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ENGINEERING GEOLOGY OF THE HOGBACK MONOCLINE: A NEW APPROACH TO BACKSLOPE DESIGN IN TILTED SEDIMENTARY ROCKS

by

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Backslope design is an important facet of engineering geology and one in which little progress has been made during the past several years. This is particularly true where slopes are in rock. Soil mechanics has gained stature through acceptance of shear testing and computer analysis of proposed designs. Despite the demands of modern highway systems for longer, deeper cuts, rock slope design has remained a static science, dependent solely on field observation and devoid of innovation. Rarely has a new approach to backslope design been developed, particularly a design which blends geological knowledge with modern construction techniques to maximize stability through efficient use of intraformational engineering characteristics.

In June, 1972, the Geology Section of the Central Materials and Testing Laboratory of the New Mexico State Highway Department was requested by Technical Services and Engineering to design a backslope for the reconstruction of U.S. 550 through the Hogback monocline at the San Juan River near Waterflow, New Mexico (fig. 1). The design which evolved and is proposed for construction may have been used in other states but is unlike any other within New Mexico.

U.S. 550 is one of the more heavily traveled two lane routes in the state. It connects the sprawling Ute and Navajo Indian reservations with Farmington, the economic hub of the Four Corners area. Heavy trucks of the petroleum and mining industries vie with farm tractors and even horse-drawn wagons as traffic impediments.

The main construction problem between Shiprock and Farmington occurs at the Hogback monocline, where a high ridge of steeply-dipping sandstone, shale and coal has forced the highway directly against a large irrigation canal adjacent to the San Juan River. Diversion structures and gates involved in the irrigation project would make relocation of the river and canal expensive; therefore, it was judged less costly to relocate the additional lanes of traffic into the ridge.

The Hogback monocline marks the northwestern limits of the San Juan basin in this area. It strikes approximately north-south and dips 40° east. Two formations are encountered in the monocline, the Cliff House Sandstone and the underlying Menefee Formation. Both are members of the Mesaverde Group of Cretaceous age. The Cliff House beds in the cut consist of two, platy to massive, tan, medium-grained, siliceous sandstones separated by 34 feet of interbedded tan sandstone and gray, gypsiferous, fissle shale. The upper, thin-bedded sandstone is 45 feet thick; the lower sandstone is 32 feet in thickness. As separated here, about 550 feet of uppermost Menefee will be cut. The upper 67 feet of the Menefee is a relatively competent, tan to gray and orange sandstone and siltstone interbedded with gray carbonaceous shale. Beneath this, and grading into it, is a less competent layer of 195 feet of friable, gray, carbonaceous shale; a sandstone tongue lies near the base of the shale. This tongue is of special interest to the Highway Department because it is one of the few sandstones in the state known to pass the Los Angeles abrasion and

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Figure 1.
Eastward approach of U.S. 550 toward dip slope of Hogback monocline.

the magnesium sulfate soundness (freeze-thaw) tests for construction aggregate. Further south, in the interior of the aggregate-poor San Juan basin, this recent discovery assumes major proportions. The unit is irregular, both in thickness and hardness. The harder beds are a gray orthoquartzite, weathering dark brown, the less indurated portions grade to tan. In the cut section, the bed was not recommended for presplitting and benching because of its discontinuity. Beneath the tongue, occurs a 40-foot layer of gray, siliceous, fine to medium-grained sandstone containing spherical calcareous nodules. The remainder of the cut is comprised of about 250 feet of gray to black, carbonaeous shale and coal seams, containing a few thin sandstone lenses.

Initial discussion with departmental personnel indicated dissatisfaction with the performance of past designs in large cuts of steeply-dipping, interbedded sediments. Usually, such designs have included slopes graded to the more prominent bed, or rock type, within the cut, with horizontal benches cut at intervals to catch talus and debris from less competent beds unable to stand at steep angles. Differential weathering and undercutting of overlying beds have more often resulted in displacement of large talus blocks and eventually caused complete breakdowns of the slope. Occasionally, backslope failures have resulted from the low shear strength of incompetent materials.

It was decided that a good slope design should utilize the maximum inherent strength of each bed, consistent with a reasonable factor of safety, and yet it must not oversteepen or overstress the weaker beds. Any practical design requires that it must be capable of being described in the project plans, laid out by project personnel, and readily constructed by normal construction techniques.

Modeling clay was used to explore a number of designs. One model included a new concept of presplitting vertical faces in the competent sandstone beds; benches constructed on top of each sandstone bed, and each bench sloping with the dip of the beds. Slopes in the less competent shale and coal beds were flattened sufficiently to allow them to support their own weight plus the weight of the overlying formations. To give the underlying beds "room" to lay back, each layer was skewed or flared away from the road as its lower surface rises above grade. The angle of skew was dependent upon the slope required in the underlying beds, the thickness of the underlying beds and the dip and width of any benches desired on underlying competent layers.

A field inspection was made of the beds in this particular cut, which are well exposed along the present roadway. It was decided that three layers, the two massive sandstone beds of the Cliff House Sandstone and the sandstone bed within the Menefee could be presplit.

The interbedded sandstone and shale bed separating the sandstones of the Cliff House and the upper 67 feet of the sandstone and shale considered to be the top of the Menefee were designed with 3/4:1 slopes. The remaining shale and coal were judged to be safe at a 1:1 slope, for three reasons: (1) the extreme arid climate of the area, (2) sandy zones existing within the section, and (3) because most precipitation would be diverted by the benches above and would flow with the dip (on the benches) to the ditch section. An important factor in the design of the cut slopes was the relatively mild fracturing of the subject beds in the cut section. Apparently these beds are less disturbed than might be anticipated because they lie in a narrow band between the synclinal fold to the east and the anticlinal fold to the west. The inclination of the beds actually has been added to their competence.

The bench at the top of the lower Cliff House sandstone bed was limited to 15 feet in width since relatively little pressure is exerted on it. The bench on the Menefee sandstone has more potential for problems; accordingly, it was designed with a width of 80 feet. This width also will allow flexibility in construction of the cut, in as much as errors in slope excavation can be absorbed within it.

The design and illustration of plans for the project proved not to be overly difficult, despite several complicating features; a rising grade, a curving centerline not perpendicular to the strike, and the multiplicity of slope changes and bench widths. A detailed topographic map (fig. 2) was supplied by the Photogrametry Section and centerline cross-sections were obtained through the Computer Section. Using previously obtained geologic data, a geologic cross-section (reproduced as fig. 3) was prepared. This aided in locating the lines for presplit sites, which was done by connecting the critical or hinge points. These points are located above the stations where the rock at grade level changes slope requirements. At these points, centerline cross-sections were developed using the vertical apparent thickness of the beds encountered. A 1:1 slope will, of course, retreat 10 feet horizontally for each 10 feet of rise, and a 3/4:1 slope will retreat 7.5 feet for each 10 feet of rise. The topographic map aided in determining the limits of the excavation. The lines for drilling the presplit holes were plotted on the topographic map. A template was made for centerline cross-sections illustrating the cut profile at 50 foot intervals. The topographic map, geologic cross-section, centerline templates and artist's rendition (fig. 4) are included in the plans.

A few engineers have questioned the proposed design. The major objection seems to be that the design is unusual and difficult to visualize and would place an undue or impossible burden upon project personnel. We do agree that it is an unusual design; however, the hogback is a unique geologic structure and a satisfactory slope design demands a unique approach. Other objections were related to the possibility of overbreak during presplitting and blasting, and to the difficulty of access to the top of the ridge with drilling equipment. These problems do not result from, nor are they limited to, this design. In any elevated situation equipment must be secured on the height of a ridge. In the case of improperly presplit or overshot slopes hazardous and expensive rockfall may certainly result or, as has happened elsewhere in the state, a redesigning of the slope may become necessary, at great expense, to a much flatter angle to regain stability.

The limits to which this design can be adapted have not been fully explored. It has been found that beds dipping more than 55° will require excessively deep holes for presplitting because of the exaggerated vertical thickness of the beds. This tends to produce an expensive situation in cuts with relatively small amounts of hard, blastable rock. Further, steeply-dipping beds tend to leave shale beds exposed and unprotected through the height of the cut and run-off on extremely steep benches could cause excessive erosion.

A similar design can be used when the beds are flat-lying and the grade is inclined. A design of this type has been proposed independently by the Technical Services Section for a cut on Interstate 40 at Revuelto Creek east of Tucumcari. The

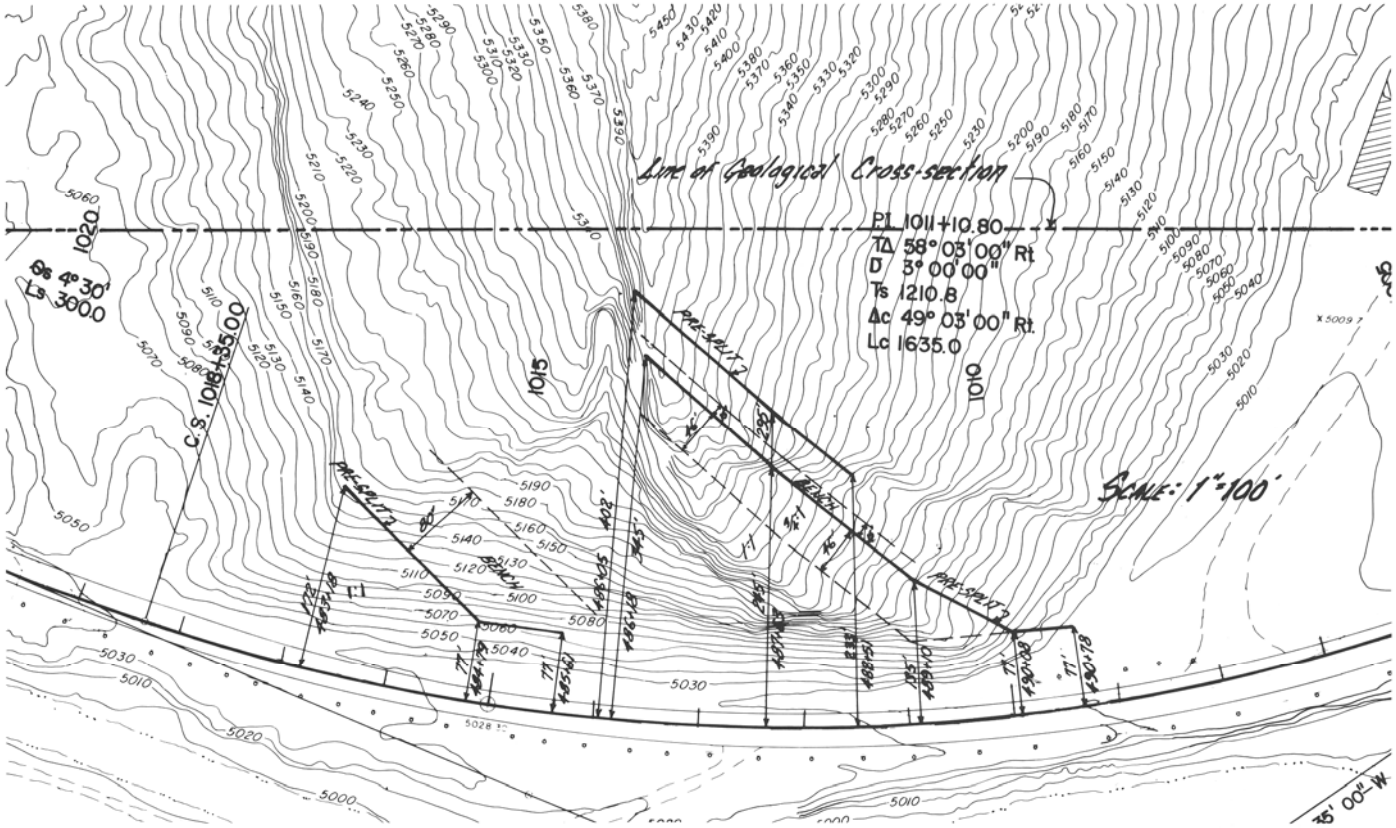

Figure 2.
Topographic map of Hogback monocline and plan view of presplit shot-hole lines and proposed centerline.

design, in this configuration, is more easily visualized, but lacks the self-draining characteristics of this design and therefore, benches are of little value. If the bedding and the grade are parallel, the design becomes a simple split or multiple angle backslope.

In summary, a fresh approach to the design of backslopes in sedimentary rock is long overdue. The design proposed for construction at this location has considerable merit, particularly where inclined beds are being crossed. The design includes varying slopes dependent upon the engineering characteristics of individual beds. Accordingly, each uniform slope dips with the apparent dip of the bedding and each slope is skewed away from the road as it rises, so that differing slopes of underlying beds can be accomodated. Presplitting of non-rippable beds is recommended and can be done either on a vertical face or a slope, as required. Benches atop competent beds will distribute run-off and serve to minimize erosion as well as providing a catchment for rockfall in case of partial slope failure. The overall concept is very similar to the results of natural weathering, which indicates good long-term stability. A final decision on whether this design will be constructed has not been made at the time of this writing, however, growing support from engineering quarters seems to favor its acceptance.

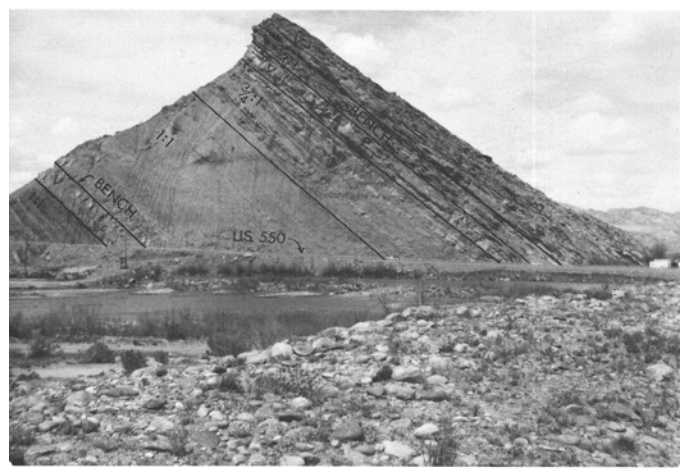

Figure 3.
Northward view of monocline across the San Juan River illustrating the planned slopes. V marks the sandstone beds scheduled for presplitting on a vertical face.

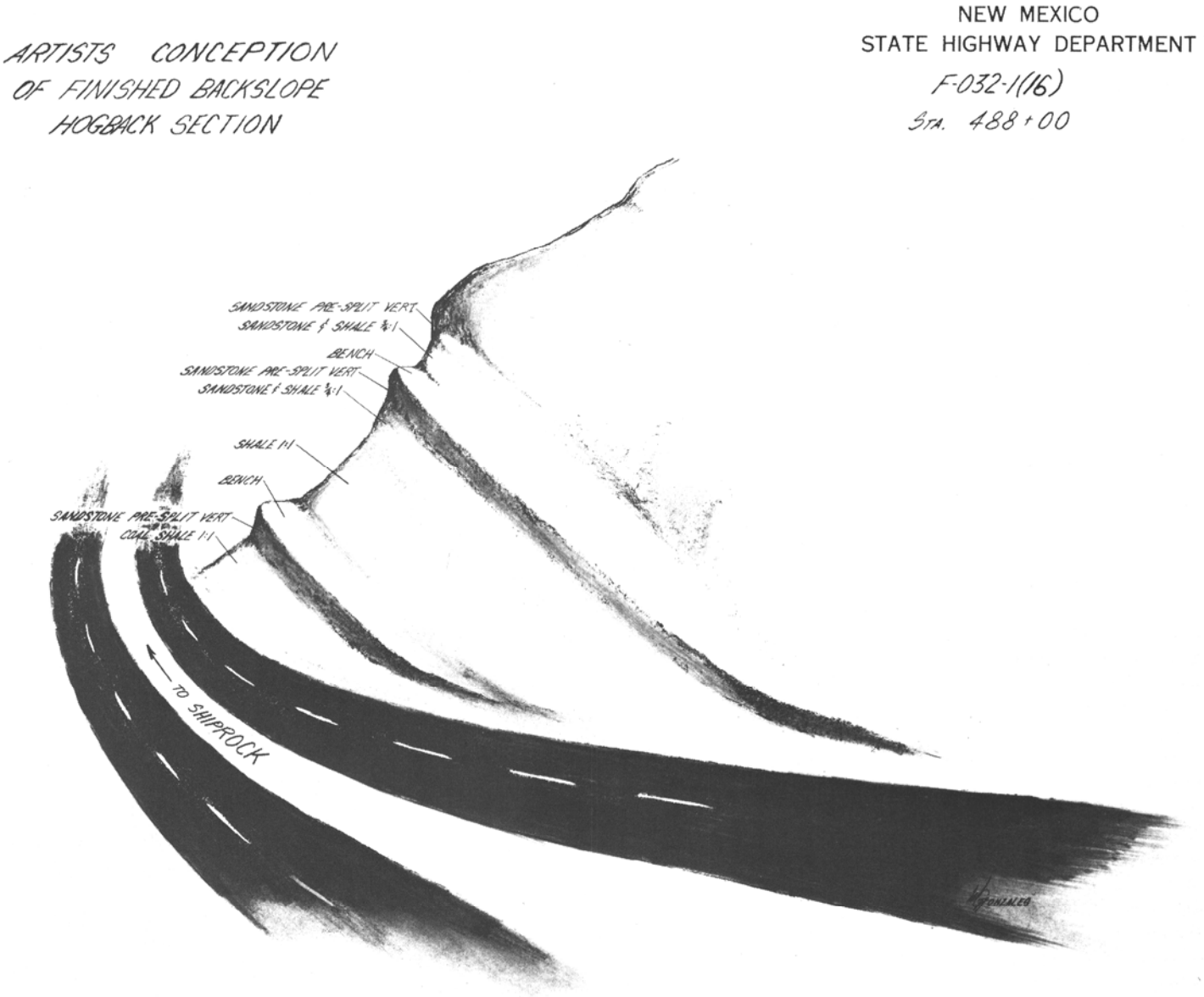

Figure 4.
Artists's interpretation of finished backslope.