FIELD NOTES FROM THE ARIZONA BUREAU OF MINES

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# GEOLOGIC CONDITIONS AND HIGHWAYS

Photo courtesy Arizona Highway Department

Fig. 1. View towards southwest from vicinity of station 820. (See figure 2.) In left middle ground rigs are set up on nose of ridge, drilling presplit blasting holes for channel relocation number 5.

## Some of the effects of geology on highway planning and construction.

by
Richard T. Moore*

### *INTRODUCTION*

In general, the modern car-borne citizen of the U.S.A. seems to take his fine, modern highways as a matter of coarse, not realizing, perhaps, that some of these roads are indeed engineering feats of great magnitude. One such piece of highway is the Arizona portion of Interstate 15. (See figure 1.) This highway, essentially a realignment of U.S. 91, which it will replace, ultimately will extend from Los Angeles, California, through the extreme northwestern corner of Arizona, on to Salt Lake City, Utah, and thence to Montana and the Canadian border.

The Arizona portion of Interstate 15 has a length of only about 30 miles (figure 2), but in that short distance it crosses an area of deeply incised stream channels, and then traverses a rugged mountain range by way of the narrow Virgin River Gorge.

Engineers have been intrigued with the possibility of building a major highway through the Virgin River Gorge for a number of years. The present alignment of U.S. 91 passes over the relatively high Shivwitz Summit in southwestern Utah where winter ice and show present serious hazards to traffic, and a continuing maintenance problem.

As early as 1946, the U.S. Bureau of Public Roads contemplated a highway through the Virgin River Gorge and made a reconnaissance study of such a project. Subsequently, the San Francisco office of the Bureau issued a report which included cost estimates for a two lane highway covering 21.75 miles of proposed road in Arizona and 8.12 in Utah, with a

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minimum design speed of 60 miles per hour. It was estimated that the Arizona portion would cost slightly in excess of $19 million. A supplement to the report was made in 1954 by the Bureau of Public Roads in which the cost of a four lane highway following the same alignment was determined. The revised total construction cost for the Arizona segment was approximately $25.5 million. With the passage of the Federal Aid Highway Act of 1956, which provided for approximately 41,000 miles of interstate highways in the United States, the Bureau of Public Roads pushed even harder for plans in initiate the construction of the Virgin River Gorge route, and in June, 1959, the Arizona State Highway Department retained consultants to undertake a detailed study and field survey of the contemplated route between Littlefield, Arizona, and the Utah line. The final recommended alignment was 21.5 miles in length with a maximum grade of 4.1 percent ascending and decending and a maximum horizontal curvature of 6 degrees. Approximately 85 percent of the route is designed for 70 mile per hour speeds and 15 percent for 60 miles per hour. The total cost for the segment of highway was estimated at $29.5 million.

By the time construction has been completed and the roadway opened to public usage, sometime within the next two years, the total cost probably will have exceeded $70 million. In 1968, it was estimated that the 3.8 mile section in the precipitous narrows region of the Virgin River Gorge would cost about $1,000 per foot making it the most expensive highway construction job, exclusive of tunnels, in all the 41,000 miles of interstate system. When completed, it may well be found that the actual cost has exceeded that preliminary figure by half again as much. A significant portion of these increases of actual cost over estimated cost, however, are not hard to account for when one considers the rate of inflation over the past 15-20 years, and, although these costs may seem excessive, a consideration of the geologic setting of the project, while not justifying the costs, does much to explain them.

It should be pointed out at this time that the Arizona Highway Department was in favor of an alternate route through a low pass to the north which, although about 3 miles longer, would have been considerably less expensive, and still would have conformed to the design specifications established for the interstate system. However, the Bureau of Public Roads, which is supplying 95 percent of the construction funds, endorsed the Virgin River Gorge alignment.

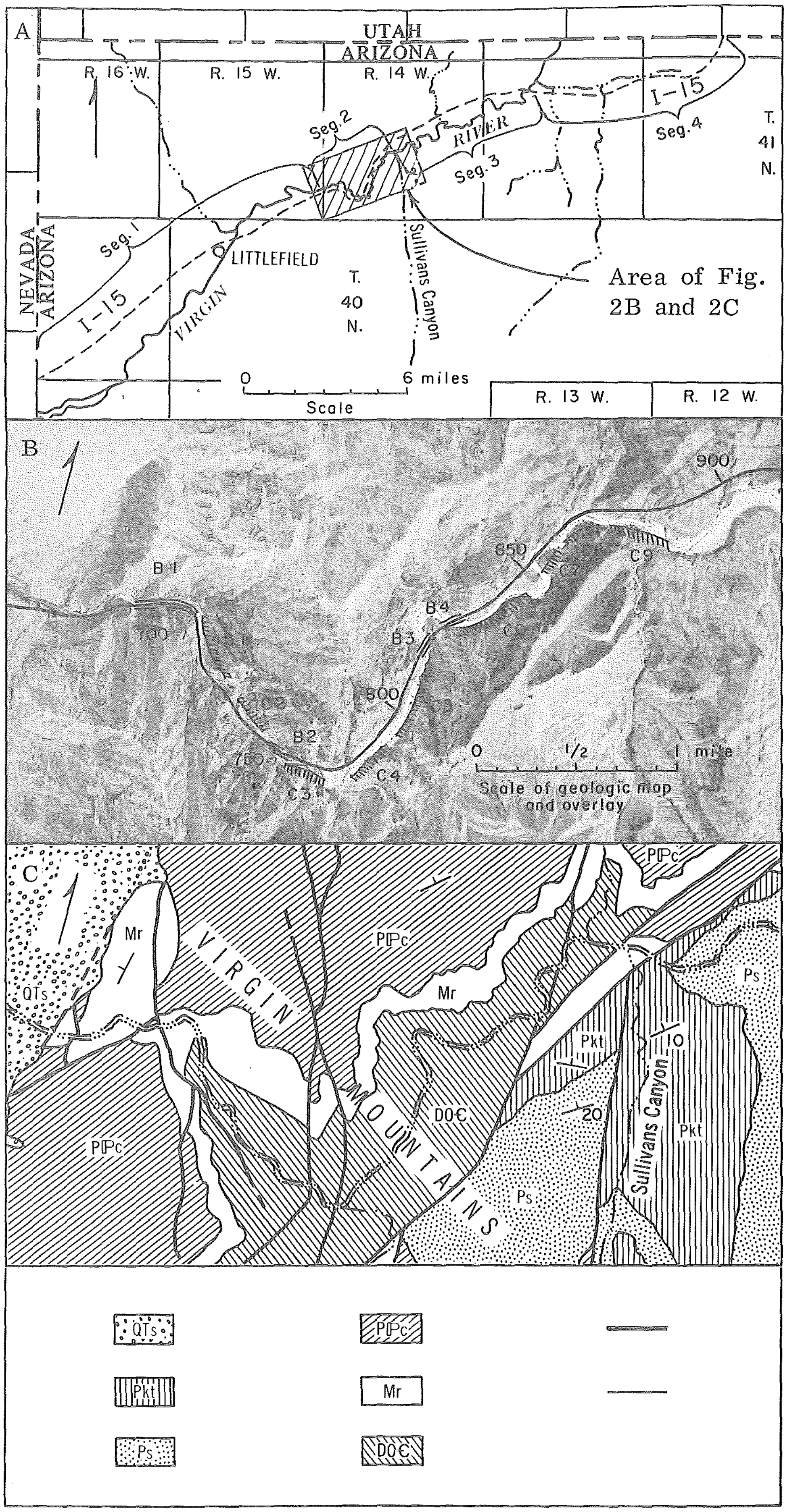


Fig. 2. Map of a portion of northwestern Arizona showing general location of Interstate 15 and aerial photograph showing details of the narrows portion of the Virgin River Gorge.

Photo courtesy Arizona Highway Department

Fig. 3. Excavation of road cut near west end of Virgin River Gorge. More than 1.2 million cubic yards of rock was removed in a 2,000-foot section of roadway by presplit blasting.

As might be expected, considering the costs, the most difficult section, from the point of view of construction, is the nearly four-mile piece starting at the western end of the Virgin River Gorge and extending to the east, to the vicinity of Cedar Pocket Wash. In this stretch the Virgin River cuts a deep, sinuous canyon through the spine of the Virgin Mountains and in places the canyon walls are as much as 750 feet high and the bottom of the canyon is no more than 70 feet wide. In this, the narrows section of the gorge, 4 bridges and 2.5 miles of channel relocation were required. Cuts of as much as 350 feet in height were excavated in solid limestone. Among the unique, situations encountered along this roadway is a bridge (figures 6 and 7) which starts out across the river bed but, because of bends in the river, ends up on the same side that it started. An idea of the magnitude of the construction job can be seen in figure 1 and 8, and the scale of the country is well examplied in figure 10. Because of the severity of the terrain and the critical effect it would have on the design and construction of the highway, an important part of the consultant's investigation was involved in a study of the geology of the Virgin River Gorge.

I wish to express my appreciation to personnel of the Arizona Highway Department for their cooperation in furnishing data for this report and also for the excellent photographs that have aided immeasurably to the discussion of this project.

## GEOLOGY

The geologic conditions that prevail along the Arizona portion of Interstate 15 can be described most concisely by dividing the alignment into four segments (figure 2A), based on the relative diversity of rock units encountered and the structural complexity characteristic of each segment.

Along the first segment, extending from the Nevada line to the mouth of the Virgin River Gorge at the west flank of the Virgin Mountains, the geology is relatively simple and structural relations are uncomplicated. Throughout this segment, the roadway is founded on essentially flat-lying Cenozoic basin-fill deposits consisting of, in ascending order, the "Littlefield Conglomerate," "Littlefield Limestone," and a thin veneer of alluvium. The "Littlefield Conglomerate" is a semi-consolidated unit containing fragments of a vareity of rock types, including limestone, sandstone, and crystalline metamorphic rocks, all derived from the Virgin Mountains. Sorting within the conglomerate varies widely, with layers of predominantly cobblesized particles being randomly interbedded with thin layers of siltstone and sandstone. The thickness of

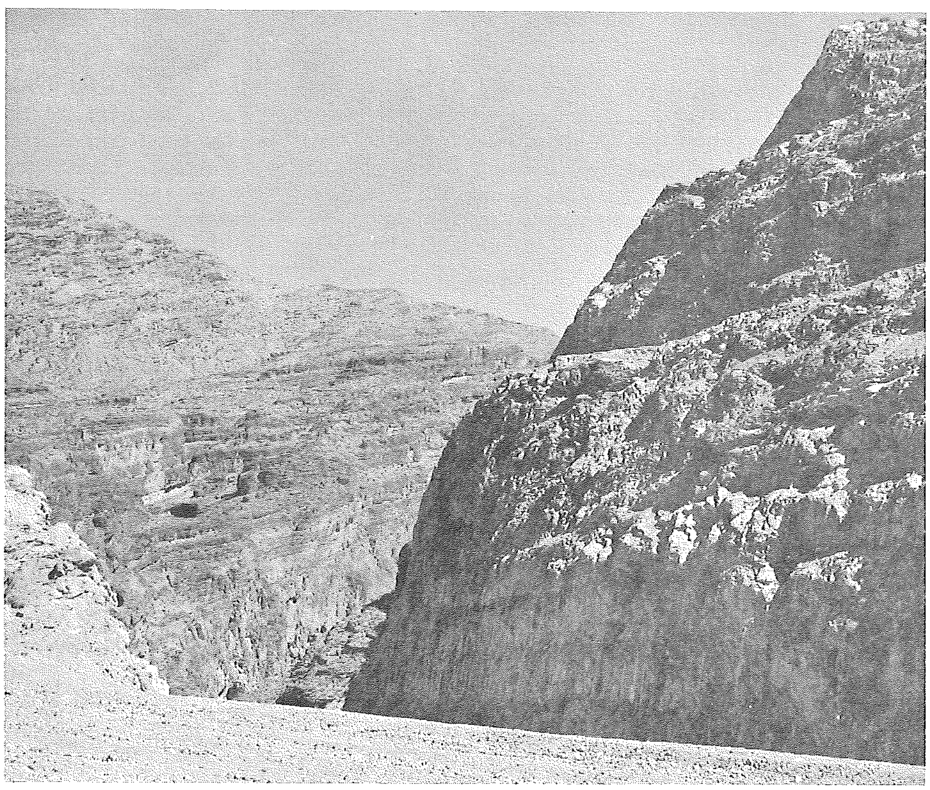

Photo courtesy Arizona Highway Department

Fig. 4. View east (upstream) from near station 691. The cut to the right is 340 feet high.

Photo courtesy Arizona Highway Department

Fig. 5. Preconstruction view of Virgin River Gorge near site of Bridge One.

the formation is unknown; observations along the Virgin River channel, however, indicate a minimum thickness of 80 feet, and judging from the surrounding land forms, it is probable that it is considerably thicker. Surficially the unit appears to be quite weak, however, this is probably the result of weathering of the exposed surfaces, and at depth the material has proven to be more competent.

The "Littlefield Limestone," which overlies the "Littlefield Conglomerate," outcrops along the banks of the Virgin River, downstream from the mouth of the Lower Gorge, and probably lies slightly below ground surface throughout the area of the alignment west of the Virgin Mountains. Where exposed, it is between 50 and 75 feet thick, and throughout the area it is essentially comformable with the ground surface. The formation is comprised of isolated cobbles and pebbles of limestone, quartzite, and crystalline metamorphic rocks imbedded in a competent matrix of calcium carbonate. Although termed a limestone, the unit probably was formed as a very dense deposit of caliche.

Segment 2, the narrows section, or Lower Gorge of the Virgin River, extends from the west flank of the Virgin Mountains to the vicinity of Sullivan's Canyon (figures 2A, B, and C). It is by far the most complicated segment in the geologic sense and the most rugged from the viewpoint of topography. (See figures 1, 5, and 8.) Rocks exposed in this segment of the alignment consist of extensively faulted, fractured, and tilted Paleozoic limestones. These are, in ascending order, undifferentiated limestones of Ordovician and Devonian age, the Redwall Limestone of Mississippian age, and the Callville Limestone of Pennsylvanian and Permian age.

The undifferentiated limestones are probably correlative with the Devonian Muddy Peak and Ordovician Pogonip limestones of Nevada. From an engineering point of view the unit can be subdivided into five members on the basis of competency; these include three, massive, hard limestone units separated respectively by two zones of thinly bedded limestone, sandstone, and siltstone. Whereas the three, hard, massive members are very competent and form cliffs that stand in near vertical faces, the two, interbedded units, because of their thin bedding and siltstone-interbeds, are less competent, more susceptible to erosion, and consequently, form slopes rather than cliffs. Also, because of their relatively softer character, the thin bedded units tend to waste away, undercutting the massive beds, and thus, landslide conditions exist locally in this unit.

The Redwall Limestone outcrops only in the western segment of the Lower Virgin River Gorge, where it has a westerly to northwesterly dip of between 20° and 30°. The upper portion of the unit is composed entirely of hard, massive, cherty limestone. The rock is highly competent and stands in vertical faces in excess of 300 feet in height. A number of caves occur in the face of the member and some of the openings are as much as five feet in diameter (figure 3). They occur along fractures and bedding planes and undoubtedly represent solution caverns. The lower 200 feet of the formation is comprised of thinly bedded alternating layers of dense limestone and chert. Locally this unit stands vertically but in other areas is has a marked tendency toward slabbing. As a whole, however, the Redwall Limestone is a very stable, competent rock.

The Callville Limestone, which overlies the Redwall, consists of alternating bands of massive to thinly bedded limestone, and occasional sandstone layers. Overall, the Callville is a hard, moderately competent unit, but locally, as where a preponderance of thinly bedded units occur, it tends to form slopes. Where encountered in the narrows segment of the Virgin River Gorge, it dips from 20° to 30° in a west to northwesterly direction.

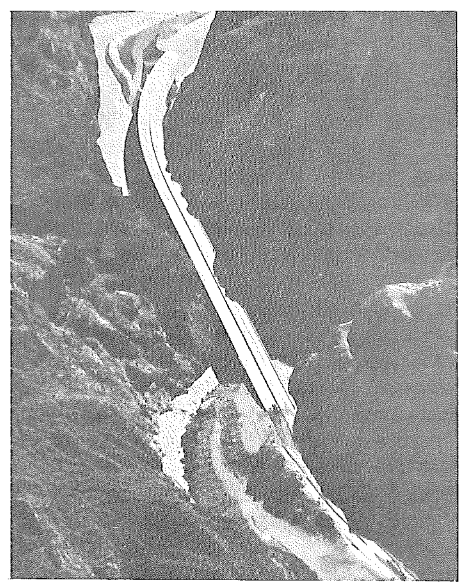

Photo courtesy Arizona Highway Department

Fig. 6. Aerial view of Bridge One. This bridge is perhaps unique in that both abutments are on the same bank of the river which here flows essentially parallel to the bridge. Note that the gorge is so narrow along this stretch that the bridge nearly fills it.

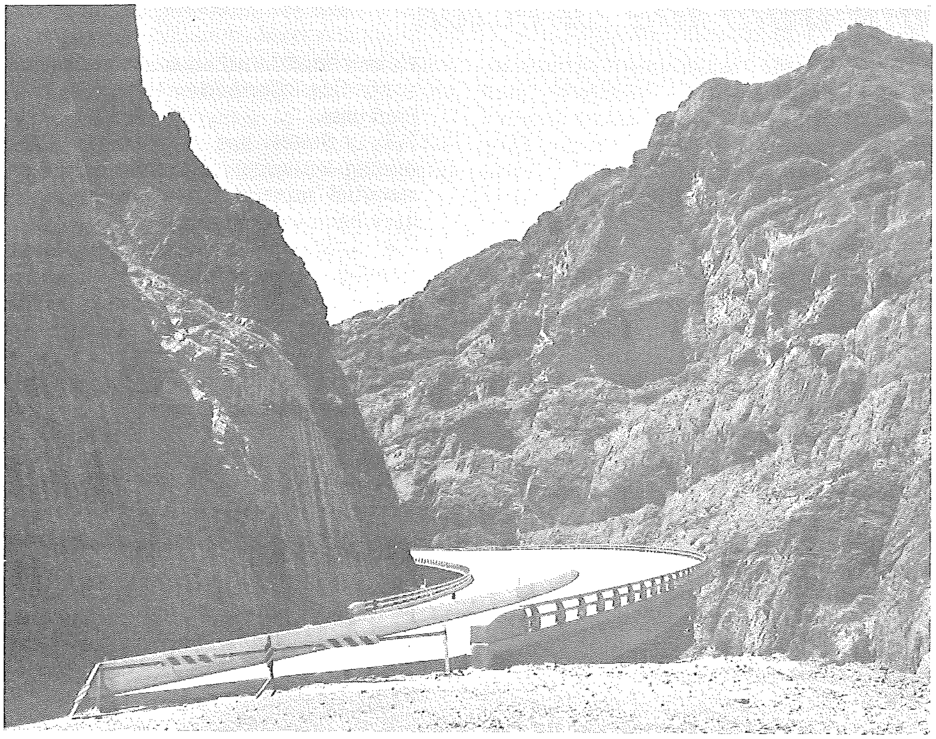

Photo courtesy Arizona Highway Department

Fig. 7. East abutment of Bridge One showing rock-cut at left excavated by presplit blasting.

The rocks within this segment have been subjected to relatively severe faulting and two major classes of faults predominate; one with a strike essentially north-south, and a second striking north 20°-25° east. The direction and amount of dip in both classes varies along strike but in general the dip is in excess of 50° and usually between 70° and vertical. Faults of the north-south class are the more abundant, and vertical displacement on them ranges from a few inches to several hundred feet. The faults of the northeast striking variety, while certainly in the minority, are by far the more important structural features in the Lower Gorge. Only three faults of this class are present, but each has a vertical displacement in excess of 500 feet and each is accompanied by severe brecciation. Intense fracturing occurs locally in the vicinity of major faults and two sets of fractures are represented; one strikes essentially north-south and the other east-west. Within the Redwall Limestone, the fractures are from 20 to 50 feet apart and in the undifferentiated limestone the spacing in on the order of from 15 to 20 feet. Healing, or recementing along fractures, has progressed to a marked degree within the Redwall Limestone but is only slight to moderate within the undifferentiated limestone. Where the fractures tend to parallel the canyon walls, massive slabs of rock have broken off and fallen down the slopes.

The third segment of the alignment, that following the Middle Gorge of the Virgin River, extending from Sullivan's Canyon, east to the mouth of Black Rock Canyon (figures 2A, 13, and 14), is marked by only relatively mild deformation and the surficial rocks are almost exclusively sandstones of the Supai Formation locally overlain by thin gravels, remnants of once more extensive terrace deposits.

In the area adjacent to the alignment of Interstate 15, the Supai Formation can be differentiated into three units. The upper and lower members are quite similar, consisting predominantly of massive, hard sandstone with interbedded thin layers of softer sandstone and siltstone. Crossbedding is common, particularly in the upper member. Both units stand vertically in natural faces, the only exception being in areas where severe fracturing has occurred.

The middle member of the Supai is composed of interbedded medium-hard sandstone and soft, sandy, red shale. The shale is platy and weathers rather rapidly to moderately gentle slopes. The amount of shale present in the member, and consequently its hardness, varies considerably throughout the area.

Along this segment, although some tilting and locally strong flexures in the strata are apparent, the only major structure is Grand Wash fault. Throughout much of the area, however, the Supai Formation displays a marked fracture pattern in which one set strikes north-south and a second set strikes east-west. The fractures of both sets are near vertical in dip, and spacing between the fractures is as close as 1 to 2 feet for those striking north-south and slightly greater for those striking east-west. Intense shattering of the sandstone, as marked by the fracture pattern, is most pronounced in the extreme western portion of the segment and in the vicinity of Grand Wash fault. Healing of the fractures is practically nonexistent.

The fourth and final segment of the alignment, that extending from the mouth of Black Rock Canyon east and

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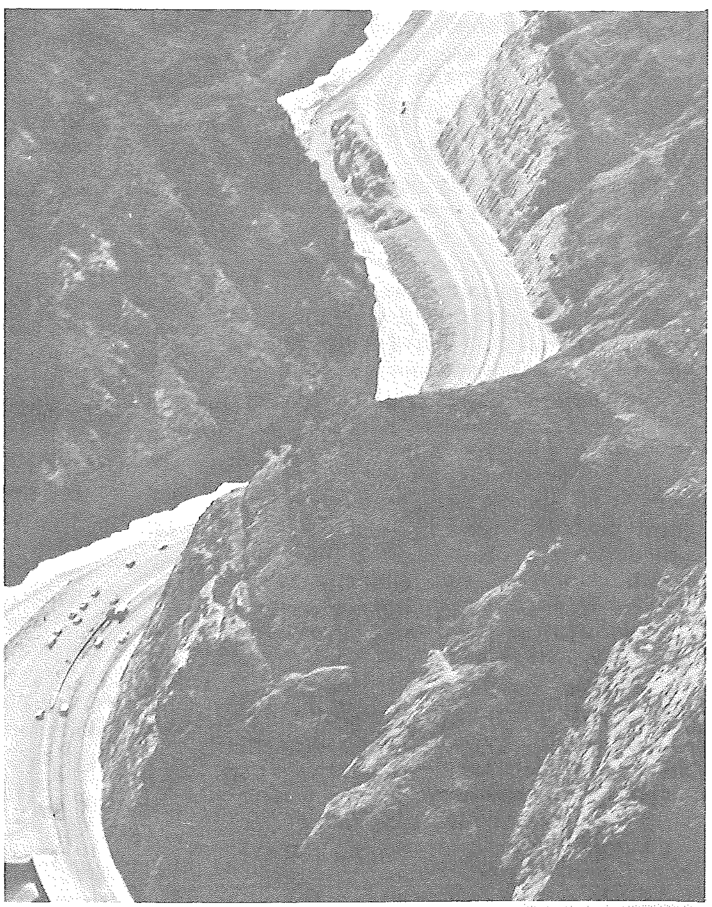

Photo courtesy Arizona Highway Department

Fig. 8. Aerial view of channel relocations and high side-hill cuts between stations 710 and 750. The channel has been relocated to the east (left of picture) and in the vicinity of station 745 (top of picture) the roadway has been constructed on fill placed out through the old channel. The vehicles give a measure of the scale of the cuts and channel relocations.

# A Note from the Director:

## LAND USE

On June 28, 1973 the National Commission on Materials Policy reported to the President and to the Congress their findings regarding the material needs of the nation and the environmental effects of the procurement and use of these materials. The following is an abstract of the Commission's conclusions and recommendations regarding land use planning and legislation.

Copies of the complete report are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

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Rational land use is one of the Nation's highest materials and environmental priorities. Every phase of the materials cycle involves the use of land and is affected by local, State, Federal, and private land use decisions. The way land is used will, in large measure, determine the extent to which the United States will be able to meet its materials needs from domestic sources.

Land use planning may affect the course of the economy decisively. Public land use decisions affect the supply of minerals and timber. They also influence uses of adjacent non-Federal lands. Thus, land use plans of Federal, State, and local governments require close coordination.

Land use planning for non-Federal land is a State and local responsibility. Although there are good examples of effective planning and controls, State and local planning generally is weak.

Competition for land is intensifying. Urban expansion, highways, airports, reservoirs, recreational subdivisions, etc., take up approximately 1.2 million acres every year. Commercial forest land declined 1.7 percent between 1962 and 1970. Surface mining, which produces 50 percent of our coal and 90 percent of all other minerals, is under attack. Materials production is prohibited or severely restricted on over 100 million acres of Federal land. Large additional areas are being proposed for restrictive withdrawals.

Valuable deposits of sand, stone, gravel, and clay are being covered up by urban growth or zoned out of effective use. Similar impacts limit sites for recyling plants and waste disposal. Strong objections are being registered on environmental grounds against proposed new power plans, transmission lines, refineries, offshore oil drilling, deepwater ports, and other processing and transport facilities.

The Commission explored the major land use problems which are judged to be crucial to the availability, extraction, processing, transport, recovery, and disposal of materials, and present detailed recommendations for each of them. They propose that Congress adopt a national land use policy and supporting statutes which require comprehensive planning for all land, both public and private, and provide for evaluation of practices and establishment of criteria which take account of economic and national security needs as well as environmental and other social values. The States and local units of government should have primary responsibility for planning and use of non-Federal lands. The Federal Government should plan and coordinate the use of Federal lands and assist the States in the formulation, coordination, and implementation of land policies for non-Federal lands.

### ON LAND USE PLANNING

*The Commission recommends that*

7.1 . . . Congress adopt a national land use policy and supporting statutes which will:

- promote comprehensive planning both for public and private lands;
- provide a means for evaluating land uses and institutions or practices and establishing criteria which take account of economic and national security needs and environmental, esthetic, and social values;
- recognize the responsibility of the States and local units of government to develop programs for non-Federal lands and assist States in the formulation, coordination, and implementation of land use planning policies;
- assist States to improve regional and local planning processes; and
- require coordination within the Federal Government and with the States, of Federal and federally assisted programs which significantly affect land uses.

### ON THE URBAN LAND USE CONFLICT

*The Commission finds that*

. . . State and local governments should cooperate to develop and adopt a comprehensive system of land use planning and zoning which recognizes the importance of preserving opportunities for extraction of common materials which are so essential in the building and maintenance of communities and tranportation systems.

*They recommend that*

7.2 . . . State governments, in cooperation with the U.S. Geological Survey, locate and determine the kind and extent of mineral deposits on land to be zoned in urban growth areas and apply this information to decisions on land uses.

7.3 . . . States use a quarrying and mining zoning classification to reserve essential mineral lands until deposits have been worked out.

7.4 . . . State and local governments develop regulations and licensing procedures to regulate truck traffic, reduce air and water pollution, set limits on noise, require visual screening, and ensure progressive reclamation of the land.

### ON LAND USE ASPECTS OF RECYCLING AND REFUSE INDUSTRIES

*The Commission finds that*

. . . remedies for the siting difficulties of the recyling industries are similar to those for the aggregate minerals industries.

*They recommend that*

7.5 . . . certain areas on the fringes of urban areas be zoned for waste processing, recyling, and disposal sites.

7.6 . . . State and local governments cooperate with secondary materials processors to develop operating codes which will reduce adverse environmental effects and conflicts with other land uses.

### ON SURFACE MINING

*The Commission concludes that*

. . . the objective of Federal and State laws and regulations should be the control of surface mining to minimize environmental degradation and provide for prompt reclamation of the land so it can be used for other purposes, rather than prohibition of surface mining. Outright prohibition is unrealistic and currently would have disastrous results for the Nation. A ban on or a significant reduction of strip mining for coal could only worsen the presently overstrained energy supply picture. On the other hand, we recognize that there are localized situations where steep terrain, unstable soil, or other conditions make it impossible to use surface mining procedures, with present technology, without serious environmental damage. Under such conditions, the laws and regulations should bar mining until environmentally acceptable technology can be developed and applied.

*Therefore, they recommend that*

7.7 . . . Congress enact legislation to assure uniform control of surface mining by providing for basic Federal standards subject to local variations.

7.8 . . . Federal and State laws and regulations be tailored to the distinctive character of each form of surface mining and to allow for the different regional environmental factors.

7.9 . . . on Federal lands, the agency responsible for management of the surface land resources should have responsibility for supervision and enforcement of requirements for surface reclamation and protection of other resources.

7.10 . . . the Federal Government survey, identify, and evaluate the sources and effects of environmental pollution and safety problems associated with surface mining.

7.11 . . . the Federal Government undertake coordinated research on short- and long-term impacts of surface mining on land management and use for both private and public lands, and strengthen current programs by:

- expanding research on effects of surface mining on other resources and methods of restoring mined sites;
- providing a properly balanced, well constructed program of applied research and demonstration of mining and mine reclamation methods; and
- applying knowledge gained to criteria and standards so as to assure rapid application of the results of research.

7.12 . . . Federal agencies with expertise in land use planning, soil science, vegetation management, erosion control, and reclamation of disturbed land cooperate with States, local governments, landowners, and mining companies by exchanging technical information and assisting them to prepare plans for coordinating surface mining with other uses of the land.

## ON MINERALS ON THE PUBLIC LANDS—EXPLORATION, DEVELOPMENT, AND ADMINISTRATION

*The Commission concludes that*

. . . mineral explorers and operators should be required to submit operating plans to the agency administering the land on which the mineral property is located; that each agency should approve and administer requirements relating to coordination with other land uses and protection of environmental values on lands under its jurisdiction; and that the land management agencies should have the authority and the means to administer the "policing" aspects of the mineral laws to insure that the requirements of those laws are met.

*They recommend that*

7.13 . . . rights to publicly owned minerals be canceled if the holder is found to be in substantial violation of the Federal mining laws or regulations governing public lands.

7.14 . . . land management agencies be notified when and by whom rights to mineral estate are initiated and when such rights are transferred, relinquished, or terminated by operation of law and that agencies be notified also in advance of substantial disturbance of the land.

7.15 . . . title to the surface estate not transfer automatically with title to mineral estate if the mineral estate is to go into private ownership.

7.16 . . . lands for surface works and installations, other than those required for entry to mineral deposits, be paid for at fair market value if allowed to go into private ownership.

7.17 . . . the law set reasonable requirements for development of mineral property or for payments to the Government in lieu of development.

7.18 . . . the law should not distinguish between kinds of mineral property as it now does for placer and lode mining claims under the General Mining Law.

7.19 . . . mineral rights terminate at the surface property boundaries, extended vertically in depth (elimination of extralateral rights), and that mineral property be described as far as possible by legal subdivisions of the land surveys.

7.20 . . . all requirements for the inception and continuity of rights to minerals in the public lands be set solely by the Federal Government.

7.21 . . . the Federal land managing agencies be granted full authority to regulate and administer the environmental aspects of ore finding, development, and production on the public lands.

7.22 . . . royalties be collected by the Government on values yielded from publicly owned minerals.

## ON THE MINERAL LEASING SYSTEM

*They recommend that*

7.23 . . . Congress review mineral leasing laws with the objective of consolidating them into a single act, incorporating standards for coordination with other land values and uses, environmental protection, and reclamation of disturbed land where feasible.

7.24 . . . The agency responsible for management of the surface resources of the land should have the right of consent to prospecting permits and leases, including the terms and conditions for environmental protection and coordination of mineral exploration and development with other uses of the land; and that supervision of the surface management and restoration measures be delegated to the agency responsible for the management of other surface resources.

7.25 . . . the leasing system be continued for all minerals on acquired lands and the public domain lands in Kansas, Nebraska, Missouri, Minnesota, and Wisconsin.

7.26 . . . Congress amend the Materials Act to define as precisely as possible the mineral materials subject to sale under this Act.

7.27 . . . all mineral interests reserved by the Federal Government, where title to the surface is in non-Federal hands, be placed under the Mineral Leasing System.

7.28 . . . Congress provide authority for sale of the Government's mineral interest to the surface owner, at fair market value, upon a determination that the land is not valuable for minerals, and that authority be provided to sell valuable mineral interests at appraised market value where there is a clear showing of need to unite the surface and subsurface titles in order to permit development of the surface of the land, especially in areas subject to current or imminent urban expansion or in places where it would be impracticable to develop a mineral deposit.

## ON THE AVAILABILITY OF MATERIALS FROM PUBLIC LANDS

*The Commission concludes that*

. . . the vast storehouse of natural resources on the public lands is not as vast as it appears.

. . . extenisve as they are, the public lands are not large enough to allow each special interest group to have all the land it wants devoted exclusively or even dominantly to a narrow specialized use.

. . . the need for a continuing, dynamic program of land use planning should not excuse unwise constraints on yields of materials, but that planning should aim to use public lands to gain the optimal net public benefit.

They believe that public benefit can be optimized on the National Forests and BLM lands by a policy of multiple use, as defined in the Multiple Use and Sustained

Yield Act. They accept the concept of the Act that wilderness preservation is consistent with multiple use and that preservation of land for wilderness can be a part of the web of interlocking land uses on large tracts of Federal land.

They recognize the difficulties in planning and executing multiple use programs. Not the least of these is the balancing of values which can be measured in dollars against imponderable social and environmental values. Exact prediction of yields of goods and services is difficult as they will vary with shifts in national priorities and social values. Although conflicts over contested land uses cannot be settled as easily under the multiple use policy as under a system of classification for restricted or dominant use, the flexibility of multiple use management for most land offers options for reappraising and revising today's determination in the future.

*They recommend that*

7.29 . . . efforts to revise, update, and refine long-range, comprehensive multiple use plans for the National Forests and BLM lands should be strengthened and accelerated with opportunity for advisory participation of all concerned and interested individuals and groups including a broad cross section of the general public.

7.30 . . . Congress complete action on an organic act for the Bureau of Land Management to provide permanent authority for multiple use management of the public domain lands to be retained in Federal ownership.

7.31 . . . public land areas proposed for classification as wilderness or for other purposes which preclude or seriously restrict extraction of industrial materials should be identified promptly to protect them against piecemeal encroachment and to determine without undue delay what will be the land base for producing materials.

7.32 . . . Congress establish and conform to the principle that mineral surveys, inventories of all other resources, and land use planning be completed for affected areas before decisions are made to withdraw Federal lands permanently from production or seriously restrict exploration and economic development of their resources.

7.33 . . . all public values, economic as well as social, be evaluated before final classification of public lands.

7.34 . . . land use planning be coordinated among Federal agencies and, to the extent feasible, with planning by States and local governments.

7.35 . . . Congress and the Executive Branch provide for balanced funding of multiple use programs so that various uses are given attention in proportion to their importance and needs, as otherwise a multiple use pattern tends to become preclusive or dominant use.

7.36 . . . protective reservations by "Presumed Executive Authority" be confined to those absolutely necessary to protect administrative sites, developed recreation areas, research areas, and critical environmental values and be canceled if revised mining laws provide satisfactory environmental controls.

7.37 . . . executive agencies receive orders and support sufficient to complete, as soon as possible, the land transfers and land classifications authorized by the Alaska Statehood Act and the Alaska Native Claims Act.

### ON THE LAND USE REQUIREMENTS OF THE ENERGY SUPPLY SYSTEM

*The Commission recommends that*

7.38 . . . States expedite long-range planning for the use of land needed for power plants, transmission lines, refineries, and other facilities needed to assure essential services in an environmentally acceptable manner. This will require close cooperation with the power utilities, the oil industry, and Federal licensing agencies as they will need at least 10 years lead time for power plants and 5 for refineries.

7.39 . . . Federal and State licensing procedures be simplified to place authority to issue construction and operation permits in a single agency at each level.

7.40 . . . transmission lines be constructed with long spans, towers at heights which require little clearing, natural screening, and designed so as to have optimal esthetic values.

7.41 . . . joint use of rights-of-way by utilities be encouraged whenever uses are compatible.

7.42 . . . Congress authorize formation by interstate compact of regional commissions to obtain sites to assure effective and economical operations of fuel and power systems.

### ON THE CONTINENTAL SHELF

*The Commission concludes that*

. . . the mineral resources of the Continental Shelf should be developed to the fullest extent feasible and that adequate deepwater port and offshore unloading facilities be constructed to receive increasing quantities of oil and liquefied natural gas from foreign sources in an environmentally acceptable manner.

*They recommend that*

7.43 . . . the Federal Government encourage orderly development of the undersea mineral resources and essential deepwater port facilities, and expedite settlement of related environmental issues with all possible speed.

7.44 . . . the Federal Government expand programs for collecting and disseminating basic geological and geophysical data in order to relate mineral development to other resources and values effectively and to evaluate leasing proposals fairly.

7.45 . . . the Federal Government, in cooperation with coastal States and associated educational institutions and industries give high priority to expanding research in the ecology of the Continental Shelf especially with respect to preventing adverse effects of mineral exploration or development as they concern marine life, recreation, and other values.

7.46 . . . all oil and gas leases contain stringent safety requirements, based on the best technology available, with strict enforcement clauses.

7.47 . . . new deepwater ports and offshore docking facilities licensed or constructed by Army Corps of Engineers be constructed with the least possible adverse environmental impairment, and that full Federal powers be exercised to assure that these facilites are used so as to avoid oil spills or other events likely to do serious environmental harm.

7.48 . . . Congress explore the possibility of improving statutory standards for strength and safety for American tankers and requiring that foreign tankers delivering oil to U.S. ports meet the same standards.

## NEW CIRCULAR

**Arizona Bureau of Mines Circular 16, STRATA-BOUND SULFIDE DEPOSITS AND SUGGESTIONS FOR EXPLORATION IN ARIZONA, which is the first report to be published in the Bureau's re-activated Circular series, will be released this fall.**

**The report, which was written by John S. Vuich, Assistant Geologist in the Bureau, describes strata-bound massive sulfide deposits in general and suggests exploration procedures applicable to Arizona in particular. Models of mineral-metal distribution, hydrothermal alteration, and stratigraphic relationships are depicted at both district and single-deposit scales. The potential for occurrence of strata-bound massive**

sulfide deposits in Arizona is discussed and areas considered favorable for regional study are outlined. The circular includes a selected reference section in which are listed numerous reports that describe in greater detail strata-bound massive sulfide deposits, Arizona Precambrian stratigraphy, and some Arizona massive sulfide deposits.

The Circular, illustrated with several figures and photographs, will be priced at a nominal charge to non-residents of Arizona and is free to residents of the State.

I - 15 *Continued*

north to the Utah line, is founded on essentially flat-lying shales, sandstones, and limestones of the Supai, Kaibab, and Moenkopi formations.

The Supai Formation, described previously, is overlain by the Kaibab Formation which in the vicinity of Interstate 15 is comprised of four distinct members. The basal member consists of generally thin bedded, relatively soft, buff sandstone and drab, silty limestone. It is not continuous in the area but forms lenses and pockets at the contact of the Kaibab Formation with the underlying Supai Sandstone. The member, where present, is a slope-former and is generally covered with talus debris.

Overlying the basal unit is a massive, competent, gray limestone containing a high percentage of chert. Numerous cleavage planes, which to a large degree have been healed, dissect the member. It forms vertical cliffs and is quite resistant to erosion.

Photo courtesy Arizona Highway Department

Fig. 9. Details of cut in vicinity of station 737. This side-hill cut is approximately 300 feet high. The attitude and fractured nature of the limestone necessitated the cutting of five benches as catchments for falling rock.

A second soft member separates the lower hard member from the upper hard member. It tends to form a natural slope of about 30° and generally has a moderately thick talus cover. It consists of gray, medium-hard to soft, silty limestone containing considerable chert as bands and nodules.

The upper hard member is comprised entirely of competent, massive, gray, cherty limestone which stands in vertical cliffs and is quite resistant to erosion.

Overlying the Kaibab is the Moenkopi Formation which underlies the roadway from the head of Black Rock Canyon to the Utah line. Within the area of the highway alignment the formation consists predominantly of thin-bedded siltstone and shale with occasional thin layers of silty limestone. A trace of gypsum is present throughout much of the shale. Both the shale and the limestone beds are weak, incompentent rocks, easily eroded, and unstable on steep slopes. In the vicinity of the Utah line, the beds have been subjected to considerable warping and folding. Across the flats at the head of Black Rock Canyon the formation is

Photo courtesy Arizona Highway Department

Fig. 10. Aerial view of Bidge Two and channel relocation south of roadfill. An impression of the scale of the river gorge and the construction project can be obtained from the relative size of the tractor trailer rig on the roadway (view looking north).

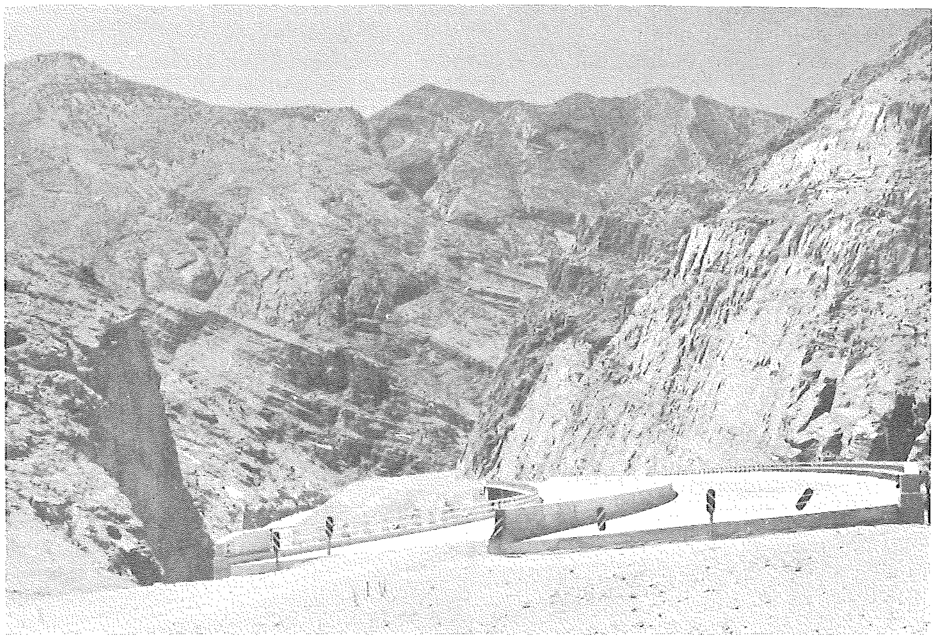

Photo courtesy Arizona Highway Department

Fig. 11. View southest from station 820 of east abutment of Bridge Three, channel relocation 5, and roadway constructed on fill placed in old channel. (Compare with Figure 1.)

covered to a variable depth by alluvium. Its attitude is similar to that of the underlying Kaibab Formation, that is, essentially flat with flexures in which dips of 3° to 7° in a northeasterly direction are developed locally.

## *ENGINEERING PLANNING AND CONSTRUCTION*

Along segment 1, from the Nevada line east to the western flank of the Virgin Mountains, geologic conditions are simple and the engineering planning and construction of Interstate 15 along this segment was relatively straightforward. The only major earth moving project on this segment of the highway occurred approximately midway between Littlefield and the Nevada line where fills on the order of 160 feet in height were required in the crossing of Coon Creek and Big Bend Wash. Although the requirements for fill material exceeded that available from the cuts, suitable borrow was readily available in the immediate area.

Two structures were required on this segment—an interchange at Littlefield, and a bridge crossing the Virgin River approximately one-half mile north of Littlefield. As originally designed, the bridge crossing the Virgin River at Littlefield was to be supported on piers founded on spread footings. This design, however, was not predicated on actual field investigations of the foundation conditions and, when construction was started and excavation for the footing pads were made, it was found that quicksand conditions existed at about 30 feet below stream gradient and spread footings would not support the structure. To correct the situation, the excavations were backfilled with 6-7 feet of 1-2½ inch crushed rock and then with river run. Piling was then driven into the crushed rock zone and the piers were founded on the pilings.

One further interesting aspect of the Littlefield bridge centers on the occurrence of numerous springs in the vicinity of the eastern approach. These have been responsible for extensive deposits of travertine, and it was necessary to excavate to the base of the spring aquifiers and backfill, placing French drains for a distance of 700-800 feet east of the abutment, in order that the bridge approach and roadway in that area could be founded on firm material. Geological examination of this area, however, had predicted the necessity for this and appropriate measures were taken during the engineering planning phase to accommodate the condition.

Once the decision to follow the Virgin River Gorge with Interstate 15 had been made, the detailed topographic features of the area became the primary factors controlling the precise location of the alignment. These dictated following very closely the Virgin River channel within the lower gorge and, at the eastern end of the alignment, the bed of Black Rock Canyon; it is within these areas that the geologic conditions had the most important bearing on design and the future performance of the route.

The Virgin River, in cutting its way through the main mass of the Virgin Mountains, drops from an elevation of 2,195 feet above sea level at the mouth of Sullivan's Canyon (figure 2C) to an elevation of 1,890 feet at the west end of the Lower Gorge—a descent of only 305

Photo courtesy Arizona Highway Department

Fig. 12. View looking west at side-hill cut near station 845. Although the rock is moderately fractured, presplit blasting produce a smooth and even face.

Photo courtesy Arizona Highway Department

Fig. 13. View west toward Cedar Pocket — Grand Wash fault segment of I-15.

feet in a channel distance of about 4.81 miles. The channel thus offers a highly desirable alternative to the Shivwitz Summit Route, which crests at an elevation of nearly 5,000 feet. However, among the interstate specifications that must be met, the more important minimums are: design speed, 60 miles per hour; maximum horizontal curve, 6 degrees; maximum grade, 4.1 percent; maximum length of crest or sag of vertical curves, 400 feet; and a minimum width (four lanes, median, and shoulders) of 80 feet.

In general, the Inner Gorge section presents no problems as far as maintaining required grade and vertical curve specifications. The river, however, was not constrained by interstate specifications concerning maximum horizontal curves, and it becomes readily apparent that in order to construct a highway to these specifications a number of modifications would be required in the gorge in order to straighten it out. This is perhaps best illustrated by the fact that the final alignment in this segment is approximately 17 percent shorter than the original channel length (4.81 miles of channel vs. 3.99 miles of alignment).

Several combinations of channel relocations, tunnels, and bridges were considered. In the final analysis, all tunnels were eliminated because faulting and attendant fracturing proved to be severe at each provisional tunnel site, thus indicating the necessity for excessive support. In essence, then, it became necessary to "daylight" these tunnels, and very deep side hill cuts resulted. In designing the cut slopes, a fine balance had to be struck between the maximum steepness that could be maintained in order to produce the least rock breakage, and thus the greatest economy, vs. the susceptibility of the several rock units to raveling and caving on overly steep slopes, in part as the result of the fractured nature of the rock. In practice, it was possible to maintain relatively steep slopes through the use of presplit blasting (figures 3, 4, 7, 8, and 9). Notwithstanding this technique, however, considerable benching, and in places, flattening of slope was required; and, as between Stations 675 and 695, a distance of 2,000 feet, about 300,000 cubic yards of overbreak occurred. Side hill cuts on the order of 300 feet in height are not uncommon in the Lower Gorge, and some of these required as many as 5 benches, each approximately 50 feet high, as catchments for falling rock.

The extensive amount of channel relocation, approximately 2.5 miles in a road distance of not quite 4 miles, required a fairly detailed hydrologic study be made of the present and potential gorge section. The U.S. Geological Survey has maintained gaging stations on the Virgin River since 1929, including a station at Littlefield where the maximum flood of record, occurring in March 1938, is 22,000 cubic feet per second. The peak flows at Littlefield were taken as representative of the flow in the River throughout the length of the project. It further was deemed necessary, however, to determine the peak river flow on the basis of a 50 year recurrence interval as a safe criterion for the design of the channel relocations and the several bridges to be located within the gorge.

On the basis of the hydrologic study, it was recommended that a design flow of 46,900 cubic feet per second in the Virgin River be used. On this basis, a channel width of 50 feet was assumed and using the design discharge of 46,900 cubic feet per second, the channel section would flow a maximum depth of about 26.5 feet and have a maximum velocity of 24 feet per second. In general, topographic considerations already

Photo courtesy Arizona Highway Department

Fig. 14. Aerial view of Bridge Five across Virgin River. The original proposal called for an arch structure but foundation conditions were later found to be unsuitable and a three-span pier-supported structure was built.

dictated that the proposed highway grades were to be carried between 50 and 60 feet above this channel bottom, thus indicating that the channel section proposed would be satisfactory. In fact, at a depth of flow of 40 feet, the channel would have a capacity of about 91,000 cubic feet per second which is in excess of the projected 500 year frequency flood, as determined in the hydrologic studies.

A second phase of the hydrologic study involved the type and extent of embankment protection required. All the embankment in the gorge was constructed of randomly placed material from the rock cuts, but, because of the volume and velocity of the water expected to be carried in the channels, it was recommended that the slopes of all roadway embankments which form a side of the river channel be protected with individually placed, that is derrick placed, stone or riprap having an equivalent diameter of 4.5 feet or an equivalent cube of about 3.7 feet, using smaller stones as necessary to fill the voids. Rock of that size was readily available from the blasting operation required to excavate the roadway and channel cuts. It was also recommended that the selective placement of rock be to a thickness of at least 10 feet.

Four bridges were required in the Lower Gorge section of the alignment (figure 2B) and on two of these geologic conditions dictated special procedures be adopted for the stabilization of the abutments and piers.

On bridge 1 (figures 2B and 6), the central pier is founded on the lower member of the Redwall Limestone which in this area (figure 2C) dips downstream (westerly) at about 35° and is moderately fractured due to the proximity of the major fault. The fracturing, coupled with the slabby nature of the lower Redwall, created a very unstable foundation condition upon which to support the bridge pier. In order to stabilize the rock, a 2.5 foot cap of concrete was poured on the area of the footing. A total of 40 holes, each 40 feet deep, were drilled into the concrete and rock and then rock bolts were set in tension in these holes. The whole unit was then pressure grouted to form a massive footing for the pier.

On bridge 4 (figure 2B), cavernous conditions were found in the area of the east abutment which were too great in volume to permit economic filling by grouting. An alternate solution was therefore developed whereby the cavern was alternately filled with readily available broken rock and then blasted to compact the fill material. After the caves had been essentially elmininated in this way, a pad was prepared for the poured abutment by alternately placing broken rock and mortar over the filled area until the required thickness of pad was attained.

In segment 3, the roadway is founded almost entirely on beds of the Supai Formation and no major planning or construction problems were encountered. Although somewhat more rugged than segment 1, rock volumes in cuts and fills were fairly well balanced and there was little excess rock breakage required. The fractured nature of the Supai in the vicinity of the Grand Wash fault, and to a lesser degree at the western end of the segment, required that slopes be cut back somewhat flatter than might have been desired from an economic point of view. This did not, however, pose a serious construction problem.

At the eastern end of this segment, the alignment crosses the Virgin River before entering into Black Rock Canyon. As originally recommended, the structure proposed for this location was an arch bridge, presumably with the skewbacks founded on firm Supai Sandstone in either embankment. Site examination prior to final design, however, indicated that bedrock at the eastern abutment was more than 50 feet beneath sand fill as the result of an old scour hole cut by the Virgin River. This necessitated that the design be changed and that a pier-supported bridge be substituted for the arch structure.

It seems desirable at this point to stress the importance of making preliminary site examinations and subsurface studies of foundation conditions before any final design criterion are established for such structures as bridges and overpasses. The money saved by eliminating unnecessary design and redesign is frequently greater than that which would be spent on the actual site examination. Unfortunately, such site examination and exploratory work frequently only shows up as important in retrospect, and the "buyer" of the structure usually finds it hard to see beforehand that such expenditures can contribute greatly to both the success and economy of the project.

The principal factor that dictated locating the alignment along the south side of the drainage in Black Rock Canyon was the relative susceptability of the slopes to rockfalls and landslides. On-site examination indicated that these hazards were greatest on the north slopes where, because of the attitude of the formations and the steepness of slope, several slides and rockfalls had occurred in past time. These were in all cases initated near the contact of the Supai-Kaibab formations, where the softer Supai rocks, eroding more rapidly, were removed from beneath the Kaibab, leaving it unsupported and suceptable to caving.

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