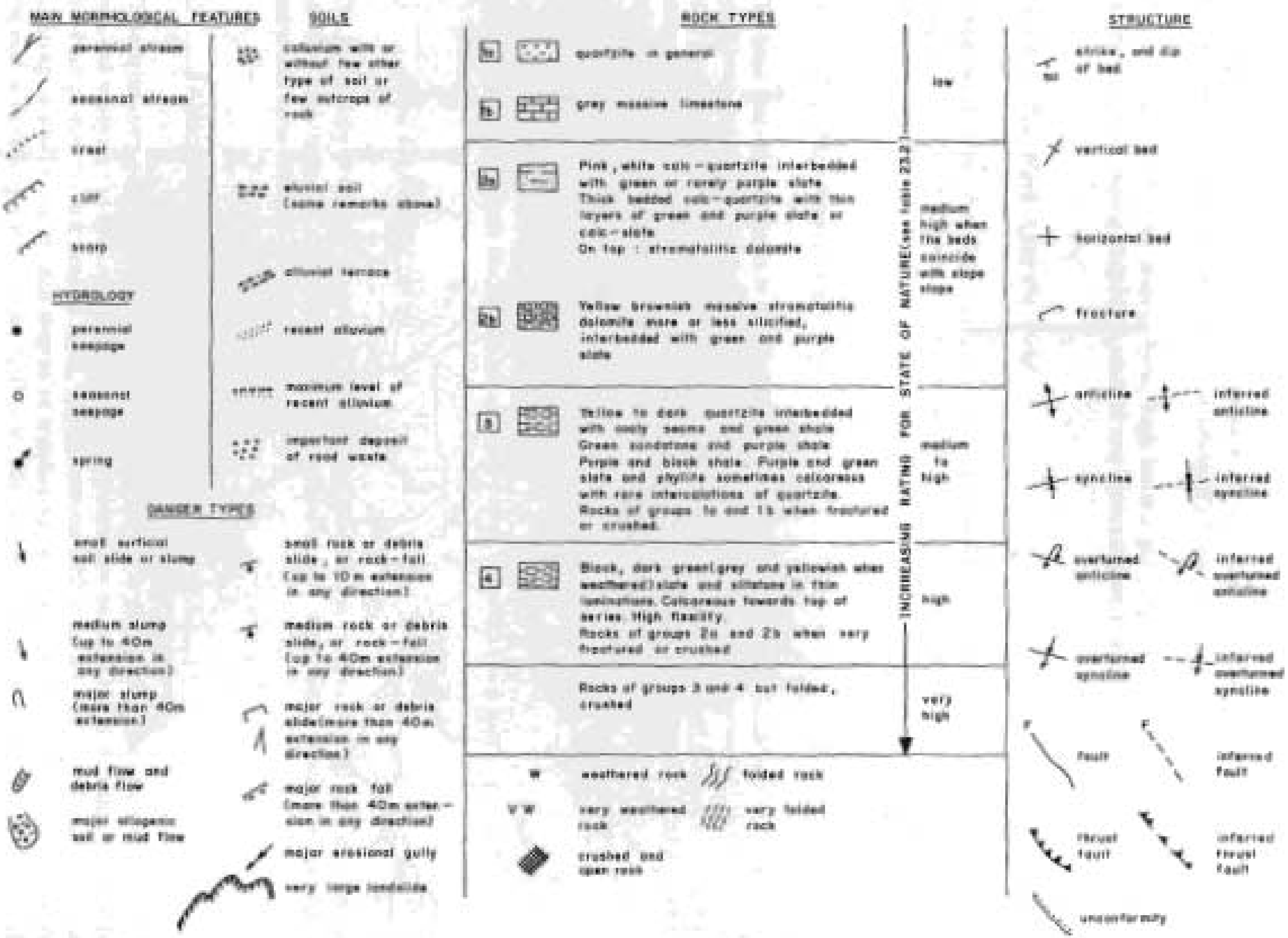


Fig. 23.3(b) Index to the engineering - geological map of Fig 23.3(a)

e) *Hydrological Map*

The hydrological map is prepared on the base map with the help of the field data, rainfall data, and the field map. It should include all gullies and their types and influence area, the nature of the gully (perennial, seasonal, springs, and seeps, with their discharge size), wet areas, lakes, rivers, streams, glaciers, and canals. The possible areas of cloudburst, areas prone to landslide-damming, glacial lake outburst flooding, groundwater conditions, and perched water tables should also be incorporated on the map.

f) *Land Use Map*

The land use map is prepared on the basis of the air photo study as well as additional information and features provided by the field survey

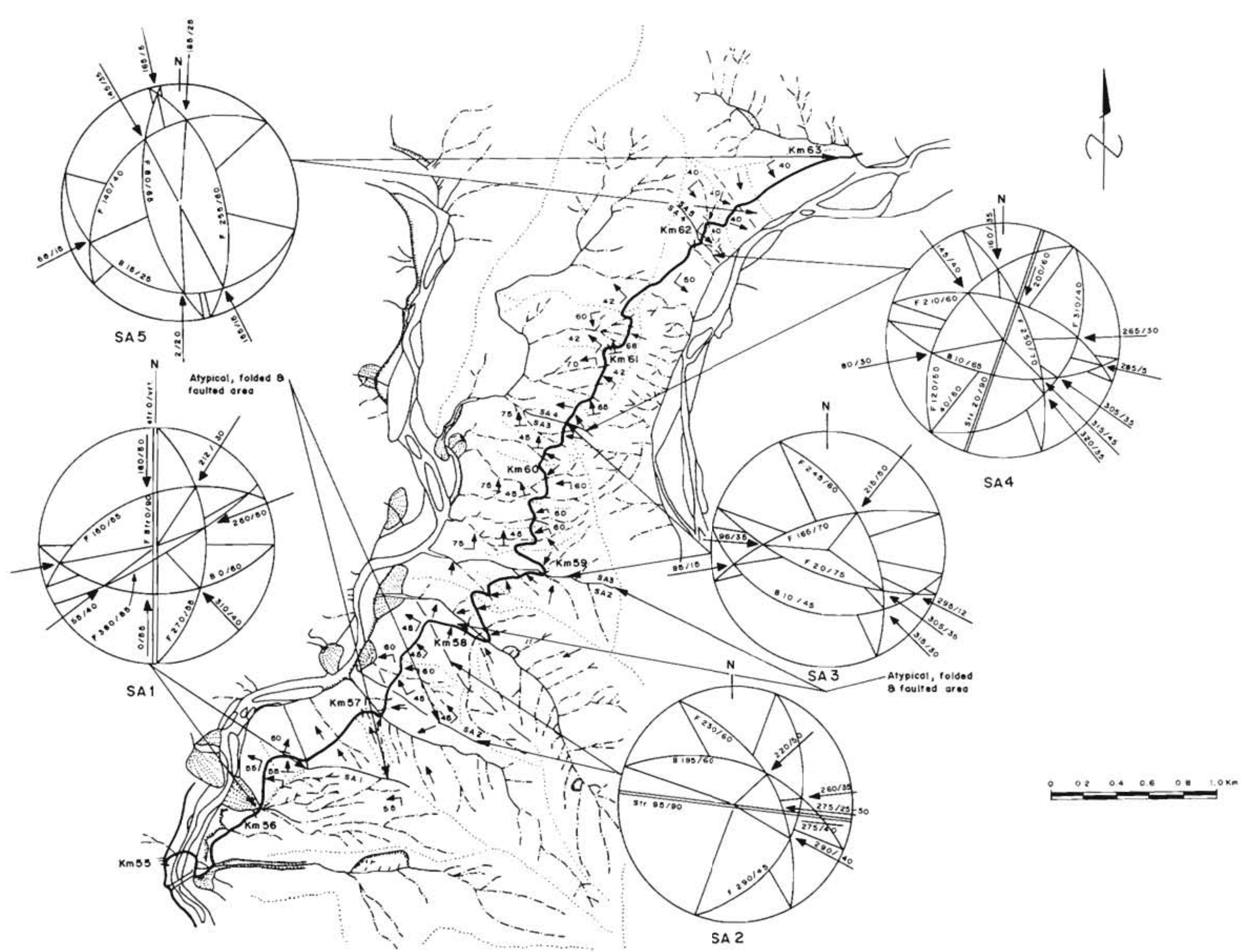
g) *Morphostructural Map*

The morphostructural map is prepared on the base map by plotting the information collected from the field and from the study of air photos. The dip direction of the natural slope should be shown for every slope unit (Fig 23.4a and 23.4b). The slope angle data collected from the field should be plotted on the morphostructural map. The map also includes the structural areas' Schmidt plots of the joints, bedding, and foliation drawn from the pole nets.

As already mentioned, it is possible to divide the rocky zones into structural areas in which the rock contains a similar structural pattern at any point. This is of major interest, because this important feature of rocky zones allows one to assign rockslide magnitude and structural hazard probability to nodes' sets or hazard facets.

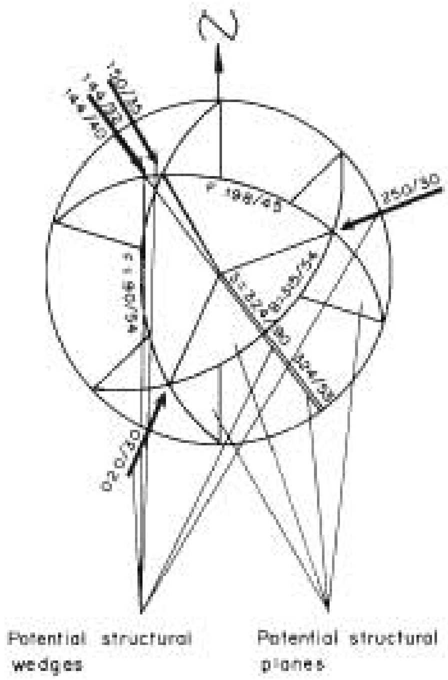
The structural areas are delimited in overlaying the results of a regular interval, field sampling of rock structural measurements on to a Schmidt Pole Net. The pole net allows the design of the representative Schmidt projections of the various structural areas (Fig. 23.5). In general, any significant change in the bedding or foliation orientation or dip angle indicates a change in structure and therefore a new structural area has to be set up.

Contouring techniques are described in Chapter 9. It is worth mentioning that the bedding or foliation planes should be contoured separately from the joints. After contouring the poles, the planes of maximum concentration should be drawn on the net together with the natural slope direction and angle (from the field observation). The Schmidt Net plots should be drawn on the morphostructural map at some distance from the route and the exact limits of the structural areas should be indicated (Fig. 23.4a and 23.4b). Figure 23.6 gives examples of various maps prepared during the feasibility stage.



Source: Louis Berger Int'l Inc. Rapti Roads (1985)

Fig 23.4a Morphostructural map of Fig 23.4(a)



SA3
(Structural Area)

Stream, ravine

Major crest

Minor crest or spur

Limit of slope unit other than stream or crest

Direction of slope

Structural Area: Area with the same main structural features

Limit of structural area

Inferred limit of structural area

Structural Slope Type

Slope controlled by BEDDING

Slope controlled by a FRACTURE SYSTEM

B Bedding plane (dip azimuth/dip angle)

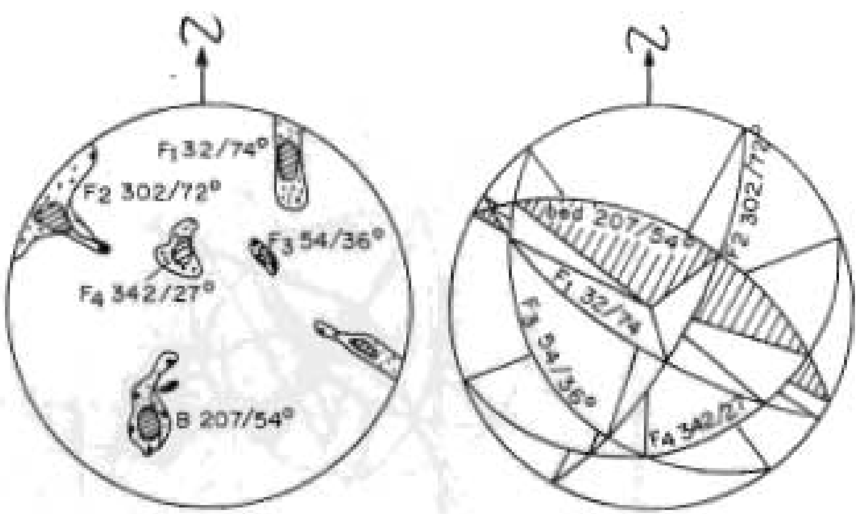
F Fracture plane

S Strike of vertical plane

→ Wedge formed by the intersection of two planes

All values in degree (1-360°)

Fig 23.4b Legend for the morphostructural map Fig 23.4(a)



Source: Wagner et al. 1988

Figure 23.5 Pole maxima of discontinuities and their upper hemispherical projection

The pole maxima (left figure) are represented by corresponding great circles on the right figure.

23.3.5 *Background on Hazard Mapping*

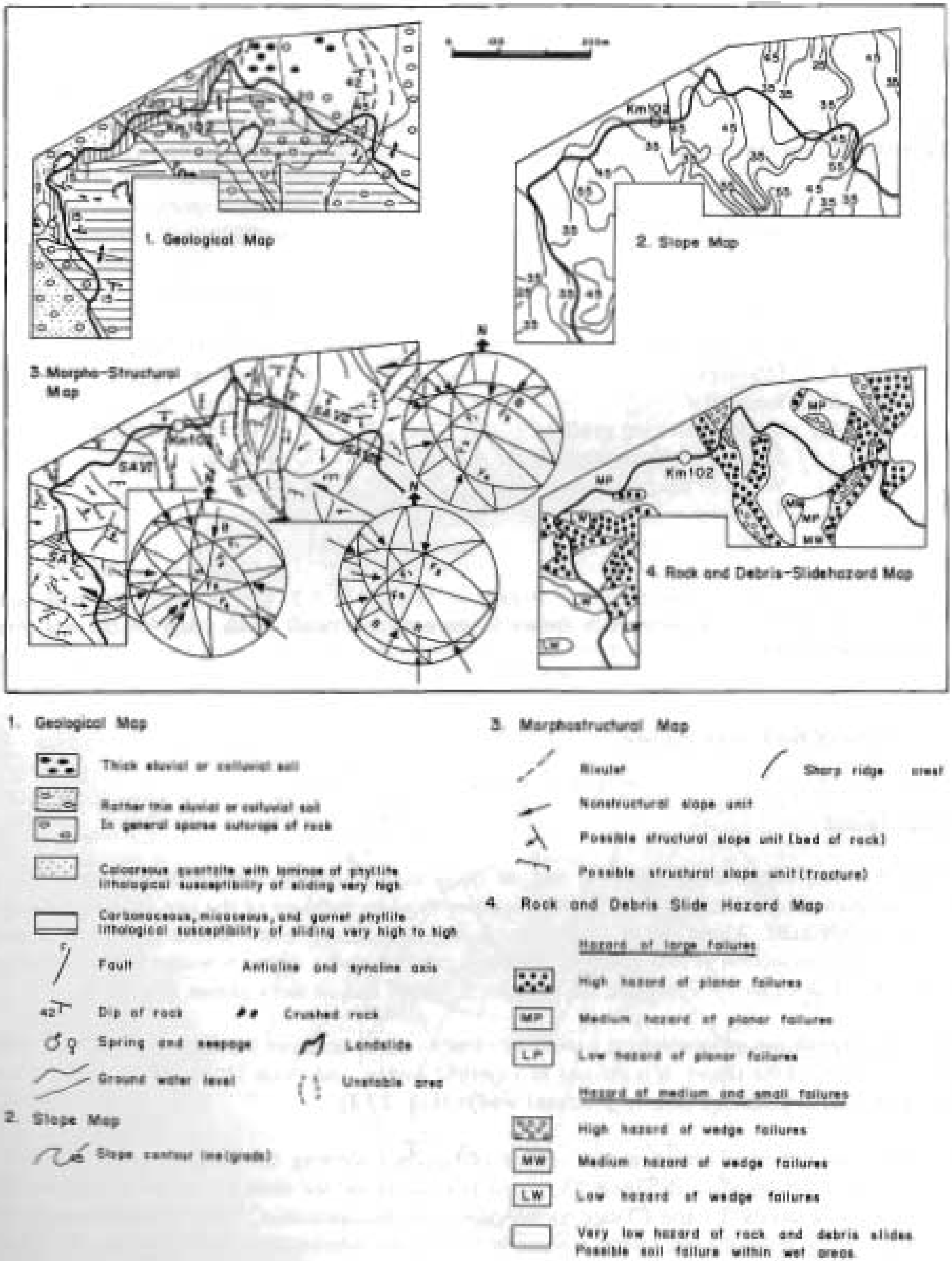
a) *Introduction*

The feasibility stage studies and maps provide us with accurate and detailed information on such attributes as soil and rock types, their spatial distribution, structure of rock, drainage and groundwater conditions, slope angles, and land use. Therefore, it becomes possible to reveal the interrelationship among various attributes and combine them in separate groups for rock and soil hazard maps and risk analysis.

Tables 23.2 and 23.4 provide the state of nature ratings for rock and soil slopes respectively. The ratings for dangers and triggers are the same as in the prefeasibility stage, as are the procedures for hazard and risk calculations. A hazard map is one of the final goals of the feasibility stage. This map will be prepared by using Tables 23.2 and 23.4 and with the help of the maps described in Section 23.3.4. Two hazard mapping methods will be further described.

The ranges of hazard rating and hazard level recommended are given below.

Range of hazard rating	Hazard level
Less than 0.30	Low
Between 0.31 and 0.60	Medium
Between 0.61 and 0.90	High
More than 0.90	Very high



Source: Wagner 1988
(work done in association with the Swiss Association for Technical Assistance [SATA] on the Lamosangu-Jiri Road Project).

Fig. 23.6 Examples of geological, morphostructural, slope, and rock slope hazard maps, km 101 to 103 of the Lamosangu-Jiri road

b) *Rock and Soil Slope Attributes*

Let us recall that rock and soil slopes attributes, which are described in detail in Tables 23.2. and 23.4, can be divided into the attributes given below.

ROCK	SOIL
1. Rock structure	1. Slope angle
2. Relative relief	2. Relative relief
3. Hydrogeology	3. Hydrogeology
4. Drainage	4. Drainage
5. Rock type	5. Soil type
6. Rock weathering grade	6. Assumed soil depth
7. Spacing of discontinuities	7. Tectonics
8. Width of discontinuities	8. Land use
9. Tectonics	
10. Land use	

All these attributes have been discussed already in Section 23.3.3. One of them, the rock structure attribute from which the type of rock failure is assessed and rated, needs more details and these are discussed below in (c).

c) *Types of Rock Slope Failure*

Wedge failure

Freedom of movement along a joint or bed, or along any two intersecting geologic planes, may occur when the plane or the intersection dips in a direction close to the slope of the site and when it is gentler than the slope itself. Along cut or eroded slopes, freedom of movement is also possible if a geologic plane, or an intersection of two geologic planes, is parallel to the slope. A wedge pattern results when there is freedom of movement along the interesection(s) of two or more planes (Fig 23.7).

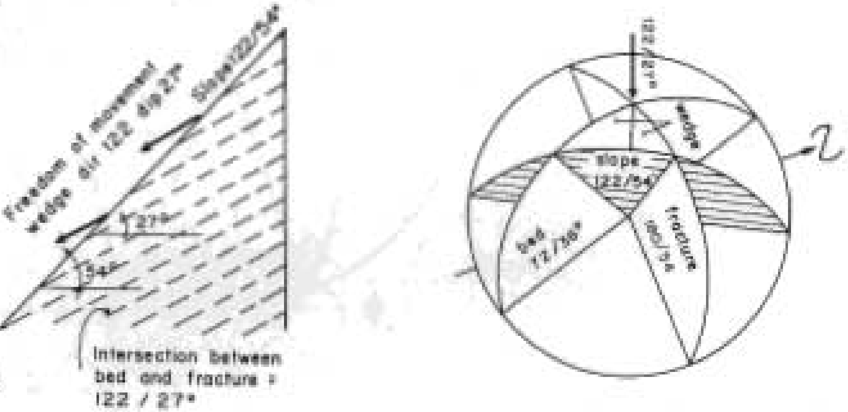
When a wedge shows an intersection parallel or close to the direction of the slope (up to 32° on each side of the direction of the slope), it is defined as a **central wedge**, and, from 32° to 65°, as a **lateral wedge**. Beyond 65°, it is described as a **very lateral wedge** (Fig. 23.8)

The structural pattern of a rock is thus very important in governing the behavior of a rock slope. For instance, the central wedge, in Figure 23.7, acts as a 'keystone' for other more lateral wedges. When it slides, two new slopes, F1 and F2, are formed along the discontinuities. These slopes are then exposed to wedge sliding along the two lateral wedges formed by the intersections of the bedding and F1 and F2 respectively.

As the number of wedges increases, the process just described repeats itself again and again and new slopes are formed along wedge planes (Fig. 23.9). The possibility of a large rockslide is thus inferred from an increasing number of wedges (see Fig. 23.10).

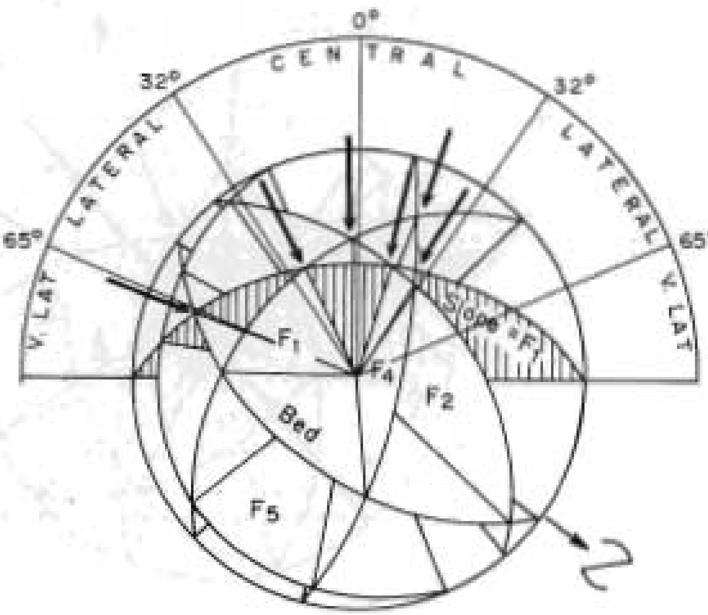
Plane Failure

A rock plane failure is possible whenever a class of joints, bedding, or foliation dips lie in a parallel direction to the slope with an angle equal or lower than the slope angle. When the slope is parallel to such discontinuities, it is called a dip slope. In both cases, there is a "freedom of movement" as per the wedge failure type shown above. In addition, it was demonstrated (Krahenbuhl and Wagner 1983) that the hazard of a plane failure increases with the number of wedges related to the plane of the failure (Figs. 23.8, 23.10, and 23.11).



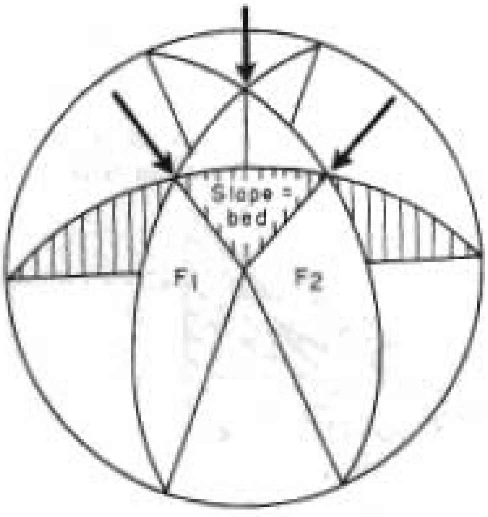
Source: Wagner et al. 1988

Figure 23.7 Central wedge and freedom of movement
The arrow represents the direction and dip of the structural wedge. The slope, indicated by S = 122°/54°, is not a dip slope.



Source: Wagner et al. 1988

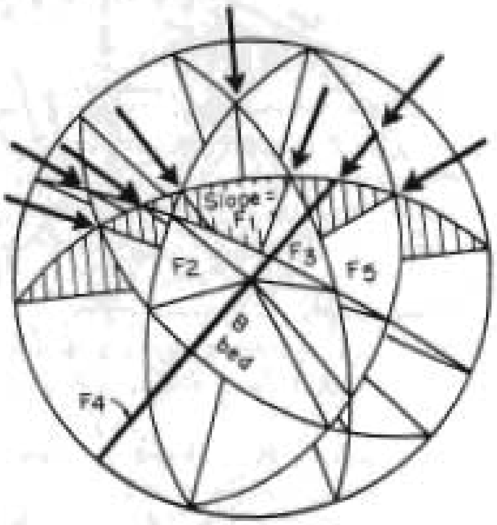
Figure 23.8 Central lateral and very lateral wedges
The slope, indicated by S= F1, is also controlled by fracture F1 and is a dip slope.



Source: Wagner et al. 1988

Figure 23.9 Central wedge acting as a keystone which, after sliding, frees the movement of lateral wedges

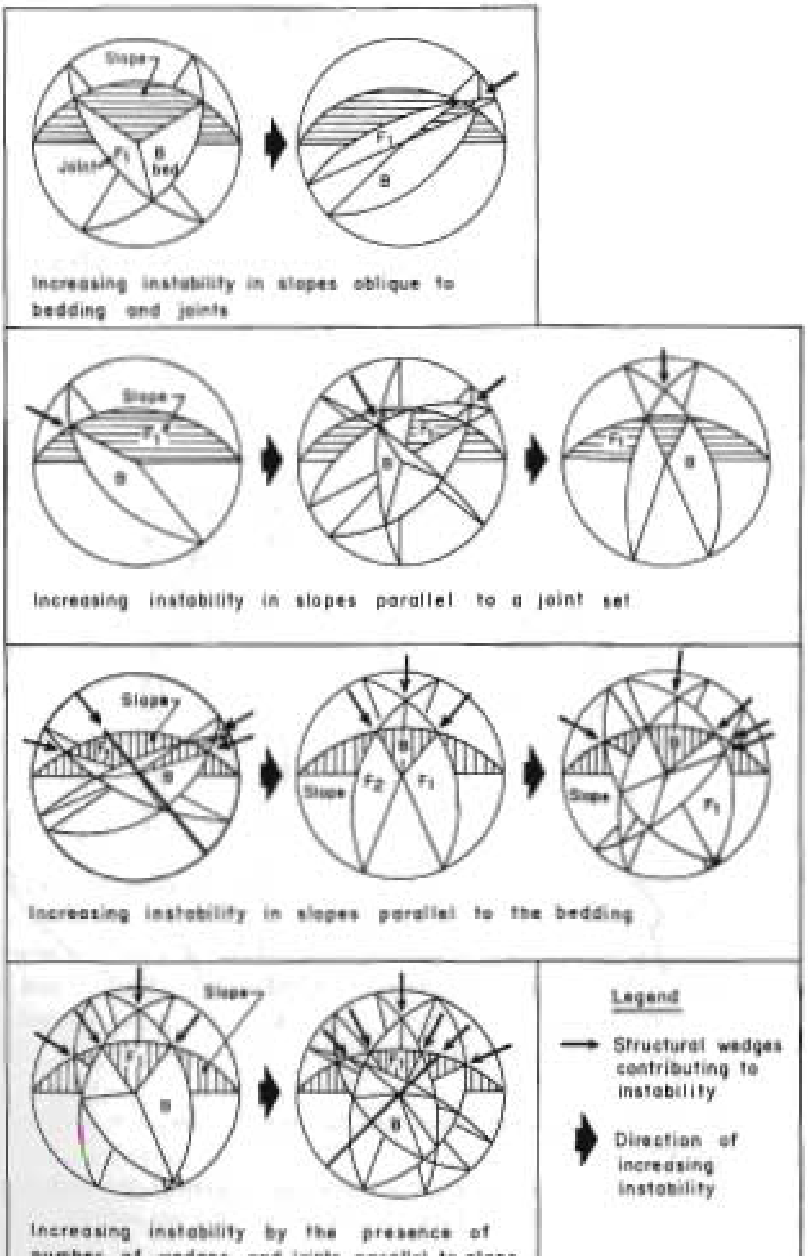
Arrows represent structural wedges. The slope is also controlled by the bedding of the rock.



Source: Wagner et al. 1988

Figure 23.10 Fan of wedges, the slope S = F1 is controlled by fracture F1

The numerous structural wedges, represented by arrows, indicate a potentially large rock slide.



Source: Krähenbuhl and Wagner 1983

Figure 23.11 Relationship between the slope and the orientation of discontinuities showing a gradual increase of the instability pattern

Topple Failure

A rock topple may occur whenever the following structural pattern outlined below is present (Fig. 23.12).

The rockslope is steep enough. Its dip should be at least 55°. It is considered that such a steep slope will include more or less wide, overhanging rock areas.

A steep joint, F1, with a dip of 60° - 90°, which strikes parallel (or roughly parallel) to the rockslope strike, is present and dips into the rockslope. A tolerance angle of 20° is admitted for the joint's F1 strike.

Another joint, F2, which strikes also parallel to the rockslope's strike, cuts F1. A tolerance angle of 20° is also admitted for the joint's F2 strike.

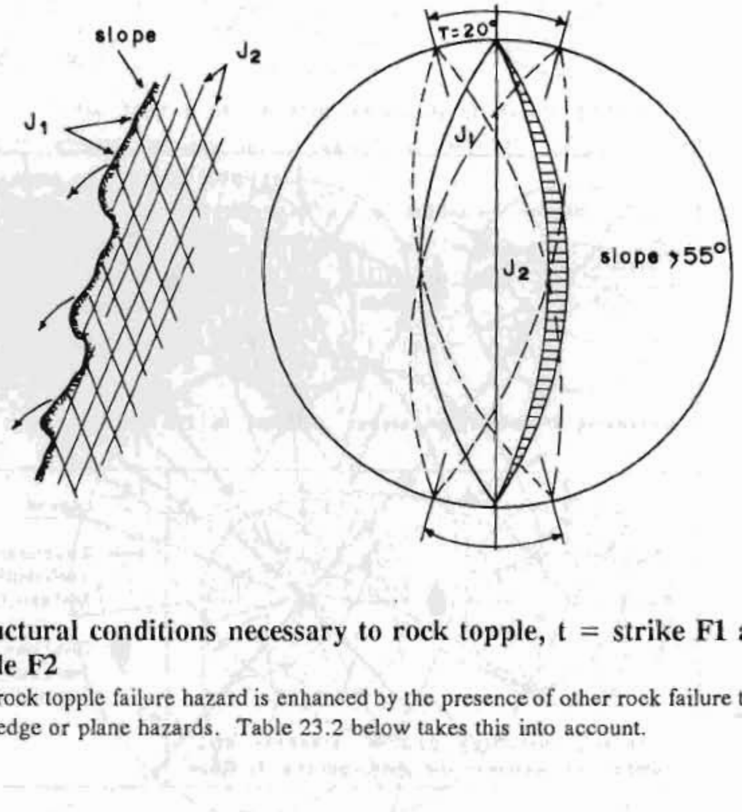


Fig. 23.12 Structural conditions necessary to rock topple, t = strike F1 and tolerance angle F2

The rock topple failure hazard is enhanced by the presence of other rock failure type hazards such as wedge or plane hazards. Table 23.2 below takes this into account.

d) *Rock Slope Hazard Attributes and Rating*

The structure of the rock and its relationship to a given rock slope (with its proper angle and orientation) are the decisive criteria that permit classification of the rock failure, and type of hazard which may occur in this rockslope. Table 23.2 below gives a list of different ratings for given relationships between the rock structure and the slope. The structural rating, together with the type of failure which may occur, is found in superimposing the structural area projection valid for the site on the slope of this site.

The cumulation of the other ratings with the structural one (listed on Table 23.2) will provide the total rating for the type of rock failure hazard found with the above described super-imposition. According to what has been discussed above, and after having finalised the cumulation with Table 23.2, the rockslope hazard ratings will finally be presented as given below.

Type of Failure	Probability	Hazard Level
1. Small to moderate size rockslide (wedge failure)	low	less than 0.30
	moderate	between 0.31 and 0.60
	high	between 0.61 and 0.90
	very high	more than 0.90
2. Moderate to big size rockslide (plane failure)	low	less than 0.3
	moderate	between 0.31 and 0.60
	high	between 0.61 and 0.90
	very high	more than 0.90
3. Rock topples	low	less than 0.3
	moderate	between 0.31 and 0.60
	high	between 0.61 and 0.90
	very high	more than 0.90

e) *Soil Slope Hazard Attributes and Ratings*

The soil slope hazard rating procedures do not differ much from those of the prefeasibility stage. The data collected in the feasibility stage provide more accurate assessments of slope angle, drainage, hydrology, soil type, soil assumed depth, and land use. This is incorporated on the feasibility stage hazard rating table (Table 23.4). At the same time, it is also necessary to distinguish three major types of unstability hazard, i.e.:

- flows (debris flows and mudflows),
- slides (debris or colluvial slides, mudslides), and
- gully erosion.

The probability of occurrence of one of these specific types of unstability has to be assessed in the field. It is, however, often difficult to decide which type of unstability may occur. The type of material and hydrogeological/drainage conditions may be a guide to selection of a specific type of unstability (see Table 23.3). As shown by this figure, however, several types of unstability may occur at the same time. In a gully, for example, gully erosion may occur simultaneously with debris or mudflow and slides caused by lateral bank undercutting.

Table 23.2 Feasibility Stage, Hazard Ratings for Rock Slopes

No	Attribute	CHARACTERISTIC				Rating		
		Expected mode of failure						
		Central wedge (number)	Lat.-very lateral wedges (number)	Plane failure	Topple slope $>60°$	Wedge	Plane	Topple
1	Relation between rock structure and slope	0	0	0	0 or 1	0	0	0.03
		0	1	0	0 or 1	0.07	0	0.09
		0	more than 1	0	0 or 1	0.09	0	0.01
		1	0	0	0 or 1	0.10	0	0.12
		1	1	0	0 or 1	0.20	0	0.22
		1	more than 1	0	0 or 1	0.22	0	0.24
		more than 1	0	0	0 or 1	0.24	0	0.25
		more than 1	1 or more than 1	0	0 or 1	0.27	0	0.29
		Possible Circular Failure (for very random orientation in soft or very weathered rock)				0.25		
2	Relative relief	h : 0 - 10m h : 11 - 50m h : 51 - 100m h : 101 - 150m h : more than 150m				0.00 0.03 0.06 0.07 0.09		
		No seeps No springs				0.00		
		No springs Rare seeps				0.08		
		No springs Seeps				0.10		
3	Hydrogeology	Rare springs Seeps				0.12		
		Springs and seeps				0.14		

Table 23.2 Feasibility stage, hazard rating for rock slopes

No	Attribute	Description	Subdivision	Rating
4	Drainage	Seasonal, perennial gully, less than 1m deep*	Up to 50m on both sides	0.01
		Seasonal, perennial gully, 1 to 5m deep*	Up to 50m on both sides	0.02
		Seasonal, perennial gully, more than 5m deep*	Up to 50m on both sides	0.04
		Tributary (small river or stream)	Up to 75m on both sides	0.06
		River	Up to 100m ton both sides	0.08
5	Rock type	Quartzite, dolomite, limestone, and other massive rocks		0.00
		Calcschist		0.02
		Phyllite, schist		0.03
		Shale, mudstone, marl		0.4
		Alternating/interbedded hard and soft rock		0.05
		Weak rock in general		0.06
6	Discontinuity spacing (average per type of rock)	Wide (more than 1m)	Calculate average rating for one type of rock in a given area Modify the rating according 1) to waviness (average/type of rock) 2) to infilling material found locally waviness decreases the rating clay infilling increases rating	0.00
		Moderate		0.03
		Close		0.06
		Very close		0.08
7	Discontinuity width (average per type of rock)	<0.1mm		0.01
		0.1 - 1mm		0.02
		1 - 5mm		0.03
		5 - 20mm		0.05
		more than 20 mm		0.06
8	Rock Weathering (average per type of rock)	Fresh rock		0.00
		Slightly weathered		0.02
		Moderately weathered		0.03
		Highly weathered		0.04
		Completely weathered		0.05

* for perennial gullies increase rating accordingly.

Table 23.2 **Feasibility stage, hazard rating for rock slopes (cont.)**

No	Attribute		Description	Rating
9	Tectonics	Major fault	Up to 50m on both sides	0.10
			onwards for 50m to 100m on both sides	0.08
			further onwards for 100m up to 100m up to 200m on both sides	0.03
		Major anticline	Up to 25m on both sides	0.08
			onwards for 25m up to 50m on both sides	0.06
			Further onwards for 50m up to 100m on both sides	0.01
		Major syncline	Up to 50m on both sides	0.06
			onward for 50m up to 100 on both sides	0.04
			Further onwards for 100m up to 200m	0.02
10	Thickly vegetated forest.			0.00
	Moderately vegetated forest.			0.01
	Sparsely vegetated meadows.			0.02
	Barren and dry, cultivated land.			0.04
	Wet cultivated land			0.05

After having selected what type of soil unstability hazard can be attributed to a given soil slope, with the help of Table 23.4 and other field criteria, a cumulation of all the attributes is implemented in using Table 23.4. The soil slope hazard ratings will finally be presented as given below:

Type of Failure	Probability	Hazard Level
Slide	low	less than 0.30
	moderate	between 0.31 and 0.60
	high	between 0.61 and 0.90
	very high	more than 0.90
Flow	low	less than 0.30
	moderate	between 0.31 and 0.60
	high	between 0.61 and 0.90
	very high	more than 0.90
Gully erosion	low	less than 0.30
	moderate	between 0.31 and 0.60
	high	between 0.61 and 0.90
	very high	more than 0.90

Table 23.3 Frequency of soil unstability versus type of material

	Frequency (when other unfavourable conditions are present)				
Type of instability	Debris/colluvial slides	Mudslides	Debris-flows	Mudflows	Gully erosion
Material	basic conditions: springs and/or seeps. Bank undercutting	basic conditions: springs or/and seep. Bank undercutting	basic conditions: presence of gully	basic condition: presence of gully	basic conditions: gully even small
Abundant clayey-silt or silty clay Matrix > = 50% (CL-ML, CL) with gravel, cobbles (boulders)	rather rare	Very frequent	Rare	Very frequent	rather rare rotational slides when bank undercutting
Clayey-silt or silty clay matrix < 50% (CL,ML,CL)	Rather frequent	Rather rare	Rather rare	Frequent	Rather frequent rotational slides or slides when bank undercutting
Abundant silty matrix, < 50% (ML) with gravel, cobbles (boulders)	Rather frequent	Frequent	Rather rare	Frequent	Very frequent
Silty matrix, < 50% (ML) with gravel cobble, boulders	Very frequent	Rare	Frequent	Rather rare	Very frequent
Abundant sandy matrix (SP,SM, SM-ML) > = 50% With gravel, cobbles, (boulders)	Frequent	Rare	Frequent	Rare	Very frequent
Sandy matrix (SP, SM,SM-ML) < 50% with gravel, cobbles, (boulders)	Rather rare	Very rare	Very frequent	None	Frequent
Abundant gravel (GM, GM,-ML), poor matrix, with cobbles and boulders	Rare	None	Rather frequent	None	Rather rare
Dominant coarse material (cobbles, boulders)	Rare	None	Rare	None	Rare
Dominant very coarse material, (boulders)	Very rare	None	None	None	Very rare

Table 23.4 Feasibility stage hazard ratings for soil slope

S/N	Attribute	Description	Subdivision	Ratings		
				For expected slide	For expected flow	For expected gully erosion
1	Slope angle	Very gentle	0 - 10°	0.00	0.12	0.06
		Gentle	11 - 20°	0.04	0.14	0.08
		Slightly steep	21 - 25°	0.08	0.10	0.10
		Moderately steep	25 - 30°	0.12	0.00	0.12
		Steep	31 - 35°	0.14	0.00	0.14
		Very steep	36 - 40°	0.14	0.00	0.12
			40 - 45°	0.12	0.00	0.10
			more than 45°	0.10	0.00	0.08
2	Relative relief	Very low	0 - 10m	0.00	0.00	0.00
		Low	11 - 50m	0.03	0.03	0.03
		Medium	51 - 100m	0.06	0.06	0.06
		High	100 - 150m	0.09	0.06	0.09
		Very high	more than 150m	0.12	0.12	0.12
3	Water content	Dry		0.00	0.04	0.05
		Moist		0.05	0.05	0.08
		Wet		0.07	0.08	0.10
		Flowing springs		0.10	0.10	0.10
4	Drainage	Gully less than 1m deep	Up to 50m on both sides	0.00	0.04	0.04
		Gully from 1 to 5m on both sides*	Up to 50m on both sides	0.04	0.06	0.06
		Gully more than 5m deep*	Up to 50m on both sides	0.06	0.08	0.06
		Stream	Up to 50m on both sides	0.08	0.08	0.00
		River	Up to 100m on both sides	0.08	0.08	0.00
5	Soil type	Cemented alluvium		0.00	0.00	0.02
		Alluvial terrace or fan	GW, GP, GM, etc.	0.04	0.02	0.10
		Recent point bar	GW, GP, GM, GC, etc.	0.12	0.12	0.12
		Colluvium	GP, GM, etc.	0.12	0.12	0.10
		Moraine	GP, GM, GC, etc.	0.12	0.12	0.12
		Talus deposit	GP, etc.	0.12	0.12	0.10

* for perennial gullies increase rating accordingly

Table 23.4 Feasibility stage hazard ratings for soil slope (cont.)

S/N	Attribute	Description	Subdivision	Rating		
				For expected slide	For expected flows	For expected gully erosion
5	Soil type	Debris flow deposit	GM, GC, etc.	0.10	0.10	0.10
		Sandy soil	SW, SP, SM	0.10	0.12	0.12
		Clayey silty soil	SC, ML, CL, OL, MH, CH, OH, PT	0.10	0.12	0.10
		Eluvium	SMOSC	0.06	0.08	0.10
6	Soil, thickness	Very shallow	Less than 1m	0.00	0.04	0.02
		Shallow	1 - 3m	0.04	0.12	0.04
		Medium	4 - 6m	0.08	0.08	0.08
		Deep	7 - 10m	0.10	0.04	0.12
		Very deep*	more than 10m	0.12	0.02	0.12
7	Land use	Thickly vegetated		0.00	0.00	0.00
		Moderately vegetated		0.03	0.03	0.03
		Sparsely vegetated or meadows		0.06	0.06	0.06
		Barren land or dry cultivated		0.09	0.09	0.09
		Bad land or wet cultivated land		0.12	0.12	0.12
8	Major fault	Up to 50m on both sides		0.14	0.14	0.14
		Onwards for 50m		0.07	0.07	0.07
		Further onwards for 100m		0.03	0.0	0.03
9	Major anticline	Up to 50m on both sides		0.08	0.08	0.08•
		Onwards for 50m		0.04	0.04	0.04
		Further onwards for 100m		0.02	0.02	0.02
10	Major syncline	Up to 50m on both sides		0.04	0.04	0.04
		Onwards for 50m		0.02	0.02	0.02
		Further onwards for 100m		0.01	0.01	0.01

* except for thick and coarse material deposits.

e) *Remarks on Ratings*

Let us underline that the proposed ratings of Tables 23.2 and 23.3 are empirical, subjective, and deductive. As a general rule, these ratings have to be modified according to further field observations or other experiences on this topic.

The attribute "bank undercutting" is not included in Table 23.3. It has been considered that this attribute belongs to the trigger category because such bank undercutting is supposed to intervene when cloud outburst, stream/river dam burst, and floods take place.

f) *Methods of Hazard Mapping*

Two types of hazard mapping method are proposed here. Both have been experimented with and used in the Himalayan framework. The first method, Method No 1, is based on regular node digitization. A cumulation of the ratings is done on each node. The nodes are then sub-divided according to the type of failure and the range of hazard rating. The PC software, SHIVA, (Wagner et al. 1990) is derived from this method.

Method No 2, the so-called Line Hazard Mapping, is based on the subdivision of the survey line into facets to which a hazard rating is attributed. Both methods use the same procedures for surveying, e.g., a detailed description of the attributes at each major variation along the line and within the corridor.

23.3.6 *Digitized Rock Slope Hazard Mapping*

Method No. 1

The data collected during the survey are all included on the different maps prepared during the post-survey office work, e.g., slope map, engineering-geology map, hydrogeological map, and morphostructural map. Each attribute will be digitized with the help of a 4x4 cm grid after having traced 4x4 cm units, with their coordinates, on the maps (Fig. 23.13). The grid has to be photocopied on to transparent film. Each attribute's rating will be then written on a digitization sheet (Fig. 23.14) (see Annex 2).

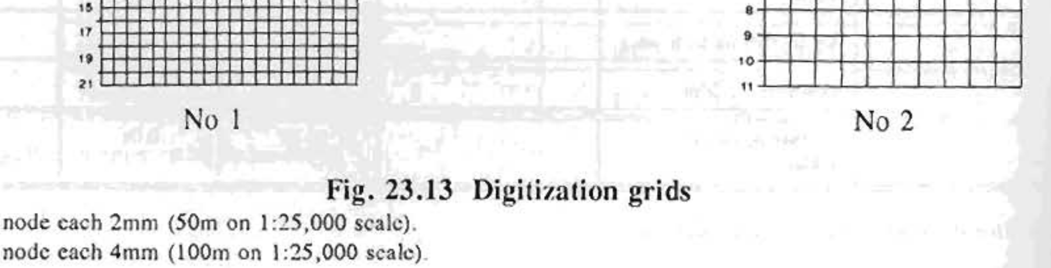


Fig. 23.13 Digitization grids

No 1, one node each 2mm (50m on 1:25,000 scale).
No 2, one node each 4mm (100m on 1:25,000 scale).

The selection of Grid 1 or Grid 2 will depend on the accuracy desired and on the scale of the map. Type No 1 needs a far longer period of digitization (400 nodes instead of 100 nodes).

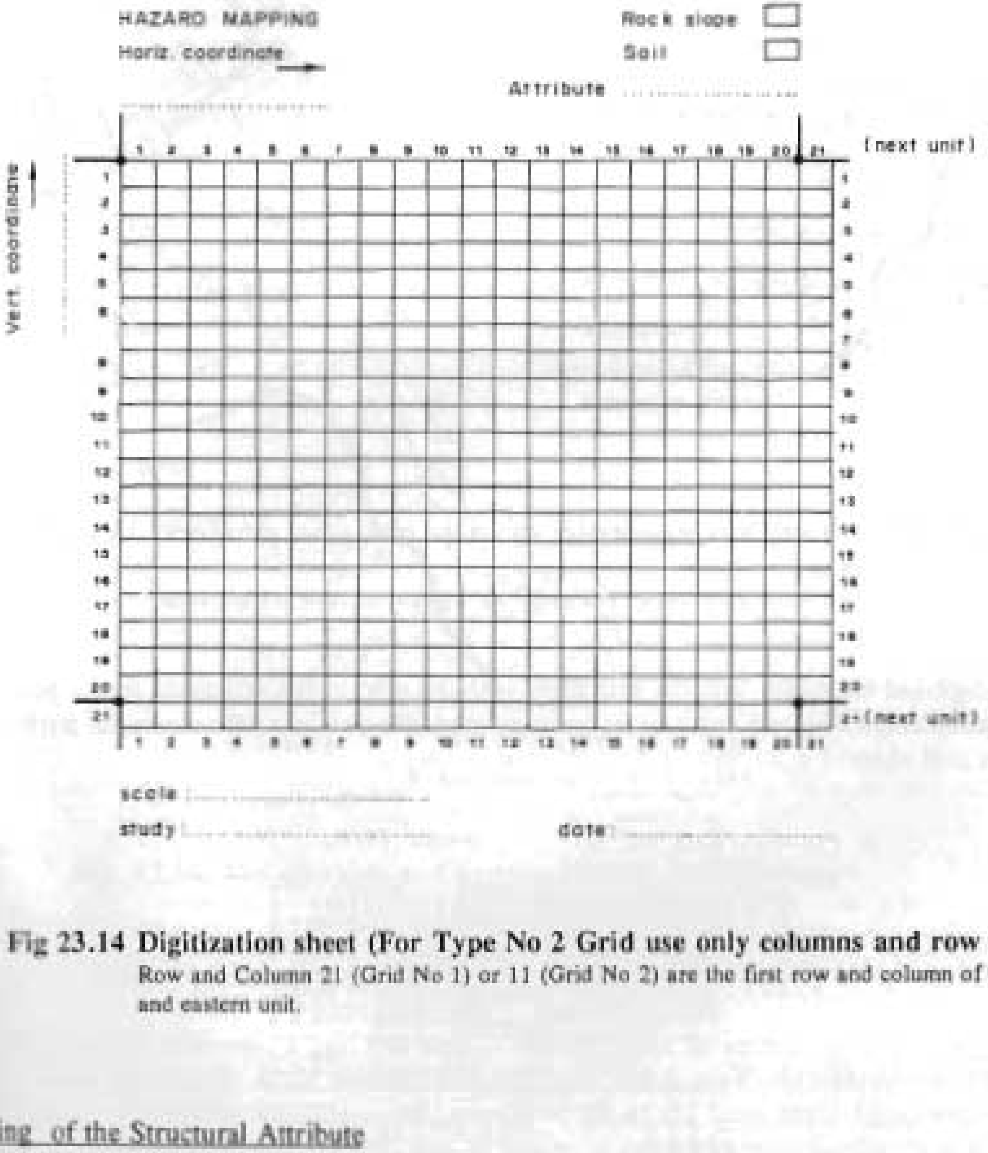
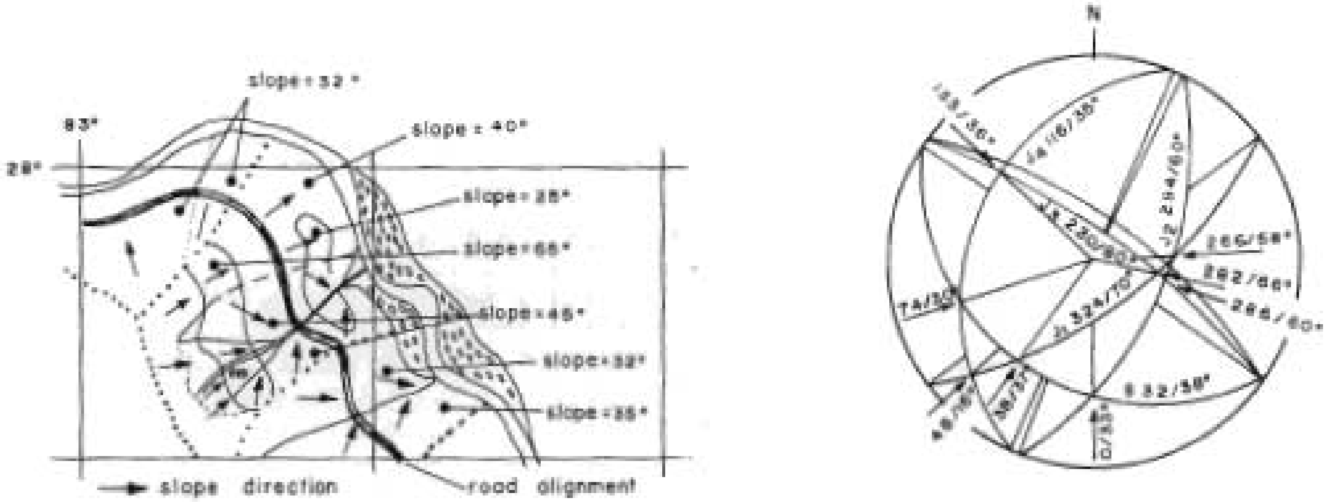


Fig 23.14 Digitization sheet (For Type No 2 Grid use only columns and row up to 11)
Row and Column 21 (Grid No 1) or 11 (Grid No 2) are the first row and column of the next southern and eastern unit.

a) Rating of the Structural Attribute

The rating of the structural attribute is implemented with the help of the slope map, the morphostructural map, and the engineering-geology map. Each unit of slope (i.e., a unit with a defined slope angle and direction) is compared with the representative structural projection(s) of the structural area(s) to which the unit of slope belongs. With the help of the grid, each node of the grid sheet is rated (see Figs. 23.15, 23.16), as long as the nodes are rockslope nodes, with the help of Table 23.2.

Remarks - when plotting the structural projection with the slope map "tolerance angles" have to be admitted between the structural features (wedges and planes) and the slope angle and direction. The size of the tolerance angle will depend on the pole scattering shown on the pole net.



Unit 1 Unit 2

Figure 23.15 Plotting a representative structure of a given structural area with the slope map

The whole area belongs to a single structural area. The whole area is rocky.

After having digitized the nodes with the grid film, with the help of the structural area 1 projection on the super-imposed slope map and engineering geology map, the ratings of the structural attribute are as follows on the grid sheet (Fig 23.16).

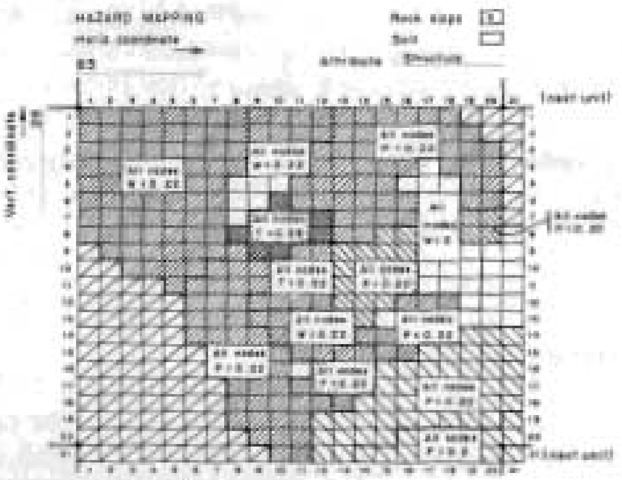


Fig. 23.16 Digitization sheet with structural attributes

W for wedge rock, wedge failure (small to moderate sized failures).
P for rock plane failure (moderate to large sized failures).
T for topple rock failure.

b) *Rating of the Other Attributes*

The procedure for rating the other attributes is similar to that of the structural attribute. The various attributes that are not included on the maps (for example, the relative relief attributes) are delimited, according to instructions in Table 23.2, on tracing paper sheets subdivided into 4+4cm units with their reference coordinates. The other attributes, which are already delimited on the various maps, (subdivided into 4x4cm units) are rated directly on these maps with the grid film. The ratings are reported on the digitization sheet (see examples in Figs. 23.17 and 23.18) which shows the digitization of the drainage and hydrogeological attributes).

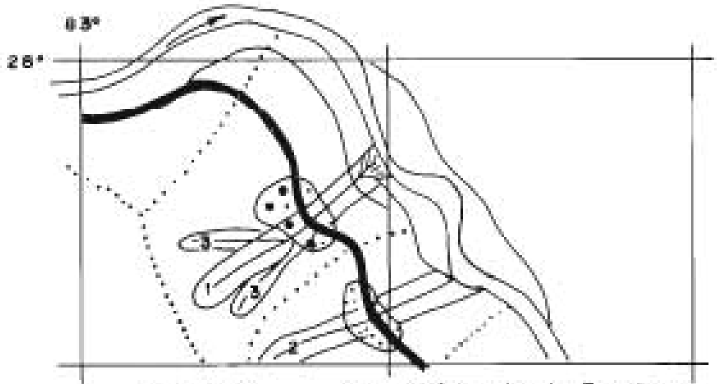


Fig. 23.17 The drainage and hydrogeological attribute zones

c) *Execution of the Rockslope Hazard Map*

After having digitized the different ratings, one has to cumulate them on each node of the studied zone. This is done by using grid sheets. After implementing this cumulation work, the total ratings have to be subdivided into hazard probability classes as Low, Moderate, High, and Very High. Subdivision is done according to the hazard levels of the different types of failure as is proposed in Section 23.3.5d.

These types of failure hazard, with classes of probability, are reported on a transparent base map (divided into 4+4cm units) with the help of the grid film applied below the base map. In order to simplify the work, the classes of probability with their type of feature have been previously coloured in their own specific colour on the cumulation grid sheets.

A rockslope hazard map is the result of this final work. A PC programme, including a spread-sheet facility like Lotus, will shorten cumulation and hazard map execution a great deal. Figure 23.6 shows a rockslope hazard map.

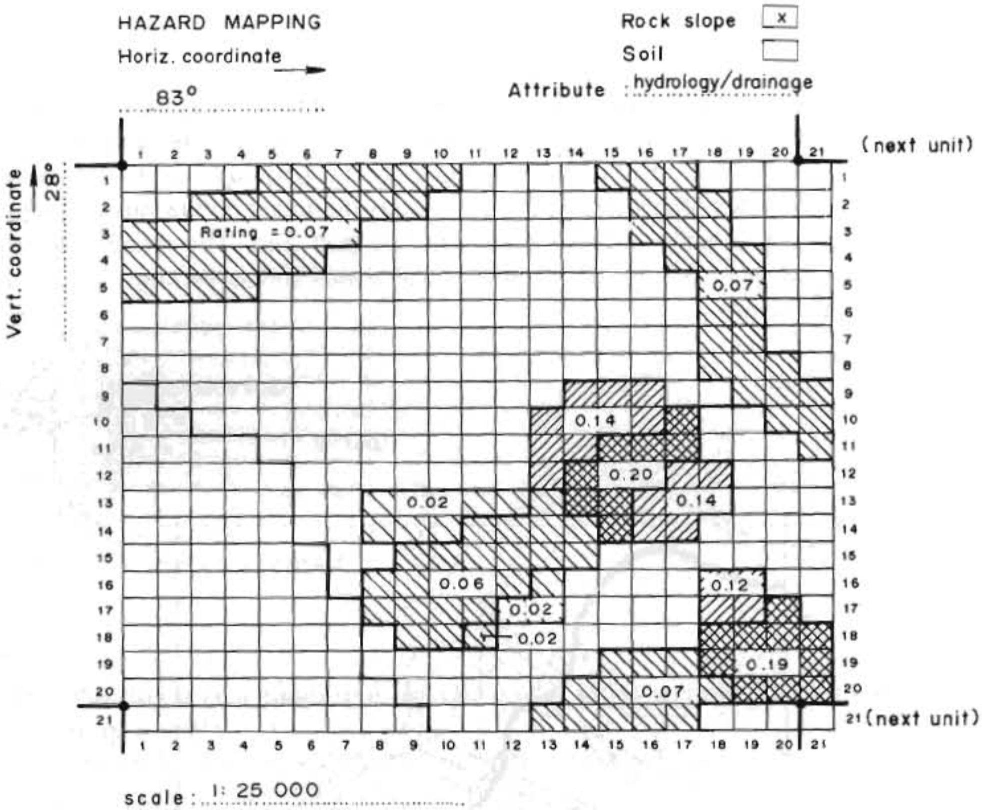


Figure 23.18 **Rating of the drainage and hydrogeological attribute zones on a digitization sheet (Unit 1)**

23.3.7 *Digitized Soil Slope Hazard Mapping (Method No 1)*

The digitized soil hazard map procedures are similar to those of rockslope hazard map ones. They consist of digitization on each node of the different attribute ratings, with the help of the feasibility stage hazard rating (Fig. 23.4) and the different maps related to soils (slope map), engineering geology, hydrological-drainage, and land use). The digitization grids and grid sheets are used for inputting the ratings. In the second stage, the different digitized ratings are cumulated on final grid sheets. The cumulation grid sheet ratings are then subdivided into low, moderate, high hazard, and very high hazard classes as proposed in Section 23.3.5(e).

The results of the cumulation grid sheets are finally reported with the help of the digitization grid on a base map. Figure 23.19a, and b show a rock slope and soil slope hazard map executed with digitized map proceedures.

The advantage of the digitized hazard map type is that it permits systematic coverage of the whole road corridor. The time needed to prepare a map is, however, substantial, particularly if PC spread-sheet programmes are not available.

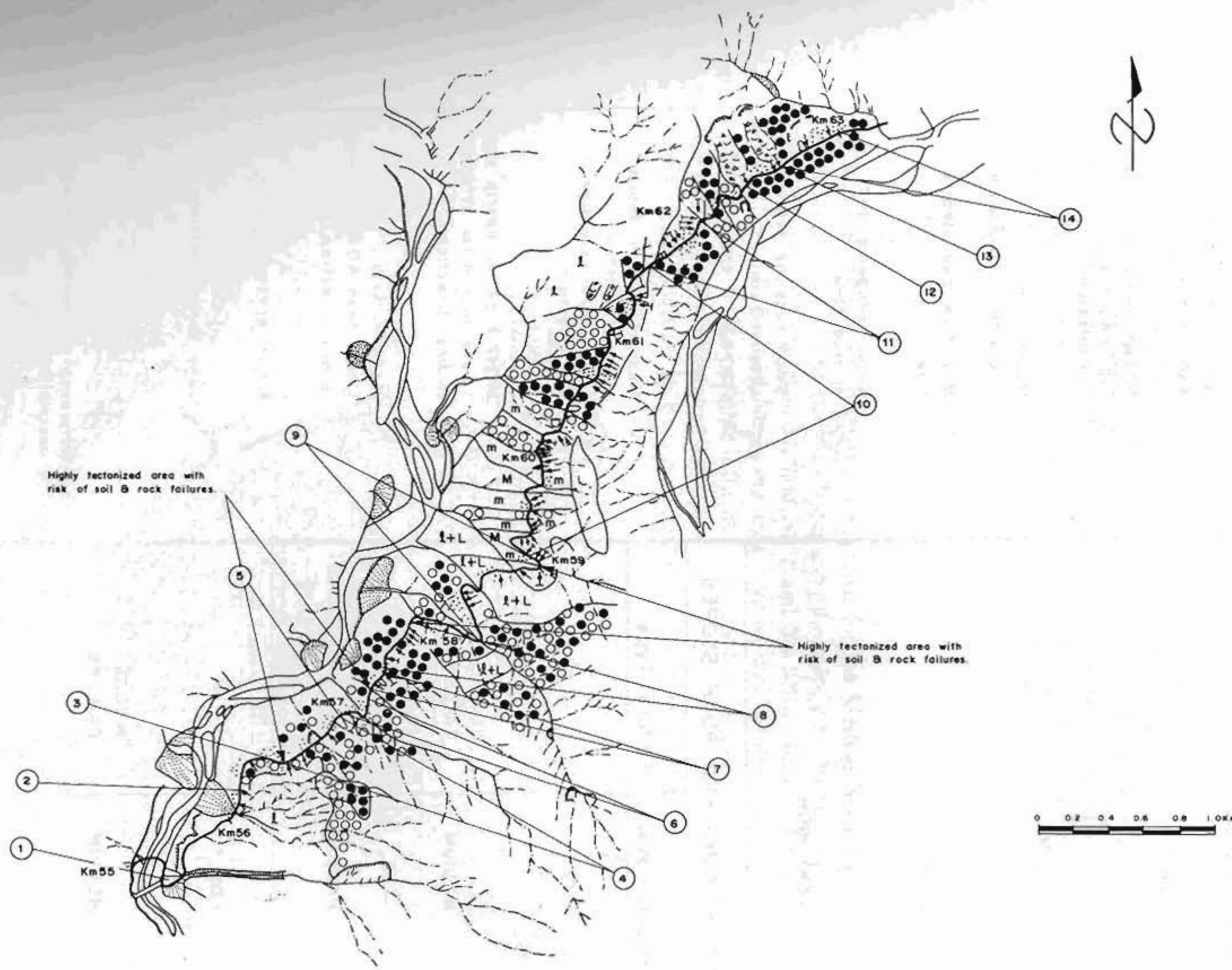


Figure 23.19(a) Rock and soil slope hazard map

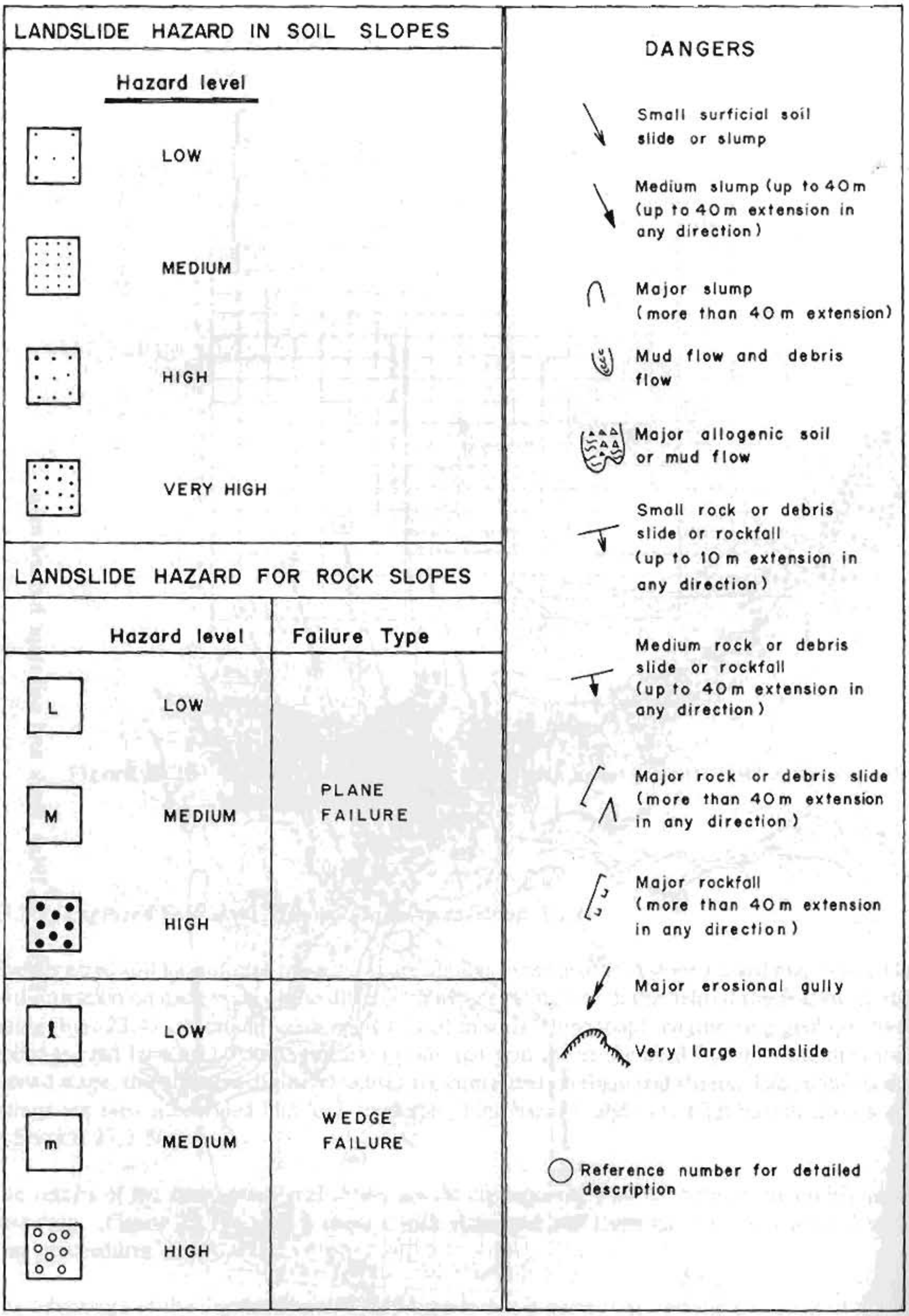


Figure 23.19(b) Index of rock and soil slope hazard map 23.19(a)

23.3.8 *Line Hazard Maps*

Method No 2 is based on the filling of rating tables along the road line at each major change of one or more attributes during the survey. These major changes correspond to the successive observation points which are marked down on the field map. This permits the delimitation of hazard facets above and below the road, with their specific rating, all along the road line. Other transit lines, with their observation points, and corresponding rating tables, have to be undertaken with especially questionable zones. In this case, one should always start the transit lines from reference observation points on the road line. Figure 23.20 shows the procedure used for surveying the road line. Figure 23.21 is an example of a rockslope hazard map prepared by computer.

The Survey

The survey does not differ from the survey conducted for the Method No 1 digitized hazard map (Fig. 23.22). The difference lies in the method of preparing the map, e.g., by super-impossing different maps with the help of rated grid sheets in Method No 1 and the delimitation of hazard facets directly in the field in Method No 2. In Method No 2, the area covered will be often narrower compared to the area covered by Method No 1. The possible influences of hazardous areas beyond the strip covered along the road corridor will thus not be included and taken into account. With Method No 2 also, the rating of the facets is sometimes difficult for there is no cumulation system as in Method No 1.

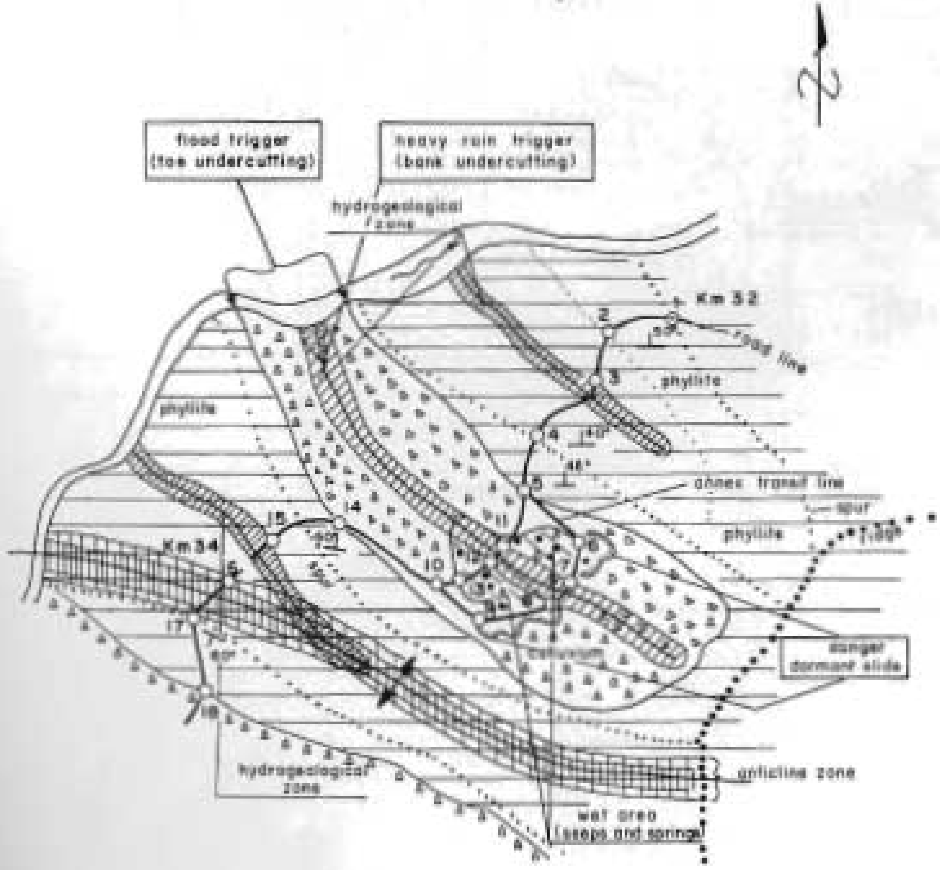


Figure 23.20 Method of surveying for hazard maps

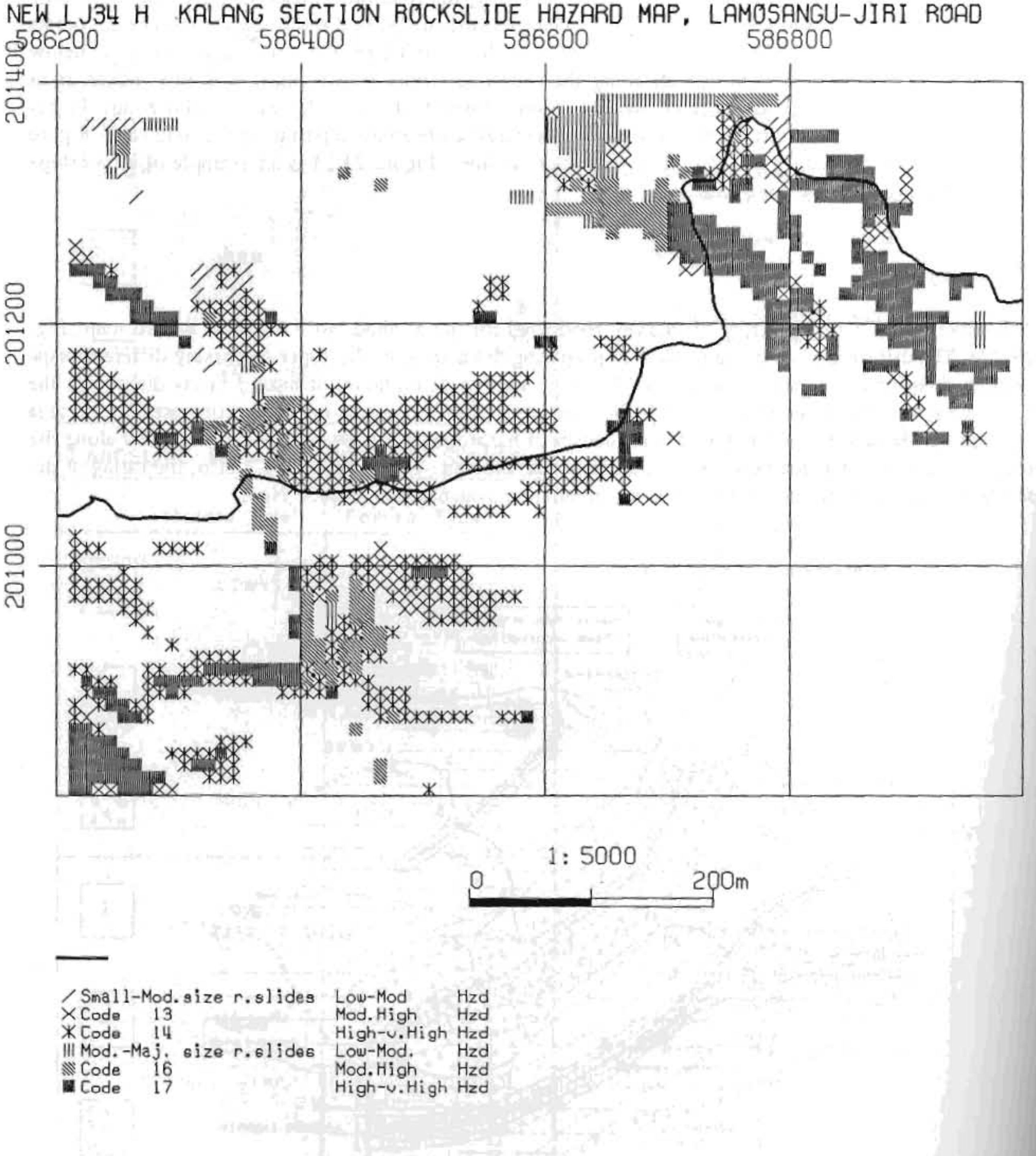


Figure 23.21 Rockslope hazard map obtained with the SHIVA programme

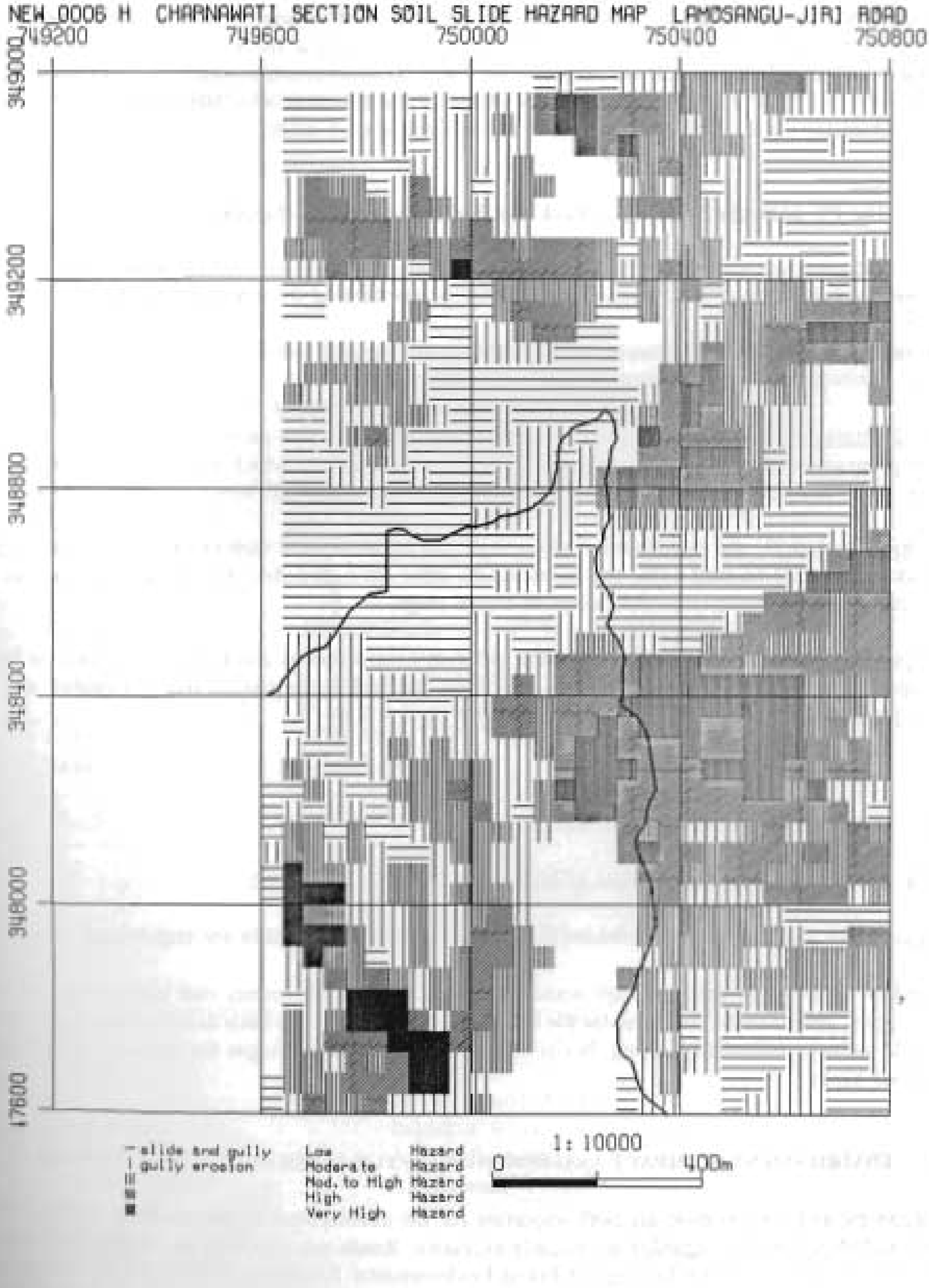


Figure 23.22 Soil hazard map with SHIVA programme

At each of the points along the road and annexed lines, there is a major change or even several major changes in the attribute rating: slope angle and/or direction, material (rock or soil), hydrogeological or drainage conditions (springs, gully or stream with their influential zones), structural conditions (structural area at each side of the anticline), or influence zone of the anticline core. Between 6 and 9 there is a danger (dormant slide). The chainage has to be indicated at each point.

23.3.9 *The PC Software SHIVA for Rock and Soil Slope Hazard Mapping*

A PC Landslides and Unstability Hazard Mapping software, called SHIVA, and executing node maps, has been available since 1990 (Wagner et al. 1990). It was derived from Method No 1.

This programme includes three main menus, and they are outlined below.

1. A digitizing menu for inputting the elevations and attribute codes on node units. A new version of the programme will very soon include a digitization table system which will permit the inputting of elevations and codes with more speed and accuracy.

2. A hazard menu for the calculation of slope angle and orientation on each node, for the calculation of rockslope hazard on each node, and for rating the other attribute codes. The hazard menu allows one to execute the cumulation of the ratings in a final stage.

3. A plot menu for attributing symbols to the different hazard classes and for printing the final hazard maps. Figures 23.21 and 23.22 show rockslope and soil slope hazard maps prepared with the programme SHIVA.

23.4 MAJOR AND HIGH VOLUME ROADS

23.5.4 *Feasibility Stage Assessments of Major and High Volume Roads*

The guidelines for feasibility assessments for medium roads are applicable for major roads as well.

Feasibility stage assessments of high standard roads should use rigorous risk assessments of risks, technologies, and hazards, and consider the use of advanced technology such as tunnelling, rock bolting, landslide gallery, controlled blasting, horizontal drains, and several bridges for the same river to avoid hazardous banks.

23.5 ENVIRONMENTAL IMPACT ASSESSMENT (EIA) FOR MEDIUM AND MAJOR ROADS

Development and conservation are both important for the development of mountainous regions. These cannot and should not be regarded as mutually exclusive. Roads can also help in conservation and eco-development based upon the findings of Initial Environmental Evaluation (IEE), if the environmental impact assessment is carried out. The following guidelines are presented for Environmental Impact Assessment (EIA).

23.5.1 *Environmental Impact Assessment (EIA)*

Traditional highway planning, design, construction, and maintenance mainly account for economy and traffic flow only. In many cases, the following problems have been overlooked:

- landslide aggravation,
- noise pollution,
- air pollution,
- aesthetic deterioration,
- ecological disturbances, and
- loss of investment, human use values, and quality of life.

Construction of hill roads, keeping in mind conservation principles, requires a clear understanding of environmental resource parameters, factors influencing them, and the causes and effects spatially and temporally. Environmental impact assessment is an essential tool in this respect.

23.5.2 *Resource Parameters and Influence Factors*

The environmental resource parameters are listed below.

PHYSICAL	ECOLOGICAL	QUALITY OF LIFE
Noise	Fisheries	Population
Air	Plant and Vegetation	Health
Water	Wildlife	Safety
Land	Micro-organisms	Education
		Income
		Employment
		Culture
		Mobility

Factors influencing the environmental resource parameters are listed below.

NATURAL ACTIVITIES	HUMAN ACTIVITIES
Rainfall	Agriculture
Erosion	Infrastructural Works
Earthquakes	Industrial Work
Landslide-dams	Animal Husbandry
Outburst floods	Recreational Works
Weathering	
Landslides	
Glacial Lakes	

These parameters and factors are interdependent and can be further sub-divided into several categories. Assessments and quantifications of the impacts on the resource require detailed breakdowns and specific techniques to quantify and predict. The uncertainties in prediction require probabilistic methods. Natural activities and human activities are there before and after any development project. Environmental impact assessment must depict all possible situations and clearly identify the impacts ascribed to the project under study. In many instances, emphasis and focus on the adverse impacts caused by the project lend to heavily biased analysis and ascribe the causes and effects from natural and other human activities to the project in question. The acceptance of such studies by decision-makers, and the effective and wider dissemination of the results of such studies can cause difficulties and may even be misleading at times. However, the task of separating natural and human causes, socioeconomic activities without a road and with a road, and the effect of one resource parameter on another resource parameter is not simple or objective at present. As far as hill roads in developing countries are concerned, the most important aspects are erosion, landslides, deforestation, investment loss due to the frequent washout of roads, and socioeconomic distortions from the absence of matching programmes in other sectors.

23.5.3 *Environmental Problems to and from Roads*

a. *Impact of Road on Environment*

The assessment of the environmental impacts of any proposed project is not possible unless the impacts from activities resulting from other than the project in question, for the timespan under consideration, is ascertained. In other words, natural and human resource parameters are under the continual influence of natural activities as well as human activities other than the project in question. The impacts that could be fully ascribed to the project in question would be the net impact (resulting from the difference in impacts between the impacts from the project and the impacts from non-project activities).

The impact of the road on the environment may be a result of impacts from construction activities, impacts from maintenance activities, impacts from the movement of equipment and vehicles, and socioeconomic and demographic impacts resulting from or accelerated by roads.

These factors may further be sub-divided as given below.

CONSTRUCTIONS	MAINTENANCE/POST CONSTRUCTION
Excavations	Landslide clearance
Side casting	Heating bitumen
Blasting	Heavy equipment/vibrations
Quarrying	Concentrated drainage discharge and erosion
Tree felling	Labour camping
Use of firewood and fossil fuel	Road blocks
Land and house acquisition	Vehicle emission
Construction camping	Vehicle noise
	Traffic accidents

OTHER ROAD-INDUCED HUMAN ACTIVITIES

Ribbon development
Commercial logging
Health facilities
Supply of inputs
Tourism
Food supply
Market extensions
Agricultural extensions
Industries
Infrastructure
Hazard wastes

The nature and extent of physical and ecological impacts depend upon the alignment selection, design standards, and construction and maintenance technology to be adopted. However, the socioeconomic impacts are largely the function of the area development plans and programmes in other sectors.

Lower investments, initially, on investigations, analyses, designs, and mitigatory measures, would result in greater adverse impacts insofar as the disturbances from road activities are not adequately matched by the protection required for the slopes. The road and the protection measures are sometimes helpful in minimizing the extent of natural hazards existing before the road. Such benefits are not accounted for in the traditional economic analysis.

b. *Impact of Environment on Road*

The impacts to the project are essentially the impacts from non-project activities measured in terms of loss of investment, which may be treated as a capital resource parameter among other resource parameters.

In the case of hill roads in the fragile mountain ecosystem of the Hindu Kush-Himalayas (HKH), the impacts to the road become important because natural phenomena, such as landslide-damming and outbursts, deep-seated landslides, glacial lake outbursts, river undercutting, earthquakes, and high erosion caused by climatic and geological activity, are predominant over other human activities. These activities wash out considerable chunks of the road system once every few years. Risks can be different for the same degree of natural hazard depending upon the level of intervention into the hazard and the degree of hazard mitigation adopted by the project. However, major natural hazards often defy analysis and realistic control measures, especially so in the developing countries where resources, funds, and modern technology are scarce.

23.5.3 *Guidelines*

- Environmental impact assessment (EIA) for all major roads, both new constructions and improvements of existing ones, should be carried out with the purpose of:

- identifying possible positive and negative impacts to the physical and ecological resources and human use and quality of life values resulting from the proposed project for various alternatives;

- selecting the alternative that will possibly cause least degradation to the environment;

- preparing a plan for the selected alternative, which, upon implementation, will result in a minimum level of degradation of the environment; and

- providing a monitoring programme to measure the level of plan implementation and the degree of effectiveness of the environmental provisions.

o At the initial stages of project planning, Initial Environmental Examination (IEE) should be carried out to determine whether EIA level studies should be performed.

o Information from other studies, such as engineering-geological studies and economic studies, should be properly used in IEE and EIA.

o Simplified and subjective assessment is suggested, at present, for those items for which objective methodology and reliable data are not easily available.

o The methodology for a fundamental EIA approach must include:

  - description of the project;
  - definition of the study area and area of influence;
  - identification of significant environmental parameters and natural and human activities which are likely to have an impact on these parameters;
  - collection of information on the current level of environmental parameters, e.g., physical and ecological resources and human use values;
  - collection of baseline data on natural and socioeconomic activities in the area of influence at the time of project planning;
  - assessment of beneficial and adverse impacts with or without the project, based on the information collected, comparisons of alternatives, and plan of mitigatory measures for recommended alignment;
  - monitoring plan for different project cycles;
  - preparation of environmental base map;
  - review and comments from relevant experts and the project proponents; and
  - final recommendations.

o An unbiased assessment of environmental impact should indicate both "without the project" and "with the project" cases.

o Table 23.5 is a matrix for summarizing EIA findings.

Table 23.5 Environmental impact assessment summary chart

Environmental Resource Parameters	Environmental Resources under The Influence of Various Factors Influencing Environmental Resources: Before road: Natural	Before road: Human Activity	During and After Road: Natural	During and After Road: Human Activity (excluding road)	During and After Road: Road Activities: Construction Activity	During and After Road: Road Activities: Post Construction Activity	Net Environmental Impact During Service Life of Road: Impact of Natural Activity	Net Environmental Impact: Impact of Socio-economic Activity	Net Environmental Impact: Impact of Road: Construction Activity	Net Environmental Impact: Impact of Road: Post Construction Activity	Remarks
PHYSICAL											
Noise level, decibel											
Air pollution, high, low											
Water quality, good, bad											
Ground water table, metre											
Forest cover, sq. m.											
Erosion Area, sq. m. Soil loss, cu. m.											
Landslides Area, sq. m. Volume, cu. m. Soil loss, cu. m.											
ECOLOGICAL											
Fisheries Types, nos Extent available											
Plant & Vegetation Types, nos Extent available											
Wild animal Types, nos Extent available											
QUALITY OF LIFE											
Population											
Education No. of schools Literacy, %											
Health No. of health posts Infant mortality, % Average life span, yrs Foreign diseases, types											
Income, Rs											
Employment Farm, % gain Off-farm, % gain											
Accidents Traffic Landslides Floods											
Investment Loss, Rs Road Others											
Land use Agriculture, Ha Pastures, Ha Horticulture, Ha											
Cultural Value No. of Historical Monuments No. of Ethnic Groups											