

**WEST VIRGINIA DEPARTMENT OF TRANSPORTATION  
DIVISION OF HIGHWAYS  
DESIGN DIRECTIVE**

**DD-403  
GUIDE FOR DESIGN IN CUT  
SECTIONS THROUGH BEDROCK**  
*July 1, 2006*

Transmitted herewith for your information and use is the Guide for Design In Cut Sections Through Bedrock, dated July 1, 2006.

Attachment

**GUIDE FOR DESIGN IN CUT  
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## INTRODUCTION

This cut slope design guide for bedrock is general in nature and is intended to provide some of the philosophy for designing bedrock cuts. These guidelines are not inflexible. Design guidance for all situations is not to be expected.

This guide has been developed over many years and to provide some insight into past concepts that still hold true, excerpts from R. F. Baker's presentation at the "3rd Annual Symposium of Geology as Applied to Highway Engineering" held in February of 1952 are as follows:

"One of the most troublesome problems in the design of highways in West Virginia is the proper slope to be used in rock excavations. The problem is confused by several factors. One of these is the wide variety of sedimentary rocks that are present. The formations range in strength from the indurated clays of the Creston Red Shales of the Dunkard Series to the hard limestones of the Greenbrier formation and the equally hard Berea Sandstone of the Portage Series.

West Virginia like all other states must satisfy the tug-of-war between the construction and maintenance costs. If construction costs were no problem it would be simple to design a road that was maintenance free insofar as the rock cuts are concerned. The ideal solution, however, is to cut construction costs until there is no more excavation than necessary to achieve a condition requiring no maintenance."

## PRINCIPLES OF SLOPE DESIGN IN ROCK CUTS

Initially, it would be well to summarize some of the basic principles that are involved in arriving at the proper design of slopes in rock excavation. These principles are essential to a highway problem but may not be applicable to other types of problems.

1. The primary purpose of a good design is to eliminate or minimize maintenance costs due to the weathering of exposed bedrock. One should remember that if this purpose is not fundamental, there is no problem to designing slopes. The debris from the exposed face tends to (1) clog ditches that result in pavement failures, (2) block shoulders that lead to a more dangerous and less useable highway, and (3) produce rock-falls onto the pavement proper, leading to dangerous conditions for drivers and vehicles.
2. The constructed slope must be as steep as possible in order to keep construction costs at a minimum. This second requirement combined with the first forms the bracket for the design problem. One factor that influences the design is the relative costs of removing material by contract versus that of maintenance. In West Virginia the cost per cubic yard of excavation by contract ranges from 1/3 to 1/4 that required for maintenance forces to remove the debris. The figure will vary from state to state, but contract work will be less expensive due to the larger quantities involved with contract work, and the more localized nature of the earth moving.
3. The proper design of slopes is directly related to the physical characteristics of the bedrock. While there can be little argument with this statement, there is considerable question as to what measurable characteristic of the bedrock is most suitable for correlation with the slope design problem. In addition, the effects of climate, type of blasting, and erosion are related to the proper slope design. It is the opinion of the writer that there is no reliable technique for determining the ultimate slope of an exposed bedrock, unless there is an exposure of the same material in the same area and the exposure has been open for a period practically equivalent to the design life of the proposed grade.

Through experience, field reconnaissance, and the use of proper references, an adequate design can be completed. The need to observe and study existing cuts and natural slopes cannot be over emphasized.

## REFERENCE MATERIAL

The West Virginia Geological and Economic Survey has numerous maps and books that detail the bedrock characteristics of the State. Many counties have been surveyed by the Natural Resources Conservation Service, and reports have been compiled that describe the engineering characteristics of the soils.

The Federal Highway Administration sponsors research into rock and soil design. This research has been used to prepare manuals that recommend design procedures. One such manual, detailing rock slope design, is Rock Slopes: Design, Excavation, Stabilization, No. FHWA-TS-89-045. A useful reference to help in the designing of soil cuts is Landslides, Analysis and Control, Special Report 176, sponsored by the Transportation Research Board, National Academy of Sciences.

Rock and soil mechanics text books are excellent sources of design information.

## GEOLOGIC DESIGN INFLUENCES

### **Red Shales**

Cuts to be designed in the red shale beds of the State must be carefully considered, or there will be future maintenance problems. These shales can weather rapidly and contain weaknesses that are zones of possible failure. It is not unusual to find slickened surfaces from past movement. Slopes in this material generally must be 1:1 or flatter to ensure adequate performance. It is mandatory that areas of proposed cuts be field checked and existing slope areas be studied.

A large percentage of the red shale beds are found in the Division of Highways Districts 1, 3, 4, 6 and 7.

### **Sandstone**

Massive sandstone beds can generally be designed with steep slopes  $1/2:1$  and steeper. Seldom does the lithology and composition of the rock require slopes to be flatter. However, many times the structure of the rock will dictate flatter slopes.

Many massive sandstone beds are located in the counties south of the Kanawha and New Rivers.

### **Limestone**

Another major concern for the road designer is the limestone bedrock of the State. The eastern counties of the State - Monroe, Greenbrier, Pocahontas, Randolph, Pendleton, Berkeley and Jefferson Counties - contain major outcroppings of limestone. Cuts must be designed considering the solution channels and residual clay soils. These conditions must be evaluated in design to prevent post-construction failures that result from sink holes, slope collapse, and erosion.

### **Permian Period Bedrocks**

In the northwest area of the State, Jackson County north to Ohio County and eastward as far as Doddridge County, there is a collection of bedrock that is possibly of the Permian Period. The strata requires detailed study to ensure stable designs. Many of the shales are weak and the soils that form from them are prone to instability. Slopes must generally be flattened and benches used to catch debris. Designs generated for this area should be verified by field observations of existing slopes.

### **Lake Sediments**

Two areas of the State have major remnants of ancient lake deposits. These sediments are unstable, and many landslides have formed.

One area is located along the Monongahela, Cheat, West Fork, and Tygart Valley rivers. In addition, some lake soils may be found along smaller tributaries. These soils were deposited in an ice age lake, Lake Monongahela. The lake covered major portions of Monongalia, Marion, and Preston Counties. Isolated areas of sediments are found in adjacent counties.

The other major lake deposits are found along a valley that runs through portions of Kanawha, Putnam, Cabell, and Wayne Counties. These deposits resulted when Teays Lake

existed.

Proposed cuts for the areas where these lakes existed must be designed taking into consideration the highly unstable soils that occur there. A designer must ensure that evaluations have taken into consideration high clay percentages, low shear strengths, high liquid limits, and high moisture contents before a design is finalized. Slopes of 5:1 have failed in these deposits.

## **DESIGN OF CUTS IN BEDROCK**

### **Bedrock Type**

Four bedrock types are considered in the cut slope design. The types are not classified along distinct geologic standards; rather, they are typed according to slope angles considered appropriate. Thus Type 1 encompasses rock that will stand on a 1/6:1 slope. Type 2 is rock that can be cut at 1/2:1. Type 3 is rock that will stand on 3/4:1. Type 4 is rock that will stand on 1:1.

**Type 1** - Hard and Medium-Hard Limestone and Sandstone and Hard Shale Compressive Strength: 8000 and above psi.

This bedrock occurs in massive and laminated formations varying in the degree of dip. In some instances, soft seams of other types of material, such as coal or shale, may occur.

Some types of shale are harder and more resistant to weathering than medium-hard sandstone. These shales are basically located in the eastern portion of the State and are in Ordovician, Silurian and Devonian time periods. The Slake Durability Index of these shales should be above 95 percent.

**Type 2** - Soft Limestones and Sandstones, Medium-Hard Shale and Siltstone or Interbedded Combinations. Compressive Strength: 4000-8000 psi.

This classification encompasses a large percentage of the material encountered in West Virginia. In many areas of the State, coal and soft shale seams are prevalent in these formations.

The Slake Durability Index of the shale in this type would be between 51 and 94 percent.

**Type 3** - Soft Shale Interbedded with Siltstone, Sandstone or Limestone. Compressive Strength: 1000-4000 psi.

The shale beds in this bedrock are not massive and the interbedded, harder bedrock may vary significantly in thickness. Without the interbedded seams of siltstone, sandstone or limestone, this would be a Type 4 bedrock.

**Type 4** - Soft and Very Soft Shale. Compressive Strength: 1000 psi.

These shales, especially the very soft ones, are considered indurated clays by some when fissility is lacking. When soaked in water, they usually disintegrate into particles quite rapidly. The Slake Durability Index for these shales would be between 0 and 50 percent.

The beds of this rock are usually massive and do not contain interbedded seams of siltstone or sandstone. However, there may be seams or harder shales.

### **Dip**

A major portion of the State's bedrock design will be in areas where the dip is flat, usually 5° or less.

There are localized areas within the southern, central and northern parts of the State where the bedrock dip may exceed 5°. In the Eastern Panhandle and along the eastern border there are extensive areas where the dip is in excess of 5°.

When the bedrock is flat, the design slope ratios and benches will generally follow the design guide chart.

On projects that contain bedrock with dips that are in excess of 5°, it will be necessary to determine the relationship between the dip and the roadway centerline. The orientation of these features will influence the design.

Bedrock dipping into the roadway may require the use of a slope ratio that equals the dip angle, otherwise rock slides may occur. In a cut slope that contains bedrock dipping away from the roadway, it may be possible to more nearly follow the design guide chart. It should be kept in mind that the cuts made in dipping bedrock may have rough slopes and irregularly shaped benches.

The angle between the dipping bedrock and the roadway can occur at a multitude of values, therefore, it may be necessary for the designer to devise several alternatives.

### **Fractures**

When faults and joints are encountered, they must be considered in the design. In many cases the design may be treated as in dipping bedrock. Also, reference should be made to rock mechanics manuals. Several have been sponsored by the FHWA and are in print.

### **Benching and Backslopes**

Slopes designed on a ratio of 2:1 or flatter normally will not require benches. The main purpose to include benches would be to catch boulders that might roll down the slope.

Slopes designed on a ratio of 1½:1 generally should have a bench near the roadway grade. However, if it is felt that eroded material from the slopes will be minimal and rolling boulders will not be a problem, the low bench could be deleted. Intermediate benches may be necessary if strata are present from which boulders could be formed. These benches should be located along the base of the boulder generating zones.

Generally, slopes designed with ratios of 1:1 and steeper should have a bench 5 feet above the ditch grade and at intermediate intervals. There may be exceptions to this, especially if cuts are being designed in hard to median hard rock. In these cases the bench 5 feet above the ditch may not be required. This bench may be set at 5 feet above the ditch grade regardless of the material involved at the discretion of the Engineering Division.

Bench levels paralleling the road may be essentially horizontal and controlled by backslope height to bench width ratios or may be variable in elevation when controlled by lithology, feature attitudes, or roadway grade changes. The benches should be sloped toward the roadway on a slope of 15:1. There may be exceptions, however, these would be infrequent and would be handled as individual cases.

### **Bench Elevation**

The height of the first bench above the ditch grade will generally be 5 feet. However, there are times when this height will be controlled by the contact surface between different strata. These contact surfaces may be the result of hardness, lithology, feature attitudes, etc. Also, there are times when the condition may be the result of a changing roadway grade. Geometrical constraints may require a bench 5 feet above the ditch even though a contact surface dictates otherwise, for example a bench to ensure sight distance. See the design guide chart for general conditions.

### **Bench Width**

Benches are needed to provide impact areas to reduce rock rolling and to retain material weathering or sloughing from the slopes.

The first bench above the ditch and intermediate ones should not be less than 15 feet wide when used on arterial routes. On local service and collector routes the minimum width can be 10 feet.

The width of a bench used at the base of the overburden layer, along the top of the cut, may be a minimum of 10 feet for all route types.

### **Backslope Height**

The height of slopes between benches, above the first bench, is generally held to a maximum of 50 feet. However, under certain conditions this interval may be extended to 60 feet or even 70 feet. This should only occur for limited intervals, along the roadway, when massive, competent bedrock is encountered or when slope ratios are 1½:1 or flatter.

The backslope vertical height in relation to bench width should be calculated using the following ratios:

<b>Rock Type</b>	<b>Bench Width</b>	<b>Backslope Vertical Height</b>
1	1	2½
2	1	2½
3	1	2¼
4	1	2

The backslope height obtained by use of this calculation should be rounded up to the next even value, if odd or fractional values are obtained.

Since changes in rock type and height of cut make it difficult to adhere to any exact ratio, the guides are suggested as an aid in determining a stable slope with minimum maintenance.

## **Overburden Zone**

### **General**

Materials in this zone are soils and bedrock - weathered or unweathered - that possess the stability characteristics of soil.

Preferably slopes in the overburden should be on a ratio of 2:1; however, 1½:1 ratios may be adequate in dry overburden and open terrain. The use of slopes flatter than 2:1 are not uncommon and are required in the soil portion of the overburden with weak strength parameters. The deciding factors in choosing a slope ratio will be the condition of the overburden and its properties, at the time of design, as well as that estimated for the future.

The strength parameters or the location of an overburden deposit may mandate that a detailed investigation and analysis be completed before a design is recommended. Colluvium, especially in those areas where subsurface seepage exists, requires detailed analysis. Certain regions that contain Permian red shales, lacustrine deposits, coal refuse, waste sites, reclaimed land, poorly drained soils, soft or fissured clays, impermeable soils, and landslides - active or dormant - will require detailed study before slope ratios are decided upon.

A safety factor of 1.25 is generally the minimum value acceptable for long term stability and is used for collector and local service class roads and areas where failure would not damage existing facilities of substantial cost or significance. On roads of higher class - arterial - or in areas where failure might cause damage to substantial facilities, a safety factor of 1.50 should be used.

### **Slope**

When possible, the slope in the overburden should be on a 2:1 ratio. Flatter slopes should be considered if there is any possibility of instability. When the length of the backslope would become excessive and some sloughing could be tolerated, a ratio of 1½:1 would be acceptable. A rule of thumb definition for excessive backslope would be "a slope above the bench or the break point of a ratio break/bedrock to soil that is about 100 feet in length."

In some designs, it may be necessary to use a slope ratio steeper than 1½:1. This condition would occur where the existing ground surface is steeper than or almost equal to 1½:1. Steeper slopes would be considered when excess sloughing would not create hazardous conditions or extensive maintenance. If the steeper slopes were not used, hillside scalping would occur. These cases would be considered as economic risk areas. Sloughing of overburden would be expected, but the benches would accommodate the material with some maintenance expected.

### **Design Type**

In most overburden design situations, one of three methods will generally be recommended for use: (1) benching; (2) ratio break/bedrock to soil (broken backslope); or (3) rounding.

Rounding is the least desirable treatment for overburden areas. Whenever possible, the ratio break/bedrock to soil should be used in lieu of the rounding. Rounding could be used when overburden is less than 5 feet deep.

If the overburden at the top of the rock cut is 5 feet to 10 feet deep, consideration should be given to using a ratio break/bedrock to soil design.

When the overburden at the top of the rock cut is over 10 feet thick, the design should generally consist of a 10-foot wide bench with a backslope on a 2:1 ratio, whenever possible.

When the overburden at the top of the rock cut is more than 10 feet thick, it may be necessary to analyze the stability of the overburden before a design is recommended. Generally, benches are necessary along with flat backslopes. In these situations, the overburden bench may have to be more than 10 feet wide.

### **Table of Design for Cut Sections Through Bedrock and Overburden**

This table is an outline that should be followed when designing bedrock cuts. All situations are not covered, but with its use, observations of existing cuts, and the application of the state of the art soil and rock mechanics principles, an adequate design will be possible.

Upper case letters with lower case letter subscripts are used to identify slope height (H), backslopes ratios (S), and bench width (W). Subscript lettering for the design characteristics will be between a and r. The subscripts between s and w are reserved for benches and slopes in the overburden.

The base of the cut design may start from a V-ditch; however, hydraulic or geotechnical requirements may dictate alternate widths. The table outlines the use of a 4-foot wide ditch. Ditches wider than 4 feet are an exception for geotechnical reasons, and are designed on a case by case basis.

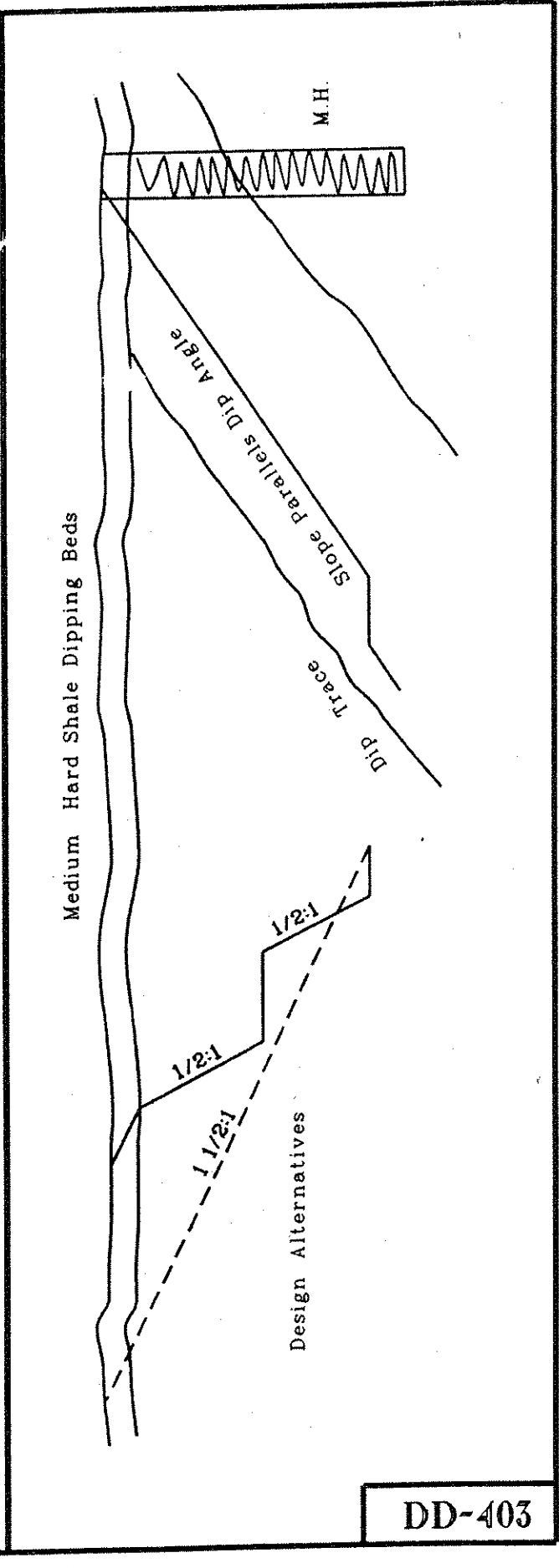
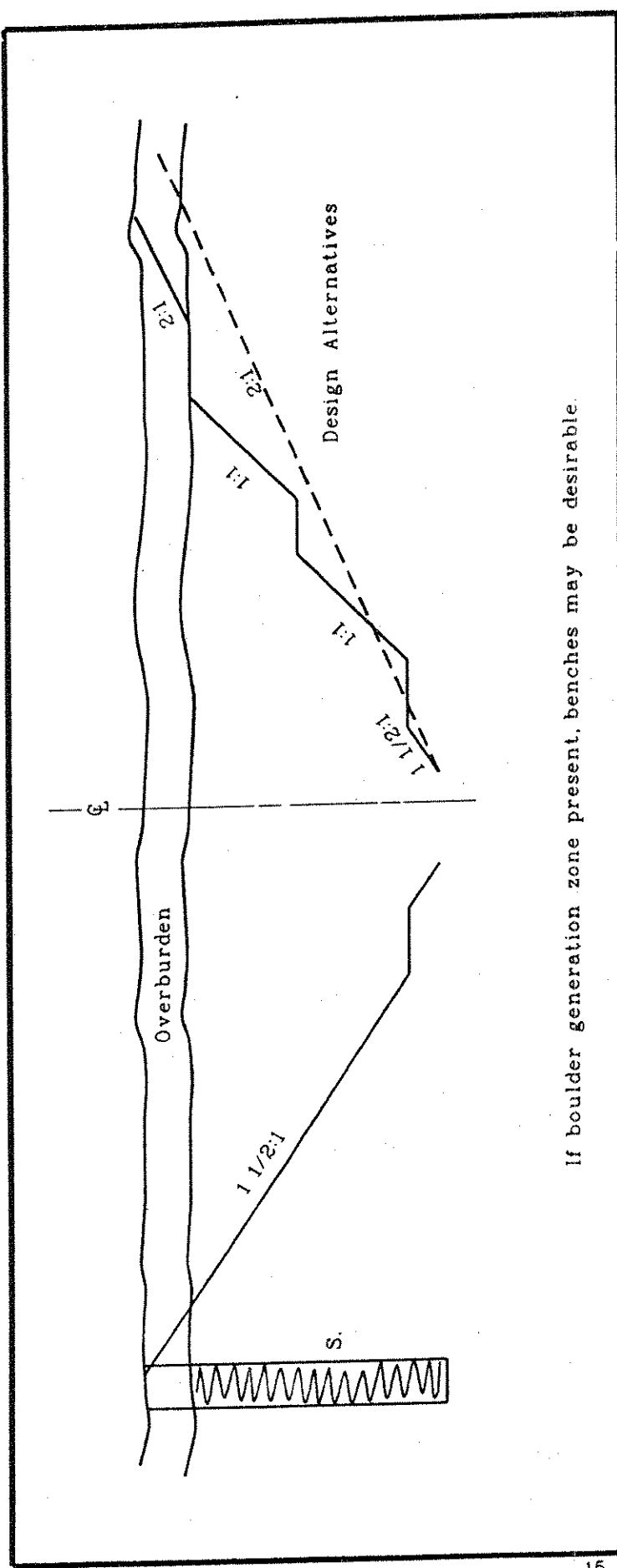
Bench widths are designed considering both backslope heights and type or roadway. Higher standard roads with high traffic volumes will require wider benches.

TABLE FOR DESIGN OF CUT SECTIONS THROUGH BEDROCK AND OVERBURDEN							
TYPE OF BEDROCK	HEIGHT OF CUT IN FEET	HEIGHT BETWEEN BENCHES IN FEET		WIDTH OF BENCHES IN FEET		BACKSLOPE RATIO HORZ./VERT.	
		Ha <sup>1</sup>	Hb Hc etc.	Ws (min.)	Wb Wc etc. <sup>2</sup>	Sa	Sb Sc etc. <sup>4</sup>
1. Medium hard to hard sandstone and limestone, and hard shale	over 50	5-50	50±	10	10-20	1/6:1	1/6:1
	under 50	-----	-----	10	-----	1/6:1	-----
2. Soft sandstone, medium hard shale, soft limestone, siltstone or an interbedded combination	over 50	5-25	50±	10	10-20	3/4:1	½:1
	25-50	5-25	20-45	10	10-20	3/4:1	½:1
	under 25	-----	-----	10	-----	1:1	¾:1
3. Soft shale interbedded with siltstone, sandstone, or limestone	over 50	5	45± <sup>3</sup>	10	10-20	1:1	¾:1
	25-50	5	20-45	10	10-20	1:1	¾:1
	under 25	-----	-----	10	-----	1 ½:1	-----
4. Soft shale <sup>5</sup>	over 45	5	40± <sup>3</sup>	10	-----	1 ½:1	1:1
	25-45	5	20-40	10	10-20	1 ½:1	1:1
	under 25	-----	-----	10	-----	2:1	-----

**NOTE: SEE NARRATIVE AND FIGURES FOR DETAILS.**

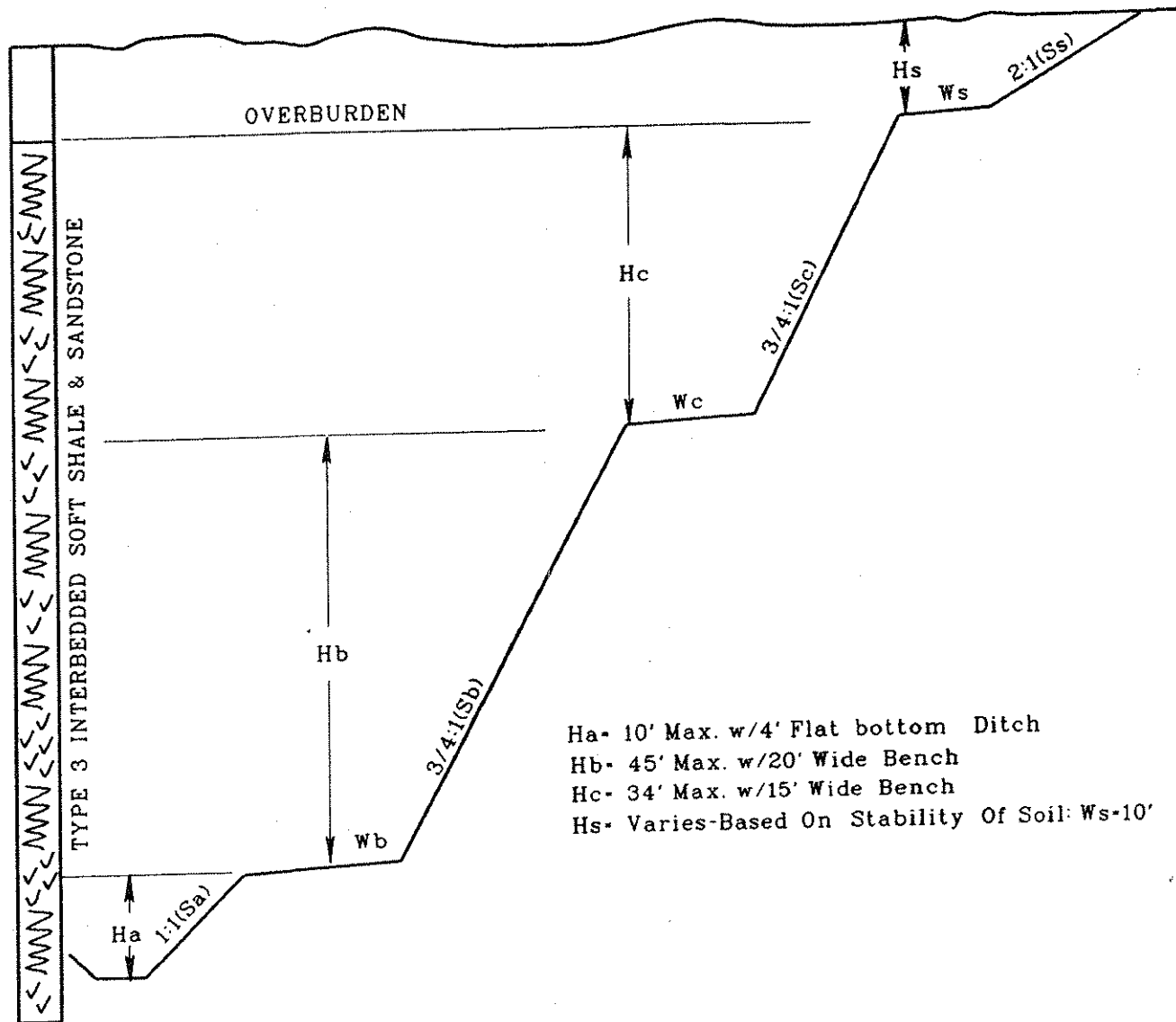
- For Types 3 and 4, five feet may be added to Ha when a 4-foot wide roadway ditch is used. Use a minimum 4-foot roadway ditch for Type 1 when Ha is over 25 feet.
- Roads classified as arterial should have benches designed as follows: When the backslope above the bench is 25 feet or less, use a minimum 15-foot wide bench. When the backslope above the bench is greater than 25 feet, use a minimum 20-foot wide bench. Lower standards may be used on individually determined cases.

3. In individually determined cases, the slope may be daylighted on a 1½:1 or flatter ratio for heights in excess of noted maximums.
4. The slope ratio in the overburden (Ss) should be 2:1, whenever possible.
5. Alternate designs acceptable (See narrative and figures).



If boulder generation zone present, benches may be desirable.

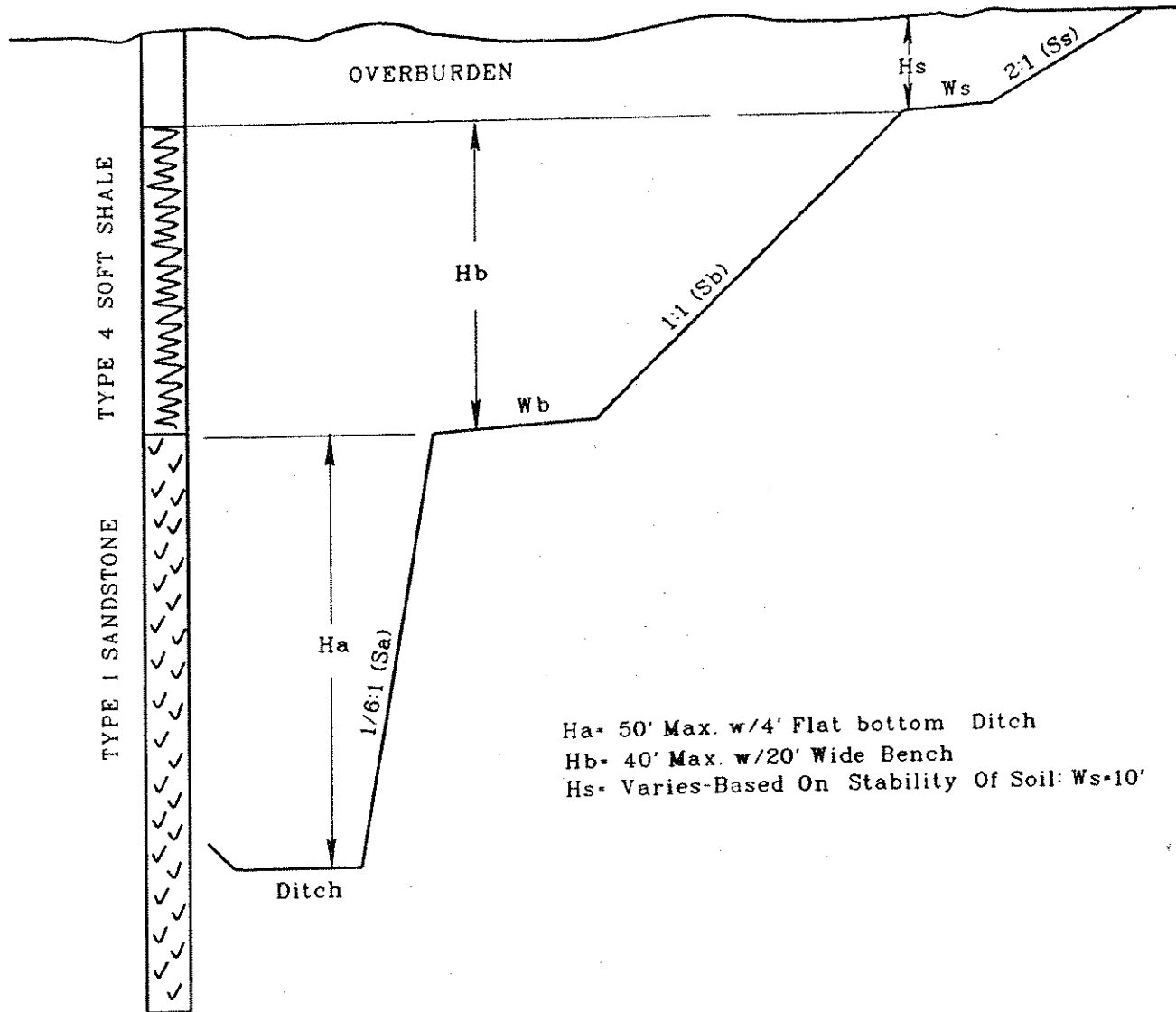
# TYPE 3 BEDROCK HORIZONTAL BEDDING



- Ha- 10' Max. w/4' Flat bottom Ditch
- Hb- 45' Max. w/20' Wide Bench
- Hc- 34' Max. w/15' Wide Bench
- Hs- Varies-Based On Stability Of Soil: Ws-10'

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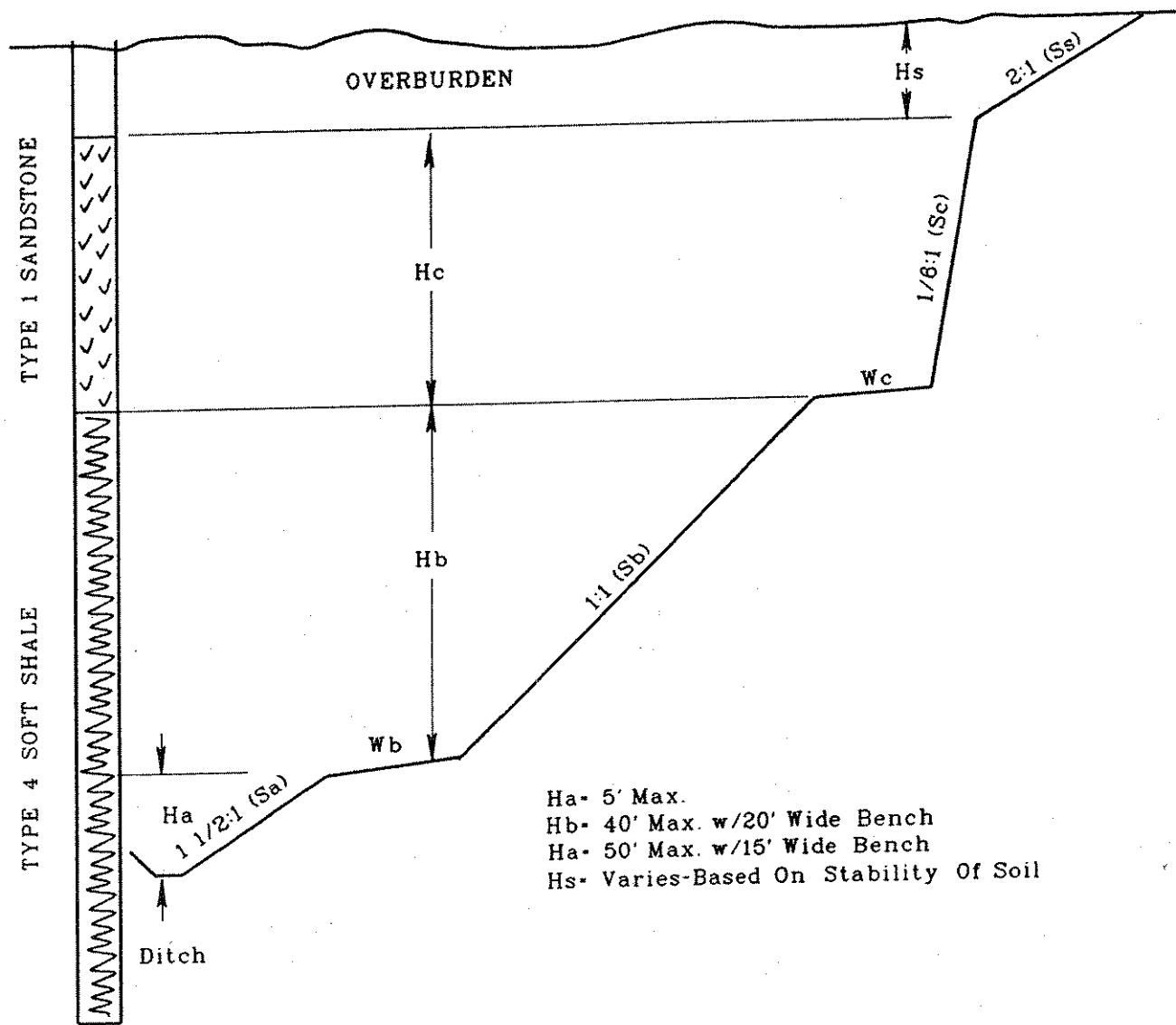
# TYPE 1 & TYPE 4 BEDROCK HORIZONTAL BEDDING



$H_a$ - 50' Max. w/4' Flat bottom Ditch  
 $H_b$ - 40' Max. w/20' Wide Bench  
 $H_s$ - Varies-Based On Stability Of Soil:  $W_s$ -10'

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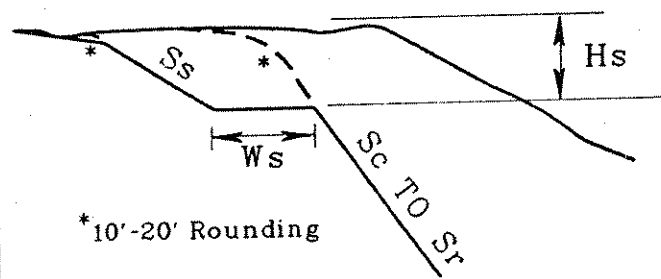
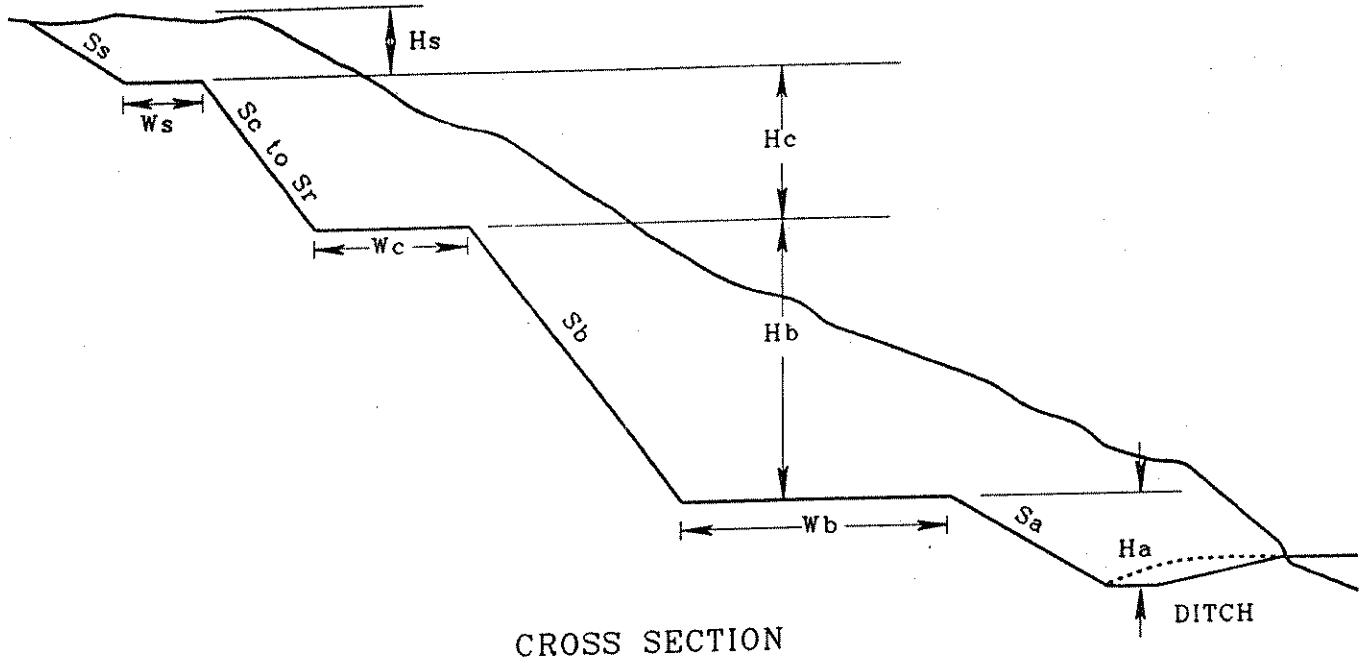
# TYPE 4 & TYPE 1 BEDROCK HORIZONTAL BEDDING



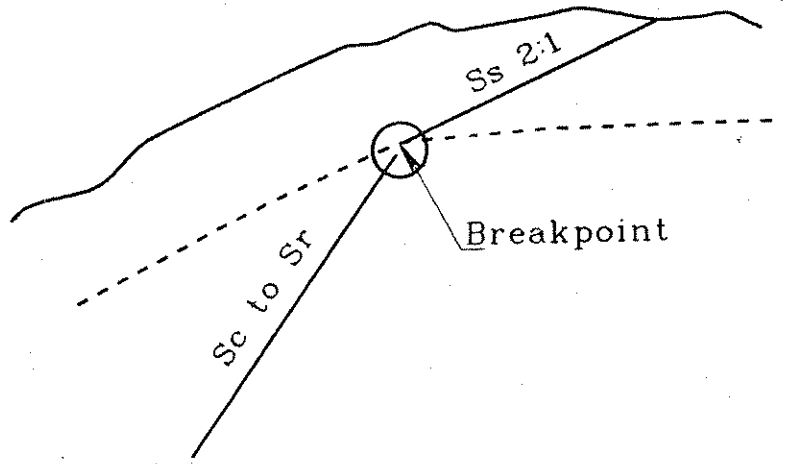
Ha- 5' Max.  
 Hb- 40' Max. w/20' Wide Bench  
 Ha- 50' Max. w/15' Wide Bench  
 Hs- Varies-Based On Stability Of Soil

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# DESIGN OF CUT SECTIONS THROUGH BEDROCK & OVERBURDEN

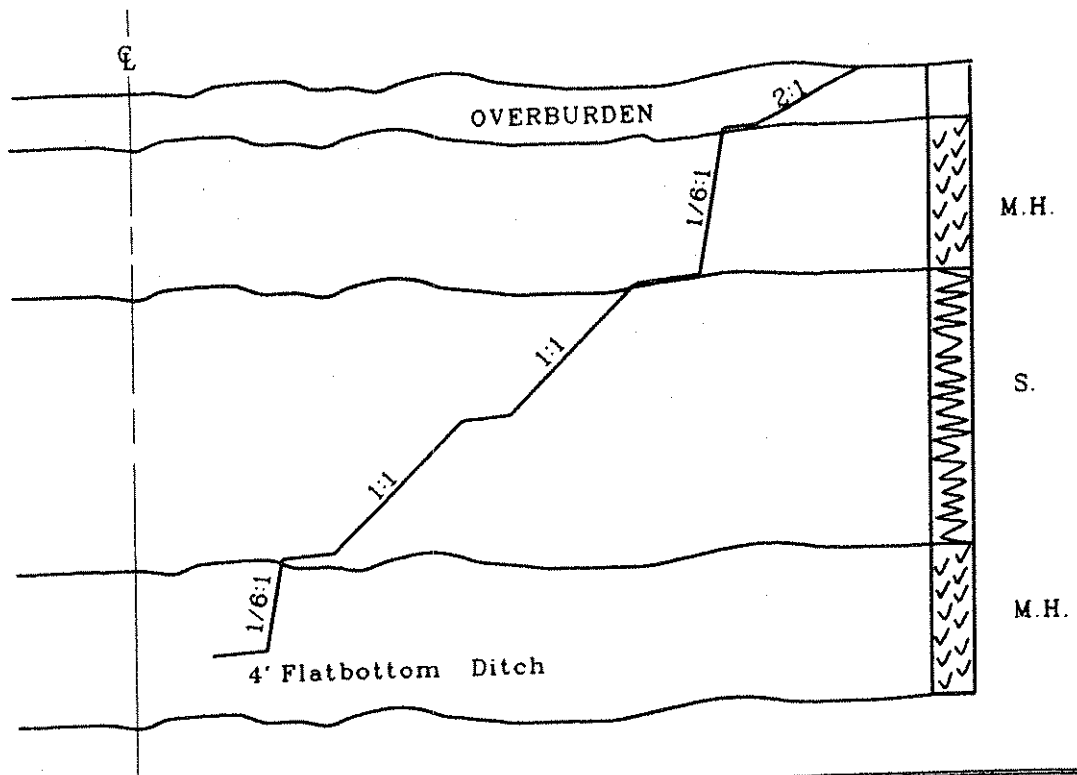


\*10'-20' Rounding

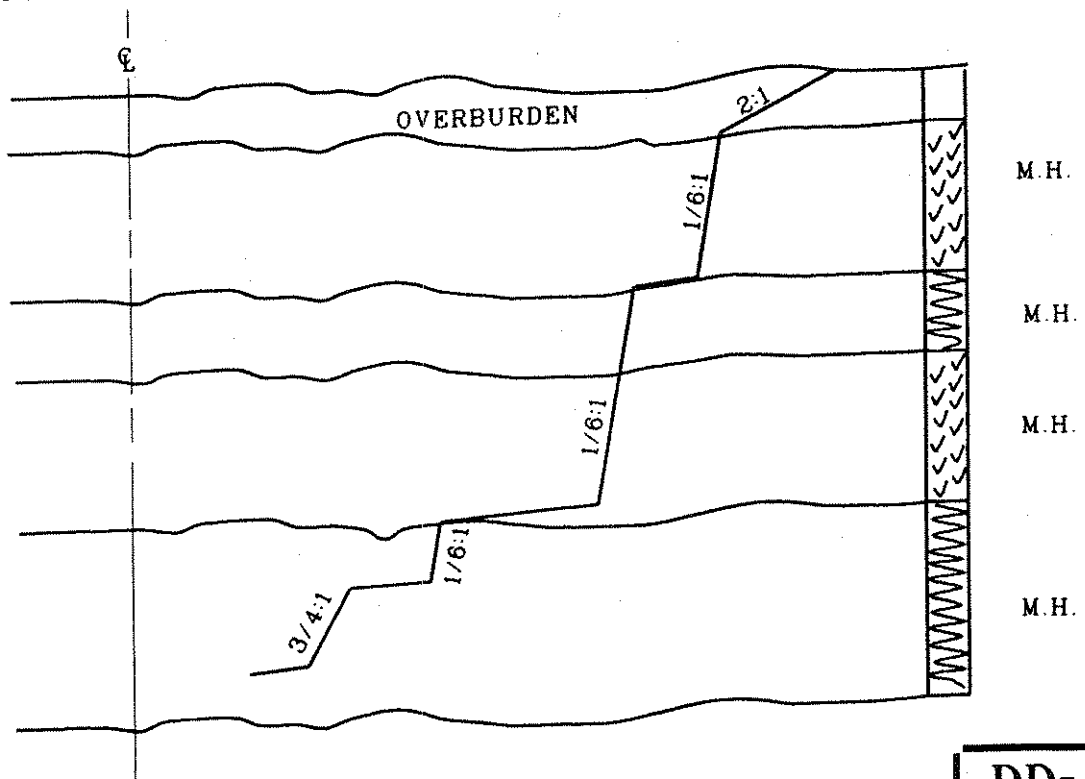


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# SANDSTONE & SHALE HORIZONTAL BEDS



# SANDSTONE & SHALE HORIZONTAL BEDS



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