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16. Abstract

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It was recognized that the information collected in Virginia was limited in scope relative to the tremendous variability in characteristics and conditions that exist for rivers throughout the United States. Thus, in order to cooperate in a regional to national effort, this information was transmitted to the Hydraulics Section of the Federal Highway Administration where it was used to verify and modify the predictive models.

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FINAL REPORT

MAJOR FACTORS AFFECTING THE PERFORMANCE OF BRIDGES DURING FLOODS

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Virginia Transportation Research Council
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In Cooperation with the U.S. Department of Transportation
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ABSTRACT

The models used to predict the depth of scour that might occur in a river when a bridge is constructed across it were based on laboratory data. Within the decade of the 1980s, the Federal Highway Administration encouraged the states to collect field data on flooding and its effect on bridges. These data were used to verify the models for those conditions and geographic areas for which the data were applicable. High water during floods is the test of such models. Thus, after the severe flood in November 1985, as much information as possible was collected and compiled about the flood waters, the geology of the site, the configuration of the river and its flood plain, the bridge, and the damage done by the flood at four sites. Some of the data were used to calculate hydraulic parameters, and depths of scour; and the sediments collected were processed to determine their engineering properties. At least a year after the calculations were made, the Federal Highway Administration issued a technical advisory (1) on scour at bridges which contained recommendations that would have changed the results had they been available when those calculations were made.

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INTRODUCTION

Many hydraulic engineers spend their careers preparing hydraulic designs for bridges and other drainage structures but never witness a full-scale field test of their designs. Nature's worst case test of the design of these structures is usually a catastrophic flood. After such an event, the concern of the local engineer is to repair damage and restore normal services as quickly as possible. Thus, the local official ordinarily does not have time to compile data and to study the mechanism of the failure of the bridge.

Whether caused by natural or cultural changes, severe flooding has occurred throughout Virginia more frequently than anticipated. Many approaches and some bridges have been inundated, yet there is a lack of readily available data on the effects of these floods on the structures. If information were collected about the flood waters, the geology of the site, the configuration of the river and its flood plain, the bridge, and the damage that was done during a given period of flooding, it could be used to verify and possibly modify the predictive models that are used in the design of bridges.

PURPOSE AND SCOPE

The specific purpose of this study was to collect and analyze as much data as might be found available on the effects of the November 4, 1985, flooding of a few selected bridges in the Salem and Staunton construction districts of the Virginia Department of Transportation (VDOT). The final objective was to submit the information, by means of a report, to the Federal Highway Administration (FHWA) so that it could be used to verify or modify the models that are used to predict the hydraulic characteristics of streams.

Because of the many variables involved, and the difficulty of obtaining pertinent information months after the event, the scope of the study was limited to those bridges for which the most useful information could be collected for analyses of case histories.

METHODOLOGY

The acquisition and processing of the large volume of data that was needed to assess the magnitude and effects of the flooding were organized into tasks.

The bridge engineers for the Salem and Staunton districts each submitted a group of flood damage reports on bridges in their district. After the reports were screened, 12 bridges were chosen to be visited. The site evaluation involved a quick assessment of the nature of the materials in the flood plain and in the stream bed, the flood plain development, the extent and type of damage, the ability to document the damage (most sites had been repaired), the presence of scour, and generally the potential of the site to yield useful information. After the assessments, four bridges were chosen for study.

The only site in the Salem District was in Roanoke County in the Piedmont physiographic province at the most northeastern crossing of secondary Rte. 666 over Back Creek, approximately 5 mi south, 18° east of the center of Roanoke. The other three sites were in the Staunton District in the Valley and Ridge physiographic province. One was in Rockbridge County, approximately 8.5 mi north, 11° east of the center of Lexington. From Lexington toward Goshen, Rte. 39 crosses the Maury River just west of Rockbridge Baths. Two sites were in Rockingham County. One was on the west side of the Shenandoah Valley, approximately 7.75 mi west of Harrisonburg and just south of Rte. 33 where Rte. 613 crosses the Dry River. The other was on the east side of the Valley, approximately 11.5 mi east of Harrisonburg and 2 mi east of McGaheysville where Rte. 649 crosses the south fork of the Shenandoah River (see Figure 1).

The plans and profiles of the highway facility as designed and constructed were acquired from the VDOT's files. Preliminary engineering information such as the foundation studies at the proposed locations for the abutments and piers was also acquired. It was assumed that, precluding any earlier severe flooding, this information would adequately represent the preflood conditions.

To determine the current configuration of the stream bed, the flood plain, and the site, the districts' survey crews ran stream cross sections and profiles and provided site plans for each of the study bridges in their respective district.

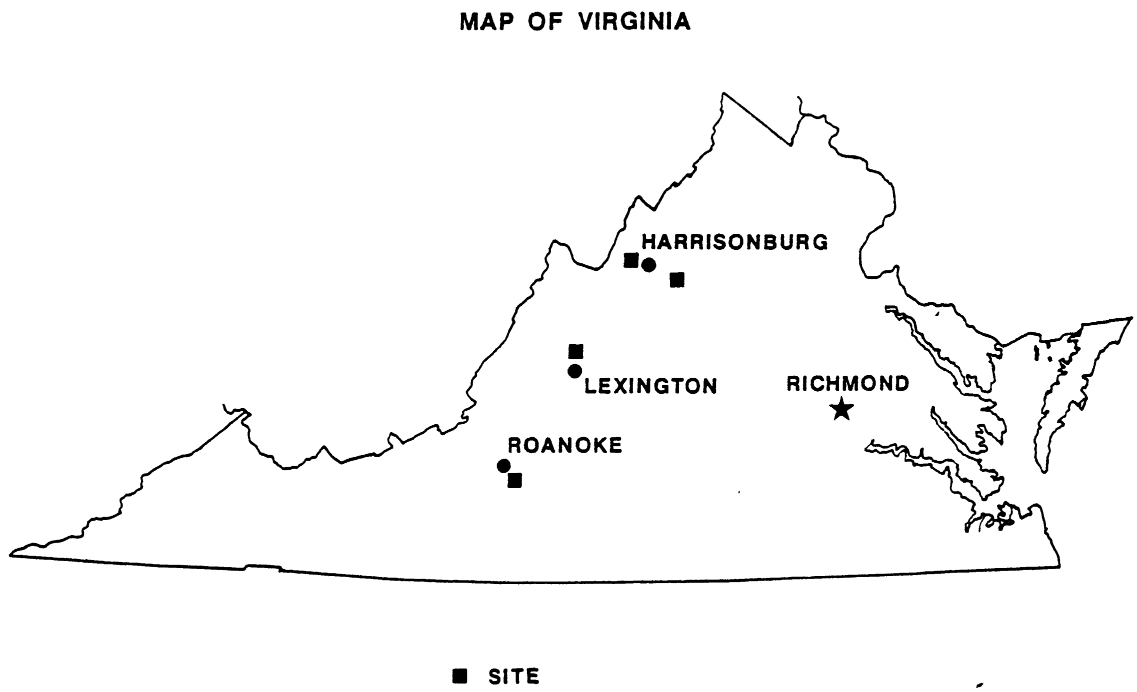

Figure 1. Locations of the four bridges that were investigated.

The geologists and drill crews made soundings at the four sites to provide information on the materials that were available for transport by flood waters. Most often, casing was driven through a layer of pebbles, cobbles, boulders, and silty sand; the length of casing was cleaned out; and a 2-ft split spoon sampler was driven 2 ft below the end of the casing by a 140-lb hammer with a 30-in drop. This procedure was repeated every 5 ft or until the sediment became cohesive enough to maintain the integrity of the hole without casing, at which time the use of casing was discontinued. The grain size distribution and Atterberg limits were determined when enough material to run the tests was recovered. When enough data on the sediment were available, the material was given a soil classification.

Photography was used to document various aspects of damage, scour, topography, and surficial sediments. The maximum discharges for the peaks of flooding at the four sites were provided by the Water Resources Division of the U.S. Geological Survey.

Once the basic information was in hand, the Hydraulics Section of VDOT calculated the average approach velocity (ft/s), average approach depth, froude number, critical stress (when it was exceeded), general degradation of the streambed, contraction scour (if any), and pier scour d_s (ft). The calculations on scour are not current because they were made prior to the transmittal by the FHWA of a technical advisory that contained updated recommendations that related to the calculation of scour.

RESULTS

The results for a study of this type do not lend themselves to the rather standard reportorial presentation. Some of the results will be presented to the FHWA as computer printouts, floppy disks, microfilm, aerial photographs, 35 mm slides, etc. The Hydraulics Section of the VDOT compiled large amounts of information and organized the material in the categories of "Hydrology," "Site Characteristics," and "Hydraulic Performance." This information is presented under "Hydraulics," and the attachments are transmitted separately. The geologic information is presented under "Geology."

Hydraulics

Route 666, Back Creek

Attachments — The attachments, transmitted separately, include the following data:

- o November 1971 survey (microfilm)
- o August 1986 survey (book)
- o 1973 bridge plans (microfilm)
- o Hydrologic and hydraulic evaluation (including floppy disk)
- o Plotted plan, stream profile, centerline profile

Hydrology

Morphology

- o Drainage area: 48.5 sq mi
- o Stream slope: 36.9 ft/mi
- o Stream length: 16.8 mi
- o Terrain: mountainous, predominately forested

Discharge (Q)

- o November 1985: 17,000 cfs
- o 1%: 8,500 cfs

Site Characteristics

River

- o Alignment: series of geologically confined sharp bends
- o Channel: 40'± wide, 8'± deep
- o Flood plain: 300'-400' wide

Bridge/Road

- o 97'-1" single span
- o Shelf abutment: 1 1/2:1 riprapped slope
- o Finished grade (ELTRD): 906.0'-904.8'
- o Low chord (ELLC): 901.0'-899.8'

Flood Damage

- o Riprapped fill slope in front of abutments removed to abutment footing
- o Apparent scour of streambed

Hydraulic Performance

Approach Section (100' upstream)	o	Q = 17,000 cfs: 5 Nov 85
	o	Channel depth: 23.9'
	o	Channel velocity: 7.6 fps
	o	Flood plain depth: 16'
	o	Flood plain velocity: 2-5 fps
Bridge Section	o	Depth: 23.8'
	o	Velocity: 12.5 fps
	o	Q through bridge = 15,123 cfs
	o	Q overtopping = 1,918 cfs
Exit Section (100' downstream)	o	Channel depth: 18.9'
	o	Channel velocity: 9.9 fps
	o	Flood plain depth: 11'
	o	Flood plain velocity: 1-5 fps

Route 39 Maury River

Attachments

The attachments, transmitted separately, include the following data:

- o November 1949 survey (microfilm)
- o September 1986 survey (two books)
- o 1953 bridge plans (microfilm)
- o Hydrologic and hydraulic evaluation (including floppy disk)
- o Plotted plan and profile sheets

Hydrology

Morphology	o	Drainage area: 330 sq mi
	o	Stream slope: 18.2 ft/mi
	o	Stream length: 41.8 mi
	o	Terrain: mountainous, predominately forested
	o	25% of watershed is controlled by Lake Merriweather
Discharge (Q)	o	November 1985: 87,700 cfs
	o	1%: 49,330 cfs

Site Characteristics

River	o	Straight alignment
	o	Solid rock channel bed
	o	Channel: 130' wide, 10' deep
	o	Flood plain: generally expanding, confined right, 500' left

Road/Bridge	o	308' bridge: 41'-69'-85'-69'-41'
	o	One shelf abutment, 1 1/2:1 slope, one vertical abutment
	o	Solid piers
	o	45^{o} skew
	o	Finished grade: 1118.5'-1119.4'
	o	Low chord: 1114.4'-1115.6'

Flood Damage — 500' flood plain contraction scoured toe of abutment, caused abutment and embankment failure, adjacent span dropped in river.

<u>Hydraulic Performance</u>

Approach Section (85' upstream)	o	Q: 87,700 cfs
	o	Channel depth: 29.2'
	o	Channel velocity: 14.7 fps
	o	Flood plain depth: 19'
	o	Flood plain velocity: 4 fps
Bridge Section	o	Q: 87,700 cfs
	o	Q through bridge: 68,772 cfs
	o	Velocity through bridge: 17.8 fps
	o	Q weir: 19,212 cfs
Exit Section (140' d.s.)	o	Q: 87,700 cfs
	o	Channel depth: 23.9'
	o	Channel velocity: 21.8 fps (critical)
	o	Flood plain velocity: 5 fps

<u>Route 649: South Fork Shenandoah River</u>

Attachments — The attachments, transmitted separately, include the following data:

- o April 1964 survey (microfilm)
- o November 1986 survey (books)
- o Plan sheets No. 3 and 4, Profile sheets No. 3A and 4A
- o 1965 bridge plans (microfilm)
- o Hydrologic and hydraulic evaluation (including floppy disk)

<u>Hydrology</u>

Morphology	o	Drainage area: 1,139 sq mi
	o	Stream slope: 27.5 ft/mi ±
	o	Stream length: 61.3 mi
	o	No significant watershed detention
	o	Percentage forested: 45%

Discharge (Q)	o	5 Nov 85	94,500 cfs (U.S.G.S)		93,650 cfs (VDOT)
	o	42.9%	17,600 cfs	10%	44,100 cfs
	o	4%	64,200 cfs	2%	82,800 cfs
	o	1%	105,000 cfs	0.2%	157,500 cfs

Site Characteristics

River
- o Alignment: gentle curve
- o Channel: 220'± wide, 10'± deep, uniform
- o Flood plain: 900'± west side, open land, gentle slope; high bluff east side, wooded

Bridge/Road
- o Bridge: 389'9" (5 spans)
- o Shelf abutments on piles
- o 4 sets of 3-column piers on piles
- o Finished grade (ELTRD): 1001'-1002'
- o Low chord (ELLC): 997' - 998'
- o Pier width to river: 3' (no significant debris)
- o Approach roadway overtopping: 992.8'

Flood Damage
- o Severe contraction and pier scour at west abutment and pier 1
- o Abutment front slope damaged, flood plain in front of abutment to river bank degraded 10'
- o Entire riverbed degraded 3'± from 200'± upstream of the bridge to 300'± downstream of the bridge
- o No general riverbed degradation indicated by available data

Hydraulic Performance

Approach Section (400' upstream)
- o Q: 93,650 cfs (November 5, 1985)
- o Channel depth: 28'
- o Channel velocity: 8 fps
- o Flood plain depth: 16'
- o Flood plain velocity: 3 fps
- o Channel froude no.: 0.27

Bridge Section
- o Depth: 31' (with scour hole)
- o Velocity: 8.5 fps
- o Q through bridge: 77,119 cfs
- o Q overtopping approach: 17,164 cfs

Exit Section
- o Q: 93,650 cfs
- o Channel depth: 30.8'
- o Channel velocity: 10.7 fps
- o Flood plain depth: 16'
- o Flood plain velocity: 3 fps

Route 613: Dry River

Attachments	The attachments, transmitted separately, include the following data: o 1965 Bridge plans (microfilm file) o 1986 Contour map by photogrammetry o 1966 Road plans (microfilm file) o Hydrologic and hydraulic evaluation (including floppy disk)

Hydrology

Morphology	o Drainage area: 76.9 sq mi o Stream slope: 107 ft/mi o Stream length: 15 mi o No significant watershed detention storage o 100% forested
Discharge (Q)	o November 5, 1985: 20,950 cfs o 42.9% 2,360 cfs 10% 5,120 cfs o 4% 7,080 cfs 2% 8,840 cfs o 1% 10,890 cfs 0.2% 16,340 cfs

Site Characteristics

River	o Alignment: Channel curves through site. Divided into two main channels upstream and thru bridge. One channel downstream. o Channel: 70'-80' wide, 5' deep; extremely coarse bed material
Bridge/Road	o Bridge: 272'-2"; four 67'-6" spans o Vertical abutment/wingwalls o Three solid piers founded in river jack bed material o Finished grade: 1436.5'-1437.6' bridge, 1432.5' approach o Low chord: 1432.5' - 1433.6' o Pier width to flood: Out of line by $10^{\circ}\pm$ with upstream channel, in line with downstream channel, in line with flood plain
Flood Damage	o Pier 2 settled vertically 2' on downstream end and 0.5' on upstream end o Some scour of bank and overburden at upstream side of south abutment

Hydraulic Performance

Approach Section (260' upstream)	o Q (November 5, 1985): 20,950 cfs o Channel depth: 8' o Channel velocity: 6 fps o Flood plain depth: 4' o Flood plain velocity: 2.5 fps o Channel froude no.: 0.505
Bridge Section	o Depth: 12' o Velocity: 9.2 fps o Q through bridge: 20,450 cfs o Q overtopping: 620 cfs
Exit Section	o Q: 20,950 cfs o Channel depth: 10.5' o Channel velocity: 11.3 fps o Flood plain depth: 5' o Flood plain velocity: 3 fps

Geology

Rte. 666 and Back Creek

General

Rte. 666 and Back Creek in Roanoke County were in an interesting area very close to the contact between the Blue Ridge complex of metamorphic and igneous rocks and the Valley's sedimentary rocks. For approximately 6 mi, within the middle reaches of Back Creek, its course is controlled by a thrust fault that carried a biotitic gneiss of the Blue Ridge complex up and over the early Cambrian members of the Valley sequences. South of Roanoke, much of the gneiss has been eroded from an area of approximately 15 sq mi that appears as a protrusion of Valley formations into the Blue Ridge complex. The change in patterns is obvious on the geologic map (2) and is easy to discern on the aerial photograph because of the heavily forested slopes within the Blue Ridge complex of rocks and the pasture and heavily developed terrain within the area underlain by the sedimentary rocks of the Valley. Back Creek meanders from one side to the other of a 300- to 400-ft-wide valley. At the site of the distressed bridge, the valley opens up a bit more. As might be expected with a gneiss, the various layers within the rock have different susceptibilities to erosion. Thus, both upstream and downstream from the bridge, ledges of the more resistant layers crop out in the stream bed. At the bridge, the gneiss was covered by 2 to 4 ft of sand, silt, and some pebbles and cobbles.

Sediment Description

An auger was used to drill two holes in the flood plain downstream of the bridge, one hole on each side of the stream. Hole 1, off the north end of the bridge, was in the more typical material for this area, and split spoon samples were taken for its entire length. Hole 2 was bag sampled from 0.0 to 5.0 ft and from 5.0 to 11.3 ft. These sediments were principally fine to coarse grain sands with some silt. Near the top of hole 1, there was enough clay in the sediment that the sample from the split spoon maintained its integrity while it was being handled. Deeper in the hole there was less clay, and it was segregated in layers. Toward the bottom of the hole, the percentage of recovery became very poor, and the material had no cohesive properties. (See Table 1 for specific information on the samples that were retrieved from the two holes.)

TABLE 1

Properties of Sediment for Rte. 666 Over Back Creek

Hole: Sample	Elevations	Depths	Blows per Ft	Atteberg Limits	Soil Classification
1:1	894.0 to 892.0	0 to 2	4 & 5	LL-27; PI-3	A4
1:2	892.0 to 890.0	2 to 4	5 & 9	LL-26; PI-8	A-2-4
1:3	890.0 to 888.0	4 to 6	10 & 9	LL-20; NP	A-2-4
1:4	888.0 to 886.0	6 to 8	11 & 19	LL-21; NP	A-4(1)
1:5	886.0 to 884.0	8 to 10	10 & 13	LL-17; NP	A-1-b
1:6	884.0 to 882.0	10 to 12	15 & 24	Not enough sample	A-1-2
2:1	No	0 to 5	Bag	LL-26: NP	A-2-4
2:2	Information	5 to 11.3	Samples	LL-18; NP	A-2-4

Rte. 39 Over the Maury River

General

This site is located toward the northwest side of the Valley. Approximately 1.5 mi upstream from the bridge, the Maury River exits the Goshen Pass where it winds through very steep terrain (2,000 ft relief in 1 mi) that is underlain by the Clinch sandstone and the sandstone, shale, and quartzite of the Clinton formation. Out of Goshen Pass, the Maury River has a relatively straight reach of approximately 3 mi where it flows southeasterly across the structure of the Martinsburg shale and several middle and lower Ordovician limestones and dolomites (3). At the bridge, limestone is exposed in the river bottom, and the piers are set on bedrock.

Sediment Description

Two holes were drilled at this site. Inasmuch as the damage at this site involved the breaching of the embankment and the subsequent collapse of abutment A, hole 1 was drilled far enough east of the bridge that the original embankment materials were penetrated. Hole 2 was located just west and north of the toe of the new embankment for abutment A.

The fill material was described as a stiff to hard, reddish brown, clayey silt with scattered pebbles and cobbles. Only in split spoon sample 1, which was taken from the fill, was enough material recovered to run tests. All other attempts to sample holes 1 and 2 were hampered by the presence of cobbles. At a depth of 12.7 ft, the flood plain alluvium of brown, fine to medium grained sand with pebbles, cobbles, and small boulders was encountered. Limestone bedrock was at 20.1 ft deep, or an elevation of 1097.2 ft. Hole 2 was in a disturbed area at the base of the new fill; thus the upper 3 ft was a mixture of fill and alluvium. Then, there was approximately 6 ft of alluvium that was yellowish brown, very loose sandy silt with some pebbles and cobbles on top of the limestone bedrock at an elevation of 1093.9 ft. (See Table 2 for the test results.)

TABLE 2

Properties of Sediment for Rte. 39 Over the Maury River

Hole: Sample	Elevations	Depths	Blows per Ft	Atteberg Limits	Soil Classification
1:1	1111.8 to 1109.8	5.5 to 7.5	13 & 15	LL-30; PI-8	A4(3)
1:2	1106.8 to 1104.8	10.5 to 12.5	25 & 31	Not enough sample recovered	
1:3	1101.8 ---	15.5 on a cobble; no movement; no sample			
2:1	1097.9 to 1095.9	5.5 to 7.5	50 & 50	No sample; drove small cobble in front of tube	

Rte. 649 Over the South Fork of the Shenandoah River

General

The Rte. 649 bridge site was on the southeast side of the Valley, over the Elbrook dolomite that was deeply weathered. The residuum from the Elbrook was somewhat plastic yet seemed to be very erodable. However, the river ran close to the northwest slope of the Blue Ridge Mountains, and formations such as the Swift Run, Weverton, and the Erwin have contributed sandstone and quartzite pebbles, cobbles, and boulders to the bedload of the South Fork of the Shenandoah River (4) (see slides

C-6 and D-3). These large, tough particles have armored the bed of the river, thus protecting the residuum from all but the most severe floods. The east end of the bridge sits on what might be called the first terrace, and the west end sits on an embankment that had been built across the flood plain.

Sediment Description

The information about the alluvium and residuum that was acquired during the preliminary engineering phase is shown on attachment 190-24 08 F. The time and cost of floating a drill on the river precluded the duplication of the earlier effort. Thus, only three holes were drilled and sampled. These holes were located on the west side of the river in proximity to the site of the extreme contraction scour. Hole 1 was located 45 ft upstream of a point on the side of the bridge that was midway between abutment A and pier 1. It was just upstream of the contraction scour hole on a ramp that had been constructed, using flood plain materials, to allow safe passage for the cattle that broused on both sides of Rte. 649. The elevation of the top of the hole was approximately 3 ft below the elevation of the flood plain. Hole 2 was located under the downstream side of the bridge midway between abutment A and pier 1 within the scour depression and near the bottom of the ramp that led up to the flood plain surface. Hole 3 was in line with the other two holes and approximately 100 ft downstream from the side of the bridge.

These holes were discontinued at a depth of approximately 43 ft because it was considered that 34 ft of residuum would adequately represent the nature of the residuum, and there was little likelihood that any erosion would reach those depths in the near future.

The alluvium was from 10 to 15 ft thick on the flood plain and from 6.7 to 7.4 ft thick in the river bed. It was brown and somewhat loamy close to the grassy pasture surface, becoming brownish gray with depth. The alluvium was described as pebbles and cobbles in a silty sand. The residuum was 36 to 71.7 ft thick across the job site and had a relatively uniform appearance throughout its depth. It was a medium stiff to very stiff, yellowish brown to mottled plastic clay. Nevertheless, there were differences in the material that are reflected in the different engineering soil classifications. (See Table 3 for the test results.)

Although some of the large particles in the river's bed load may come directly from the tributaries to the river, many of them come from the layer of alluvium on the flood plain. Many of this type of large particle are in the boulder bars on the west side of the river, upstream and downstream of the bridge (see roll D, slides 10 and 11, respectively). It was thought that these bars resulted from a decrease in the river's velocity. The location of the upstream bar was probably determined by the decrease in the velocity of the flood waters as they flowed into the mass of water that was partially dammed by the embankment across the flood plain, whereas the location of the downstream bar was

TABLE 3

Properties of Sediment for Rte. 649 Over the South Fork
Shenandoah River

Hole: Sample	Elevations	Depths	Blows per Ft	Atteberg Limits	Soil Classification
1:1	970.3 to 969.3	7 to 8	50 & 45*	Sample tube was on a pebble	
1:2	966.3 to 964.3	11 to 13	8 & 5	LL-46; PI-17	A-7-6(12)
1:3	961.3 to 959.3	16 to 18	6 & 5	LL-45; PI-17	A-7-6(12)
1:4	956.3 to 954.3	21 to 23	7 & 14	LL-47; PI-13	A-7-5(9)
1:5	951.3 to 949.3	26 to 28	12 & 15	LL-42; PI-12	A-7-5(9)
1:6	946.3 to 944.3	31 to 33	8 & 9	LL-39, PI-10	A-4(8)
1:7	941.3 to 939.3	36 to 38	10 & 16	LL-41, PI-8	A-5(8)
1:8	936.3 to 934.3	41 to 43	21 & 30	LL-36; NP	A-4(7)
2:1	968.8 to 966.8	6 to 8	24 & 28	Sample tube was on a pebble	
2:2	963.8 to 961.8	11 to 13	22 & 24	LL-41; NP	A-5(7)
2:3	958.8 to 956.8	16 to 18	18 & 41	LL-42; PI-9	A-5(3)
2:4	953.8 to 951.8	21 to 23	36 & 48	LL-40; PI-10	A-4(2)
2:5	948.8 to 946.8	26 to 28	12 & 28	LL-42; PI-14	A-7-6(10)
2:6	943.8 to 941.8	31 to 33	11 & 18	LL-43, PI-14	A-7-6(7)
2:7	938.8 to 936.8	36 to 38	0 & 1	No sample, too soft	
2:8	933.8 to 931.8	41 to 43	6 & 1	Not enough sample	
3:1	965.3 to 963.3	10.5 to 12.5	7 & 8	Not enough sample	
3:2	960.3 to 958.3	15.5 to 17.5	12 & 20	LL-38; PI-7	A-4(6)
3:3	955.3 to 953.3	20.5 to 22.5	9 & 12	LL-48; PI-18	A-7-5(12)
3:4	950.3 to 948.3	25.5 to 27.5	5 & 9	LL-41; PI-11	A-7-5(7)
3:5	945.3 to 943.3	30.5 to 32.5	8 & 15	LL-49; PI-9	A-5(9)
3:6	940.3 to 938.3	35.5 to 37.5	11 & 31	LL-43; PI-10	A-5(5)
3:7	935.3 to 933.3	40.5 to 42.5	12 & 31	LL-42; PI-7	A-5(6)

* 1/2-ft intervals.

controlled by the decrease in velocity where the flood waters could again spread out after having passed under the bridge at an increased velocity because of the contraction phenomenon. It was thought that knowing the size of the largest boulders would be useful because these boulders are a measure of the minimum velocity of the water that moved them to their present locations. The dimensions and identification of the slides that were taken of them are listed in Table 4.

TABLE 4

Large Boulders in Boulder Bars

Location	Roll	Slide	Dimensions in Inches
Upstream bar	D	15, 16, 17	22 x 12 x 11
	D	18	22.5 x 12.5 x 10
	D	19, 20	15 x 14 x 10
	D	21	23 x 13 x 12
	D	22, 23	29 x 12 x 8.25
Downstream bar	D	31	24 x 12 x 7
	D	32	16 x 9 x 8.5
	D	33	23 x 10 x 7
	D	34	37 x 15 x 10
	D	35	Did not measure; roughly cubic
	D	36	39 x 17 x ? (buried)
On west bank	D	37	Did not measure; roughly cubic
	D	38	Did not measure; roughly cubic

Slides 1 through 9 of roll D show various aspects of Lower Lewis Run, a tributary to the South Fork of the Shenandoah River that contributed boulders to the river. The run was similar to many other such streams coming off the west slope of the Blue Ridge Mountains. Frames 24 through 30 show some of the conditions that existed 8 months after the flood at the Shenandoah River bridge site.

Rte. 613 Over Dry River

General

The Rte. 613 bridge over Dry River was located on the northwest side of the Valley over the Conococheague limestone, which dips to the southeast. The site was approximately 0.2 mi southeast of the contact with the Elbrook dolomite. The bedrock is deeply weathered with 11 to 23 ft of alluvium and 8 to 31 ft of residuum overlying partially weathered limestone. Most of the watershed for the river upstream of the bridge was underlain by such sandstone formations as the Oswego, Clinch, Chemung, Hampshire, and Pocono (4); there were many cobbles and boulders of these types of materials in the bed of the river.

Based on limited field observations and on the Rawley Springs, Virginia, and Briary Branch topographic maps of the U.S.G.S. (attached), many of the streams in this region had braided channels during high flow. This was especially so at the Rte. 613 and Dry River bridge site.

Sediment Description

Even though five drill holes were planned for the Dry River site, it was noted in the request for the work that three of these soundings could be eliminated. By the time drilling could begin, water was in the main channel of the stream and access to the river bottom was limited. The information from the preliminary engineering foundation study was available, and it was unlikely that the planned soundings could be drilled before rising waters and uncertain weather conditions made working on the stream bed untenable. Therefore, the sounding off the downstream end of pier 2 was drilled on December 9, 1986, and the drilling equipment was removed from the stream bed. The description of the sediments in 1986 was quite similar to that recorded in 1965 (see attachment 201-22---10F). The alluvium, a mix of pebbles, cobbles, and boulders in silty to coarse sand, was 11 to 23 ft thick. The residuum was a yellowish brown to mottled plastic clay that had been weathered from the underlying limestone and was 7.6 to 30.7 ft thick.

Earlier in the fall while the streambed was still dry, areas of 1 sq yd were delineated with orange paint at three locations. Thus, those portions of the particles that were exposed received some orange paint. Each particle with orange paint on it was measured by hand in three dimensions. Using the field measurements, the approximate volume of each particle and then the nominal diameter of a sphere of that volume were calculated. The particles were classified according to Wentworth's particle size classification (cited in 5), using their nominal diameters, as boulders, large cobbles, small cobbles, very large pebbles, and large pebbles. The grain size distributions for these three samples are shown in Figures 2, 3, and 4. The size for 100 percent passing was determined by taking the size of the largest boulder and rounding up to the next hundred. As is frequently the case with extremely coarse particles, the number and size of the boulders strongly affect the skew of the distributions. Removing the boulders from the samples and recalculating the distributions (see Table 5) show that with respect to the remaining particles the distributions are quite similar.

In addition to the sizing of the square yards, the largest boulders within sight of the bridge were measured. The dimensions of the boulders and identification of the slides that were taken of them are listed in Table 6.

Observations

Rte. 666 and Back Creek

At Rte. 666 and Back Creek in Roanoke County, the damage was limited to the erosion of the protective slopes for the abutments. The abutments were on piling and were not appreciably damaged. The previous bridge had been upstream from the present bridge, and the southwest abutment of the previous bridge, located on the flood plain, was removed. The northeast abutment that was relatively close to the base of a steep ridge remained but did not appear to be in such a position as to affect the present abutment during flood conditions.

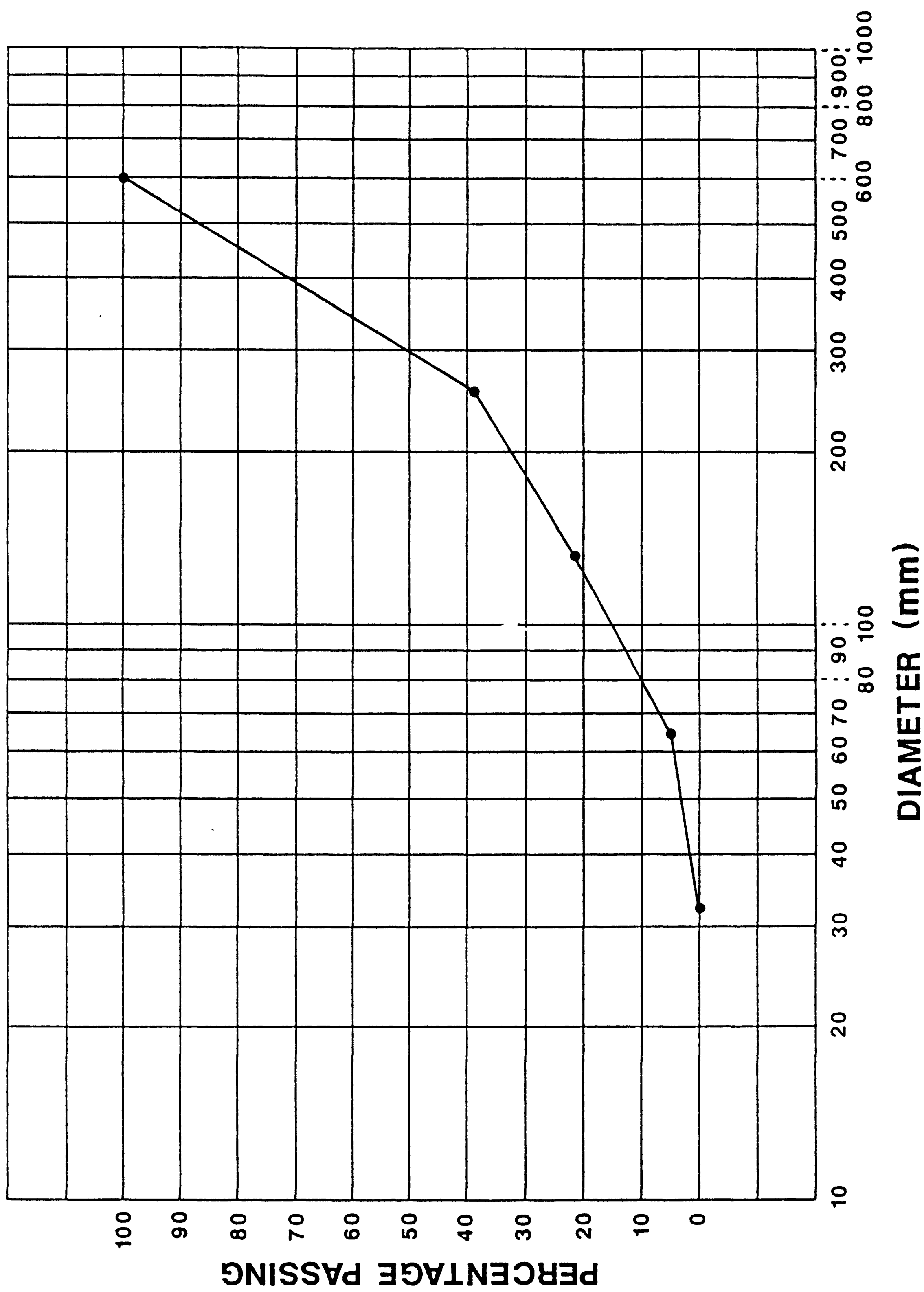

Figure 2. Grain size distribution for the upstream square yard, Dry River and Route 613.

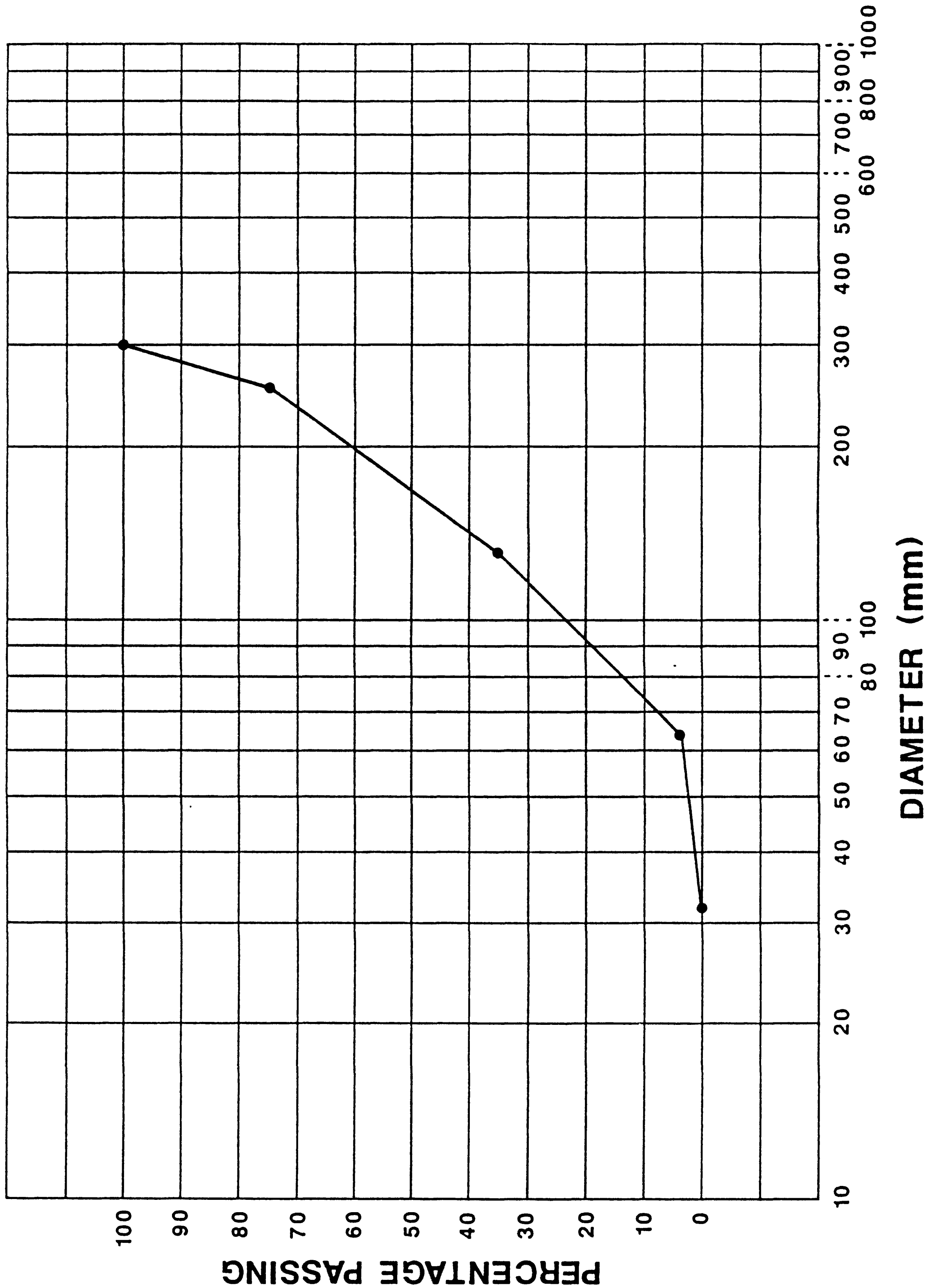

Figure 3. Grain size distribution for the northern downstream square yard, Dry River and Route 613.

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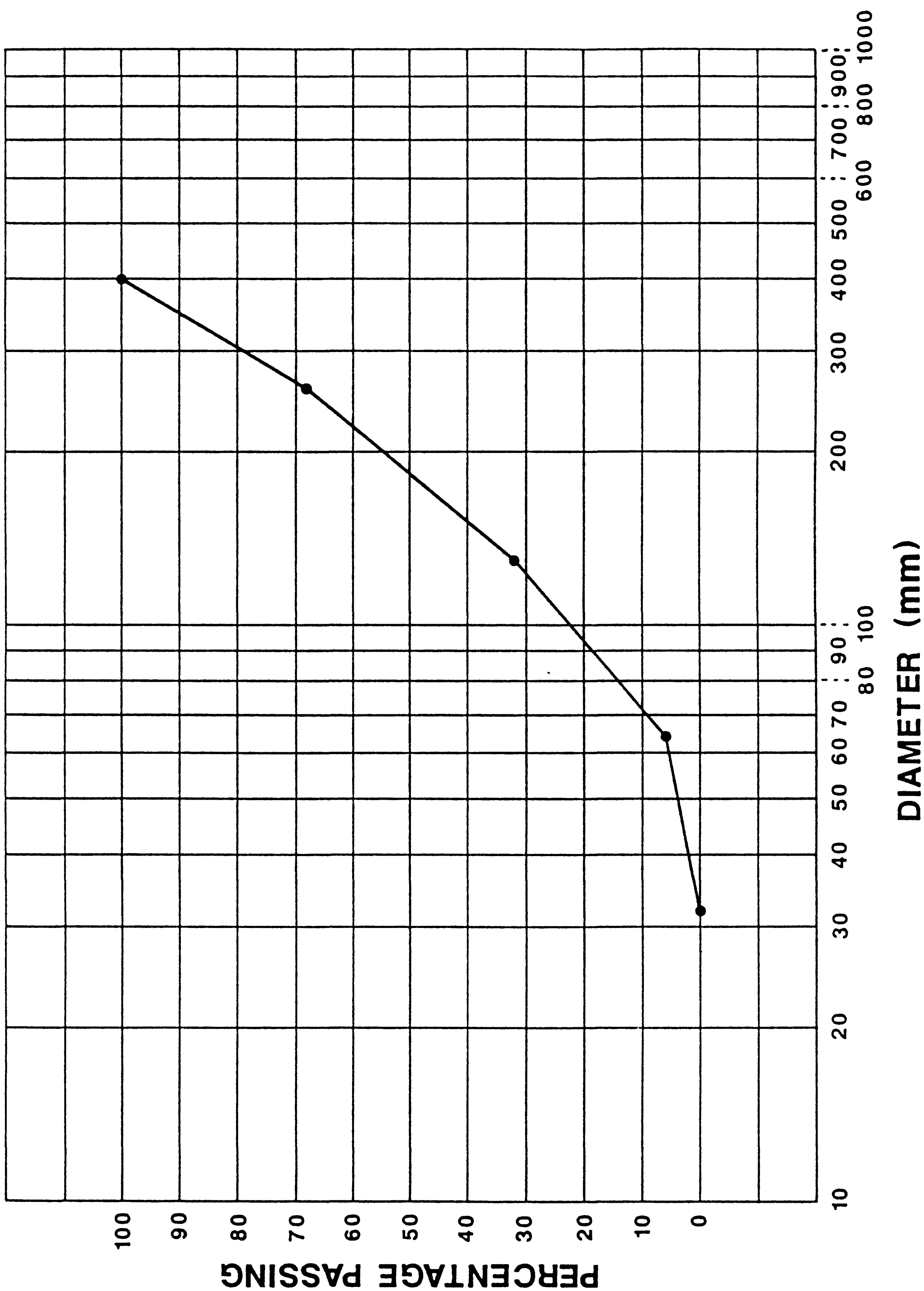

Figure 4. Grain size distribution for the southern downstream square yard, Dry River and Route 613.

TABLE 5

Grain Size Distribution of Cobbles and Pebbles: Percentage Passing

Sample	Size (mm) 256	128	64	32	16
Upstream	100	53.7	11.4	0.1	0.0
Downstream N.	100	47.2	5.0	0.02	0.0
Downstream S.	100	46.8	8.7	0.2	0.0

TABLE 6

Large Boulders in Bed of Dry River

Location	Roll	Slide	Dimensions (in)
Underbridge	E	6	32 x 15 x 5
	E	7	20 x 20 x 14.5
	E	8	16 x 15 x 13
	E	9	29 x 18 x 10
	E	10	27 x 19 x 12
	E	10	33 x 20 x 8 to 19
Upstream of bridge	E	11	24 x 19 x 18
	E	12	25 x 12 x 10
	E	13	26 x 18 x 14
	E	14	32 x 17 x 9 to 17
	E	15	41 x 16 to 20 (buried)
Downstream of bridge	E	16	40 x 24 x 22
	E	17	32 x 20 x 12
	E	18	30 x 18 x 15
	E	19	28 x 21 x 20
	E	20	38 x 21 x 20 tapers
	E	21	Main boulder same as in 20, looking at almost square end. 300 ft from bridge looking downstream.
	E	22	Approximately same location as in 21. Looking at tapered end of boulder with pier 2 in the background.
	E	23	Typical bed material

Rte. 39 Over the Maury River

The Rte. 39 bridge over the Maury River in Rockbridge County failed. The piers and west abutment were founded on bedrock and were not damaged. All of the watersheds connected to this study were forested and contributed trees as debris to the flood waters. This was especially so with the Maury River where it came through Goshen Pass. (See slide B-11 [Appendix A] of the handrail that was replaced, possibly because of battering by debris.) Approximately 8.5 mi downstream in Lexington, a foot bridge crossed the Maury River, and evidence of the debris that was in the river was in a debris jam of at least one-half an acre that was trapped behind the low-level foot bridge.

Rte. 649 Over the South Fork of the Shenandoah River

Where Rte. 649 crossed the Shenandoah River, the bridge was as impressive as the Rte. 39 bridge over the Maury River with the deck well over 20 ft above the normal water level. With a very wide flood plain and an armored bed over a deeply weathered carbonate, this site was complex. The boulder bars previously mentioned are shown on slides D-10 and 11. As slides D-12 and 13 show, this bridge would have failed if the piers and abutments had not been placed on piling. During a period of low, clear water during the summer of 1987, the top approximately 6 in of all the footings for piers 2 and 3 were observed. This observation corroborates the cross section that was measured by the survey crew in 1986. As was mentioned in the section on geology, the alluvium was approximately twice as thick in the flood plain as in the river bed. Inasmuch as the most noticeable particles in the alluvium were the pebbles, cobbles, and boulders, it is interesting to theorize as to whether the alluvium in the stream bed is only half as thick as that in the flood plain because much of the finer particles were winnowed out thus concentrating the coarse particles in a thinner layer. As a remedial measure, carbonate riprap was placed on the abutment slopes and around piers 1 and 4. Concern was expressed as to whether the steel in the pilings would corrode if it were exposed to oxygenated water. After an April 1987 flood, it was noted that sand was deposited on top of the riprap island and that vegetation had begun to grow. Perhaps the voids below the water line also trapped fines and the environment around the pilings will be less oxygenated.

The 1964 abutment site soundings 1-2 and 9-10 were approximately 100 ft west and 75 ft east of their respective river banks. The east terrace was 14 ft higher than was the flood plain to the west. With approximately the same thickness of very coarse sediment on each side of the river, the top of the residuum is 12 to 14 ft higher on the east side of the river. The east side of the river may be an older terrace that has not been reworked as recently as has the west side. In 1964, approximately 12 ft of the residuum was above the bed of the stream on the east side and thus was susceptible to erosion. However, the east bank was lined with sycamore and other trees that apparently provided stability at this point. The stream bed was at the same level as the top of the residuum on the west side of the river; thus the residuum was barely exposed to the erosive power of the river. The 1986 stream cross section shows the elevation of the stream bottom to be 967 ft, 2 to 3 ft below the top of the residuum on the west side of the river. With fewer trees on the west bank, it may now be more susceptible to erosion than before the 1985 flood.

There was significant flooding of the South Fork of the Shenandoah River and its tributaries on April 7, 1987. Black and white photographs (logged in Appendix B) were taken during the flood and again on April 21, 1987, and were included in the transmitted information. Photographs 12 and 18, taken on April 21, 1987, were marked to show the water level that was recorded on the corresponding photographs (numbers 14 through 16) taken during the April 17, 1987, flood. Photographs 15 and 16 (April 17, 1987) show two bents of pier 3. It seemed that two rules or standards with white backgrounds and dark colored marks showing tenths of a foot could be attached to the two bents so that the difference in water level at the two bents could be photographed.

Aerial photograph 8-082-718-052, transmitted separately, shows the bridge at such an angle that its relationship to the flood plain in 1983 is well documented. The river bank was east of pier 1. Magnification of the image shows the light pattern of a scour hole in the flood plain around pier 1.

This last observation about the Shenandoah River site also applies, in concept, to the Dry River site. The plans for the Rte. 649 bridge over the Shenandoah show that the footings for pier 1 were set 9 ft higher than the footings for the other piers, presumably because pier 1 was on the flood plain approximately 35 ft west of the river's west bank. Although the footings for pier 1 were buried 3.5 ft below the surface of the flood plain, approximately 11 ft of scour at pier 1 left 5 ft of piling above the stream bed and pier 1 approximately 35 ft east of the 1986 bank of the river.

That hindsight judgments are easy to make is no reason not to make them. Therefore, keeping in mind the dynamic aspects of most drainage systems, it seems that VDOT would have been better off to absorb the additional cost of placing the pier 1 footings at the same elevation as the footings for the other piers. If that had been done, no riprap would have been required to maintain the stability of pier 1. Two benefits would have accrued. The cost of the riprap for the piers would not have been incurred, and the environment around piers 1 and 4 would not have been changed by placement of the riprap. Even though under the post-1985 flood conditions, the riprap had to be placed, there has to be some question or concern for the effect of the riprap on the river's cross section and what will happen during the next major flood.

<u>Rte. 613 Over Dry River</u>

At Rte. 613 and Dry River in Rockingham County, the bridge was severely stressed during the 1985 flood. During the initial visit to this site, the river was dry, and it was noted that the surface of the stream bed was undulating with as much as 2 ft of relief over relatively short distances (see slides B-20 and 21). The cross section for the proposed centerline showed that the stream bed surface was also undulating in 1965. The location for pier 2 was approximately 1.5 ft higher than the locations for piers 1 and 3. Pier 2 was designed to be 1.5 to 2.0 ft shorter and placed at a higher elevation than were the other piers. Although the geology was similar to that at the Shenandoah River site, with very coarse alluvium over a silty residual clay, it was not planned to use piling. Pier 2 settled more than 2 ft at its downstream end and approximately 6 in at the upstream end. In addition, there was a question as to whether pier 2 tilted slightly to the northeast (see slides G-20 and 21). The data from the Shenandoah River and Dry River sites certainly suggest that in a dynamic environment such as a river, before the footings are placed at different elevations in order to save on the cost of labor and materials, consideration should be given to the

- worst case consequences of a severe flood
- cost of remedial measures
- cost of interrupted travel to the public
- effect on public safety
- effect of the remedial action on the stream cross section and its response to high-energy water.

For approximately 1,320 ft upstream from the bridge, there appeared to be multiple channels. The Briery Branch Quadrangle, a 7.5 minute series topographic sheet, shows three or four channels with two principal channels passing under the first and fourth spans, joining approximately 300 ft downstream of the bridge. The June 1983 aerial photographs corroborate the information on the map. The 1985 flood changed the river bed on both sides of the bridge. From the initial visit until now, the main channel has been close to the middle of the bridge, passing under the southwest end of the third span along the northeast side of pier 2. The principal channel comes at pier 2 at a slight angle from the northwest (see black and white photographs for April 17, 1987, Nos. 36 and 37).

The effect of old piers or any large object in the stream bed on the flow should be considered before locating the new piers. In Dry River, the southwest side of one of the old piers is somewhat downstream and approximately 29 ft northeast of the downstream end of pier 2. With high water, the effect is to restrict the water between the 2 piers and create considerable turbulance in the water. Such a concentration of water appears to increase its carrying power. Photographs for April 17, 1987, (28 through 30) are off the downstream end of pier 2. Photograph 30 shows the turbulance of the water that was constricted between the old pier and pier 2. The sound of moving cobbles etc. was audible at this point on the bridge. As a remedial action, carbonate riprap was placed along both abutments and around each pier.

STATUS OF STUDY

The responsibility of the VTRC, within the organization of the study reported on, was to coordinate and assist in the collection and organization of the data (6). Thus, no conclusions or recommendations are offered. With the transmittal of this report and the accompanying information, it is considered that the Council's responsibility to the study has been satisfied.

ACKNOWLEDGMENTS

The authors gratefully acknowlege the advice and encouragement of S. R. Davis and J. Sterling Jones of the FHWA. Thanks are also due the many surveyors, geologists, and photographers of the VDOT who helped collect the data in the field and the materials technician supervisor, M. O. Harris, who determined the engineering properties of the sediments. Special thanks go to Ellen Phillips who recorded the large particle measurements on a chilly, cloudy October day in 1986, before water got up in Dry River. The study described in this report was financed with Highway Planning and Research funds and was monitored by the Federal Highway Administration.

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APPENDIX A

LOG OF SLIDES

Date	Roll and No.	Subject
7/3/86	A 2	Roanoke County, Rte. 765; Mason Creek: Downstream from bridge bedrock in stream bottom.
	A 3	Bridge from east side.
	A 4	Looking upstream, under bridge: note bedrock.
7/3/86	A 5	Rte. 740, Mason Creek: Upstream from bridge.
	A 6	Bedrock exposed in stream bottom near abutment.
	A 7	Area that had washed away from abutment.
	A 8	Close up of abutment.
	A 9	Material used as fill, plus stain on abutment.
	A 10	Looking downstream, abutment and gravel. Stain may indicate level of previous sediment.
	A 11	Abutment, wood buttress material, previous concrete repair.
	A 12	Same as 11, different perspective.
	A 13	Riprap from upstream side of bridge.
7/3/86	A 14	Rte. 666, First Bridge N. of Rte. 657, Back Creek:
	A 15	Camera misfired.
	A 16	Bedrock in stream bottom.
	A 17	Upstream from bridge, debris hanging in tree.
7/3/86	A 18 Site 1	Rte. 666, Third Bridge N. of Rte. 657, Back Creek: Shows erosion behind N. abutment and portion of old abutment upstream of bridge.
	A 19	New fill around S. abutment and new concrete at base of abutment.
	A 20	Bridge bearing and P.C. concrete support.
	A 21	Debris on beam.
7/3/86	B 1	Upstream of bridge showing bedrock exposed.
	B 2	Downstream pool just beyond bridge and old concrete.
7/3/86	B 3	Rte. 660 and Back Creek: Pier over, deck downstream, abutments O.K.
	B 4	N.E. abutment.
	B 5	Deck downstream.
	B 6	One half of deck turned over.
	B 7	Looks like trimy concrete and some bedrock adhering to bottom of pier.
7/3/86	B 8 Site 2	Rockbridge County, Rte. 39 Over Maury River: Debris.
	B 9	Debris around ends of piers 2 and 3.
	B 10	Replaced embankment, abutment, and first span.
	B 11	Water was over deck, looking upstream at repaired handrail.

APPENDIX A (continued)

7/3/86	B 12	Rockingham County, Rte. 731 and Briery Branch: Downstream channel just below bridge.
	B 13	Upstream under bridge; low clearance; area had been cleaned up (bulldozed).
	B 14	Debris pushed aside, bank or levee opposite side.
	B 15	Bank.
7/3/86	B 16 Site 4	Rte. 613 and Dry River: Downstream end of pier 2 settled approximately 2.4 ft.
	B 17	Hole dug to expose footing.
	B 18	Some of material removed from hole and concrete pier from previous bridge.
	B 19	End of pier 2 and footing.
	B 20	Downstream at bridge, undulating bed, Calvin Boles standing in low area.
	B 21	Part of depression, sand in bottom, notebook for scale.
7/18/86	C 2	Rockingham County, Rte. 340 and Lower Lewis Run: Looking upstream at collapsed bridge.
	C 3	Area eroded from behind abutment, before or after collapse.
	C 4	Closer view of eroded area.
	C 5	N. abutment is O.K.
	C 6	Area upstream of road has been cleaned up.
	C 7 Site 3	Rte. 649 and S. Fork Shenandoah River: From downstream,west end of bridge and the eroded abutment slope.
	C 8	Looking upstream at bridge, debris on pier 3, boulder bar in background.
	C 9	Pier 1 and W. abutment, disrupted concrete riprap, footings out of water, contraction scour removed flood plain material.
	C 10	W. bank downstream from bridge, note boulders in upper layer of flood plain.
	C 11	Panning downstream, can see upper end of boulder bar.
	C 12	Main portion of downstream boulder bar.
	C 13	Debris on pier, but then water was over the deck.
	C 14	Debris on trop of pier.
	C 15	Upstream boulder bar, taken from bridge.
	C 16	Upstream side of bridge, toe of abutment protection.
	C 17	Path for cows, and disrupted riprap.
	C 18	Debris around walnut tree.
	C 19	Same as 18, different perspective, can see all four piers.
	C 20	Contact between river jack and probable lens of silty alluvium.
	C 21	Contact of cobbles and boulders with lens of finer sediment.
	C 22	Different perspective of contact.

APPENDIX A (continued)

7/24/86	D 1	Rockingham County, Rte. 340 and Lower Lewis Run: Where natural channel empties into widened channel 300 to 500 ft upstream of bridge site.
	D 2	Same as 1.
	D 3	Further back from site for 1.
	D 4	Same as 1 different vantage point.
	D 5	After 4, turned around and shot 5 from same spot.
	D 6	Eastern edge of gravel (pit that has lowered the base level of erosion for Lower Lewis Run).
	D 7	Bridge from downstream.
	D 8	Undercutting near gravel pit.
	D 9	Area of undercut bank; tree was removed.
	D 10	Rte. 649 and South Fork Shenandoah River: Upstream boulder bar, note shrubs or small trees; they were stripped of foliage in 1987 flood.
	D 11	Downstream boulder bar.
	D 12	Pier 1 footings appearing to float on water.
	D 13	Note reflection of light under right corner.
	D 14	Contact between cobble-boulder layer and fine-grained lens.
	D 15 to 23	Logged in Table 4 of text.
	D 24	View of upstream half of upstream bar.
	D 25	Downstream half of upstream bar; rule is in center of frame. Prior to 1985 flood the river bank had been midway between pier 1 (top of footing showing) and pier 2.
	D 26	Angled view of pebbles, cobbles, and medium boulder.
	D 27	Debris with engineer's scale for scale.
	D 28	Same as 27, different exposure.
	D 29	Piece of concrete rip rap approximately 300 ft downstream from bridge.
	D 30	Other rip rap near same piece; scale inserted.
	D 31 to 38	Logged in Table 4 of text.
	E 1	Looking west on Rte. 649 at dip that serves as cross over for very high flood waters.
	E 2	Same as 1, house of owner is at top of slope.
	E 3	Different perspective with Massanutten Mountain in the background.
	E 4	Misplaced.
	E 5	Rte. 613 and Dry River, looking at pier 2 from the north, downstream to left. Note that attempt at channelization left approximately 5 ft of material between the channel and the pier. The 1987 flood moved that material around.
	E 6 to 23	Logged in Table 6 of text.

APPENDIX A (continued)

8/86	F 1 to 27	Rte. 649 and South Fork Shenandoah River: 1 through 11, downstream side; and 12 through 27, upstream side are of questionable value. It was thought that portions of the bridge or items of known size such as beer cans could be used for scale to allow photogrammetric measurements.
	F 28	Can see under footing, upstream bent: pier 1.
	F 29	Site of contraction scour starts between two piers.
	F 30	Contraction scour area; note man and rod.
	F 31	Contraction scour with man and rod for scale.
	F 32	Debris against walnut tree with rod for scale.
	F 33	Same as 32.
	F 34	East end of bridge, scour behind pier 4.
	F 35	Rte. 613 and Dry River, scour hole off south abutment with rod for scale.
	F 36	Same as 35, different perspective.
	F 37	Looking up high water channel.
	F 38	Rockbridge County, Rte. 39 and Maury River: Boulders in bed with rod for scale.
10/86	G 2	Rockingham County, Rte. 613 and Dry River: Looking down from bridge, at angle, at ground truthing cross for photogrammetry, and at southwest (S.W.) corner of old pier approximately 6 ft from the new pier 1.
	G 3	River bed off downstream end of pier 2.
	G 4	Square yard outlined in orange paint, large particles were measured by hand; downstream and southernmost square yard.
	G 5	Square yard, downstream: not counted.
	G 6	Square yard, downstream, northern most.
	G 7	Same as 4, but with black dots on white paper to mark the corners of the square.
	G 8	Same as 5, but with corners remarked.
	G 9	Same as 6, corners remarked, groundtruthing cross upper third of frame.
	G 10	Square yard: upstream and groundtruthing cross.
	G 11 to 13 and G 22	Part of the technique of ground based photogrammetry.
	G 14 to 15	Area where manipulation of sediment has exposed considerable sand and on downstream, taken from the bridge.
	G 16	Large quartzite boulder downstream, 5.5 in pencil for scale.
	G 17	Main channel downstream of bridge, rather narrow and deep.
	G 18	Further downstream from 17.
	G 19	Around bend and further downstream from 18.
	G 20 to 21	Different exposures, is pier 2 vertical?
	G 22	Buckets, camera, and photographer working upstream side of bridge and being careful of power lines. The camera was a measured 40 ft from the ground.

APPENDIX B

LOG OF PHOTOGRAPHS

Black and White Photos of 1987 Flood

Date	No.	Subject
4/17/87	2	Tributary to S. Fork Shenandoah, Lower Lewis Run, upstream from Rte. 340.
	3	Same as 2, slightly different perspective.
	4	Opening to bridge: rip rap.
	5	More of bridge.
	6	Looking upstream under bridge.
	7	Same as 6, slightly different exposure.
	8	Erosion from behind N.W. wingwall.
	9	Stream pouring into gravel pit.
	10	South Fork Shenandoah River, approximately 0.8 mile upstream of Rte. 649 taken from east bank and Rte. 642.
	11	Same as 10, slightly different perspective.
	12	Also upstream of Rte. 649.
	13	Looking east to west, Rte. 649 across the Shenandoah.
	14	Looking east to west, Rte. 649 better shot at west abutment.
	15	Magnifying glass helps to identify specific pieces of rip rap and allows marking the high water level. Pier 3, with debris, is in main channel.
	16	Same as 15, different exposure.
	17	Looking upstream at flotsam.
	18	Same flotsam near bridge.
	19	Debris around pier 3.
	20	Sycamore downstream, near upstream end of boulder bar.
	21	Walnut upstream, near midpoint of boulder bar.
	22	Rip rap upstream side of west abutment.
	23	Entrance to western flood plain.
4/17/87	24	Rte. 613 and Dry River (tributary to North River that flows into S. Fork Shenendoah). Look from N. to S. Middle pier is No. 2, it settled in 1985 flood.
	25	Debris on pier No. 3.
	26	Same as 25, different exposure.
	27	North side of river, overflow near abutment.
	28	Downstream end pier No. 2, rip rap approximately 6 in under water right side of pier.
	29	Same as 28, different exposure.
	30	Moved to left of pier No. 2 over main flow that runs between pier 2 and pier of previous bridge, said pier is to the left and 5 to 10 feet downstream. Could hear cobbles tumbling.
	31	Debris in main channel.
	32	Debris further downstream, heading for inside of bend.

APPENDIX B (continued)

4/17/87	33	Looking downstream.
	34	Same as 33.
	35	Debris lodged on pier No. 3.
	36	Looking W., stream flows E., hard to S. through trees, can see water that comes down channel shown on 43.
	37	Same as 36, main flow center of photo, auxiliary channel comes in from right.
	38	S. abutment, upstream, scour hole from 1985 flood.
	39	Downstream side of bridge, looking N., rip rap around pier No. 1, boulders etc. in middle-right of photo were bulldozed there after 1985 flood.
	40	Same as 39, different perspective.
	41	Rip rap around pier No. 1.
	42	Rip rap against S. abutment, auxiliary channel into background.
	43	Southern most auxiliary channel.
	44	Limestone rip rap for S. abutment.
	45	Trying to show slight dip in rail at pier 2. Can see water plunge just beyond, but between pier 2 and the old pier.
4/21/87	2	Tributary to S. Fork Shenandoah, Lower Lewis Run, upstream from Rte.340.
	3	Same as 2.
	4	Same as 2, but can see bend in main channel.
	5	Inlet of bridge and rip rap.
	6	Under bridge looking downstream.
	7	Same as 6, different perspective.
	8	Outlet of bridge, looking upstream.
	9	Boulders under bridge, looking upstream.
	10	N.W. wingwall.
	11	Same as 10.
	12	Rte. 649 and S. Fork Shenandoah River, based on recognition of rip rap and shape of tree, flood level is inked onto this photo and 18.
	13	Stream near bridge.
	14	Same stream as in 13.
	15	Clearer out flow of stream into muddy Shenandoah.
	16	Bents 4, 3, 2 and 1, showing flow around middle pier of the third bent.
	17	Same as 16, different exposure.
	18	Rip rap and flood plain with flood level marked.
	19	Upstream; walnut tree to right; branches that appear to be in the middle of stream are bushes that are growing on the upstream boulder bar.
	20	Walnut tree upstream.
	21	Sycamore tree downstream near upstream end of boulder bar.
	22	Cow path under bridge.
	23	Concrete poured around top of rip rap.
	24	Rip rap W. abutment, working toward stream.
	25	Rip rap along edge of cow path.
	26	Rip rap along stream side edge of cow path.

APPENDIX B (continued)

	27	Rip rap between stream and cow path shows extent of silting in.
	28	Pier 1, rip rap showing just below water level.
	29	Opposite end of pier 1.
4/21/87	30	Looking downstream, standing on cow path.
	31	Rte. 613 and Dry River (trib. to North River that flows into the S. Fork Shenandoah) rip rap along N. abutment and debris at end of pier 3.
	32	Looking S., still strong flow along pier 2.
	33	Same as 32.
	34	Debris at upstream end of pier 3.
	35	Rip rap downstream end of pier 2.
	36	Main channel along N. side of pier 2.
	37	Debris and rip rap pier 3.
	38	Debris ? Pier 1 or 2.
	39	Looking downstream.
	40	S. abutment with scour hole from 1985 flood.
	41	Same as 40, different exposure.
	42	Downstream side of bridge, good shot of south side of old pier that is relatively close to pier 2.
	43	Main channel near upstream end of pier 2.
	44	Mouth of south channel.
	45	South channel.
	46-48	South channel, different perspective.
	49-53	Stream bed working from S. toward main channel trying to show changing water depth.
	54	Showing dip in railing at pier 2.
	55	Same as 54, different exposure.

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