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Trip B-4

ENGINEERING GEOLOGY AS APPLIED TO HIGHWAY CONSTRUCTION

by

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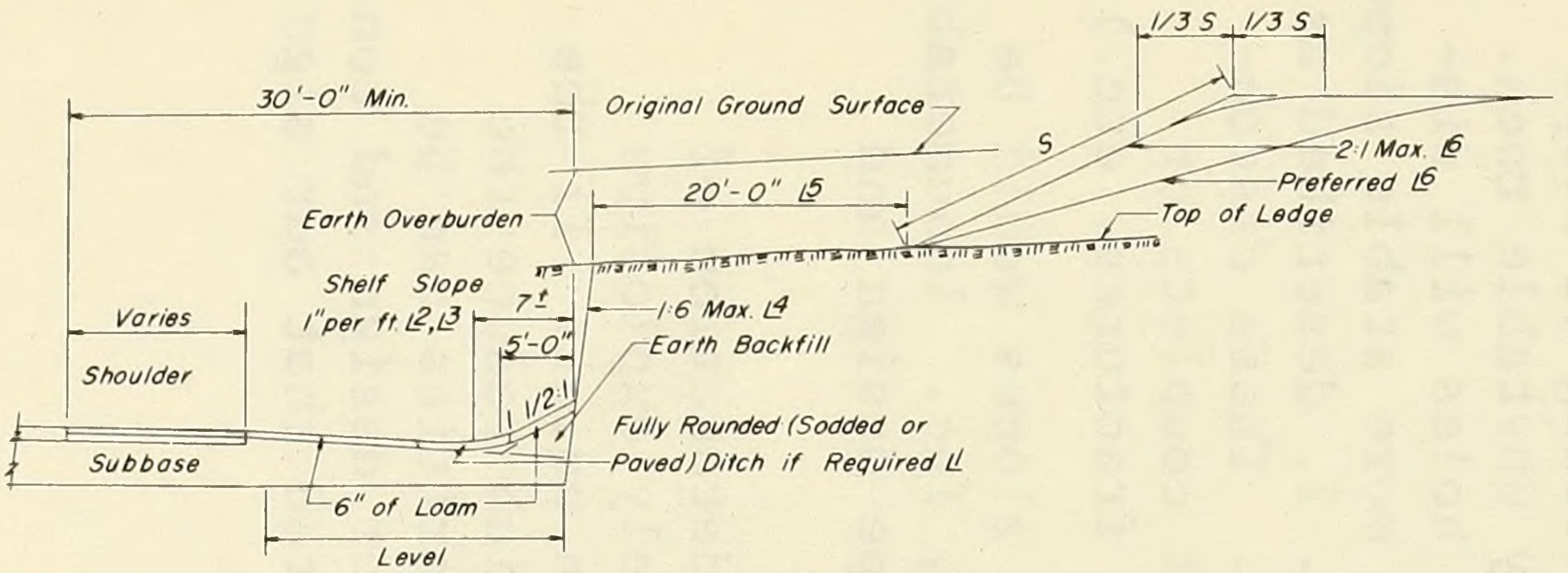
Highway design of rock slopes is based on standards, Fig. 1. These standards incorporate geometrics, safety, and rock competency towards developing the ultimate design. Falling rock landing on the traveled portion of a highway is unsafe.

In general, the design of rock slopes is based on detailed geologic mapping and full depth rock coring. No laboratory testing of rock is done. Rock cores, outcrops, and the mica:feldspar-quartz ratio (m/f+q) are utilized for slope analysis. Testing of metamorphic rock in Connecticut will yield numbers, but the application of the numbers is questionable. Other methods like the Rock Quality Determination (RQD) (Deere and others, 1967) are useful in the more competent gneisses. The crux of the problem is: we need information on what does not come up in the core barrel. In situ testing is needed to be successful in designing slopes; unfortunately, existing methods such as the flat-jack or pressure chamber are too expensive. Inexpensive methods of in situ rock testing are desperately needed for the design of rock slopes in civil works projects.

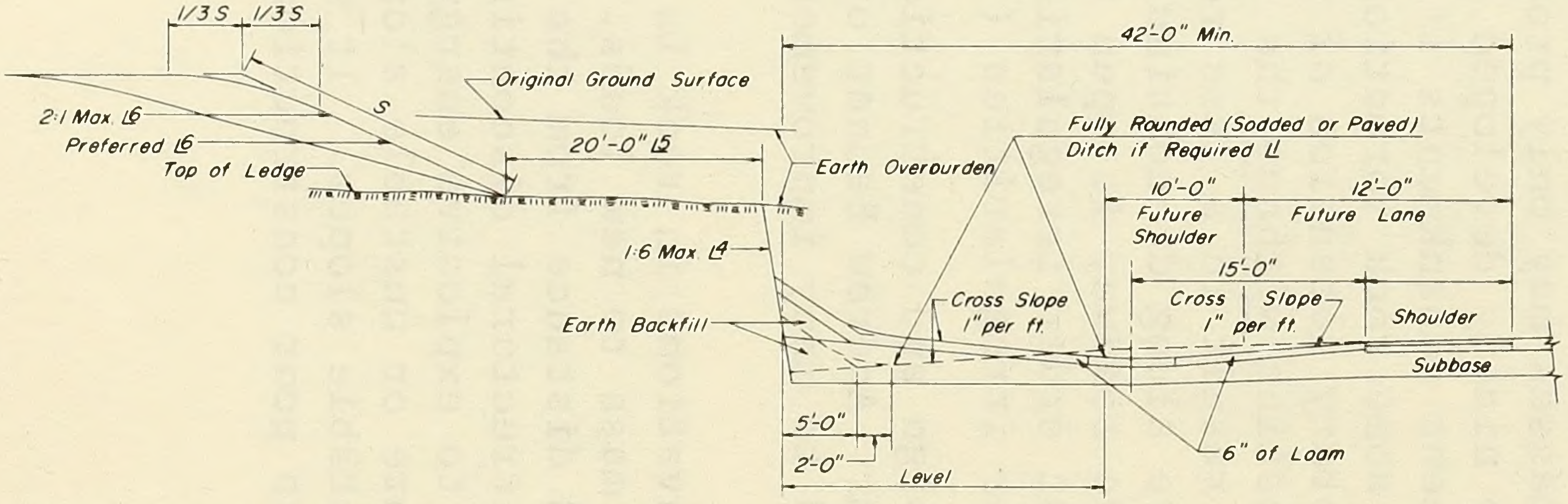
Determination of the proper construction method to achieve a design slope can be a problem. The methods utilized to excavate mass rock can determine the actual slope to be produced. Controlled slope holes to develop slopes in many rock masses may only produce a temporary slope, in which failure can occur. The nicely developed slope with exposed half holes can end up in the adjacent embankments if failure occurs during construction. Therefore, in some rock formations, presplitting of slope holes may result in the temporary retention of potentially unstable rock. In such cases, controlled blasting <u>without</u> the slope line holes will dislocate the unstable rock and result in a less regular but more stable slope. Otherwise, progressive failure along discontinuities, Fig. 2, described as rock fall, may occur after the roadway is open to traffic. These discontinuities are classed as first order irregularities (joint couplets or faults, etc.) and second order irregularities (joints and fractures, etc.).

No commentary on the design and construction of rock slopes would be complete without mentioning Mr. Andrew Bednar of Hercules, Inc. Innumerable discussions with him have led to many improvements in slope design and construction.

A problem with deep excavations in rock is that the detonation of explosives subjects the rock mass to new loads. Fortunately explosive energy dies out with time and distance from the detonation point. If the rock mass contains numerous structural discontinuities which reduce the competency and are subjected to explosive energy, irregularities can be dislocated resulting in failure or unstable slopes. Proper design and construction are necessary for stable slopes. It may be stated that our significant slope problems are due to poor construction.

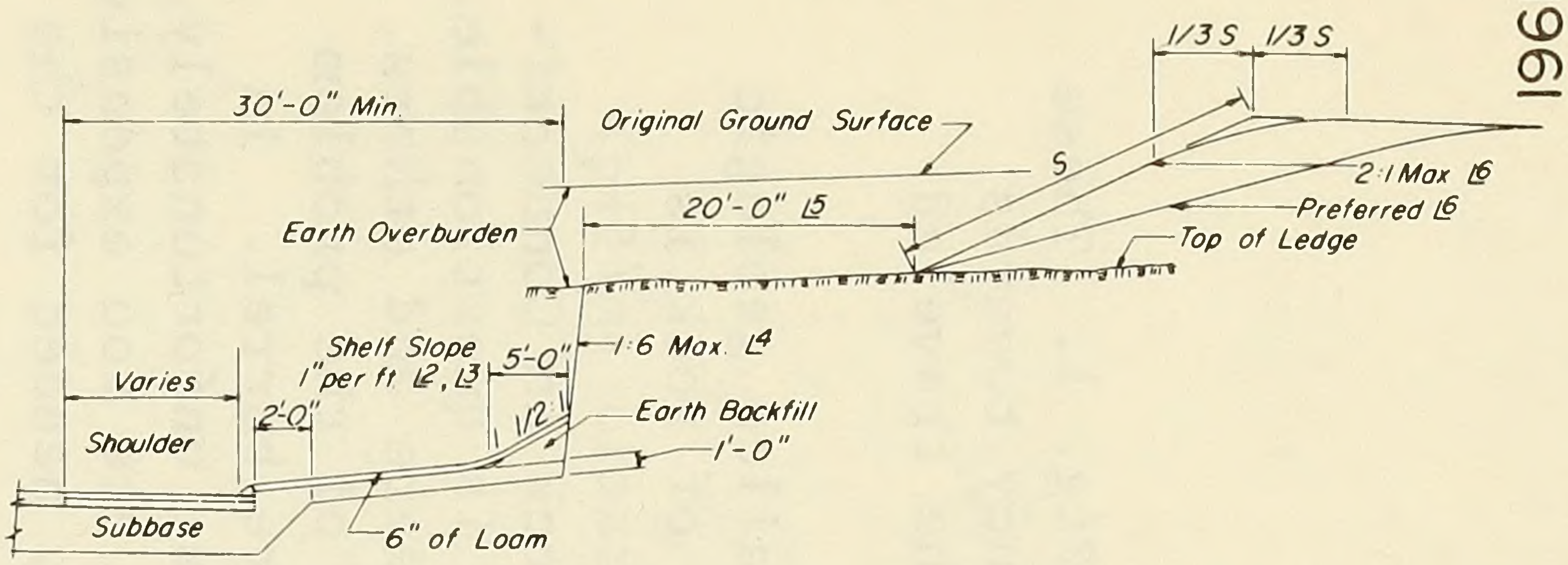


PARTIAL SECTION IN ROCK CUT WITH
SHELF SLOPE DOWNWARD FROM SHOULDER



PARTIAL SECTION IN ROCK CUT IN THE MEDIAN L7

FIG. I DESIGN STANDARD
CONN. HIGHWAY DEPT.
MISCELLANEOUS DETAILS
VARIOUS CLASSES



PARTIAL SECTION IN ROCK CUT WITH
SHELF SLOPE UPWARD FROM SHOULDER

1/ Fully rounded (Sodded or Paved) ditch if required. Ditch construction shall be 2" of sod on 4" of loam or 2" Bituminous Concrete (Curb and Paved Ditch Mixture) on 4" of additional subbase. Width of ditch to be determined by the designer. If curbing is required, entire shelf area is to be raised accordingly. Where ditch is utilized, the 5'-5' rounding is not required.

2/ In general, slope towards gutter where drainage is a minor consideration. Slope away from gutter: (a) on high side of superelevated curves, (b) where drainage is a major consideration, (c) where icing conditions are prevalent or (d) severe rock fall may occur.

3/ To be increased as rock competence decreases or as height of rock cut increases.

4/ To be decreased as rock competence decreases or as height of rock cut increases.

5/ When rock is encountered in the field at an elevation lower than anticipated during design, the width of the top shelf may be reduced from 20'-0" to a minimum of 5'-0".

6/ Slopes flatter than the 2:1 maximum are preferred and shall be used where site conditions allow. Generally a uniform rate of slope shall be held throughout a section. Where site conditions dictate a change from one rate of slope to another within a cut section, the length of transition shall be as long as possible to effect a natural appearing contour.

7/ Site conditions and aesthetic considerations will determine the desirability of the total removal of rock in the median.

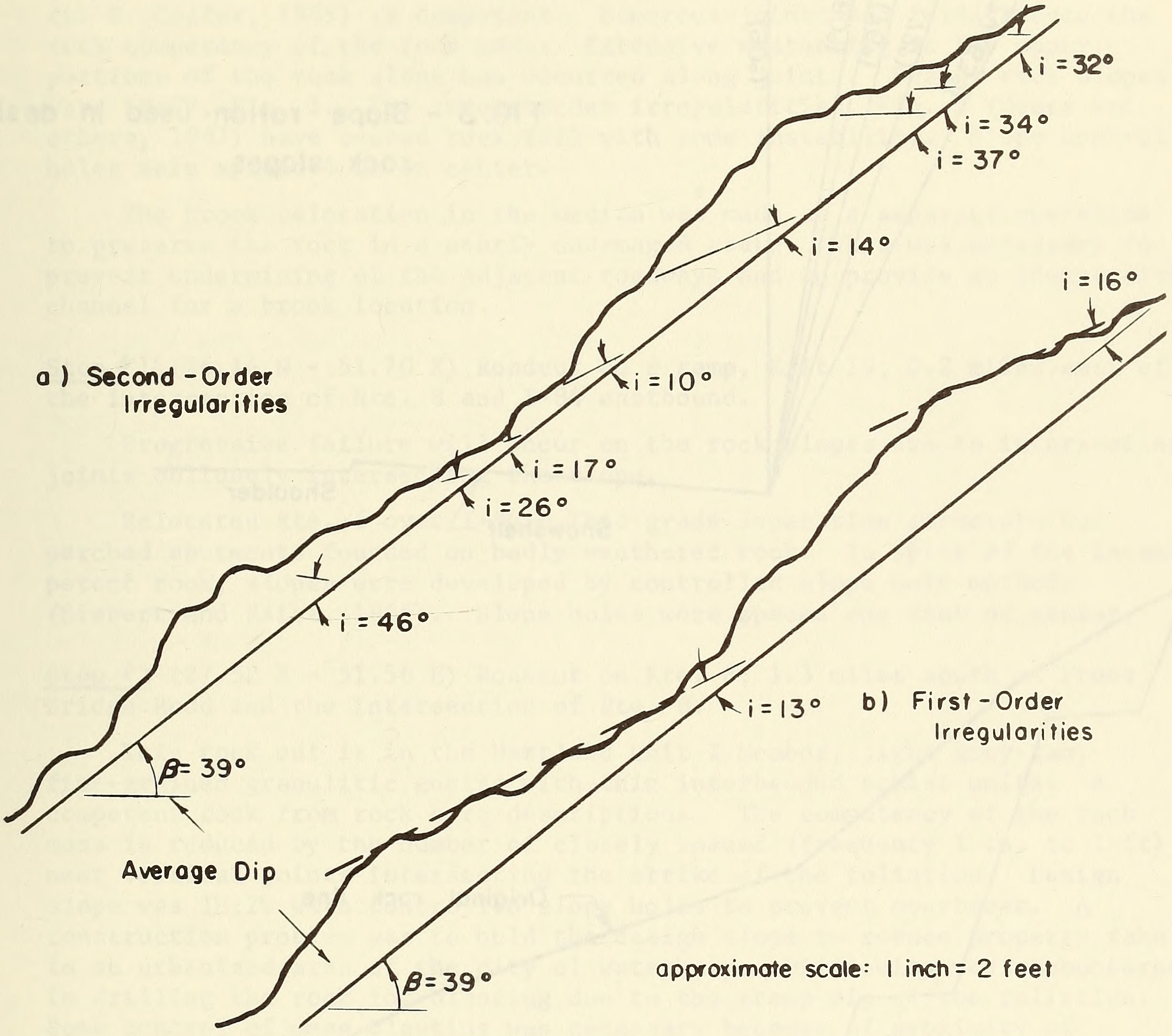


FIG. 2 AN EXAMPLE OF A ROCK SLOPE ILLUSTRATING FIRST AND SECOND-ORDER IRREGULARITIES, MODIFIED FROM DEERE (1967).

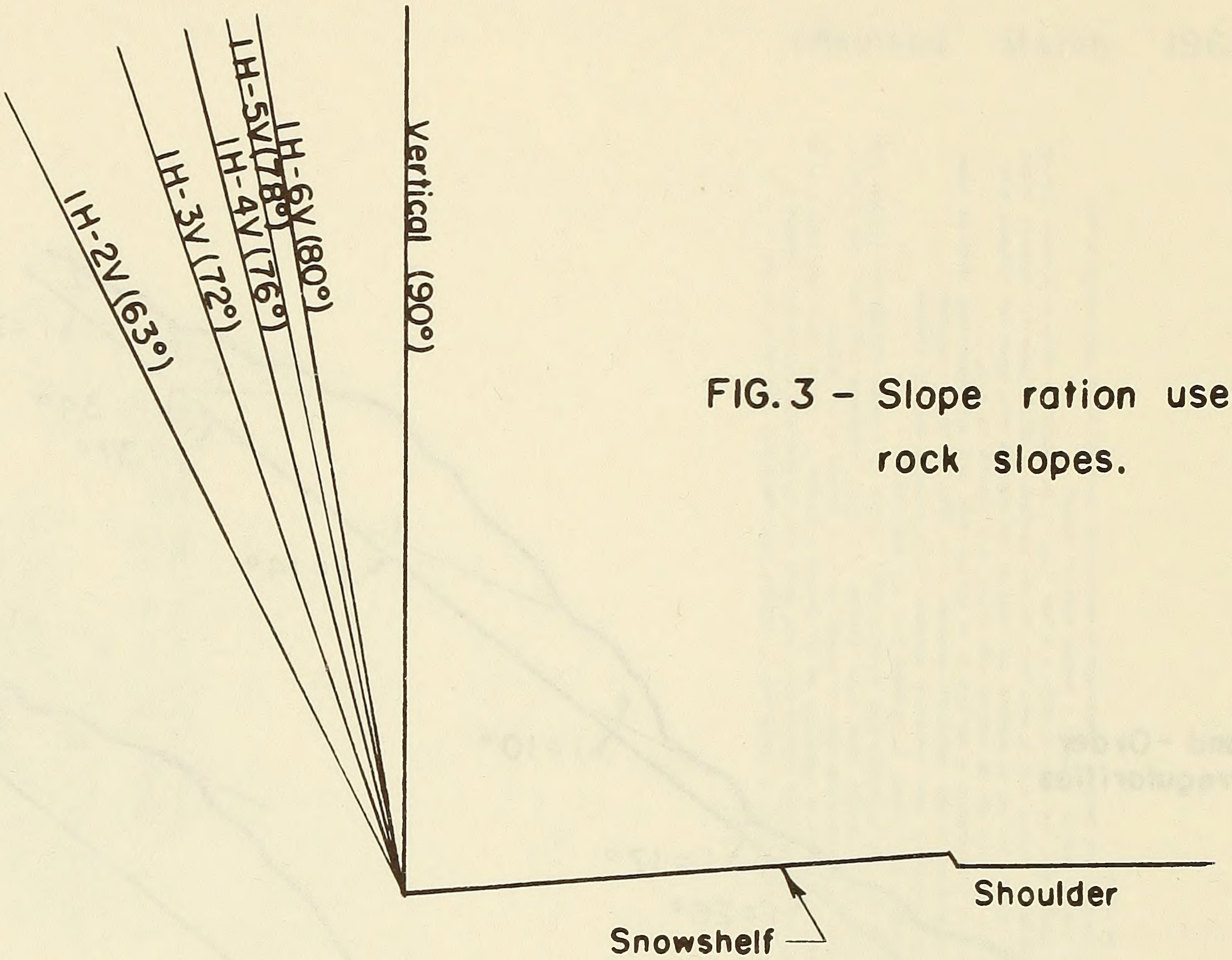


FIG. 3 - Slope ration used in designing rock slopes.

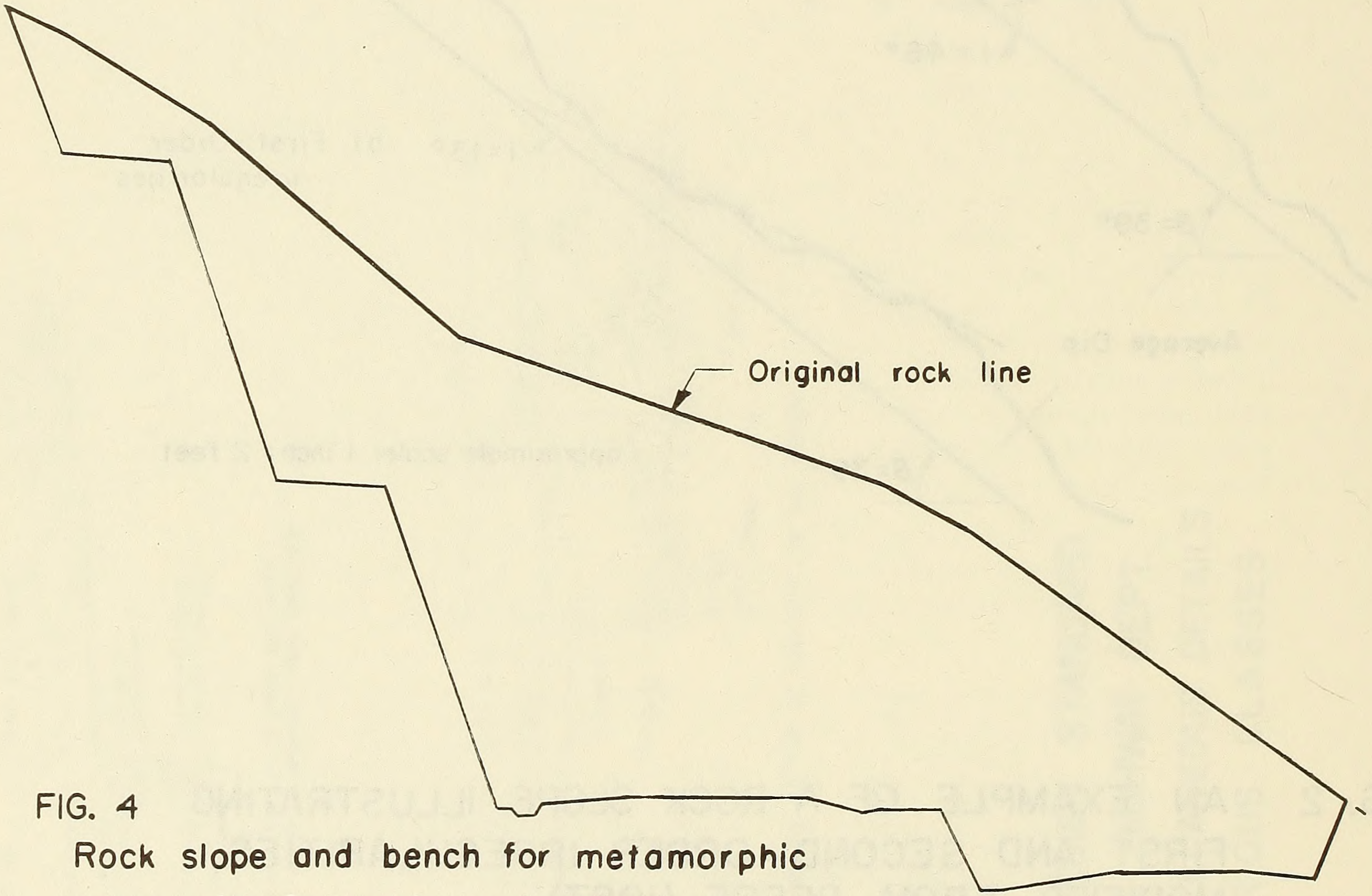


FIG. 4
Rock slope and bench for metamorphic rocks with favorable rock structure.

Stop #1 (26.14 N - 51.55 E) Roadcut on I-84; 0.3 miles east of the intersection of Rte. 8 and I-84 westbound lane.

This rock cut is in the Waterbury Formation. The rock type is a gneiss with interbedded thin schistose zones. The difference between the excavation axis and strike of the foliation is 70° dipping 70° with the excavation axis (Siebert and Raitt, 1967). Generally, the rock substance (D. F. Coates, 1965) is competent. Numerous joints and folds reduce the rock competency of the rock mass. Extensive weathering in the upper portions of the rock slope has occurred along joints. Design rock slopes were 1H:2V, Fig. 3. The second order irregularities, Fig. 2 (Deere and others, 1967) have caused rock fall with some instability. Slope control holes were spaced 4 ft on center.

The brook relocation in the median was made as a separate operation to preserve the rock in a nearly undamaged state. This was necessary to prevent undermining of the adjacent roadways and to provide an inexpensive channel for a brook location.

Stop #1A (26.14 N - 51.70 E) Roadcut on a ramp, Exit 19; 0.2 miles east of the intersection of Rte. 8 and I-84 eastbound.

Progressive failure will occur on the rock slopes due to intersecting joints obliquely intersecting the slope.

Relocated Rte. 6 over I-84 — This grade separation structure has perched abutments founded on badly weathered rock. In spite of the incompetent rock, slopes were developed by controlled slope hole methods (Siebert and Raitt, 1966). Slope holes were spaced one foot on center.

Stop #2 (27.52 N - 51.56 E) Roadcut on Rte. 8; 1.3 miles south of Frost Bridge Road and the intersection of Rte. 8.

This rock cut is in the Hartland Unit I Member, light grey-tan, fine-grained granulitic gneiss with thin interbedded schist units. A competent rock from rock core descriptions. The competency of the rock mass is reduced by the number of closely spaced (frequency 1 in. to 1 ft), near vertical joints intersecting the strike of the foliation. Design slope was 1H:2V with controlled slope holes to prevent overbreak. A construction problem was to hold the design slope to reduce property take in an urbanized area of the city of Waterbury. Difficulty was encountered in drilling the rock for blasting due to the steep dip of the foliation. Some control of mass blasting was necessary because of proximity of dwellings. Fall area is inadequate because of off-ramp. Rock has weathered very rapidly since exposure to the atmosphere.

Side note: Highway bridges and retaining walls are founded on friction and end bearing piles to protect against scour. There was some difficulty in driving due to coarse gravels in the floodplain.

Stop #3 (27.89 N - 51.33 E) Roadcut on Rte. 8; 0.2 miles south of Frost Bridge Road and Rte. 8 intersection.

Rock cut in The Straits Schist Member, Hartland Formation. This cut was designed with: a 1H:3V west slope with a 20 ft bench 60 ft above the roadway; a 1H:2V east slope with a 10 ft bench 60 ft above the roadway, and 110 ft maximum height above the roadway. The rock bench on the west slope was constructed with controlled slope hole methods 6 in. on center.

About one year after the cut was made but prior to the placing of pavement, the bench on the west slope was removed due to unstable conditions. This was a simple case of failure along faults and intersecting joints after removal of the lateral support from the rock mass. The fall area between toe of slope and the roadway is adequate to retain small rock fall. The cut slope is subject to progressive failure. The 10 foot bench on the east slope was not successfully constructed. Failure frequently occurs along fault surfaces dipping into the roadway. Smaller falls are due to second order irregularities and larger falls, to first order irregularities. Remedial rock excavation is necessary to stabilize both slopes. The rock substance is weak due to the high percentage of coarse mica. Competency is further reduced by the occurrence of first and second order discontinuities. To hedge against progressive failure the east slope should be cut back to a 1H:1V slope and the west slope to a 1H:1½V or 1H:1V. Total rock excavated in this cut, including ramps, was about 475,000 cubic yards. Controlled slope holes varied from 6 in., 3 ft, and 4 ft on center.

<u>Stop #4</u> Cut #2 (29.22 N - 50.99 E) Roadcut on Rte. 8, 2.3 miles north of the intersection of Frost Bridge Road and Rte. 8. See also Stops 16 and 17 of Trip D-5.

Two high rock cuts: Cut #1, maximum height 180 ft, and Cut #2, height 220 ft with 20 ft benches every 60 ft above roadway. Design rock slopes were 1H:3V. In Cut #2 a bench was eliminated during construction, but the shelf area at the toe of slope was not widened. Benches were designed to reduce rockfall, Fig. 4. Benches were not constructed to plans and no access was provided, hence they will become ineffective with time. Cuts are in The Straits Schist and the Hitchcock Lake Member. Rock competency is high, but reduced by second order discontinuities. A problem is rock slopes yielding along joints at the ends of the cuts due to changes in natural loads. The west slope of the lower roadway was active and some movement occurred after the cut was made. The number of cubic yards of rock removed from Cut #1 was 202,100 and from Cut # 2, 221,300; neither cut is over 500 ft long. Slope hole spacing varied from 2 to 4 ft on center.

These cuts will require remedial work to stabilize the benches, where joint intersections produce a plane of weakness.

<u>Stop #5</u> (29.81 N - 50.99 E) Roadcut on Rte. 8; 2 miles south of the intersection of Rte. 6-202 and Rte. 8.

Rock cut in the Reynolds Bridge Formation, a highly contorted gneiss. The rock substance is dense and competent, with few second order disconformities. All joints appear to be healed, yielding a strong rock mass. Average cut height is 80 feet. This is the best rock we will see for developing slopes. Slope hole spacing varies from 6 in. to 5 ft on center.

The front portion of the bench was distorted by subsequent mass blasting. Distortion occurred in the area of the stemming. Generally bench construction is difficult as mass blasting tends to lift the intersection of the face and bench floor. Depending on rock conditions, one-half of the bench may be lost.

Stop #6 (30.18 N - 50.22 E) Roadcut on Rte. 109; 1.5 miles west of intersection of rtes. 109 and 8. See also Stop 14 of Trip D-5.

The rock in this cut varies from schist to gneiss. The problems of developing stable slopes in rocks are similar to those seen at Stop #3. Here a sliding failure along a fault in the north slope illustrates the problems of stability of schist-gneiss sequences with structural discontinuities. The slide area was partially stabilized by removing some of the rock in front of the fault. This was not the best rock mechanics solution, but was the least expensive.

Stop #7 (30.49 N - 51.27 E) Roadcut on Rte. 8; 0.3 miles south of intersection of rtes. 6-202 and 8.

The rock cut on the northbound lane is in a pegmatite, schist, and gneiss sequence. The schist and gneiss were weathered. The rock cut has a gravel overburden which constantly supplies water to joints and foliation. Addition of water and exposure to the atmosphere have increased the rate of weathering. Numerous minor slides of weathered material have occurred. The dip of the foliation is 60° and the difference between the strike of the foliation and excavation axis is 80°. The dominant joint dips 30° towards the roadway and its strike is 50° from the excavation axis. All slopes were pre-split with good initial results. As weathering continues, failures occur as flows along second order discontinuities. The slope could be stabilized by reducing water infiltration and the rate of weathering without changing the cut slope.

Stop #8 (33.11 N - 50.08 E) Roadcut on Rte. 8; 1 mile south of intersection of rtes. 118 and 8.

This cut was made in a highly contorted schist and gneiss sequence without modern slope control methods. The difference between the excavation axis and the foliation or joint system is

foliation:	35°	(dip of 55° towards the roadway)
Joint 1:	65°	(dip of 65° into slope)
Joint 2:	30°	(dip of 55° into slope)

This is a case of the foliation being truncated by the excavation axis. In the lower portion of the cut slope, rock was left in place, acting as a buttress and holding some of the joint intersections intact. This rock cut has been made over nine years. Generally, it is stable and only a few falls have taken place. The excavation by older blasting methods left the rock intact. A fault-associated pegmatite occurs on the north end of the cut, and presents a potential zone of instability, but any failure should be minor.

Stop #9 (33.86 N - 50.05 E) at the intersections of rtes. 118 and 8.

This multiple cut is in a gneiss sequence and produces a three-dimensional view of the steeply dipping planar features in the rock. Dips of joints and foliation vary from vertical to 45°. The rock substance is competent, but the competency of the rock mass is reduced by the planar features. These two intersecting cuts were designed with a 1H:2V slope with a 20 ft bench 35 ft above the ramp. The relocated Rte. 118 also was designed with a 1H:2V slope and a transitional bench from the ramp which varies from 0 to 35 ft above the roadway. Controlled slope holes on 4, 5, and 6 ft centers were utilized by the contractor to control overbreak. Irregular slopes were developed due to incorrect slope hole spacings. Good slopes can be made in this rock if proper blasting techniques are used. Jointing and rock competency are generally favorable. This cut was designed under old standards. A larger snowshelf and steeper slopes should have been utilized, with the elimination of the bench.

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