VIII. ROCK DURABILITY AND SLOPE STABILITY EVALUATIONS

8.1 Introduction

Basic geotechnical techniques and geological concepts are essential to the proper design and maintenance of diversions and channels on a mining site. In this section of the design manual, guidelines for evaluating engineering and geological characteristics of rocks which are important in assessing rock durability as related to riprap and bedrock channels are given. Following the detailed assessment and guidelines, problems of geotechnical stability and site-specific conditions associated with diversions are addressed.

8.2 Rock Durability Evaluation

8.2.1 Purpose and Scope

The purpose of this section is to define and demonstrate the utility of a systematic method of quantifying durability of earth materials to predict their physical behavior if used as riprap diversion channels or for other mining-related activities. It is designed predominantly for sedimentary rock types which overlie coal seams in the eastern coal region. The procedure was developed with the primary goal of producing a reliable and adaptable method for evaluating rock durability which can be conducted economically and time-efficiently, mainly in the field. It is essentially a three-fold procedure based primarily on field observations, field tests, and selected laboratory tests. Options to perform the laboratory tests are included and their use depends on environmental demands, economic considerations at a particular site, and availability of suitable riprap at each site.

In considering rock durability relative to the service life of riprap, it is important to recognize that "nothing lasts forever". Therefore, the designer must take a very conservative approach, although most riprap linings still may require periodic maintenance, this manual has chosen a conservative approach. The recommended procedure is based on conservative values designed for a probable lengthy in-service performance of riprap. This translates into a higher factor of safety than is sometimes recommended for minimum performance. Albeit, it is considered expedient to be conservative considering the long term exposure and life of a diversion channel.

With this in mind, the durability evaluation method is described and discussed below. The step-by-step procedure, beginning with general field considerations and progressing to specific laboratory tests, is also presented in a simple flow chart in Figure 8.1. Reference to this chart may be helpful in understanding the sequence of the procedure as detailed points are described in the text.

Following this, an evaluation format for on-site evaluation is provided. Then, several rock types from Kentucky are actually evaluated using the prescribed format to illustrate and clarify proper use of the method.

8.2.2 General Considerations of Test Procedure

The durability or weatherability of rock is a critical factor whether stream diversion is being constructed with a channel in unlined bedrock or a channel with riprap as a lining. Rock properties to be considered will include composition of the rock fragment or rock outcrop and the presence of bedding, joints, etc. at the rock mass (rock outcrop) level. The term "discontinuity" will be used as a non-genetic term for bedding, joints, etc. except where benefit is derived from a more specific terminology. Aside from visual evaluations that may be made at the site, testing will be primarily that used for determining the abrasion resistance and degradation properties of aggregates. Climatic conditions at the site have a bearing on the choice of tests. Estimates of annual or seasonal rainfall and number of freeze-thaw cycles will normally be sufficient indicators of climatic conditions. In the area of interest, the eastern coal region, the climate is a temperate, humid continental-type where temperatures rarely exceed 100°F or drop below 0°F (Huddle, et al. 1963). Forty to 50 inches of precipitation are received annually, most of which is rainfall and the frost-free period is approximately 175 days between April 25th and October 15th.

In addition to these considerations, estimates must be made of the volumes of water to be carried by the diversions and the nature and amount of sediment transported.

8.2.3 Site Investigations

8.2.3.1 General

Much can be learned of the durability of rock from an investigation of the site. A first step in evaluating a site is to obtain a listing of the rock types occurring in the area. This listing may be obtained from geologic maps, geologic reports for the area and drill hole data from exploration drilling. Brief descriptions of the rocks normally accompany such listings.

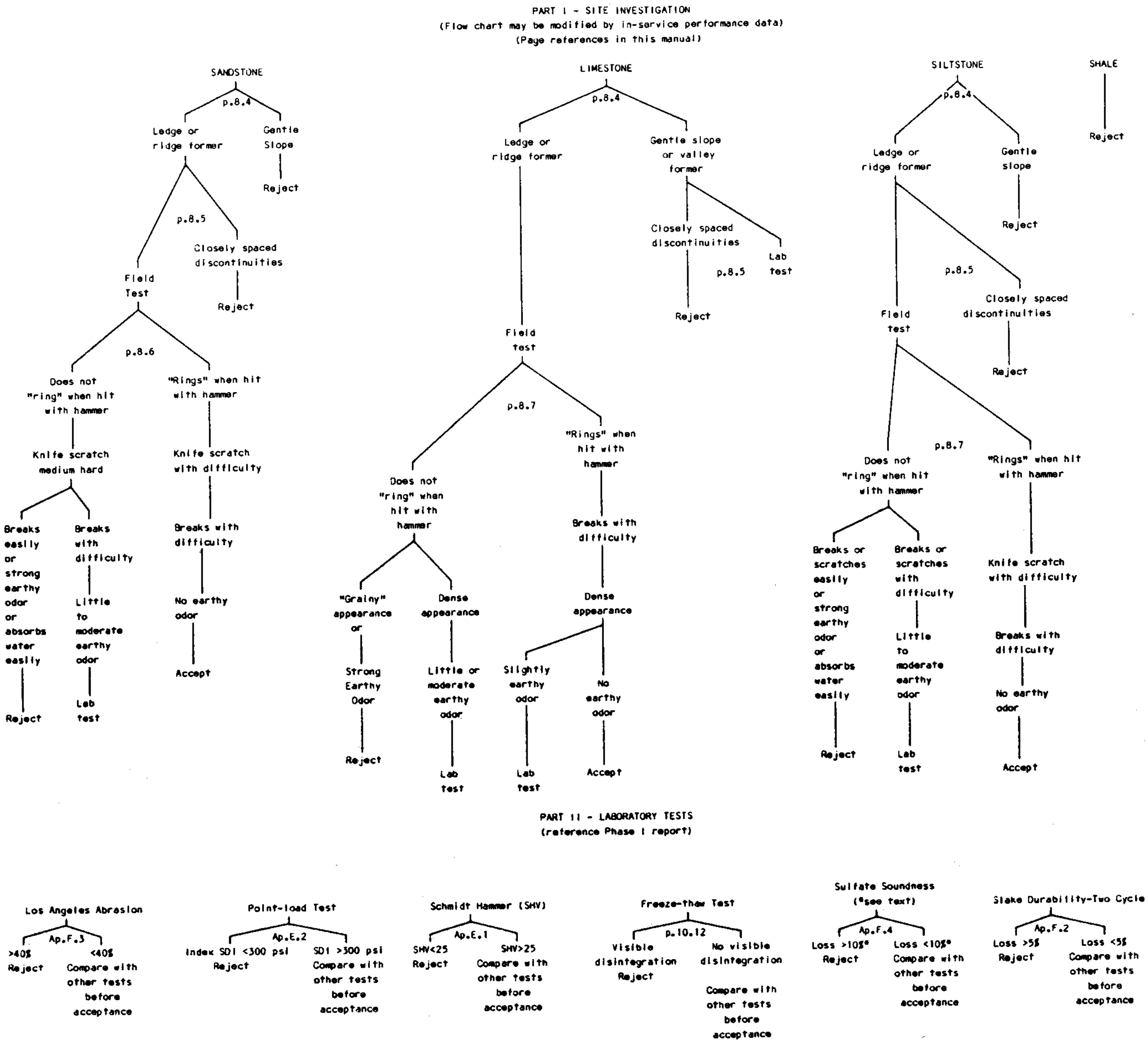


Figure 8.1. Rock durability flow chart: Procedure for evaluating rock suitable as riprap and channel lining. Part I - Site investigation; Part II - Laboratory investigation.

If such data are not available, the rock types and any sequential occurrence of them must be determined at the site from exposures. The site investigation provides the opportunity to observe the rocks in their natural setting, i.e., climate and landforms. If air photos are available for the site area, their use should be an integral part of the investigation. The site features to be considered are: landform characteristics, rock type or types, rock mass conditions, performance record and simple field tests.

8.2.3.2 Landform Characteristics

Most rocks resistant to the mechanical and chemical weathering conditions at a site will in turn be durable for the conditions prevailing in diversion channels. The correlation of ridges and benches or rock-cored terraces with known rock units in the site area is a major first step in finding durable rock. This is done by the combined use of topographic maps, air photos and observation of known rock types occurring in the area. Thus, the evaluation of the topographic control exerted by the rocks at a site is of prime importance. A geologic map is a useful tool for further designating naturally durable rock units from those unsuitable for use in constructing diversion channels.

8.2.3.3 Rock Type

In coal-producing areas the rock types in which diversion channels will be excavated or the rocks which will be used for riprap will be of sedimentary origin (see Section 8.2.6). Of these only the well-cemented sandstones and relatively clay-free limestones will have long-term durability. Shales, claystones and mudstones are not suitable for either channel construction or as riprap because of poor abrasion resistance and the tendency to slake and weather rapidly. Siltstones may fall in this category also if they are clay-rich and/or poorly cemented. As stated in the Earth Manual published by the U.S. Bureau of Reclamation (1974), any sedimentary rock with clay must be suspected of poor performance as riprap.

8.2.3.4 Rock Mass Conditions

The most durable rock as determined by testing is only as good as the rock mass from which it was obtained. Sedimentary rocks by nature have discontinuities known as bedding surfaces. In addition, all rocks regardless of origin have joints or relatively planar discontinuities caused by volume reduction or response to tectonic stresses. Joints occur in sets or many planar discontinuities parallel to one another. When these sets intersect a bedding plane, they typically form blocks which can be of similar size or an array of sizes and shapes.

Closely spaced bedding and joints are a problem for both excavated channels and riprap sources. Their orientations and spacings may be measured. In excavated channels the smaller the block the easier the hydraulic quarreying action will be. Riprap sources obviously must have block dimensions greater than the design dimensions to be suitable. Any tendency to have incipient sedimentary pactings will influence breakage of blocks into smaller blocks when blasted, transported and placed as channel lining. Riprap material should not exhibit discontinuities with spacings less than the predetermined dimension of the riprap required for a given channel size and flow.

Other significant characteristics of the rocks are a direct result of the sedimentary environment in which coal and the adjoining rock units were formed. In addition to being thinly bedded, the rocks may consist of interbedded shale and sandstone. Interbedded weak and strong layers of rock broken by joints will only be as durable as the weakest rock exposed. Also, channel deposits are prevalent in this sedimentary environment. Because of their irregular, linear geometry, durability of the rock mass may exhibit significant vertical and horizontal variability. Careful examination of the local, seemingly durable units must be made for these spatial controls where a channel is excavated or where riprap is being quarried.

8.2.3.5 Performance

A factor that should not be overlooked is the in-service performance of any local rock unit which has been exposed to the elements. There also may be local excavated sites where the performance over several seasons of both the rock in the excavated face and stockpiled material can be evaluated. Since these are the conditions prevailing at the site, such performance may be a better indicator of durability or weatherability than many of the laboratory tests. Evaluation of in-service performance of several years or more is recommended. The wearability or resistance to abrasion common to exposed bedrock in a channel can be assertained qualitatively from examination of exposures of the rock in local stream channels. If the rock forms rapids or falls or is sufficiently resistant to have localized abrasion-formed potholes rather than complete removal by erosion, the rock should perform well for the service life of a diversion channel.

8.2.4 Field Testing

Either the inherent strength of fresh rock or the weakened state from weathering processes may be judged from several field tests. A hammer, pocket knife and a 10-power hand lens are required for most simple tests. Since these are all empirical tests, it is not feasible to standardize on one size or kind of hammer, although this has been attempted.

Broken pieces of sandstone (hand specimens) may be examined with a hand lens. If the sand-sized particles are composed of glassy-appearing quartz, the chemical stability and the resistance to abrasion of the primary mineral grains will be excellent. If the grains appear to be composed of other material two possibilities exist. The grains may be fairly soft fragments of the minerals that compose limestone (calcite/dolomite); they can be scratched easily with a knife. Otherwise, they may be a mixture of minerals derived from preexisting rocks. These minerals may have decomposed, at least in part, to clays. Then, they will scratch easily and the rock will have an earthy smell when breathed upon. Only the last case can be categorically removed from further consideration.

The sand-sized quartz and limey minerals composing a "sandstone" may provide satisfactory material if the cement holding the grains together is of sufficient quantity and a durable kind. The sand-sized grains may be cemented or at least adhered together by such common cements as clay, limey cement (calcite), iron oxide (red), or varieties of quartz. To determine the degree of cementation, place a drop of water on the fresh surface. If it is absorbed, the cementing of the grains is not complete and the rock would not be very durable.

If the water is not absorbed, check for clay by breathing on the specimen and by scratching the surface with a knife. When viewed under the hand lens, clay cement will appear to allow hardy or individual mineral grains to be released from the rock matrix when the surface is scratched by a knife. Such rocks will not be durable because of the clay. Limey, iron oxide and quartz cements may permit some clay-bearing rocks to perform well and should be tested further in the laboratory. Scratch tests range from "easy" for limey cement to "impossible" for quartz. Another qualitative measure of durability will be obtained by examining the freshly broken surface with the hand lens. Tougher, more durable rocks will break across the grains and cement, while less durable but perhaps still useful rocks will tend to break around the grains through the cementing material.

The hammer is useful in several ways. The hardest and probably most durable rock will have a distinct "ring" when struck with a hammer. With a change in either kind of cement, amount of cement or weathering of the rock minerals and/or cement, the hammer blow will be either a dull ring or a "thud." Since these are qualitative measures, the terms should be defined by the field inspector by experimenting on rocks of known durability.

The hammer is also useful as a means of breaking a rock sample held in the hand. If the rock can be broken by hammer blows only with considerable difficulty, the durability of the intact sample should be good. The durability will decrease with increasing ease of breakage. Any rock that breaks easily when hand held should be considered non-durable and of no value in diversion channel construction. Additionally, because sedimentary rocks may be deposited in a layered fashion, it is wise to carry out the breakage test with several sample orientations in the hand. Subsequently, the weakest orientation will control one's choice of rock, especially if the use is riprap material.

Williamson (1978) of the USDA Forest Service has devised a simple impact test using a 1 lb. ball peen hammer. If the hammer rebounds completely with no damage to the rock, the rock quality should be high with an estimated compressive strength >15,000 psi. If fragments are formed at the point of impact, the quality will still be good (durable) with a strength estimated between 8,000 and 15,000 psi. Any impact that results in denting of the surface or complete fragmentation will reveal rocks not suitable for riprap channel construction.

8.2.5 Laboratory Testing

8.2.5.1 General

Rocks which will be eliminated as suitable riprap by visual inspection or simple field tests are those rocks which are cemented with clay or weathering to clay, poorly-cemented sandstone, or clay-rich rocks such as shale, claystone and mudstone. The remaining rock types will range from marginal to excellent in performance. Laboratory testing of these rocks will provide a basis for judging in-service durability.

A literature review (Phase I report) indicates that measures of rock durability defining durable rock for the uses described in this manual are not well defined. However, tests for resistance to abrasion, freeze-thaw cycles and strength used for other engineering applications are adaptable to durability assessment (Appendices E and F, Phase I report). Abrasion resistance is a major concern when the channel is constructed in rock without a lining, although response to water and freeze-thaw cycles is of additional concern. The durability of riprap will be defined more by resistance to water and freezing and thawing than by abrasion resistance. The tests described in the following sections address these aspects of durability. A sufficient number of tests are described so that the need for a large array of specific test equipment is reduced. While all are typically to be run in the laboratory, those that may also be conducted in the field will be identified.

8.2.5.2 Los Angeles Abrasion Test

The Los Angeles Abrasion Test or LA test is used to estimate aggregate abrasion susceptibility. As stated in the procedure outlined in Appendix F.3, a percentage loss or LA number less than 40 percent is considered as resistant or durable. This test follows the ASTM standards (1980).

8.2.5.3 Point Load Test

Durability, whether to abrasion or with regard to natural weathering under climatic conditions, is directly proportional to uniaxial compressive strength of an intact or solid rock sample. The Point Load Test which is portable and may be used in the field on hand specimens, determines the tensile strength which is converted to uniaxial compressive strength. As defined in Appendix E.2 of Phase I report, the acceptable threshold value is a value, >300, which is approximately 7,000 psi. This, in turn, is roughly equivalent to an LA number of 30 percent, indicating that the point load index value is conservative relative to the upper index value of the LA test (40).

8.2.5.4 Schmidt Hammer

The Schmidt Hammer is an alternative device for measuring unconfined compressive strength in the field. A detailed description of the method for defining strength values as indicators of durability is given in Appendix E.1 of the Phase I report. A Schmidt Hammer Value (SHV) of <25 is approximately equivalent to 7,000 psi or to an LA number of 30 percent.

8.2.5.5 Freeze-Thaw Testing

If the rock to be used in diversion channel construction or as riprap to line the channel is subject to freeze-thaw cycles, some estimate must be made of the rock resistance to mechanical breakdown from the cycles. This is a most significant factor in even short-term disintegration of exposed rock. Susceptibility of rock is the result of clay content and porosity. If the rock in question is naturally exposed in an area visual examination of the products of many cycles of freezing and thawing can serve to eliminate the rock and the test. However, where rock is to be quarried testing is recommended (Phase I report, p. 10.12).

The equipment required to conduct freeze-thaw tests is not readily available in mobile labs or in many fixed-based testing labs. Testing may be done on a contract basis making certain that ASTM Standard C666 for either freezing and thawing in water or freezing in air and thawing in water is followed. Any change in the gradation of the test can be taken as deleterious for rocks exposed, as in diversion channel service. Local weather data may be used to obtain the average freezing cycles for comparison with test results having been produced by a specified number of cycles. Judgment must also be used concerning in-service contact with moisture, i.e., rainfall, snowmelt, exposure to sun, channel flow conditions, etc. before a rock can be accepted or eliminated on the basis of the test results.

8.2.5.6 Sulfate Soundness Test

The Sulfate Soundness Test is a satisfactory substitute for the freeze-thaw test and is less time consuming and requires less costly equipment. The test procedures are defined in Appendix F.4 (Phase I report). Conservative threshold values for assessing durability are <5 percent loss for sodium sulfate tests and <10 percent for magnesium sulfate tests.

8.2.5.7 Slake Durability

In the event clay-rich siltstones, sandstones and limestones are the only available materials and they marginally meet the field criteria described earlier and the preceding index tests, slake durability testing is in order. The durability or weatherability of clay-rich rocks presents problems because the degree of induration may mislead the observer to make a performance estimate better than what will actually occur.

The Two-Cycle Durability Test is recommended because it is already required and/or commonly used by mine engineers to evaluate durability of rocks for use as rockfill embankments. Detailed explanation and procedures are given in Appendix F.2 of Phase I report. The recommended threshold value for durable riprap is an index of >95 percent.

An alternative test for assessing slake durability is the Jar-Slake Test (Appendix F.1), although this test should not be substituted unless absolutely necessary because it is highly qualitative in nature. The investigator must be aware that this test is not a definitive indicator nor is it proven to be as reliable as the Two-Cycle Durability Test.

8.2.6 Application of Procedure

The rock durability evaluation procedure is designed mainly for field use. To illustrate the step-by-step method of predicting the durability of overburden, a field inspection at a coal mine site is reviewed and potential riprap material is analyzed. Hopefully, these examples will demonstrate the practical and efficient function of the durability evaluation.

8.2.6.1 General Inspection

Roughly 25 mine operations in eastern Kentucky were observed, some of which were active and others were inactive and reclaimed, partially reclaimed, or not reclaimed. Field reconnaissance of overburden characteristics suggest that:

(a) overburden "dump rock" is commonly used as riprap,

(b) much less overburden is used compared to the available spoil following coal excavation,

(c) excavation by blasting usually produces a range of rock sizes for use as riprap.

8.2.6.2 Durability Flow Chart Evaluation

To get more detailed information on the overburden, selected rock types were described and analyzed using the durability evaluation procedure. The data sheets used to compile necessary information to assess durability are given in Figure 8.2. The flow chart is subdivided into sandstone, siltstone-shale, and limestone field evaluations, followed by a flow chart of laboratory tests.

Two rock types in eastern Kentucky have been collected and analyzed. First, a typical section of overburden exposed in a highwall was described in detail, as illustrated in Figure 8.3. Then, characteristics of the light gray sandstone (lower sandstone in Figure 8.3) were evaluated and the results are illustrated in the field flow chart (Figure 8.4). This sandstone is a ledge former, the discontinuities are not closely spaced, and it does not ring when struck with a hammer. The rock sample is moderately hard to scratch, smells very earthy and absorbs water rapidly, so it is "rejected" as material for riprap.

The upper buff sandstone described in Figure 8.3 is even more crumbly than the gray sandstone and its characteristics follow a similar flow line as the gray sandstone (Figure 8.4). However, at certain sections of the outcrop, this sandstone has closely spaced continuities so it would be rejected at an earlier point on the sandstone flow chart.

Field observations of riprapped channels indicate that some of these sandstones appear to be slowly breaking down and crumbling into smaller rock fragments and single grains, even though they have been in-service for only several years. Sediment-production and erosion within the diversion channel can potentially increase, resulting in complete failure, although further study and observation of longer stretches of channel are required to verify these suspected consequences.

A durability test was conducted on sandstones which are stratigraphically equivalent to these sandstones. The samples, taken from a nearby mining site, were tested for possible use in rock-fill embankments using the Slake Durability test as defined by the Kentucky Bureau of Highways (Phase I report, Appendix F.2). Results indicated that both sandstones meet the durability specifications for rock-fill embankments which is an index exceeding 90 percent. However, in assessing riprap durability in this mining area, it is strongly recommended that (1) a durability index of >95 be used as the limit for evaluating suitable <u>riprap</u> material and (2) results of durability tests of a rock type should <u>not</u> be extrapolated from one mining section to another

(Flow Chart may be modified by in-service performance data)
Check the appropriate boxes along flow chart lines to define the durability of rock in question.

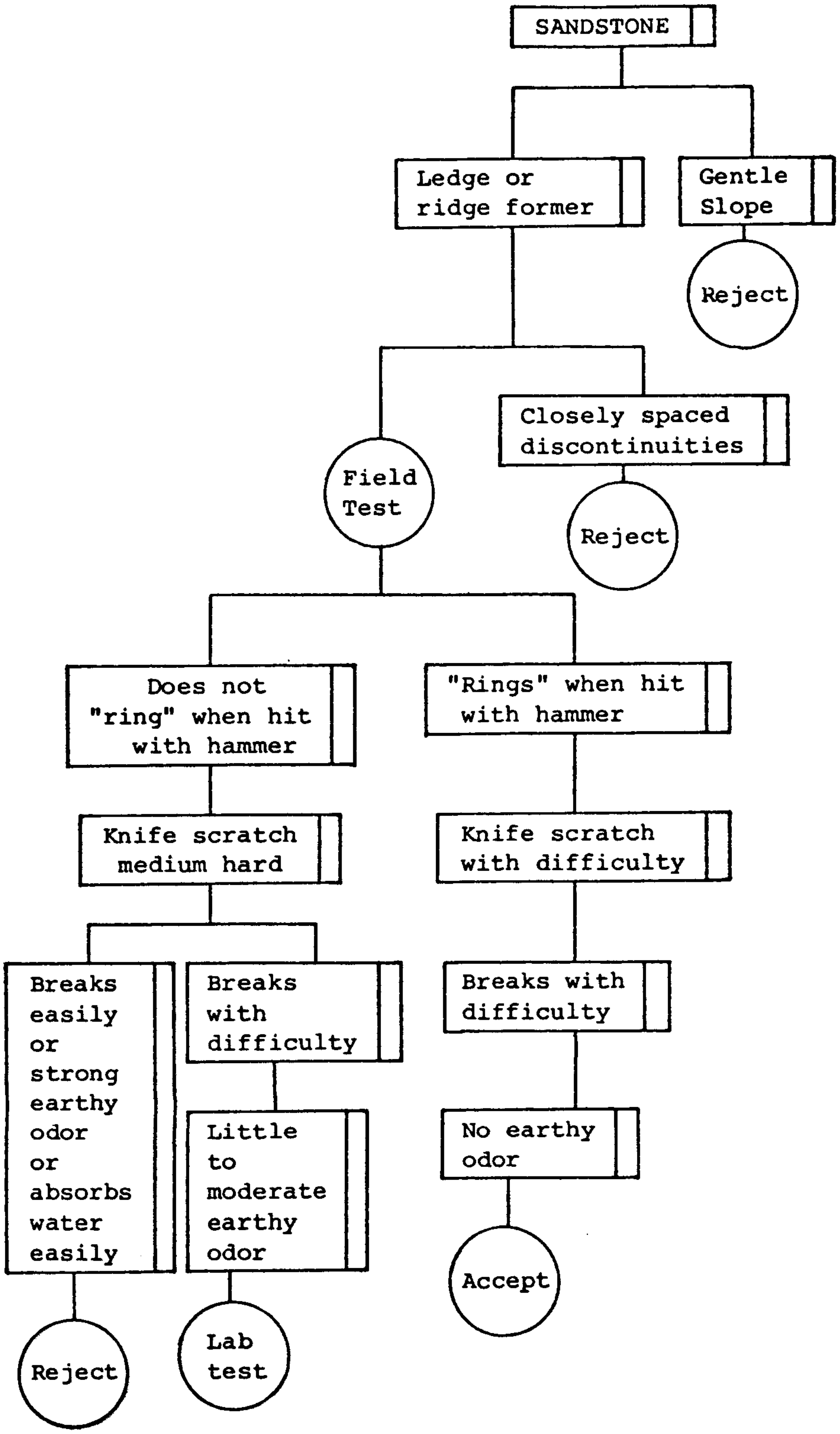


Figure 8.2a. Rock durability field flow chart.

(Flow Chart may be modified by in-service performance data)
Check the appropriate boxes along flow chart lines to define the durability of rock in question.

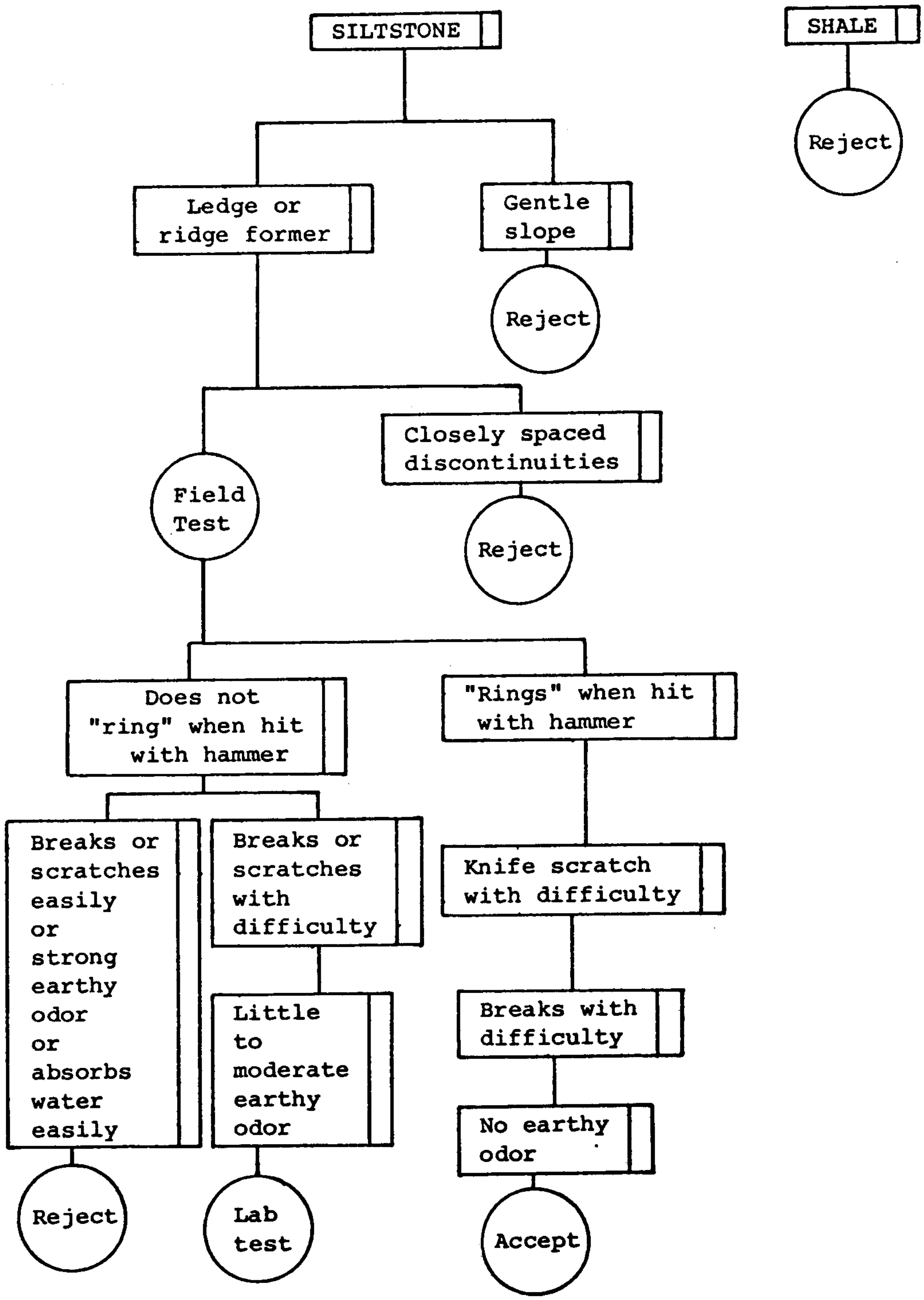


Figure 8.2a (continued).

(Flow Chart may be modified by in-service performance data)
Check the appropriate boxes along flow chart lines to define
the durability of rock in question.

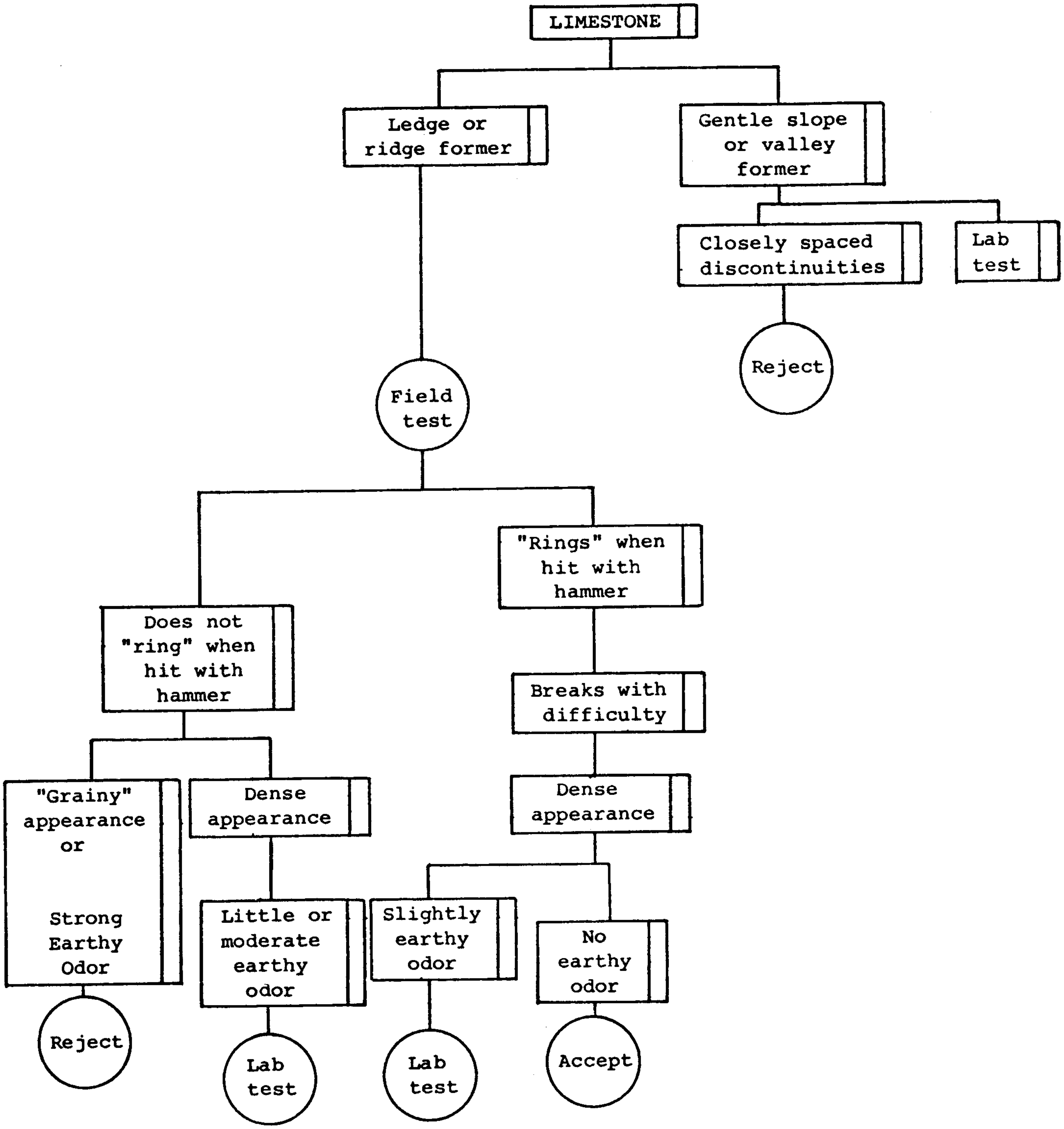


Figure 8.2a (continued)

(Flow Chart may be modified by in-service performance data)
Check the appropriate boxes along flow chart lines to define the durability of rock in question.

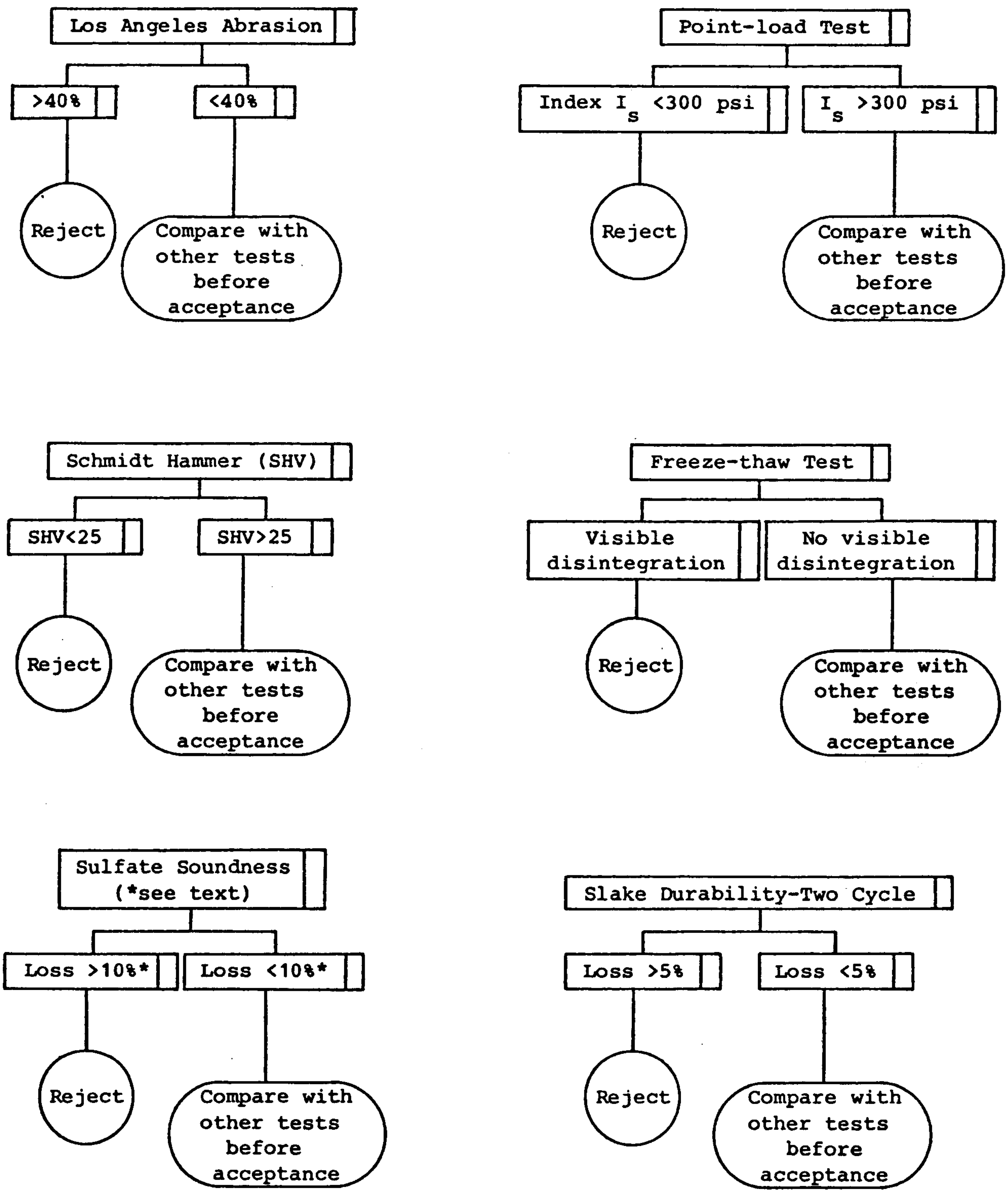


Figure 8.2b. Rock durability laboratory flow chart.

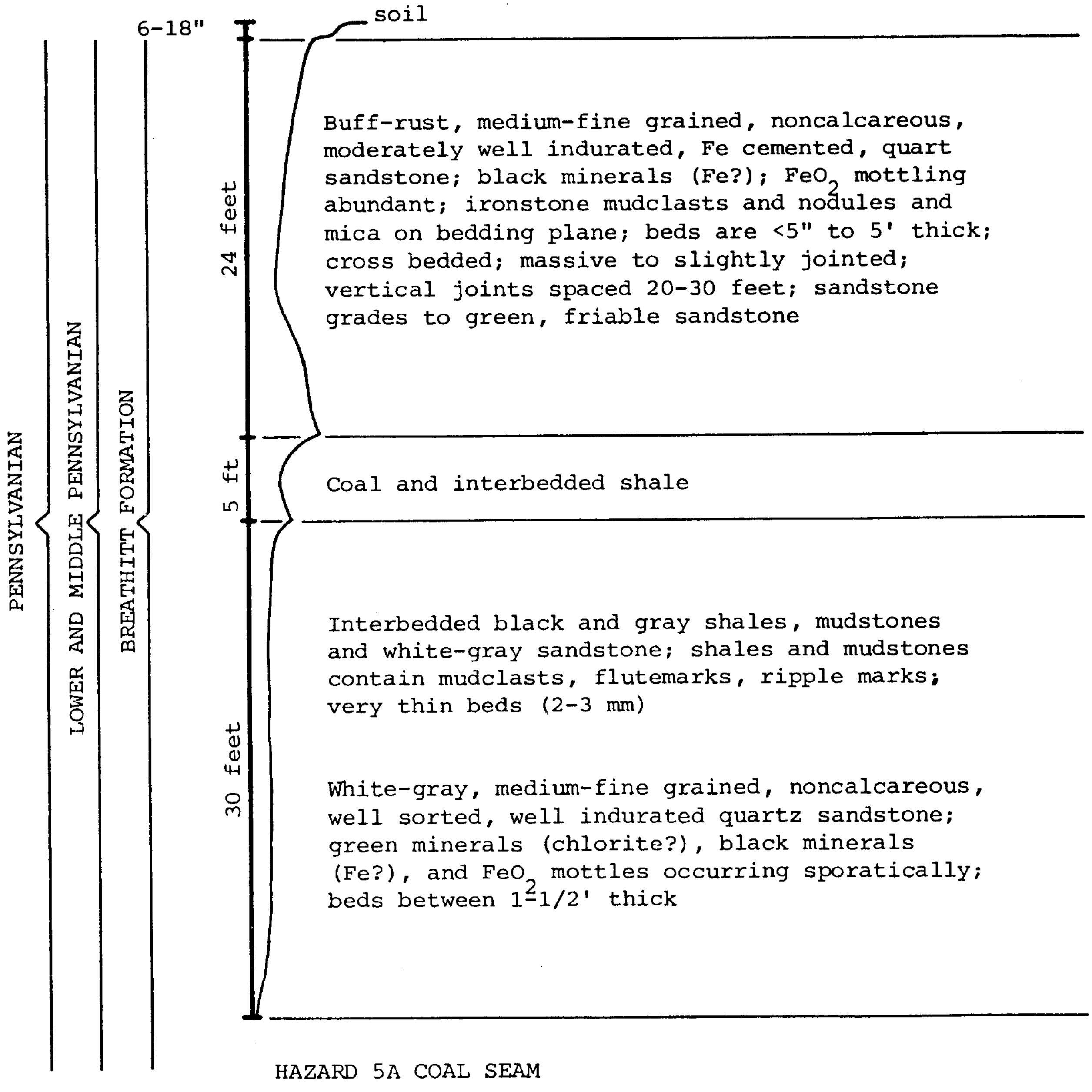


Figure 8.3. Stratigraphic description of overburden at a mine site in eastern Kentucky.

(Flow Chart may be modified by in-service performance data)
Check the appropriate boxes along flow chart lines to define the durability of rock in question.

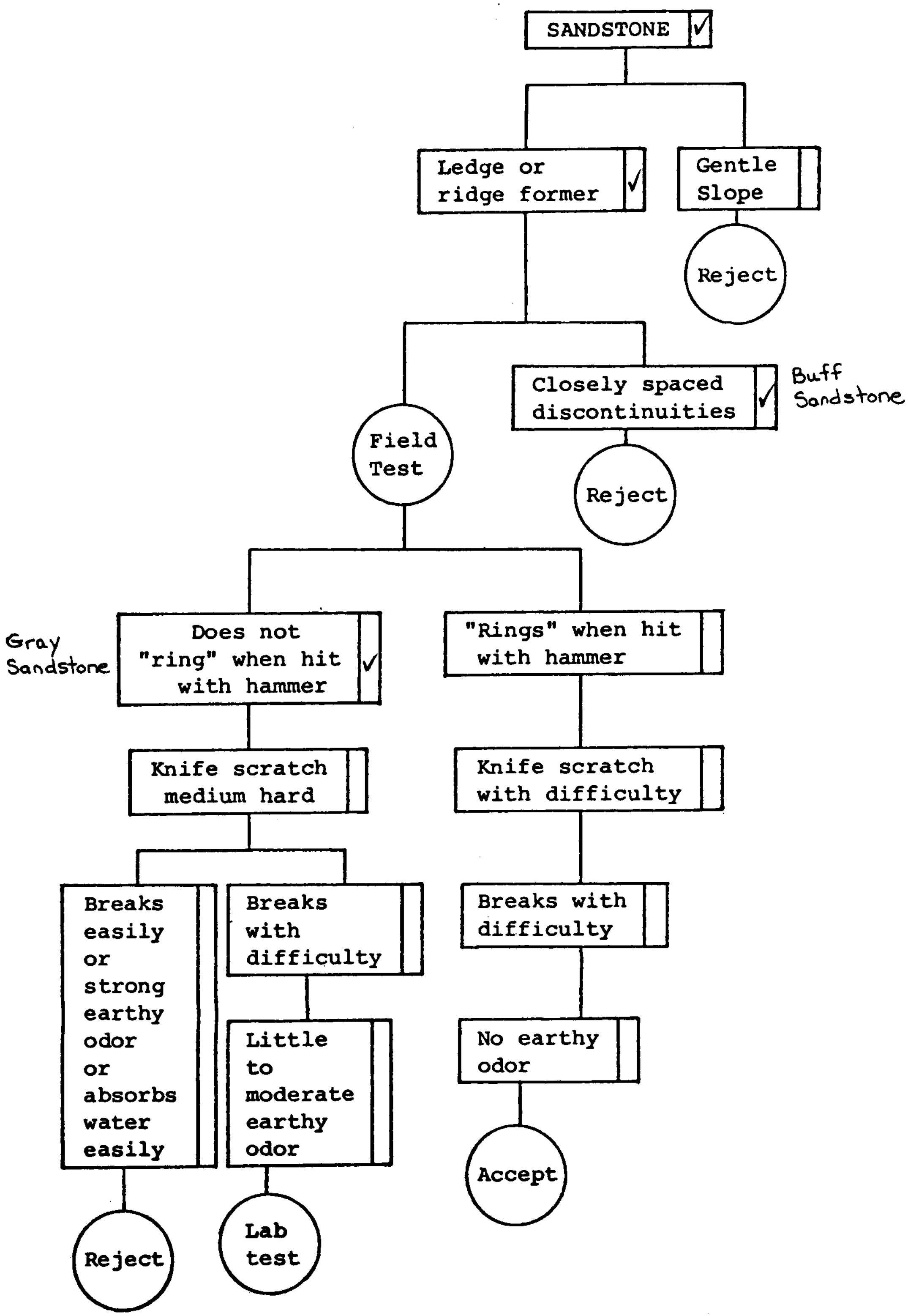


Figure 8.4. Rock durability field flow chart: example.

because rocks can vary significantly (both laterally and vertically) within very short distances.

The second rock type exemplifying the use of the durability flow chart is a gray limestone used as riprap at an inactive, partially reclaimed site. As shown in the chart (Figure 8.5), this specimen rings when hit with a hammer, is difficult to break, and has a dense appearance, but it has a slightly earthy smell suggesting clayey matrix material. Therefore, further laboratory tests should be conducted, such as the durability test and LA abrasion test (Figure 8.1).

The field performance of this particular limestone is not known. As indicated by the top of the flow charts, in-service performance over an extended period may override the results of the flow chart and these field data should be carefully evaluated if available.

8.2.7 Summary and Conclusions

Of equal importance to sizing rock riprap is the determination of durability. Suitable material is often available on site and effort should be made to select the most durable rock types.

A three-fold procedure for evaluating rock durability on coal mining sites has been presented. Rock types suitable as riprap can be identified by incorporating field observations with simple geotechnical information. In reviewing the detailed procedure, one significant component is the "in-service performance" evaluation over an extended period because it allows judgment of a rock type based on its "actual" field performance, rather than "probable" performance predicted by the other evaluations.

It must be recognized that considerable judgment is required for use of site evaluations and laboratory testing procedures described herein. All evaluations should utilize all of the site investigations. However, selected laboratory or index tests should be run on rock types that have been judged to be marginal during site investigations. The greatest number of tests should be run on these marginal rock types and generally there is sufficient interaction among the various tests described to provide a basis for judging durability on a minimum of tests.

It must be emphasized that index tests are designed for solid or intact samples. High spacing frequency and number of discontinuity sets can make a rock exposure useless for either an exposed rock channel or for riprap.

(Flow Chart may be modified by in-service performance data)
Check the appropriate boxes along flow chart lines to define the durability of rock in question.

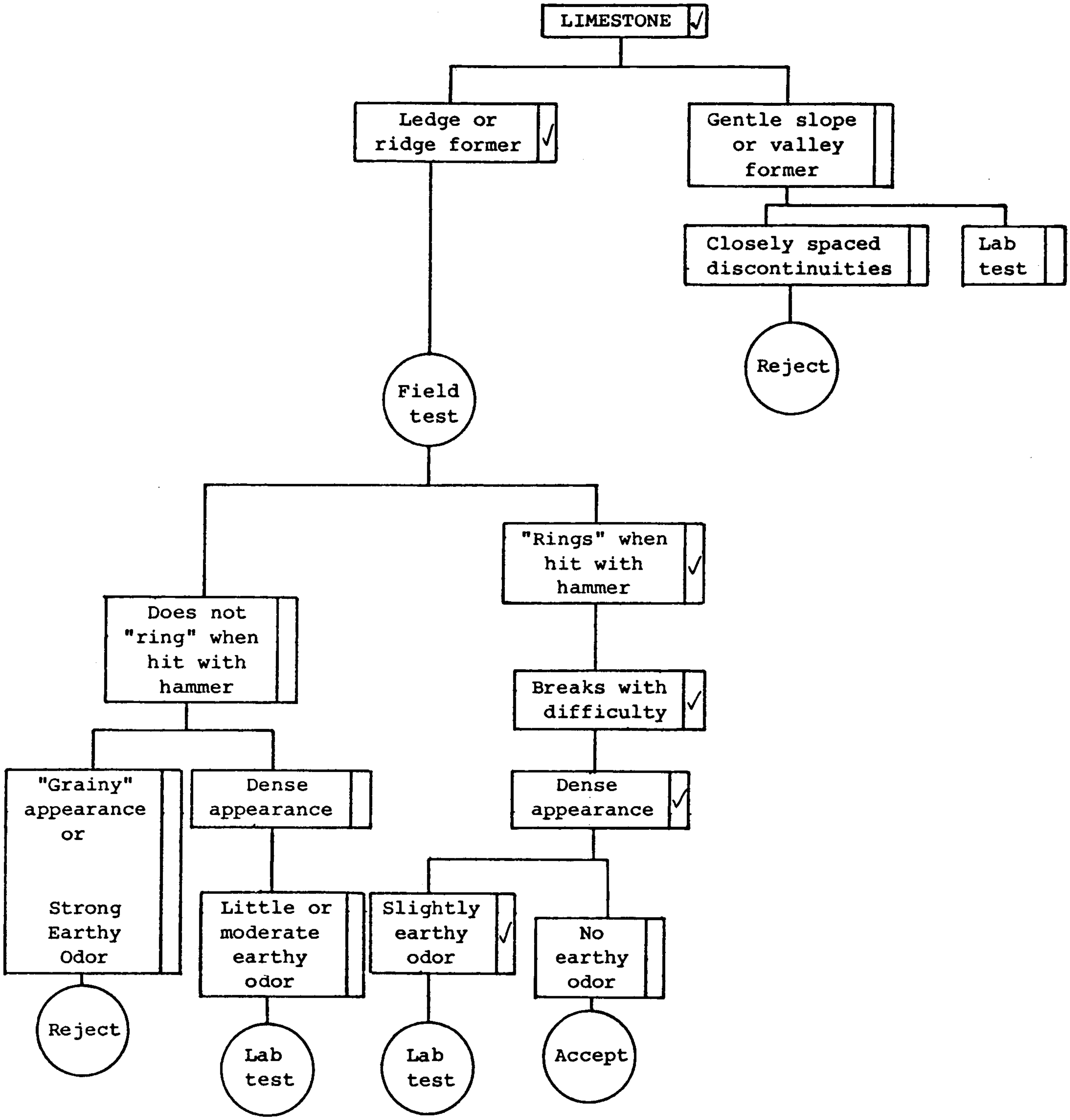


Figure 8.5. Rock durability field flow chart: example.

The ultimate goal of any of these tests or methods is to accurately predict durability and prevent consequential erosion hazards. The method recommended using information in Figure 8.1 is an effort to relate field, as well as laboratory tests, to actual service life of riprap or channels. This procedure will facilitate determination of suitable riprap for use at mining sites as economic and environmental demands intensify.

8.3 Geotechnical Stability Considerations

8.3.1 Introduction

In the following section, major factors causing slope failure are described which may influence stability of rock and soil slopes of channels. Potential problems that may be encountered in the field are addressed. Hence, it is hoped that slope failure mechanisms at a particular site can be identified to facilitate the design and maintenance of stable channels.

8.3.2 Slope Stability Factors

It is difficult to specify exact procedures to predict slope stability because stability will vary on a site specific basis as a function of natural weathering processes under a particular climate, type of rock, and use; however, general factors are known to interact with each other and determine stability of slopes. Assessment of these factors can be a valuable tool in the preliminary analysis of design channels and diversion ditches.

The following questions are important to consider prior to and during initial field observations and evaluation of slope stability at a particular diversion site:

1. Are slopes at the site currently stable?

2. Will the proposed construction activity influence slope stability at the site?

3. Could potential future changes in land use or the environment decrease slope stability at the site?

4. If the site is currently unstable, what countermeasures can be implemented that would make the site suitable for diversion channels?

5. If the site is currently stable but construction or future activities will make the site unstable, what countermeasures are necessary?

8.3.2.1 Natural Ground Surface Slope

One of the major factors to consider is the existing ground surface slope. As previously mentioned, the slope steepness of natural, in situ rock or soil material is usually a reliable indication of the inherent stability or angle of repose of the rock or soil.

Before a natural slope face is cut, the angle of repose should be measured. After the cut the "new" slope should be graded to the original slope. A guide for determining the horizontal or vertical extent of a properly graded cut slope after a 10-foot cut is made and is illustrated in Figure 8.6.

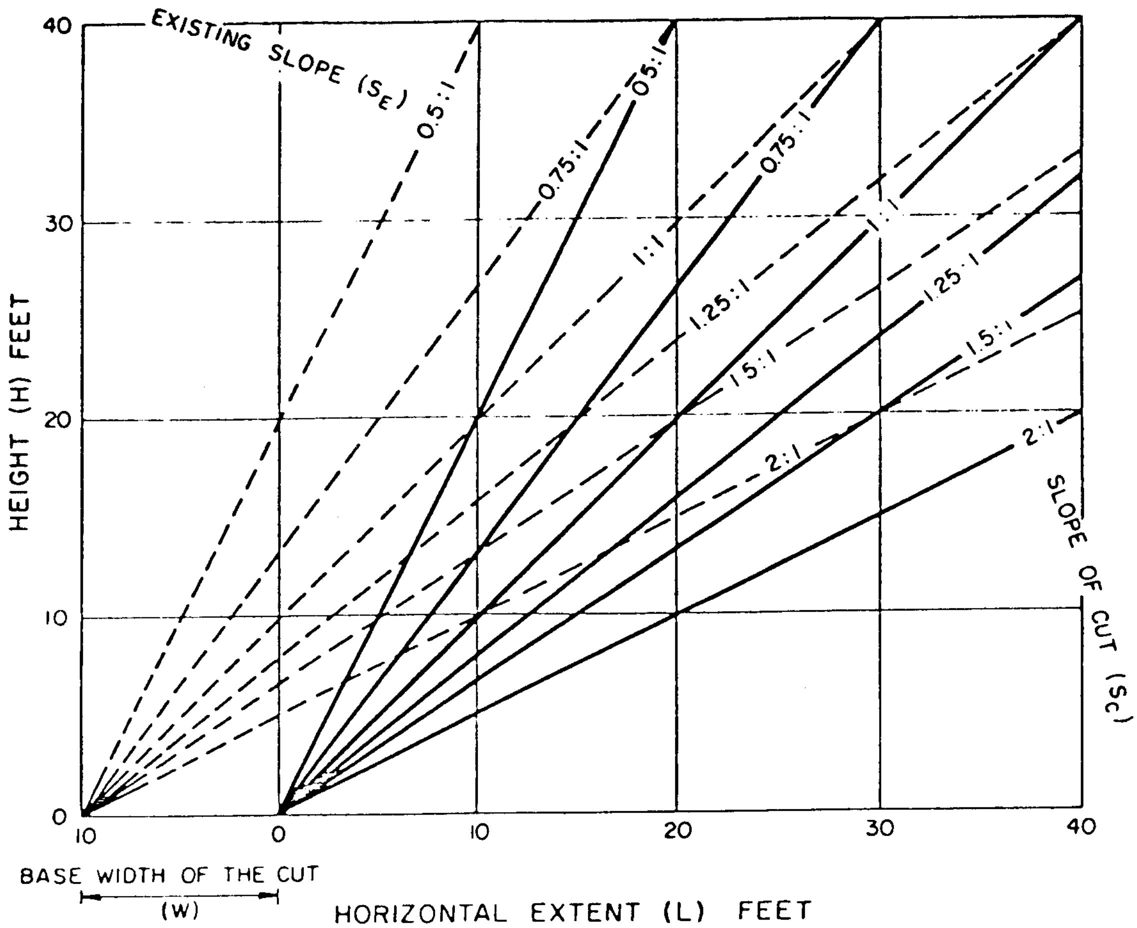
8.3.2.2 Earth Material Type

An important factor interacting with the natural slope is the type, structure, and stratigraphy of rock or surficial material. Detailed analysis and evaluation of durable and "stable" rock types for use as riprap or bedrock channels are given in the rock durability section. Figures 8.7 and 8.8 illustrate situations of potential slope failures on favorable and unfavorable bedding plane orientations. In considering slopes constructed in unconsolidated deposits and soils, generally the greater the backslope gradient and the more ground water present, the less stable will be the slope. Table 8.1 gives general guidelines for suitable side slopes of channels built in unlined and lined unconsolidated materials. General guidelines for backslopes of cut sections through rock are given in Table 8.2.

In steep slope areas in the Appalachian Basin, most soils are very shallow and larger cuts will consist mostly of shale, sandstone or limestone backslopes. Where the backslope consists of intermittent layers of shale, sandstone or limestone, it is possible that the exposed shale strata will weather and erode, thereby undercutting the more durable layers. Gentler slopes designed for the most incompetent material are required to avoid these conditions.

8.3.2.3 Ground Water

Near-surface flow of water can induce (1) excessive pressures along bedding planes or discontinuities, (2) erosion of rock by chemical solution or mechanical abrasion, and (3) increased weathering rates and disintegration by



(1) $S_E > S_C$

(2) $L = W \dfrac{S_C}{S_E - S_C}$

(3) $H = \dfrac{L}{S_C}$

FOR W ≠ 10 FEET MULTIPLY THE VALUE L AND H OBTAINED FROM THE GRAPH BY COEFFICIENT C = W/10.

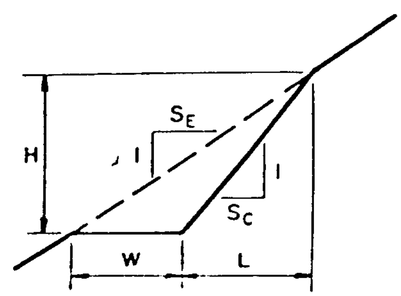
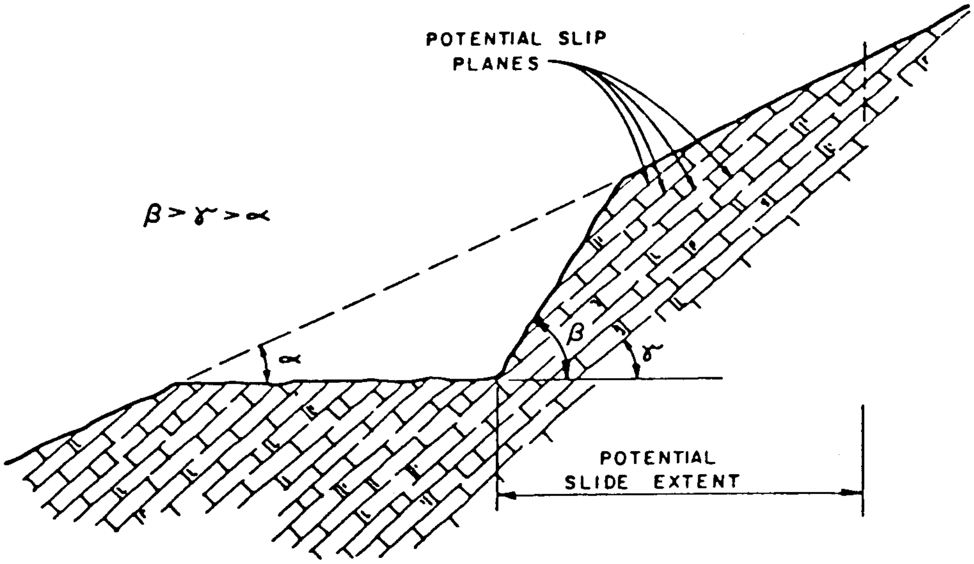
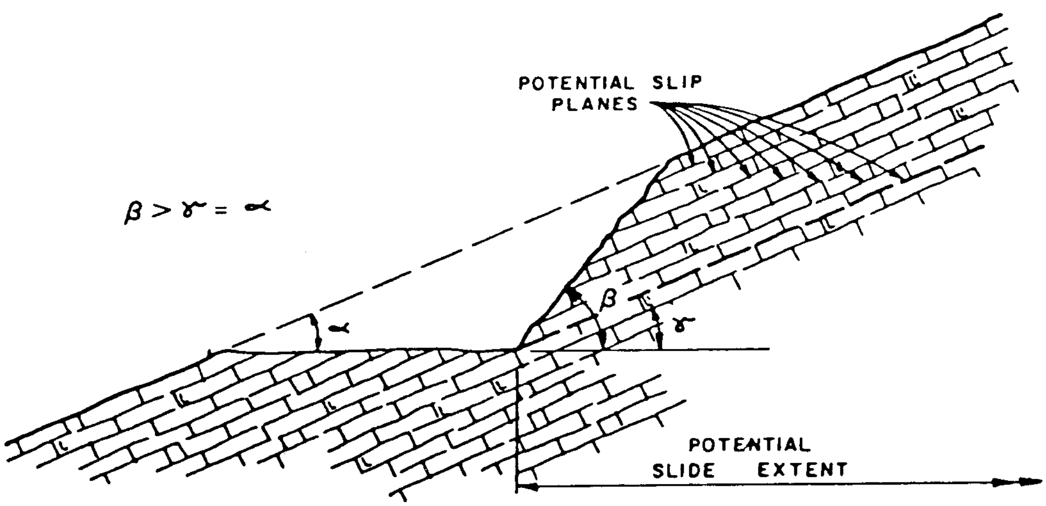


Figure 8.6. Horizontal and vertical extent of cuts for base width of 10 feet (D'appolonia, Inc.).

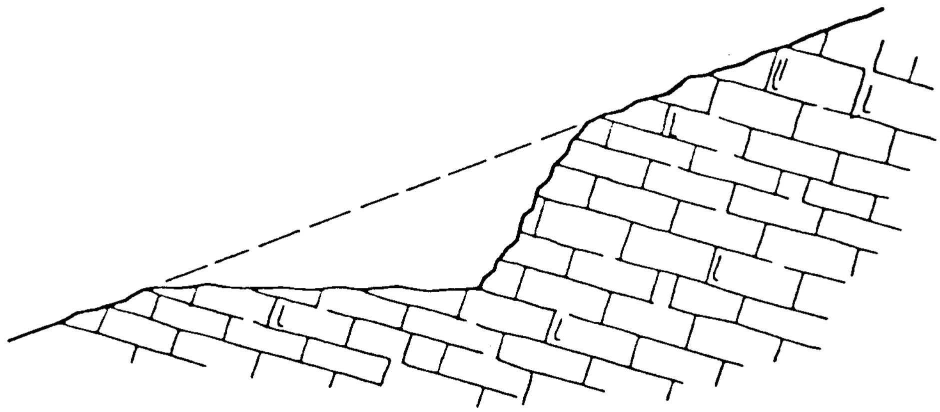


(a) Extent of potential slide small

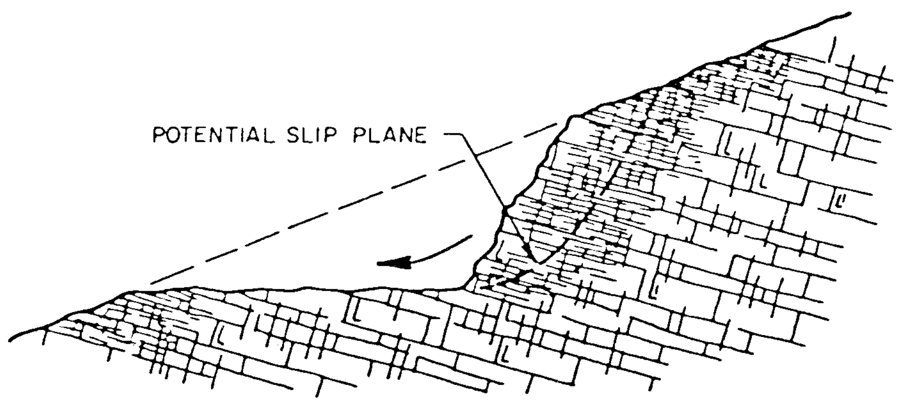


(b) Extent of potential slide severe

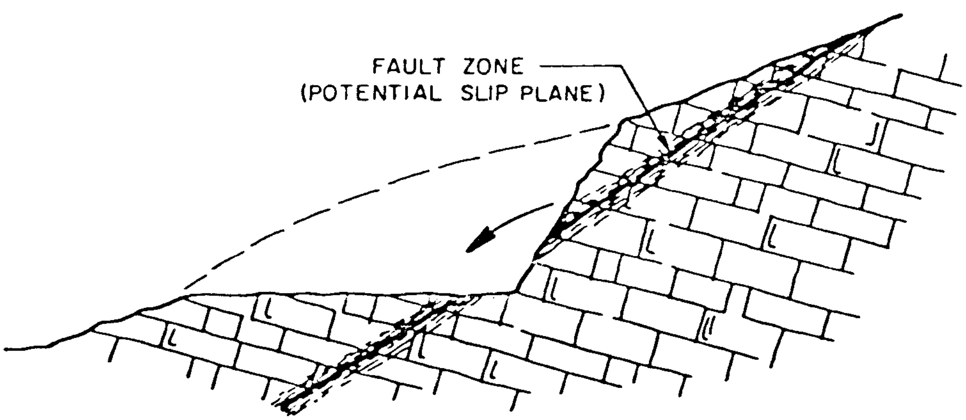
Figure 8.7. Unfavorable orientation of bedding planes (D'appolonia, Inc.).



(a) Rock is competent



(b) Rock is highly fractured



(c) Fault zone is the governing feature

Figure 8.8. Favorable orientation of bedding planes (D'appolonia, Inc.).

Table 8.1. Stable Side Slopes for Channels Built in Various Kinds of Materials (from Chow, 1959).

Material	Side Slope
Stiff clay or earth with concrete lining	1/2:1 to 1:1
Earth with stone lining, or earth for large channels	1:1
Firm clay or earth for small ditches	1 1/2:1
Loose sandy earth	2:1
Sandy loam or porous clay	3:1

Table 8.2. General Guidelines for Cut Sections Through Rock.

Type of Rock	Back Slope
Hard and medium sandstone and limestone	1/4:1
Soft sandstone, medium hard shale, limestone, siltstone	1/2:1
Soft shale interbedded with siltstone or limestone having AASHO M-145-49 granular classification	1:1 (1 1/2:1 if height of cut < 25 ft)
Soft shale having AASHO M-145-49 silty clay classification	1 1/2:1 (2:1 if height of cut < 25 ft)

freeze-thaw and wet-dry cycles. Therefore, water control is an important consideration and must be evaluated on a site-specific basis. Field investigations should include observations of seepage and surface drainage patterns, along with utilization of data from well logs. This is important in assessing possible changes in the water table and seepage from loading (produced by diversion structures and spoil placement).

8.3.2.4 Design Flow

The above factors are, in turn, modified by the amount of water which is to be carried by the diversion channel. In general, the higher the conveyance factor, the lower the channel gradient should be to resist abrasive and other forces and remain stable. Additionally, the velocity of flow is critical to stability. In general, velocities should be maintained less than 15 fps to insure long-term stability in a bedrock or rock riprap channel.

8.3.2.5 Other Stability Factors

Several other features and environmental conditions should be considered when evaluating the degree of stability within channels. These factors include: (1) the amount of precipitation or peak discharge of storms and extended wet periods, (2) infiltration characteristics of surrounding terrain, (3) vibration from blasting or earthquake, and (4) loading of the head or toe of the slope. These factors can be assessed by contacting the local or state weather service, the District Soil Conservation Service and by evaluating operations at the mining site.

8.3.3 Stability Problems Unique to the Appalachian Basin

Certain stability problems are unique to the Appalachian region due to the lithology in the basin. These problems should be considered when designing diversions through these kinds of materials.

8.3.3.1 Shale

Shales have been cited by numerous sources as a cause of slope instability and slide activity in the Eastern Coal Province. These shales are highly susceptible to chemical and physical weathering and breakdown. Slaking is a common process occurring in mining areas when these shales are wetted and loaded (Shamburger, Patrick and Lutton, 1975; Fisher, Fanaff, Picking, 1968).

8.3.3.2 Sandstone

Weakly cemented sandstones have been recognized as a problem in West Virginia and Kentucky because they are very susceptible to weathering and disintegrate into loose sands after placement. An example evaluation of a sandstone from eastern Kentucky is given in Figure 8.4.

8.3.3.3 Colluvial Deposits

Colluvium is deposited by gravity and is generally loosely deposited and has a low shear strength. This is of particular concern when constructing sedimentation control structures which often produce changes in the groundwater level. Data from test drill cores at a mining site may provide information on the depth and geometry of colluvium. Typically, terraced slopes fail at the colluvium/rock interface and failure is dependent on the depth of colluvium. Existing slopes which are <30° most often result in failure along the fill/colluvium interface regardless of the depth of colluvium.

8.3.3.4 Aquifers and Underclays

Aquifers or water-bearing seams often lead to stability problems, especially when associated with underclays and shales. The mining engineer should be aware of the presence of water-bearing units and note any springs and seeps at the coal/underclay boundary. Dewatering may be a necessary part of the mining operation to avoid adverse mining conditions and slide activity. Water well logs and domestic well information should be accessed prior to mining and post-mining diversion construction.

8.3.3.5 Existing Landslides

Existing landslides or areas undergoing creep (which can occur on slopes as gentle as 5°) may reactivate or accelerate when incised by diversion structures. The mining regulations comment against the siting of diversions in a manner such that the potential for landslides is increased. To evaluate landslide hazards judiciously before construction of diversions, the following points summarize criteria indicating past or present slope movement or suggesting potential instability. These criteria can be assessed both in the field and by use of aerial photography. Further explanation can be found in Piteau and Peckover (in press) and Phase I report, Section 10.3.2.

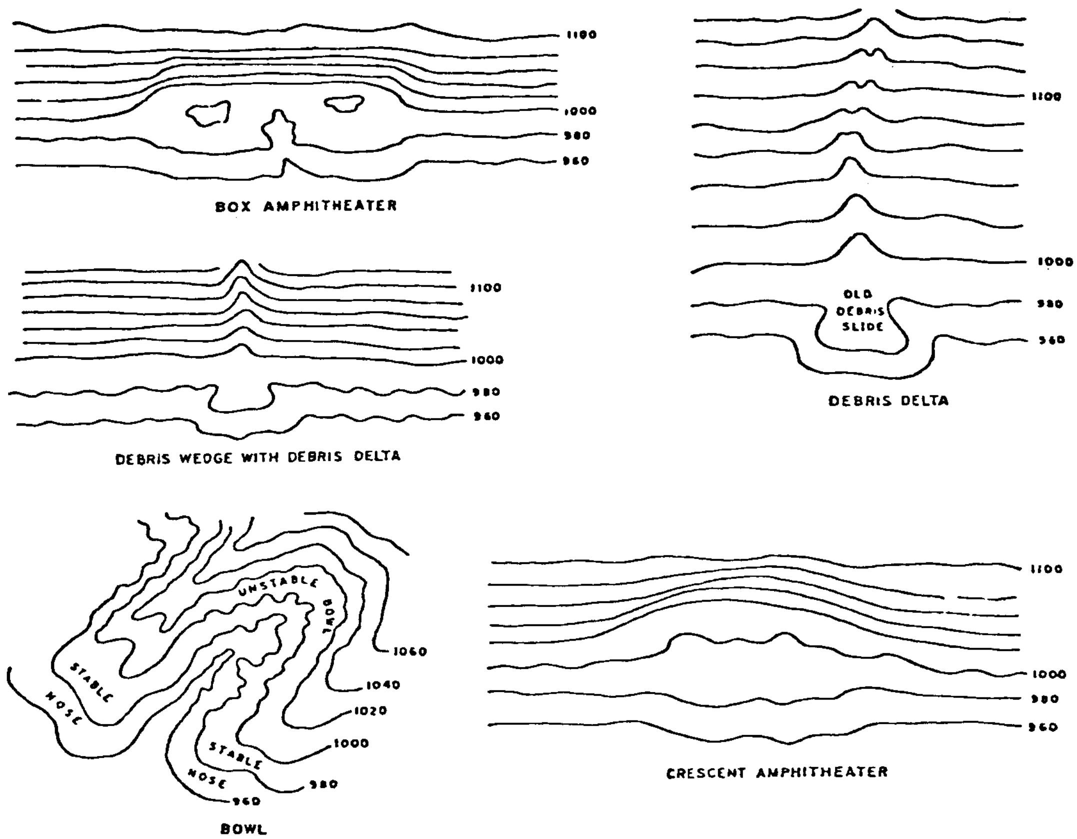


Figure 8.9. Schematic topographic diagrams of five landforms that are highly susceptible to landslides.

1. Existence of an old escarpment; indicated by vegetative and topographic patterns (Figure 8.9).

2. Existence of cracks at the top and near the toe of the slope.

3. Springs and seeps.

4. Erosion near the toe of the slope.

5. Soil piping.

8.4 References

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