United States Department of the Interior

NATIONAL PARK SERVICE
1849 C Street, N.W.
Washington, D.C. 20240
HABS/HAER Room NC300

IN REPLY REFER TO:

HABS/HAER (2270)

2 July 2001

Memorandum

To: Al Hess
Cultural Resource Specialist, BLRI

From: Christopher H. Marston
Project Leader, HABS/HAER

Subject: Addendum to Transmittal of HAER historical report on the Blue Ridge Parkway

I am pleased to enclose the official Historic American Engineering Record historical report on the Linn Cove Viaduct section of the Blue Ridge Parkway, written by Brian Cleven, edited by Tim Davis and prepared for transmittal by Kelly Young. Somehow this report was omitted when we sent you the final history report in April 2001. This report should be added to the same binder as holds the history. With the transmittal of this report, along with the previously transmitted history, drawings and photographs (sent to you in 1998), you now have a completely finished HAER documentation product. This meets the terms of the original Cooperative Agreement which originated with the field work phase in 1997. We are in the process of transmitting the original drawings, photographs, field notes, and written historic data to the HAER Collection at the Library of Congress Prints and Photographs Division, where these documents will eventually be made available to the public and digitized for access on the internet.

If you have any questions about this transmittal, please contact me at 202-343-1018, or *christopher_marston@nps.gov*. The Blue Ridge Parkway Recording Project proved to be a very successful working partnership between HABS/HAER and the park, and we hope to have a chance to work together in the future. I look forward to continuing to work together to complete the brochure on the Blue Ridge Parkway.

Project Leader, HABS/HAER — Date: 7.2.01

Attachment(s)

HISTORIC AMERICAN ENGINEERING RECORD

BLUE RIDGE PARKWAY, LINN COVE VIADUCT

HAER No. NC-42-A

Location:	Grandfather Mountain, Linville Vicinity, Avery County, North Carolina
Date of Construction:	1983
Designer:	Jean Figg and Jean Muller
Contractor:	Barrett, Daffin, and Figg/Europe Etudes
Present Owner:	National Park Service
Present Use:	Parkway viaduct
Significance:	The precast, post-tensioned segmental concrete Linn Cove Viaduct was the first structure built in the North America using the progressive placement erection method. Its topography conforming horizontal and vertical alignment made it the most complicated structure of its type in the world at the time of its construction.
Historian:	Brian Cleven, August 1997
Project Information:	The Blue Ridge Parkway Recording Project was undertaken in 1996-97 by the Historic American Engineering Record (HAER). The documentation was prepared under the direction of NPS historian Richard Quin and HAER architect Christopher Marston. For the overview documentation of the parkway, as well as photographs and drawings of the Linn Cove Viaduct, refer to HAER No. NC-42, Blue Ridge Parkway, Asheville Vicinity, Buncombe County, NC. For specific Linn Cove Viaduct documentation, see photographs NC-42-136 through NC-42-140, NC-42-256 (CT) and drawing Sheet No. 16, "Linn Cove Viaduct." Archives for HAER projects are located at the Library of Congress.

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INTRODUCTION

The Linn Cove Viaduct is significant for two reasons: its complexity and its method of construction. The geometry of its three curves was the tightest and most complex of any segmental structure in the world at the time of construction. In order for the structure to conform to Grandfather Mountain's topography its horizontal alignment included spiral curves going into circular curves with radii as small as 250' and curvature in two directions. The superelevation went from ten percent in one direction to ten percent in the other direction in 180' transitions and part way back again within the structure's 1,243' length.

Due to the severe environmental restrictions in the construction zone, Jean Muller, a pioneer in the art of precast segmental design and construction in France, designed a structure that could be constructed essentially from the top of the deck, thus requiring minimal ground access. The "progressive" placement erection method was a recent development in precast segmental construction.

Contractors built the structure by starting at one end and placing pre-cast segments continuously to the other end by cantilevering successively from one pier to the next. The progressive scheme enabled superstructure and pier segments to be transported across the previously built deck and placed by stiff-leg crane into final position. Cables were then used to post-tension each segment to the others.

The Linn Cove Viaduct was the first application of this erection technique in North America. It solved the puzzle of how to build the roadway through this particularly difficult boulder-strewn section and helped to complete the last 7.7-mile link of the Blue Ridge Parkway (BLRI). A lasting testimonial to its significance is the ten awards it won for innovative design.

DESIRE TO ACQUIRE GRANDFATHER MOUNTAIN

Grandfather Mountain and its contiguous companion, Grandmother Mountain, encompass virgin areas of forests, flowers, and cascades. At 5,964', Grandfather Mountain is the highest and most rugged peak on the Blue Ridge. It is geologically the most ancient mountain on the North American continent (Fig 1). It is composed of quartzite, surrounded by younger rocks that have eroded away through millions of years. The durability of the quartzite accounts for the towering height of the mountain.[1] For approximately seven miles the BLRI hugs the northern and eastern

[1]Granville Liles, "Grandfather Mountain and the Blue Ridge Parkway," mss, February 1987, BLRI Archives, vertical files, Cone-Price Memorial Parks file, 1.

slopes and ridges of Grandfather Mountain, affording spectacular views of hazy mountains and valleys and the peaceful Piedmont region several thousand feet below.

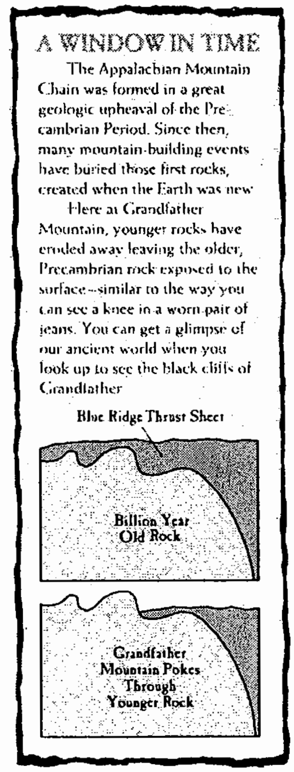

Figure 1

The vegetation of this area has intrigued botanists for nearly 200 years. The famous French botanist Andre Michaux climbed Grandfather Mountain in 1794. Michaux came on behalf of the French government to collect plants for the nurseries of Paris. He found rare plants in great abundance and variety, many new to science, including the pink Azalea *vaseyi*. This rare variety of native azalea occurs in larger numbers on Grandfather Mountain than any other place in the world.[2]

Because of the mountain's botanical diversity and scenery, the National Park Service (NPS) tried to acquire it for a number of years. While the great western parks such as Yellowstone and Yosemite were carved out of the public domain, requiring little or no private lands, the NPS acquired the eastern parks and parkways largely from private ownership. In 1918 Congress authorized the Secretary of the Interior to "accept for park purposes any lands and right-of-ways, including Grandfather Mountain, near or adjacent to the government forest reserve in western North Carolina." NPS Director Stephen T. Mather wanted to establish a park in the Southern Appalachians, but this particular effort failed.[3] Due to the section's timber resources, private interests, including the primary owner, the Linville Improvement Company, were unwilling to sell the area at a reasonable price.

Undaunted by his failure to add Grandfather Mountain to the national park system, Mather succeeded in getting legislation through Congress in 1926 authorizing Shenandoah National Park in Virginia and Great Smoky Mountains National Park in North Carolina and Tennessee. The location of these parks in the Southern Appalachians prompted the proposal in 1933 to connect them with a parkway.

Sporadic efforts to bring Grandfather Mountain under federal jurisdiction were made before the passage of the act authorizing the BLRI in 1936, which designated a general route and gave the NPS the right to acquire an average of 125 acres a mile along its length. This permitted ample width for the roadway and "bulges" at especially attractive locations for campgrounds, comfort

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[2]Liles, "Grandfather Mountain," 1; and "Welcome to the Mountain," pamphlet, Grandfather Mountain, Linville, North Carolina.

[3]Liles, "Grandfather Mountain," 2.

stations, lookouts, and other conveniences for the public using the parkway. While the average of 125 acres would not permit acquiring sizable tracts such as that containing Grandfather Mountain, it allowed larger acquisitions if other arrangements could be made.

Parkway construction got underway in September 1935 on a 12.5-mile section from the Virginia-North Carolina state line to Cumberland Knob. The first dirt was turned on Pat Murphy's farm just south of the state line on September 11. Construction soon began on other parkway sections as the land was acquired.[4]

The projection of the BLRI through the area revitalized interest in preserving Grandfather Mountain as a mountain park and establishing a major wayside rest and recreation camp on Grandmother Mountain. Park-minded advocates renewed their efforts to convert the Grandfather Mountain region into a recreation area. Led by conservationist Harlan Kelsey, they stressed the danger of irreparable damage by lumbering and other exploitation.[5] The NPS considered this to be a vitally needed addition. In 1935, NPS Associate Director Arthur Demaray was urged to acquire an 18,000-acre tract around the mountain. NPS Landscape Architect Edward Abbuehl reported that many considered it "the most outstanding mountain between the Shenandoah and Great Smoky Mountains National Parks." The United States Forest Service (USFS) made concerted efforts to acquire the mountain but met no success. Abbuehl thought the NPS might be able to purchase it by stressing potential recreational values, rather than the commercial value motivating the USFS's interest. He also recommended acquiring "Rhododendron Gardens," a 500-acre tract on the north side of the mountain containing two tracts of virgin timber. Abbuehl thought it would make a fine recreational area, especially if it could accompany the entire Grandfather Mountain tract. Rufus L. Gwynn of Lenoir, North Carolina was in the process of developing the tract for a summer colony, but lack of funds prevented completion.[6]

In 1938, the USFS proposed development for a picnic area on Grandfather Mountain's Pilot Ridge. The proposal stated that it would be "a ridge top development with fine panoramic views in nearly every direction." The area would accommodate about 250 visitors, and there would be

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[4]"Work on Scenic Parkway Link to Begin Very Soon," *The Allegheny Times* (Sparta, NC), 12 September 1935.

[5]James B. Craig, "Blueprint for Public Service--The Story of Grandfather Mountain," *American Forests*, May 1948, 3.

[6]C. K. Simmers, "Memorandum for Mr. Demaray," 27 February 1935, BLRI Archives, RG 7, Series 41, Box 57, Folder 1; and Edward H. Abbuehl, "Report on New Areas Proposed for Recreation Parks Adjacent to Blue Ridge Parkway," 1936, BLRI Archives, RG 7, Series 41, Box 57, Folder 5, 2.

the opportunity to construct a series of hiking trails.[7] Lack of funding prevented this proposal from becoming a reality.

In the mid 1940s another effort to acquire the entire mountain for park purposes failed, but it generated a great deal of interest. It included an appeal by North Carolina's governor, several magazine articles, and an entry in the Congressional Record. In a letter to conservationist Harlan P. Kelsey dated February 7, 1944, North Carolina Governor J. Melville Broughton said: "I have several times been over this area and have long felt that with its scenic grandeur, great variety of trees and other resources, it ought to be set apart for public service. It would be a loss to the state and the nation if this mountain and its immediate surroundings should be subjected to commercial exploitation."[8]

About this time the Linville Improvement Company, owner of 5,550 acres at the heart of the region containing both Grandfather and Grandmother Mountains, announced the section was available for purchase and prospects for park enthusiasts brightened. In February 1945, Kelsey obtained from the company an option to purchase several thousand acres of land along BLRI sections 2-H and 2-J, including Grandfather Mountain, for transfer to the parkway. Kelsey traveled to Washington D.C. and met with NPS Director Drury, who authorized the BLRI to accept the donation of 5,550-acres of the Linville Improvement Company's holdings on Grandfather Mountain for another recreational area (Fig. 2). Drury and the parkway staff told Kelsey that he should also try to acquire Linville Falls for the parkway.Kelsey formed the Grandfather Mountain Association to raise funds for the project. He urged an enlargement of the authorized boundary to include the approaches and flanks of the mountain, and to include acquisition of the entire Linville Gorge.[9] The total tract contained approximately 12,000 acres which, together with adjoining USFS lands could compromise a park of over 26,000 acres. There were no federal funds available at the time to purchase the property. In view of the size of the anticipated public debt after the war, appeals went out for North Carolinians to acquire this

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[7]Stanley Abbott, "Report on Conference Regarding Blue Ridge Parkway in Relation to National Forest Areas," BLRI Archives, 2; and H. E. Ochsner, Forest Supervisor, Pisgah National Forest, "Memorandum for the Regional Forester," 5 April 1938, BLRI Archives, RG 7, Series 41, Box 57, Folder 10, 1.

[8]Harlan P. Kelsey, "Shall Grandfather Mountain Be Saved?" *National Parks Magazine*, April-June 1944, 3.

[9]Sam P. Weems, "Superintendent's Annual Report," 1945, BLRI Archives, 2; "Superintendent's Annual Report," BLRI Archives, 1946; Sam P. Weems. "Monthly Narrative Report," December 1945, BLRI Archives, 2; "Monthly Narrative Report," July 1946, BLRI Archives, 2; and "Monthly Narrative Report," December 1946, BLRI Archives, 3.

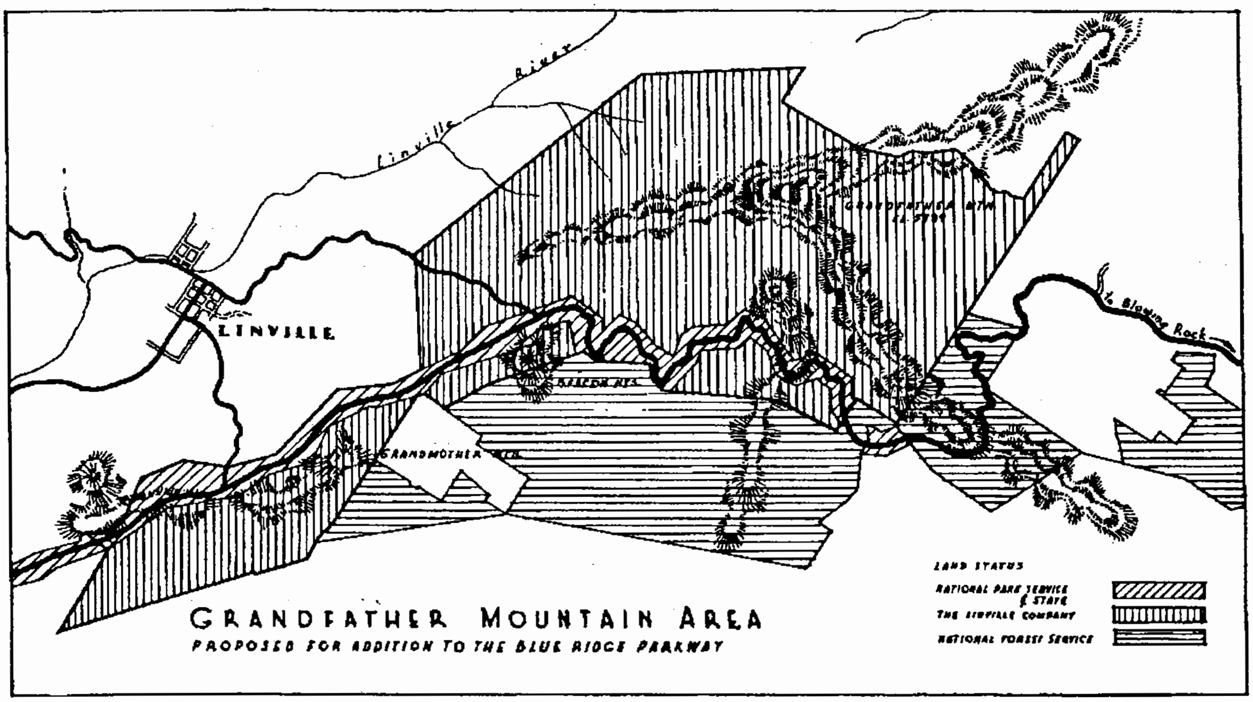

Figure 2 Proposed Grandfather Mountain Park showing the Linville Improvement Company property of 5,550 acres containing Grandfather and Grandmother Mountains. The total acquisition area is approximately 26,000 acres, rivaling Acadia National Park in size. (Harlan P. Kelsey, "Grandfather Mountain. Shall It Be Saved?" April 1944)

property by private subscription and preserve its natural beauty, possibly saving it as a memorial for fallen veterans of World War II.[10]

The state refused to get involved in the project due to its desire to devote all possible park funds to its state park system. Kelsey's option on the property expired in March 1947, and Hugh Morton, president of the Linville Improvement Company, refused to renew it, stating the NPS should concentrate on completing the BLRI. Morton announced that his company planned to develop camping facilities on the mountain and to log part of the timber. Kelsey withdrew from active participation in the project in 1948. However, the newly created North Carolina Park, Parkway and Forest Development Commission took over the project, agreeing to try to acquire the funds to acquire the mountain.[11]

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[10] "Extension of Remarks of Hon. Joe W. Ervin of North Carolina in the House of Representatives, Tuesday, March 20, 1945," Washington D.C.: United States Government Printing Office, 1.

[11] J. Carlisle Crouch, "Acting Superintendent's Annual Report," 1948, BLRI Archives, 5; Weems, "Monthly Narrative Report," January 1947, 1; and Stanley Abbott, "Monthly Narrative Report," March 1947, BLRI Archives, 1.

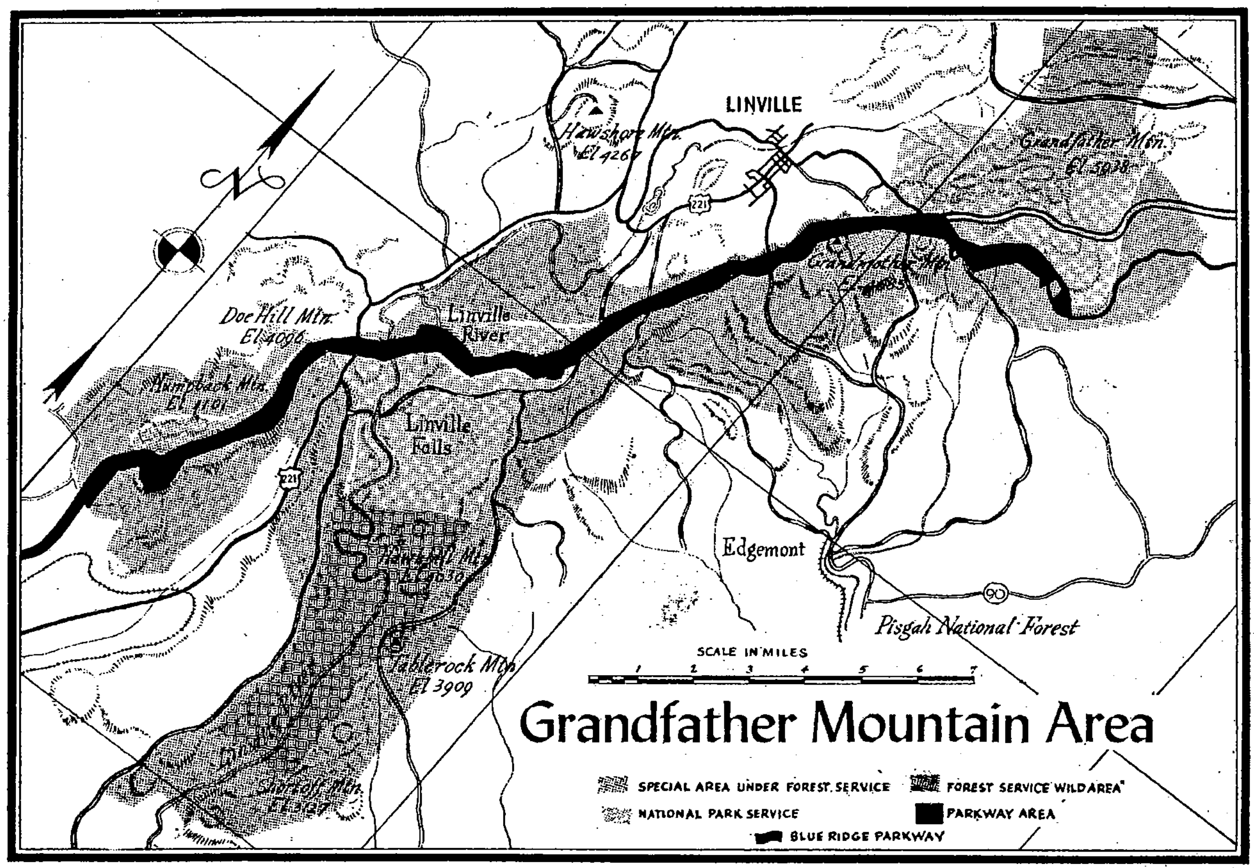

Figure 3 View of the Grandfather Mountain and Linville River Gorge areas to be acquired by the NPS and USFS. (James B. Craig, "Blueprint for Public Service--The Story of Grandfather Mountain," American Forests, May 1946)

In the summer of 1947, after sampling the views of NPS and USFS leaders, NPS Chief of Lands Conrad L. Wirth informed NPS Director Drury that the two services could come to an agreement for acquiring the Grandfather Mountain-Linville Gorge area. After three days of inspecting the area by day and inter-bureau poker at night, representatives of the two groups devised a working plan. The "Agreement between the Forest Service of the Department of Agriculture and the National Park Service of the Department of Interior, for the management of the Grandfather Mountain-Linville Gorge Special Area" set up a special administrative area of 55,000 acres of privately and publicly owned area contiguous to the parkway (Fig. 3). Of this acreage the NPS agreed to acquire approximately 7,500 acres in the vicinity of Grandfather and Grandmother Mountains[12] and approximately 5,500 acres bordering the Linville River, including the famed Linville Falls. Funds supplied by John D. Rockefeller, Jr. purchased the Linville tract.

[12]Craig, "Blueprint," 3,5.

In August 1948, Hugh Morton stated the mountain was not for sale at any price, and the BLRI advised R. Getty Browning of the North Carolina Highway Commission to proceed with the acquisition of a right-of-way through the Linville Company's holdings by condemnation.[13] On May 27, 1955, the state posted right-of-way maps for the section in the Watauga County Courthouse, but on April 26, 1957, the North Carolina Highway Commission deeded back the lands it had acquired through condemnation.[14] More on this later.

ALIGNMENT OF THE "MISSING LINK"

Settling on the final roadway alignment for this section proved to be the most difficult and drawn out ordeal faced by the parkway designers. The alignment was important since the construction site proved to be a primary design factor for the Linn Cove Viaduct. The Bureau of Public Roads (BPR), now the Federal Highway Administration (FHWA), was involved in the parkway design and provided engineering services for building the BLRI. NPS landscape architects and BPR engineers worked together as a team in all phases of the reconnaissance, location, design, and construction of the parkway's road.

Parkway reconnaissance in 1934 and 1935 concentrated on problem areas. Since it was obvious the parkway would go to one side of Grandfather Mountain or the other, its exact location on the mountain was left for a later date. In 1936, however, the Linville Improvement Company, which owned most of Grandfather Mountain, was reported to be planning to sell off the balsam and spruce along U.S. 221 (the Yonahlossee Trail). The request of the North Carolina Highway Commission to save this stand of timber spurred the NPS to ask the BPR to submit preliminary right-of-way maps to the state based on the survey line of U.S. 221. The exact route could not be confirmed until designers determined the parkway's route around Blowing Rock and to the mountain's southern approach. The NPS, however, agreed that it was desirable to save the timber in case the parkway used the U.S. 221 location. By October 3, 1938, the NPS and the BPR decided the roadway should either use U.S. 221 or a location above it, concluding the northern side of Grandfather Mountain was too rough for parkway construction.[15]

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[13] J. Carlisle Crouch, "Monthly Narrative Report," August 1948, BLRI Archives, 2.

[14] A.C. Stratton, NPS Associate Director, Letter to Dan K. Moore, Governor of North Carolina, 25 September 1965, 5,9.

[15] Harold J. Spelman, District Engineer, Bureau of Public Roads, Letter to A.E. Demaray, Assistant Director, NPS, 3 October 1938, BLRI Archives; Stratton to Moore, 3; and Edward Abbuehl, "The Blue Ridge Parkway: Blowing Rock to Linville Falls," BLRI Archives, Record Group 5, Series 38, File 8, 2.

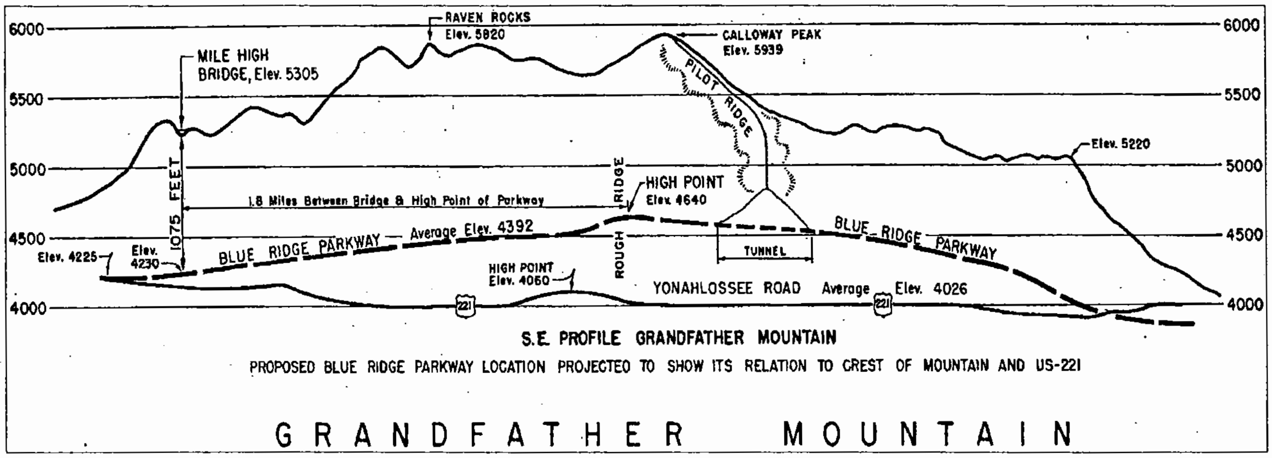

Figure 4 Profile of "high" line in relation to Grandfather Mountain and US 221.

If the parkway took over U.S. 221, the state needed to buy out all frontage rights and reroute commercial traffic. Even in 1939, purchasing the frontage rights was so difficult that the state requested the NPS to make studies of a route for the parkway above U.S. 221.[16] From landscape and engineering points of view, converting U.S. 221 to parkway standards would not be entirely satisfactory because curves of the old road left outside the new, straighter roadway would be unsightly reminders that this was a "hand-me-down" location.

It appeared that the best solution for roadway location was to seek a location above U.S. 221. Not too much was known about a higher location until the BPR completed a survey in 1940 (Fig. 4). Starting at Holloway Mountain Road, an old logging road provided an easy route (about 6 per cent grade) to Pilot Ridge. Pilot Ridge is a very long "lead" ridge tailing off from Grandfather Mountain. This approach made it possible to plan for a 1,700' tunnel through the ridge, shortening the proposed route by three-quarters of a mile and eliminating the long scar, visible to north and south-bound traffic alike, that going around the mountain would create. The eastern portal of the proposed tunnel would have been at an elevation of 4,525' with the western portal at 4,575'. By continuing to climb, the road could go over the top of Rough Ridge in a saddle at 4,640' elevation, a half-mile beyond the western portal. The saddle would be the road's high point on the mountain. No other location between the Rough Ridge saddle and U.S. 221 could be used without creating an objectionable scar. From Rough Ridge westward, there was a reasonably good route to Beacon Heights to join the existing road. Linn Cove, a very deep ravine was expected to be crossed by a standard type of high viaduct, 200' to 300' long.[17]

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[16]Edward Abbuehl, "Report on Alternate Line on Grandfather Mountain," April 1986; and Stratton to Moore, 4.

[17]Abbuehl, "Report on Alternate Line," 3.

This situation was in the study stage for many years while construction continued at other places on the parkway. By 1940, the NPS and BPR had established 400 miles of roadway location with a few exceptions, one of which was Grandfather Mountain. With a boundary of some 1,200 miles and perhaps 5,000 or more neighboring landowners, there were surprisingly few major location problems.[18]

In December 1943 the NPS requested North Carolina to furnish topographical information on the higher line so that projections could be made for comparison with the U.S. 221 location. By October 1946 the studies were complete. After reviewing the survey information, the NPS recommended the higher line. In April 1948 the BPR forwarded parkway grading plans to the state for the required right-of-way acquisition around Grandfather Mountain.

A normal right-of-way averaging about 400' was blocked out on the roadway's upper side. On the lower side, it expanded in order to eliminate small residues, to include Pilot Knob for development of a pedestrian overlook, to facilitate scenic control, and to place everything between the roadway location and U.S. 221 in public ownership, either state or federal. The state completed right-of-way surveys on this basis, and in May 1955, finally posted right-of way maps for the parkway around Grandfather Mountain in the Watauga County Courthouse.

The right-of-way requested by the NPS exceeded the 125 acres per mile the state was authorized to acquire for the parkway, but the law did not specify on what basis to obtain the 125 acres per mile. The NPS and the state normally determined this averaging by parkway sections, which were generally ten to twelve miles long. The flagged section, 2-H, around Grandfather Mountain was 5.7 miles long and the adjacent section, 2-G, was 7.5 miles. Section 2-G included the donated Moses H. Cone and Julian Price Memorial Parks, so state-purchased lands for the section averaged only 59 acres per mile. In view of this savings and the fact that Grandfather Mountain was an outstanding scenic attraction, the NPS and North Carolina State Highway Department considered this wider than average right-of-way request for 2-H a reasonable solution.

When Hugh Morton protested the location and questioned the legality of the state's exceeding the 125 acres per mile, state highway officials requested the NPS to reduce the right-of-way to 125 acres per mile. The NPS assented. The revised right-of-way (line A) averaged about 750 feet wide, which was three-fourths of the 1,000 feet needed to average 125 acres per mile. The remaining one-fourth of the requested land took in the Pilot Knob area. This right-of-way was satisfactory to the NPS. It could be acquired without moving any families or buying expensive frontage rights.

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[18]Liles, "Grandfather Mountain," 3.

On May 27, 1955, the State of North Carolina condemned and acquired the land for this high line (line A). In the meantime, the ownership of the land along this line changed hands from the Linville Improvement Company to Hugh Morton, the company's former president.[19] Morton now owned all of the top of Grandfather Mountain. There he had a very well-publicized and profitable swinging bridge and concession accessible by a low-standard road to the mountain's top. A first-rate photographer and public relations man, Morton worked for the State of North Carolina for several years and had excellent contacts with the media. Morton would use these skills and contacts to oppose the NPS's plans for the parkway. His opposition would delay the parkway's progress over Grandfather Mountain for nearly twenty years. Opposed to Line A, he proceeded to publicly blast the NPS for planning to "go across the top of Grandfather Mountain," feeling that a deep cut through the mountain would destroy the natural landmark's scenic beauty and fragile ecology.[20]

At the request of North Carolina, the NPS and the BPR then studied a location slightly above U.S. 221, known as line B. On December 1, 1955, the NPS advised the State that the higher line A with the tunnel was superior to line B and urged that acquisition of line A was in the public interest (Fig. 5).[21] The NPS felt that line B was not desirable to either line A or line C. The NPS maintained that U.S. 221 was in view close by; it was too far below Pilot Knob and Rough Ridge for reasonable foot access; it would create the greatest amount of landscape damage due to its longer length; and the topography was more irregular, necessitating deeper cuts and higher fills.

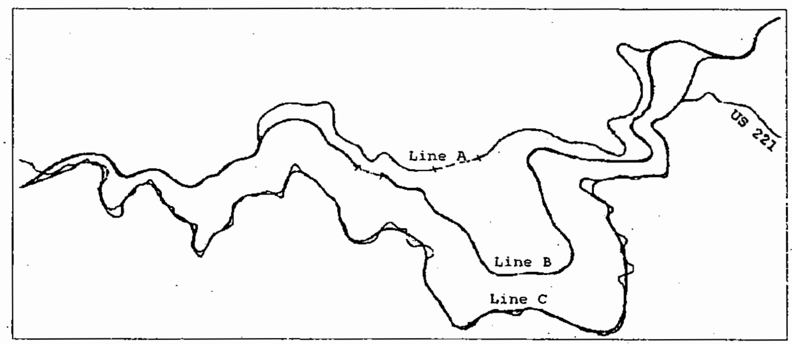

Figure 5 Map showing Lines A, B, C and US 221.

While the NPS made its case, North Carolina deeded the land acquired for line A back to Morton without any prior notice on April 25, 1957. Morton had insisted that the state completed the legal acquisition in 1939 and the additional 1955 land acquisition was, therefore, unauthorized.[22]

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[19]Stratton to Moore, 5.

[20]Abbuehl, "Report on Alternate Line," 3; Jerry DeLaughter, "Blue Ridge Parkway: The Final Gap," *Wachovia* 71, Fall 1984, 9.

[21]Stratton to Moore, 1.

[22]Stratton to Moore, 2.

In 1958, at the request of North Carolina, the NPS made a further study of line C, which called for extensive reconstruction of U.S. 221. It found line C inferior to line A.[23] Only a small portion of the existing road could be used due to its twisting nature. Regardless of where the line was placed there would still be several elbows of the old road on the inside and outside of curves presenting old road scars along the roadside. Its location was too far below Pilot Knob and Rough Ridge for reasonable foot access. Many of the finest trees on the south slopes of Grandfather Mountain would be lost by reconstruction. Line C would go around the end of Rough Ridge with heavy scars; it would need larger drainage structures; require constructing three viaducts; and would also cost the most of the three routes.[24]

The impasse between the NPS and Hugh Morton over the choice of routes lasted until 1962 when a public meeting was held by the North Carolina Highway Commission on May 31. NPS Director Conrad L. Wirth and Hugh Morton presented arguments for lines A and C, respectively. The NPS presented a three-dimensional model made of the mountain showing the proposed location of the so-called "high line" that the NPS favored and an alternate line a little lower down that went around the end of Pilot Ridge instead of tunneling through the ridge. Morton was convincing in his assertion that the NPS was going to level off the top of the mountain. Among Morton's most famous quotes was that the NPS plan to go across Grandfather Mountain was like "taking a switchblade to the Mona Lisa."[25]

Contrary to Morton's assertion and reports in the press, the NPS's preferred route was not at the crest of the mountain. Such a location would have required grades in excess of 25 percent, well in excess of NPS guidelines that limited parkway grades to 6 percent design maximum with an absolute maximum of 8 percent for not more than a quarter mile.

Many people worried that the intended right-of-way would destroy the mountain's character. The NPS faced these concerns about road scars from the beginning of parkway construction. Scars had been made, but for the most part they healed over or were hidden. For various reasons, the NPS was confident that road construction scars on Grandfather Mountain could be healed over as well. Their reasoning was based on the following factors: the Grandfather rock weathered nicely and was attractive, the side slopes of the mountain were generally better than those previously encountered in the mountains through the Mount Mitchell area where road scars healed over, the forest cover on Grandfather was such that it would hide many of the fills, and the tunnel through

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[23]Stratton to Moore, 2.

[24]"Comparison of Alternate Routes of Section 2H, Blue Ridge Parkway Around Grandfather Mountain, North Carolina," 9 April 1964, BLRI Archives.

[25]Abbuehl, "Report on Alternate Line," 4.

Pilot Ridge would eliminate several thousand feet of scar that would result if the location were lower and around the end of the ridge.

Following the meeting, the North Carolina Highway Commission appointed a special committee to study the three lines. On May 2, 1963, the committee recommended line B, a line which Morton preferred. North Carolina Governor Sanford transmitted this recommendation to Secretary of the Interior Udall on March 16, 1964.[26]

In spite of the effort by the State to settle the impasse, the NPS and the FHWA did not abandon the high line for several years. They felt they could not abandon line A which numerous studies showed to be superior to the other two.

Finally, in 1968 a route, similar to line B, was agreed upon as the most acceptable to all parties involved. By the spring of 1968, the only obstacles in the way of a settlement were a refinement of the location, an agreement on easement rights for the adjoining landowner, and the availability of funds to begin construction.

On June 27, 1968, North Carolina Governor Dan K. Moore and NPS Director George Hartzog, Jr., met in Blowing Rock, North Carolina for a luncheon preceding the dedication of E.B. Jeffress Park. The meeting gave the two leaders a chance to discuss the urgency of completing the parkway around Grandfather Mountain. Governor Moore promised the director he would deliver the deed for the final section in the fall, if the director would earmark funds to begin construction soon thereafter.

Four months later, on October 22, 1968, at a luncheon sponsored by the governor, the director, and the Blue Ridge Parkway Association, the deed was handed over. This gesture completed a commitment made by the State of North Carolina more than thirty years earlier. The festive occasion ended with a traditional groundbreaking at nearby Beacon Heights. In keeping with the director's promise, a contract had already been awarded that would complete the parkway's last link.

Construction proceeded at a satisfactory rate for several years but then ran into financial difficulties. The passage of the National Environmental Policy Act in 1969, in addition, placed more rigid requirements on construction techniques. Lack of funds delayed progress considerably in the early 1970s. As funds slowly became available, planners discovered that this particular route would require greater skill and care to protect the environment than any previous section.[27]

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[26]Stratton to Moore, 2.

[27]Liles, "Grandfather Mountain," 6.

BUILDING THE LINN COVE VIADUCT

The Linn Cove Viaduct is noteworthy for its design. Its significance stems not only from the respect with which it treated the site, but also from the novel progressive method of construction it employed. The design challenges inherent in completing the final link in the 469-mile parkway were daunting. The most critical site was across Linn Cove, a deep ravine created by a tributary of Wilson Creek, one of the best trout fishing streams in North Carolina. The terrain of this section of Grandfather Mountain is extremely steep with relatively heavy ground vegetation. It is punctuated by numerous outcrops of giant boulders that appear to be perfectly balanced in their natural repose. NPS and FHWA officials, after careful consideration, concluded that cutting a road through this area would endanger the stability of boulders and alter the natural beauty of the mountainside. Since the site itself was highly visible from other sections of the scenic roadway, both the NPS and Hugh Morton insisted that neither the construction nor the final structure could deface the existing terrain, destroy underground streams and 200-year-old trees, or otherwise mar the landscape.

From the earliest field studies dating back to the 1950s, it was clear that the concept of bridging in some form or another would be a possible solution. Each year for the period between 1969 to 1973, new alignments were projected and staked in the field. They were followed by more field studies and survey lines with no final solution being reached. There were so many design lines studied and survey lines staked that workers claimed every square foot of the ground through this section contained at least one survey stake. A commonly told joke stated there were so many lines studied that every available color was used to distinguish one design study from another. For every line it seemed engineers proposed new structures including, at least half-seriously, spanning the entire Linn Cove area with a suspension bridge. As engineers repeatedly reconnoitered the area and became more familiar with the terrain of Linn Cove, a ironic situation developed: "highway engineers sobered by the formidable obstacle to road construction, favored bridging the worst sections; while bridge engineers wary about bridge construction in such rugged terrain, endorsed the idea of proceeding through the area by cuts and fills."[28]

Studies found no feasible course to traverse the boulder formation without creating unacceptable damage to the rock formation, or at worst, dangerously disturbing the equilibrium and stability of the mountainside. Two different geotechnical engineers conducting foundation investigations confirmed the instability of the massive boulder and rock formations in this critical area. Both recommended not cutting into the formations.[29] The terrain the structure would traverse was amongst the most environmentally sensitive in the eastern United States. Grandfather Mountain

[28]Thomas O. Edick, "Remarks at the Awards Ceremony and Dedication of the Linn Cove Viaduct, Blue Ridge Parkway, Grandfather Mountain, North Carolina, 20 October 1984," BLRI Archives, 5.

[29]Edick, "Remarks," 5-8.

supports forty-two rare and endangered species, including eleven that are globally imperiled. For this reason the United Nations declared Grandfather Mountain a Biosphere Reserve, making it the first designated biosphere to be privately-owned.[30]

Finally on September 19, 1973, FHWA Engineer R.B. Cocroft suggested that this section could be traversed by constructing a viaduct following the contour of the mountain slope. While viaducts are not a common sight on most park roads, the Blue Ridge Parkway had employed a number of viaducts in order to eliminate or reduce either cuts or fills. The Linn Cove Viaduct, however, would be the longest and the first to follow the slope's contour. The idea was presented to NPS officials who agreed that this type of structure seemed the most feasible method of crossing this portion of Grandfather Mountain.[31]

Designing the Viaduct

FHWA officials discussed the problem with several consulting firms and eventually selected the joint venture Barrett, Daffin, and Figg/Europe Etudes to design the Linn Cove Viaduct and provide engineering expertise for its construction. The consulting firm of Figg and Muller were the principle designers of the structure. Plans for the viaduct were prepared in an intense four-month period of close coordination with the NPS and FHWA. The design team selected a precast concrete segmental structure since it was the only practical means of bridging the site without massive form work and construction scars.

The Linn Cove Viaduct would not be the first segmental bridge in North America, in fact several had been built earlier (Table 1). The first precast segmental bridge to be built in North America was the Lievre Bridge, located in Quebec, in 1967. Completed in 1973, the JFK Memorial Bridge, located in Corpus Christi, Texas, was the first precast prestressed segmental bridge in the United States.[32]

Probably the most interesting design aspect of the Linn Cove Viaduct was its geometry. The horizontal alignment included spiral curves going into circular curves with radii as small as 250'. The curvature was in two directions while following the contours of the mountain slope giving the structure its "S-and-a-half" or "W" shape (Fig. 6). The three curves squeezed into the 1,243'

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[30]"Welcome to the Mountain," pamphlet.

[31]Gary S. Jakovich, Linn Cove Viaduct Technical Assistant, Federal Highway Administration, Eastern District Federal Bridge Design, "Design and Construction of the Linn Cove Viaduct," MSS, n.d., 2.

[32]Conrad P. Heins and Richard A Lawrie, *Design of Modern Concrete Highway Bridges* (New York: John Wiley and Sons, 1978), 425.

Table 1 Precast Concrete Segmental Bridges in North America.[33]

Name and Location	Construction Date	Method	Span Lengths [ft (m)]
Lievre River	1967	Balanced	130-260-130
Notre Dame du Laus, Quebec		Cantilever	(39.6-79.2-39.6)
Bear River	1972	Balanced	203.75-6@265-203.75
Digby, Nova Scotia		Cantilever	(62.1-6@80.77-62.1)
JFK Memorial Causeway	1973	Balanced	100-200-100
Corpus Christi, Texas		Cantilever	(30.5-61-30.5)
Muscatuck River	1975	Balanced	95-190-95
US 50 North Vernon, Indiana		Cantilever	(29-58-29)
Sugar Creek, State Route 1620	1976	Balanced	90.5-180.5-90.5
Parke County, Indiana		Cantilever	(27.6-55-27.6)
Vail Pass	1977	Balanced	134-200-200-134
I-70 west of Denver, Colorado (4 bridges)		Cantilever	(40.8-61-61-40.8)
			134-200-200-145
			(40.8-61-61-44)
			151-155-210-210-154
			(46-47.2-64-64-47)
			153-210-210-154
			(46.6-64-64-47)
Penn DOT Test Track Bridge	1977	On falsework	124
Penn State University, State College, PA			(37.8)
Turkey Run State Park	1977	Balanced	180-180
Parke County, Indiana		Cantilever	(54.9-54.9)
Pasco-Kennewick, Columbia River	1978	Balanced	406.5-981-406.5
Between Pasco and Kennewick,		Cantilever	(124-299-124)
Washington (cable-stay spans)			
Wabash River	1978	Incremental	93.5-4@187-93.5
US 136 Covington, Indiana		Launching	(28.5-4@57-28.5)
Kishwaukee River	1979	Incremental	170-3@250-170
Winnebago County near Rockford,		Launching	(51.8-3@76.2-51.8)
Illinois (dual structure)			
Islington Avenue Extension	1979	Incremental	2@161-200-5@272
Toronto, Ontario		Launching	(2@49-61-5@83)
Kentucky River	1979	Balanced	228.5-320-228.5
Frankfort, Kentucky (dual structure)		Cantilever	(69.6-97.5-69.6)
Long Key, Florida	--	Span-by-span	113-101@118-113
(contract let late 1978)			(34.4-101@36-34.4)
Linn Cove Viaduct, Blue Ridge Parkway	--	Progressive	98.5-163-4@180-163-98.5
North Carolina		Placing	(30-49.7-4@54.9-49.7-30)
Zilwaukee, Michigan	--	Balanced	26 north bound spans, total 8087.5
(Dual structure)		Cantilever	(2465)
(bids opened late 1978)			25 south bound spans, total 8057.5
			(2456)

[33]Table 9.1 from Heins and Lawrie, *Design*, 425.

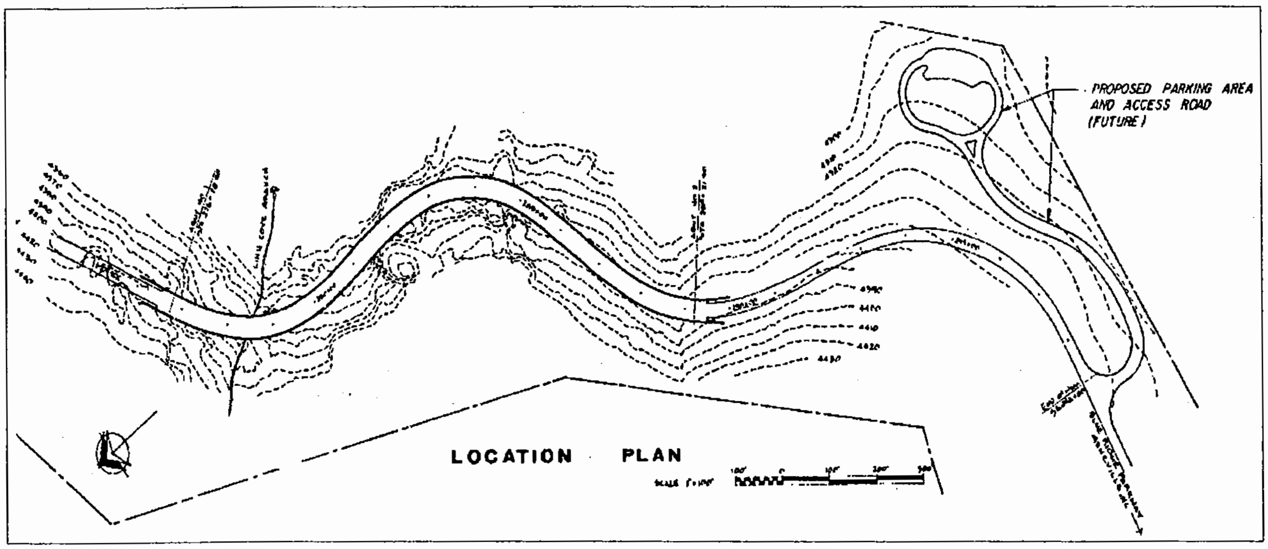

Figure 6 Preliminary location plan for the Linn Cove Viaduct and contact station parking area. (Preliminary Design Report, FIGG/Jean M. Muller)

length of the viaduct made its geometry the tightest and most complex of any segmental structure yet constructed. There were essentially no straight sections. The superelevation went from ten percent in one direction to ten percent in the other direction in 180' transitions and part way back again within the structure's length.[34]

Since building a viaduct structure by conventional means would have done irreparable damage to the environmentally sensitive area due to form work and construction of an access road along the structure's length for ground equipment, etc., the search for an acceptable construction method became a challenging engineering problem. The joint venture under technical director Jean Muller, a pioneer of the art of segmental design and construction in France during the 1960s, submitted an innovative segmental design which permitted the structure to be constructed essentially from the top of the deck with a minimal amount of ground level access required. Originally developed as a better way to build over water where setting piers and footings could be tricky, this structure type proved ideal for the location.[35]

[34]Jakovich, "Design and Construction," 3; and Jean M. Muller and James M. Barker. "Design and Construction of Linn Cove Viaduct." *PCI Journal: Prestressed Concrete Institute* 30, no. 5, September-October 1985, 5.

[35]DeLaughter, "Blue Ridge Parkway," 6.

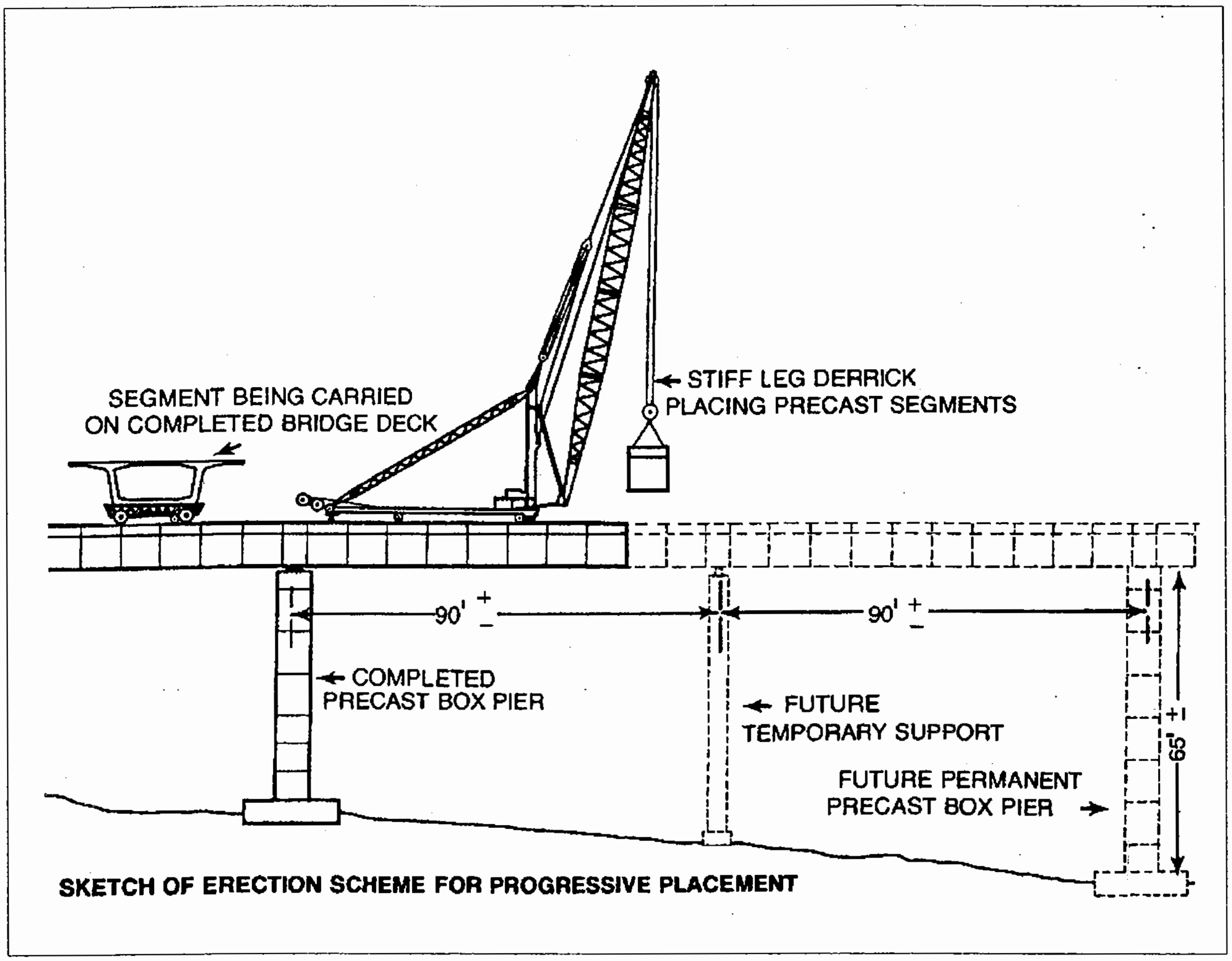

Figure 7 Schematic of construction of deck. (Segmental Report No. 11: Linn Cove Viaduct, Figg and Muller Engineers Inc.)

This erection method, known as progressive placement, was first developed by Jean Muller in 1972.[36] The Linn Cove Viaduct was the first application of this erection technique in the United States. Using progressive placement, the structure was built by starting at one end and placing pre-cast segments continuously to the other end, cantilevering each segment from one pier to the next (Fig. 7). The progressive scheme enabled bridge segments to be transported across the previously built deck and placed by stiff-leg crane into final position. Cables were then used to post-tension each segment to the others. This was considered feasible and structurally satisfactory for span ranges of 150' to 200'. For these span lengths, a constant depth segmental

[36]Figg and Muller, Inc., "Linn Cove Viaduct: Apex of Bridge Design," *Florida Engineering Society Journal*, May 1985, 1.

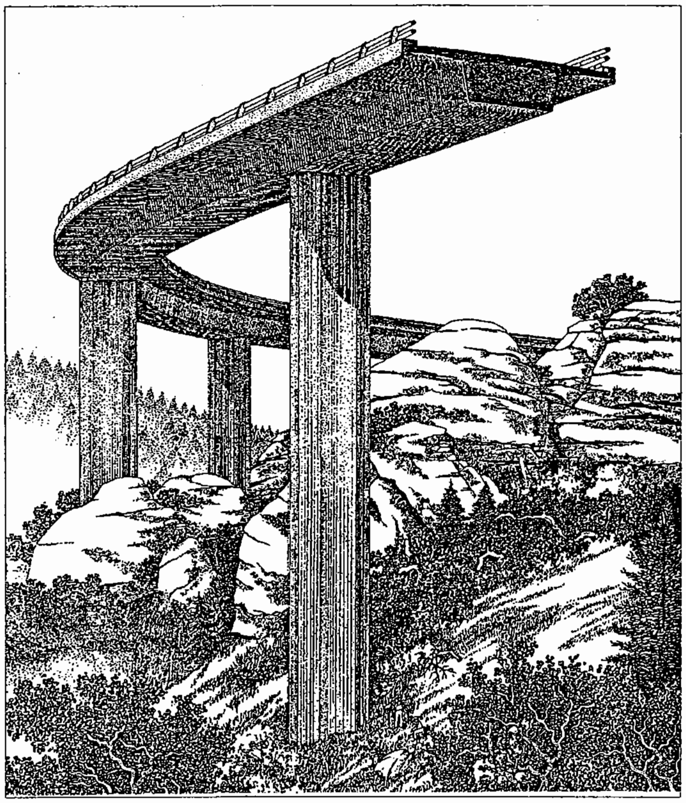

Figure 8 Cutaway of Linn Cove Viaduct as it passes around boulder outcrops. (Preliminary Design Report, FIGG/Jean M. Muller)

box girder proved to be the most economical. After site visits and analysis of possible locations for piers and supports, the maximum span length for the Linn Cove Viaduct was established at 180'. Spans were determined after locating piers to avoid natural outcrops of rock (Fig. 8).[37]

Another reason the designers chose progressive placement was that the only available access was at the southern end of the construction site. This method allowed delivery of segments, equipment, and construction materials over the completed section of the viaduct from a single access point. Also, the NPS would not permit a temporary construction road to be built through the project length, due to the concern over the stability of boulders and permanent damage to the environment. Therefore, it was necessary for the previously erected portion of the structure to be used to provide access to the pier locations and to allow construction of the precast concrete segmental piers.[38] The only construction road was from the south abutment to the second pier, a distance of approximately 260'. From this pier to the end of the structure, new segments were placed from the previously completed portion of the deck.[39]

Photomontage

Because the preservation of the enormous rock outcrops and other natural features was a major deciding factor for crossing this area with the proposed viaduct, the Region 15 office of the FHWA decided to develop highway photomontages of the viaduct site to illustrate the environmental and esthetic considerations given to the design. Photomontages provide highway

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[37]Muller and Barker, "Design and Construction," 7.

[38]Jakovich, "Design and Construction," 3.

[39]Muller and Barker, "Design and Construction," 6.

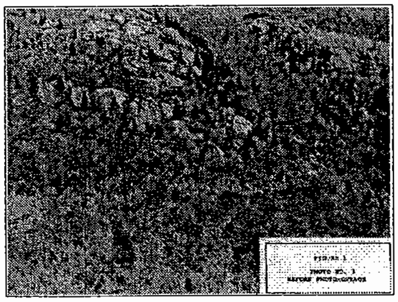

Figure 9

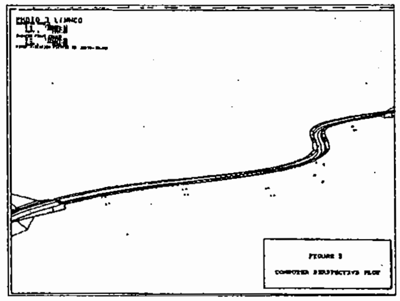

Figure 10

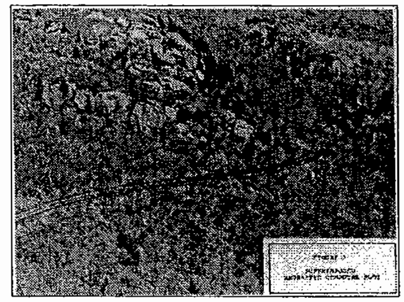

Figure 11

designers a powerful tool for illustrating how a road will look. This was one of the first demonstration projects of this technique using computers. A highway photomontage is basically a composite picture made by overlaying a computer-generated highway perspective plot onto an oblique black and white or color photograph (Fig. 9, 10, 11) The composite picture can be further enhanced by an artist to make it look more realistic (Fig. 12).

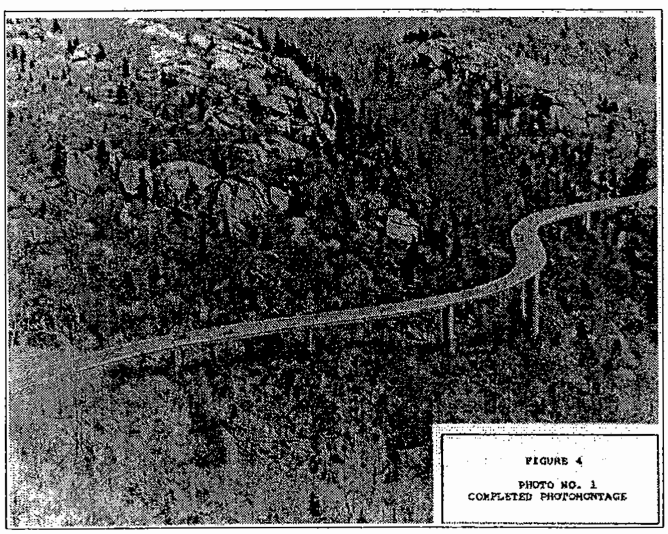

Figure 12

Due to the viewing angles, the computer-generated perspective wire-frame plot contains all hidden and visible lines for the bridge to show the box girder configuration. By manual drafting, only the visible lines were traced on the photograph. The piers were also drafted manually by extending vertical lines to intersect the ground at the four corners of the piers which were plotted by the computer. Other minute details of railings, centerline, and abutments were also drafted manually. The traced perspectives, along with the color photographs and painting instructions, were then given to an artist.[40]

<u>Constructing the Viaduct</u>

Jasper Construction Company of Plymouth, Minnesota, submitted the low bid on the project at $7,907,370 and was awarded the construction contract in October 1978. Work began in May

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[40]"Report on Highway Photomontage for Blue Ridge Parkway Viaduct at Grandfather Mountain, North Carolina," U.S. Department of Transportation, Federal Highway Administration, Region 15, Demonstration Projects Division, August 1978.

1979. Final cost of the viaduct was $9,863,384, of which $6,587,631 covered the cost of the piers and superstructure. The remaining $3,275,752 went toward foundations (drilled microshaft piles that were reinforced and grouted). Grandfather Mountain is dotted with rock outcrops that are believed to be some of the oldest in the world, and unknown rock conditions caused the need for additional microshaft pilings accounting for the increase in actual cost. Even so, the bridge was still completed on schedule.[41]

Environmental Constraints
The viaduct was located near the eastern continental divide at an elevation of approximately 4,500' above sea level. In order to preserve the natural beauty of the area, the environmental constraints during construction included provisions that no trees other than the ones directly beneath the bridge were allowed to be cut. Each tree was evaluated separately for approval for cutting. All foliage adjacent to the bridge had to be protected by a silt fence located along the entire length of the bridge. Any construction debris falling outside of this area had to be immediately retrieved. The stream flowing through the construction site was protected from siltation and other contamination and the water quality had to be constantly monitored. None of the boulders could be defaced during construction, except in instances of rock bolting. Boulders were covered with tarpaulins to prevent concrete, epoxy, or grout stains from construction activity. Any extraneous material was immediately cleaned off.[42]

Superstructure Segments
Typical box girder structures have been built with span-to-depth ratios of 1:18 to 1:25. Higher span-to-depth ratios generally produce more slender and aesthetically pleasing structures. Considering the beautiful site of Linn Cove, it was decided to use a span-to-depth ratio of 1:22 to provide a graceful structure. However, after analysis of this cross section, it was decided to increase the depth of the box and the web thickness because the shallower depth structure required a significant amount of high strength post-tensioning steel. This was because cantilever construction with large equipment weights applied at the free end induces high compressive stresses in the bottom slab. This in combination with shear stresses resulting from the torsional moment and the longitudinal shear force, resulted in a bottom slab thicker than the usual 12" for the typical section and a web width of 18".[43] The final span-to-depth ratio was 1:20.

Even though all the segments had a constant depth, no two of the 153 superstructure segments had the same dimensions. Only one of the segments in the entire bridge was straight. When the

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[41]Jakovich, "Design and Construction," 2,5; and Figg and Muller, Inc., "Linn Cove Viaduct: Apex of Bridge Design," 1.

[42]Muller and Barker, "Design and Construction," 6-7.

[43]Muller and Barker, "Design and Construction," 7.

vertical curve and tangential alignment were considered, the Linn Cove Viaduct included almost every kind of geometry used in highway construction.[44]

Short-line match-casting system

To assure that the structure would meet exacting curvature and superelevation-variation requirements, segments were laid out for the short-line match-casting system, which permits horizontal and vertical curves to be cast economically and with a high degree of accuracy. This procedure required a special casting form designed to allow deformations between the bulkhead and the match-cast segment.[45] In short line match-casting, a segment was cast against a fixed bulkhead or mold at one end and its neighboring completed segment, or match-cast segment, at the other end (Fig. 13). Contractors built-in the geometry by adjusting the orientation of the match-cast segment so that the two segments were in the correct relative alignment. The sharp curvature resulted in extreme angular deviations between the two match-cast segments requiring a casting machine that had hydraulic adjustments at all four corners.[46] To assist in obtaining adequate sealing to ensure smooth joints, the contractor installed a strip of rubberized material on the edge of the casting machine. This worked very well with the only detrimental effects being occasional pieces of rubber which would stick to the concrete. The pieces were easily removed.

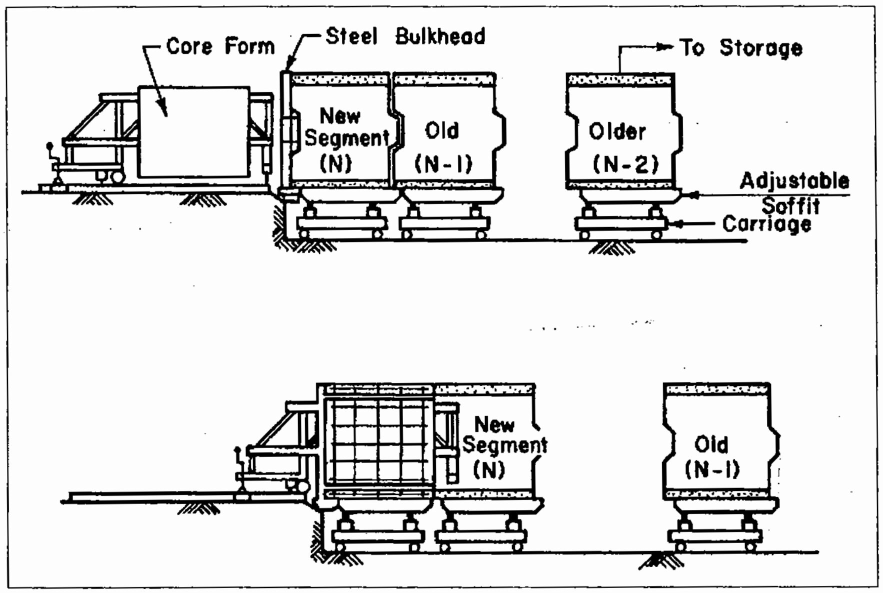

Figure 13 Schematic of short-line match-casting system as used on Linn Cove Viaduct. (Muller and Barker, "Design and Construction," 5)

Following casting, inspectors made geometry control checks to determine the amount of casting error so the errors could be corrected later on. The newly cast segment then moved to the match cast position and the cycle was repeated. Creep and shrinkage in the concrete, relaxation of

[44]Muller and Barker, "Design and Construction," 5.

[45]Muller and Barker, "Design and Construction," 9.

[46]Figg and Muller, Inc., "Linn Cove Viaduct: Apex of Bridge Design," 1.

prestressing steel, and elastic deformation of the cantilever were accounted for during the casting procedure to allow for the correct vertical and horizontal alignment to be obtained in the completed structure.[47] Casting operations began in July 1979 and were completed on September 10, 1981.[48] Production levels improved dramatically over the course of the operation from approximately one segment per two weeks in the beginning to four segments per week.[49]

The short-line match-casting system has several advantages. First, the attainment of the highest-quality concrete can be secured through plant protection. Second, the manufacture of precast segments at a plant site eliminated the need for falsework which the construction site precluded. Third, the accuracy of section and profile can be obtained, and the problem of deflections during construction could be overcome. Fourth, the dry joints produced by the system made possible speedy and economical assembly in the field and assured a perfect joint. Finally, shrinkage is practically eliminated.

The concrete box girder segments were nominally 8-1/2' long, 9' deep, and 37-1/2' across the slab (Fig. 14). The cast segments used one of the most sophisticated concrete mixtures ever developed for a segmental bridge in the United States. The coarse aggregate was crushed dolomite stone, and the fine aggregate was fine sand. Trucks transported the aggregate to the casting site located about a mile from the viaduct site. The Type 1 cement obtained the specified 28

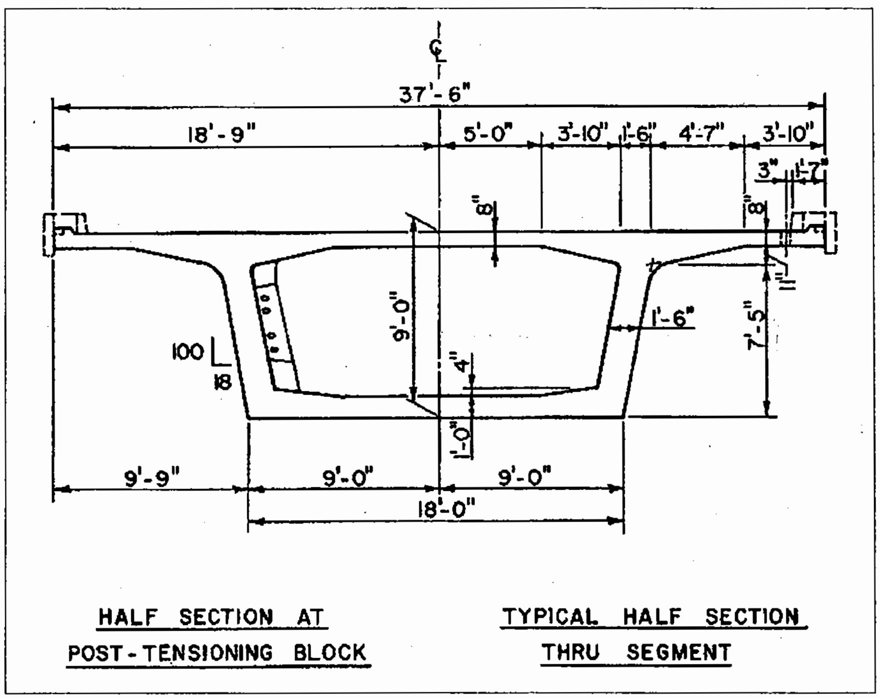

Figure 14 Typical box girder segment. (Muller and Barker, "Design and Construction," 8)

[47]Jakovich, "Design and Construction," 4.

[48]Jakovich, "Design and Construction," 5; and Figg and Muller, Inc., "Linn Cove Viaduct: Apex of Bridge Design," 1.

[49]Jakovich, "Design and Construction," 6.

day strength of 6,000 pounds per square inch (psi) and the lifting strength specified at 4,000 psi.[50] A mobile batching plant produced all the project's concrete. After initial problems obtaining the required 28-day strength of 6,000 psi for the precast segments, the contractor made adjustments in the mix design and the mobile mixer and produced concrete with strength significantly above that required.[51] Admixtures included air entraining agents, retarders, and a super water reducer to increase strength. An iron oxide pigment was also added to tint the concrete to blend with the coloration of Grandfather Mountain's existing rock.

Because of the high strength required and the heavy reinforcing in the segments, a high-range water reducer was used to enable the concrete to have a low water/cement ratio. This provided strength but still had the workability required for efficient placement and proper consolidation. Steam curing, at temperatures up to 140 degrees F, accelerated curing. This allowed the contractor to quickly obtain the 3,000 psi strength required for stripping the forms and moving the newly cast segment to the match-cast position. It generally required about 12 hours for the

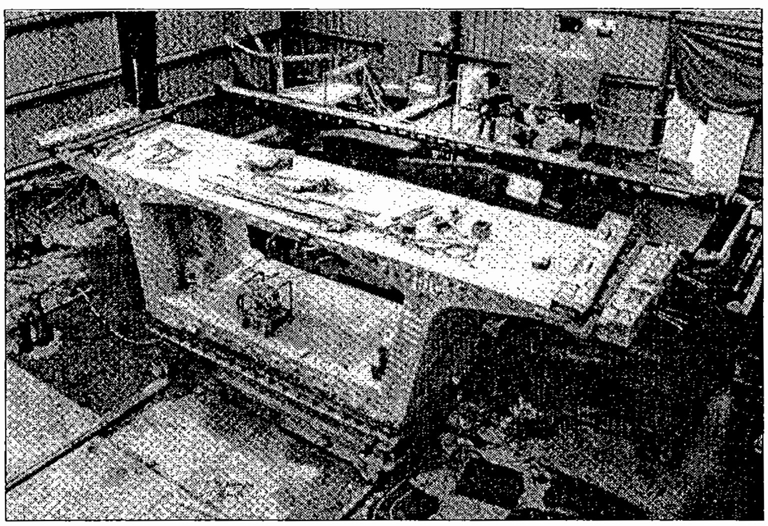

Figure 15 The casting machine was located inside a building enabling segments to be cast during the winter months. The next cast-against segment can seen. The workers are standing on the core form which moves in to form the box girder void. (Muller and Barker, "Design and Construction," 10.)

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[50]Jean Muller, "The Linn Cove Viaduct," in Barry M. Buxton and Steven M Beatty, editors, *Blue Ridge Parkway: Agent of Transition: Proceedings of the Blue Ridge Parkway Golden Anniversary Conference* (Boone, NC: Appalachian Consortium Press, 1993), 73.

[51]Jakovich, "Design and Construction," 6.

cast segment to reach this strength.[52]

Because the mountain was notorious for extreme weather conditions of below zero temperatures and winds ranging up to 100 miles per hour, the contractor enclosed the casting machine and reinforcement cage fabrication area in a metal building (Fig. 15). Completed segments were stored along the roadway leading to the viaduct site.

The severe geometry requirements of the Linn Cove superstructure necessitated some unique properties for the segment casting machine. The system had to be strong enough to support 55 tons of concrete and steel, yet flexible enough to seal around the edges of the cast-against segment, which in some instances was severely skewed because of the large degree of curvature to be obtained.[53] The three types of movement that can be required of a casting machine were all required on this project, and to a much greater degree than on any previous bridge. The first was movement in plane to obtain a curved alignment. Second, movement in elevation was used to obtain the desired vertical profile. Third, a warping movement in the form soffit produced the desired cross fall variations.

Normal geometry control procedures could not be used. The geometry of Linn Cove with 21 segments between cast-in-place closure joints would have resulted in the twenty-first segment being approximately 4" off line and 6' off grade, had not the viaduct and casting cell angular change been taken into account.

The theoretical casting curves are those curves to which segments are assembled in the viaduct so they conform to the geometric shape shown on the contract drawings. The theoretical casting curves have to take into account the geometric alignment and vertical profiles and the effect of the deflections in the superstructure that occur during and after erection. For bridges of larger radii and 3 percent superelevation, the effect is insignificant in alignment, but not in profile. For a straight bridge, the casting curve is simply the same information on the contract drawings. However, in the case of Linn Cove, whenever any segment cast horizontally in the casting cell had to be rotated about its longitudinal axis to be placed in the viaduct, the geometric profile of the segment and all its adjacent segments were very different from the alignment and profile shown on the contract drawings.

The contractor had ultimate responsibility for the geometry control of the segments during the casting operation and during erection of the cantilevers. The contractor developed theoretical casting curves from the contract documents and submitted the data to the FHWA, which

[52]Jakovich, "Design and Construction," 6.

[53]Muller and Barker, "Design and Construction," 9-10.

consulted Figg and Muller Engineers before giving approval. The engineers established a completely independent geometry control system from that used by the contractor. The primary function of this separate evaluation was to provide a system of checks and balances, thereby assuring complete and accurate geometry control.

During construction of the viaduct, the position of the superstructure matched the predicted location at all times. Joint thicknesses of 0.02" were regularly achieved due to precise casting control.[54] The stringent quality control for the production and placement of concrete resulted in the exceptional quality of the precast segments. Only two of the pier segments and none of the deck segments were rejected.[55]

Since the 30 ton post-tensioned box pier segments were relatively few in number, they were match-cast vertically outside.[56] This method involved casting the new segment above the previously cast segment with steel forms used for the side forms and a core form to cast the void in the box. The reinforcing cages (including the vertical tendon ducts) were prefabricated. The only geometry involved in casting the pier segments was the determination of the as-cast data and making minor corrections for casting variances. The as-cast data was later used when erecting the box pier segments.

Segment Placement

While many segmental structures have been designed with spans greater than 180' and some have been constructed by cantilevering a greater distance, the high torsional forces produced by the extreme curvature prohibited cantilevering over the entire 180' span as well as the use of overhead stays. For this reason, the design incorporated temporary supports placed midway between the piers. Construction of these supports, as with the permanent piers, was performed by working off the end of the erected portion of the structure (Fig. 8, p. 20).

The 1,243'-long viaduct was composed of two 98'-6" end spans, two 163' intermediate spans, and four 180' center spans. The end span, which was constructed on falsework, acted as a counterweight to permit segments in the next span to be progressively erected in cantilever. Continuity of the structure was developed by post-tensioning tendons that were made up of 19, 1/2-inch-diameter, high strength, low-relaxation, steel strands. Superstructure segments were delivered to the end of the cantilever by a low-boy tractor trailer. Because of the limited access, the truck had to be backed up the access road and onto the completed portion of the viaduct.

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[54]Muller, "The Linn Cove Viaduct," 79.

[55]Jakovich, "Design and Construction," 6.

[56]Muller, "The Linn Cove Viaduct," 73.

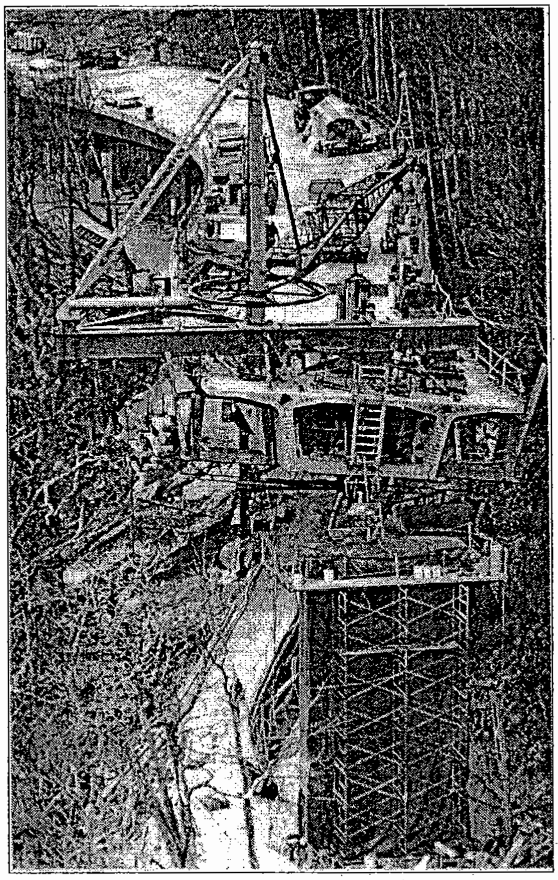

Figure 16 The contractor chose to erect the segments with this stiffleg crane attached to the end of the cantilever. This single piece of equipment controlled the construction rate of the viaduct. All material and equipment was handled with this crane. (Muller, "The Linn Cove Viaduct")

The crane that lifted the segments from the end of the truck and swung them around to the end of the cantilever was an American S-20 stiffleg crane (Fig. 16). It was equipped with a 70' boom and provided a 125 kip lifting capacity at a 25' boom radius. The crane had to be moved forward after each segment was placed. Generally, it was located two segments behind the segment being erected. The moving operation involved lifting the entire assembly, removing the steel support beams, and lowering the assembly onto steel rollers. Once the crane was supported on rollers, it was pulled forward by hand-operated winches. Then the lifting process was reversed. The steel support beams were reinstalled and the crane was tied down.

The moving operation took four to six hours to complete. The time it took to move the stiffleg crane controlled the erection rate of the superstructure segments. Incorporation of a swivel crane or modifying the stiffleg crane for faster movement would have substantially increased the superstructure erection rate.[57] The entire operation from the time the segment reached the end of the cantilever to actual attachment was 60 to 90 minutes.[58]

During the erection of a segment, temporary post-tensioning bars were used to induce a 50 psi compressive stress on the entire cross-section at the epoxy-coated joint in order to squeeze out the excess of the freshly placed epoxy and insured that the joint was completely closed. Following this, and before erecting the next segment, tendons were installed and post-tensioned to support the just-erected segment in cantilever.[59]

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[57]Muller and Barker, "Design and Construction," 13.

[58]Figg and Muller, Inc., "Linn Cove Viaduct: Apex of Bridge Design," 1.

[59]Jakovich, "Design and Construction," 2.

Flexibility in alignment control during the erection phase was provided for with a 6" long closure joint that was placed directly over the temporary support and the preceding segment. The closure joint made it possible to redirect the alignment and thereby compensate for erection error, casting error, and deviations from the expected values for creep, shrinkage, etc. The piers also offered alignment flexibility. Since the bottom precast pier segment was positioned into the footing prior to casting the footing, the horizontal and/or vertical orientation of the pier shaft could be adjusted a limited amount as necessary.[60] The contractor was able to erect two segments in one day. However, four segments, or about 34' of bridge per week was about average.[61]

Jasper Construction was able to continue erecting the structure through the winters due to their development of a movable insulating frame. In cold weather erection, maintaining a 40°F The frame surrounded the underside of the box girder section and insulated the match-cast joint to maintain an adequate curing temperature. A portable heater placed inside the superstructure provided heat as well as a string of light bulbs enclosed in a plywood boxes placed over the joint on the deck surface. Twenty segments were installed during the 1981-82 winter in temperatures

Table 2

Step-by-step procedure for the erection of a typical segment:

Step 1 - The segment was backed to the end of the bridge by truck.

Step 2 - The stressing cages were picked up by stiffleg crane and attached to the new segment.

Step 3 - The stiffleg spreader beam was lifted with the stiffleg and the lifting cables attached to the new segment.

Step 4 - The segment was lifted to clear the trailer and the slope was checked to see that it matched the degree of superelevation at the end of the cantilever. If necessary, it was adjusted.

Step 5 - The segment was lifted by the stiffleg, swung around and lowered to within about 6" of the entire cantilever and held in place previous to epoxy and tendon applications.

Step 6 - The segment was pulled horizontally to the end of the cantilever with cable winches and blocked 6" away with wood blocks. It was still supported vertically by the stiffleg.

Step 7 - The temporary thread bar tendons were threaded and the nuts finger tightened.

Step 8 - The epoxy was mixed and applied.

Step 9 - The wooden blocks were removed and the segment clamped with the cable winches to the previously placed segment at the end of the cantilever.

Step 10 - The temporary thread bars were stressed.

Step 11 - The permanent 19-strand tendons were threaded and stressed.

Step 12 - The temporary thread bar tendons were released.[62]

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[60]Jakovich, "Design and Construction," 4-5.

[61]Jakovich, "Design and Construction," 7.

[62]Muller and Barker, "Design and Construction," 13,15.

as low as 20°F using this system.[63] The system proved very effective. The development of the heating system was significant, as such a system had not been previously used in the United States. The test results of the Linn Cove project will be applicable to other precast segmental structures in the northern part of the United States and Canada.[64]

An unusual design aspect, arising from the use of temporary piers, was that in the vicinity of the temporary piers, the superstructure underwent a complete stress reversal. When cantilevering out from the temporary support during erection, a large negative moment was produced at the support causing high compressive stresses in the bottom flange of the box girder section and tension in the upper flange. Later on, as erection progressed past the permanent pier, the live load on the temporary pier decreased causing compression in the bottom flange to decrease. Ultimately, as the superstructure approached the next temporary support, the live load had been removed entirely. To deal with this stress reversal, temporary tendons were installed in the top flange over the temporary support to counteract tensile stresses during the negative moment phase. When the stresses reversed, these tendons were detensioned to avoid overstressing the top flange.[65] The physical release of the temporary strand tendons was done by acetylene torch burning the anchor wedges of the strands one at a time. The strands were burned individually to minimize shock to the viaduct.[66] Also, transverse post-tensioning was used in the top flange to reduce its thickness and also help reduce longitudinal cracking.[67]

Pier Construction

The seven pier shafts, the tallest of which was 63', are also of a precast segmental design. This enabled workers to quickly construct and immediately load a pier upon completion of its assembly, thereby minimizing delays in the erection of the superstructure. Permanent post-tensioning bars were used to interconnect the segments and close the joints between them during erection of the pier shaft. Final prestressing force was supplied by the eight 12-strand vertical tendons that were installed and post-tensioned after the shaft was completely erected.[68]

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[63]Jakovich, "Design and Construction," 7. For additional information see Jean Muller and James M. Barker, "Joint Heating Allows Winter Construction on Linn Cove Viaduct," *PCI Journal: Prestressed Concrete Institute* 27, no. 5, September-October 1982, 120-130.

[64]Figg and Muller, Inc., "Linn Cove Viaduct Demonstrates Geometrical Versatility of Precast Segmental Concrete Bridges," *Transportation Research News* 102, September-October 1982, 1.

[65]Jakovich, "Design and Construction," 4.

[66]Figg and Muller, Inc., "Linn Cove Viaduct Demonstrates," 2.

[67]Jakonich, "Design and Construction," 6.

[68]Jakovich, "Design and Construction," 2.

The foundations consisted of cast-in-place abutments at each end and seven intermediate piers bearing on 20 foot diameter footings. The foundations, which were designed by FHWA personnel, were essentially cast-in-place friction piles. This design was selected primarily for two reasons. First, subsurface conditions made spread foundations impractical. Second, a pile system was required which could be constructed using equipment and material light enough to be lowered to the pier location from the deck.[69] All pier footings were 20' in diameter and 5' in thickness. The footings were founded on variable thickness nonreinforced subfootings through which microshaft piles were drilled.[70] The 9"-diameter microshaft piles were used as foundations for all piers, temporary supports, and abutments. The microshafts consisted of three 2-1/4"-diameter reinforcing bars bundled together and grouted in place with a water, sand, and cement mixture. Reinforcing bars for all permanent foundations were epoxy-coated to resist corrosion. At the permanent piers, 24 microshafts arranged in a 20'-diameter circular pattern were used to transmit the structure loads to the substratum. The loads were transferred through friction between the microshaft grout and the walls of the hole in which it was cast. Depths of the foundations varied from 10' to 110' depending on the subsurface conditions at the foundation locations.[71]

The contractor encountered difficulties during the construction of these microshaft foundations. Although a temporary casing was permitted for drilling the holes, the contractor elected not to use it, because of difficulty in installing and removing the casing with the light equipment used. Loose subsurface material which allowed the holes to cave in before the reinforcement could be installed hampered construction of the microshafts. Furthermore, the underground voids and fissures created problems in grouting the microshafts once the reinforcing bundles were in place by allowing grout to seep out of the holes. Since the microshafts were designed as friction piles, permanent casing was originally not permitted. To help alleviate these problems, however, the NPS permitted the contractor to install perforated, permanent casing that would help prevent cave-ins while still allowing grout to seep through the perforations and produce a friction pile. Load tests were performed on test microshafts to insure that piles constructed in this manner could support the design load of 130 tons compression and 50 tons tension. The contractor adopted the use of Odex eccentric, adjustable diameter drill bit. The Odex bit was designed to pull the casing along as it drills the hole. When the hole was drilled to the required depth, the adjustable bit was retracted and withdrawn through the casing. The eccentric bit, which rotated as it advanced, acted similarly to rifling in the barrel of a gun, and allowed the holes, many of which were battered up to 4"/12" to be drilled straight instead of wandering off-line as had been the case earlier. This helped facilitate the installation of the casing, particularly in the deeper

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[69]Jakovich, "Design and Construction," 5.

[70]Muller and Barker, "Design and Construction," 11.

[71]Jakovich, "Design and Construction," 5.

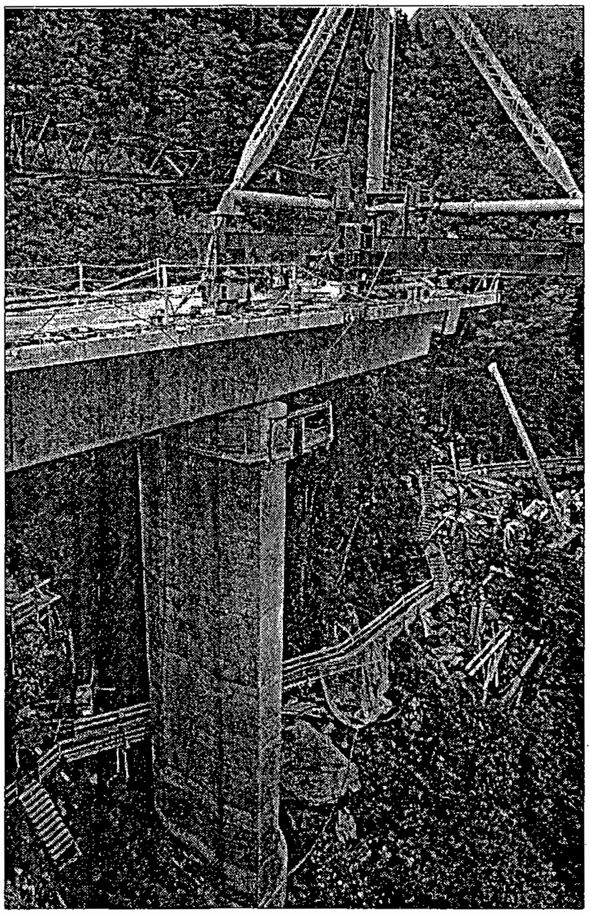
Figure 17 The temporary wooden bridge allowed workers access to pier foundations ahead of the superstructure construction. (Muller, "The Linn Cove Viaduct")

holes. After these changes were adopted, construction of the foundations improved considerably.[72]

The NPS, originally, limited work to a 25' radius of pier centers and a 30' x 40' area at each temporary bent. When it became apparent that the schedule could not be maintained unless crews could complete the pier foundations in advance of superstructure erection, the contractor was given permission to construct a narrow timber work bridge along the centerline (Fig. 17). The work bridge, while not imposing any significant damage to the mountainside, was capable of supporting the microshaft drilling equipment and enabled the contractor to get ahead of the structure assembly with construction of the foundations.[73] This drilling was the only construction activity allowed ahead of superstructure erection.

After forming the footings and placing the reinforcement and post-tensioning conduits, the contractor placed the first of the precast pier segments. A steel frame fabricated from rolled sections was placed in the footing simultaneously with the reinforcing bars. The frame provided support for the first box pier segments. The initial precast segment was placed on shims and flat jacks which enabled proper alignment. The segment had to be aligned correctly for casting variations and actual superstructure position. Movements were achieved by pumping the flat jacks one at a time or in combination. The jacks, therefore supported the segment at four points. The contractor was responsible for aligning the segment and the alignment was subsequently verified by the engineers. After verification, the footing extended approximately 1" above the bottom of the segment and the support beams for the segment were removed.

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[72]Jakovich, "Design and Construction," 6-7.

[73]Jakovich, "Design and Construction," 6-7; and "Viaduct Built form the Top Down: Sharply Curved and Superelevated Structure Leaves Slope Unscathed," *Engieering News-Record*, 28 October 1982, 22.

After the footing concrete hardened, the joint between the cast-in-place concrete and the precast segment was pressure grouted with epoxy. The purpose of the epoxy was not related to strength, but to waterproof the joint. As in the erection of the deck segments, a low-boy tractor trailer delivered the precast box pier segments over the completed portion of the superstructure, which extended to within two segments of the pier location. The segments were lifted over the end of the cantilever by a stiffleg crane attached to the cantilever (Fig. 18).

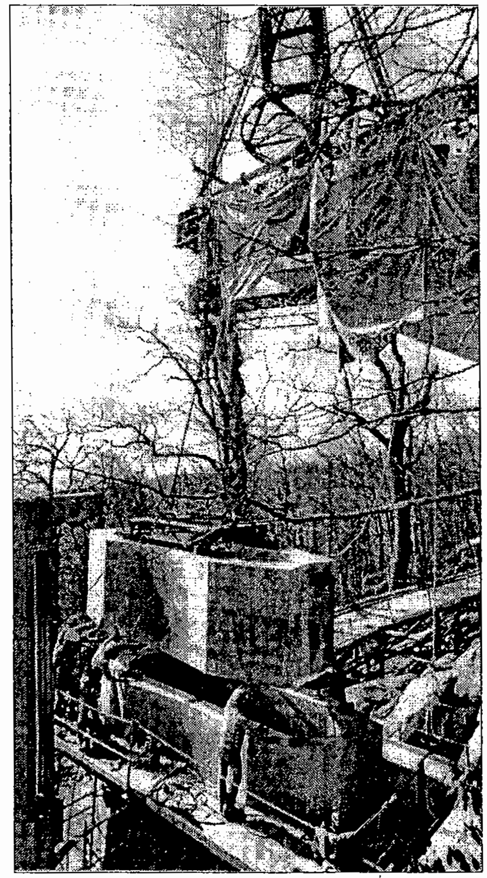

Figure 18 Precast box pier segments were lowered over the end of the completed cantilever with the stiffleg. The workmen are ready to block the segment and apply the epoxy. (Muller and Barker, "Design and Construction," 12)

The pier segments were blocked about 6" above the previous segment while epoxy was applied. The stiff-leg crane then lowered the segment to the face of the match-cast unit where thread bar tendons were installed and stressed. Each pair of segments were stressed together with thread bars. The process was repeated until all of the hollow segments were erected and the pier was ready for the cap.

The last step in the pier construction was to place the cap and stress the eight 12-strand tendons. These tendons extended from the top of the pier down through and out the side of the footings. Once stressing was completed, the tendons were grouted.[74] For earthquake protection, each pier cap has a cone-shaped pintle about 3' that projects through a hole in the box girder.[75]

Thermal movements in the structure were provided for by expansion joints located at both abutments. Neoprene bearing pads, upon which the superstructure rests at both the piers and abutments, permit the structure to expand and contract without developing excessive moments in the piers.[76] In the superstructure, the deck segments placed over both the permanent and temporary supports were constructed with diaphragms to give the structure torsional rigidity.

[74]Muller and Barker, "Design and Construction," 12.

[75]"Viaduct Built from the Top Down," 25.

[76]Jakovich, "Design and Construction," 5.

The Linn Cove Viaduct was probably one of the most complicated bridges ever built because of the following three factors: first, the environmental constraints imposed by the NPS; second, the inaccessibility of the site due to the single access point; third, vertical and horizontal alignment of its geometry. For these reasons, the FHWA made the unique structure a research site. To assist in its study, the FHWA retained the Portland Cement Associations's Construction Technologies Laboratories, Skokie, Ill., and Teng & Associates, Chicago, to place instruments for monitoring thermal and torsional strains and prestress losses. Evaluations of measurements taken during and after construction helped determine the viaduct's response to all loads and compared actual stresses to those predicted.[77]

Aesthetics
Muller called the piers in plan "curve-linear octagonal." Their eight faces alternated between flat and concave. The idea was to capture shadows from sunlight to further beautify the viaduct.[78]

Aesthetically, the completed viaduct blends with the terrain. The innovative construction scheme was highly successful. No trees other than those directly in the path of the viaduct were cut. No rock outcrops were damaged, as they had been covered during construction to prevent concrete, grout, or epoxy from staining them.

Completion
Construction of the viaduct began in 1978 and the last segment was placed in December 1982. During 1983 the contractor cast the curbing, completed the abutment, completed the grade on the north end of the viaduct which was inaccessible before it was erected, installed guardrail and applied a waterproofing membrane and wearing surface to the road deck.

Following completion of the Linn Cove Viaduct in 1983, approximately 1.3 miles of grading and six smaller-scale structures needed to be completed before the "missing link" in the Blue Ridge Parkway was opened.

On Friday, September 11, 1987, exactly fifty-two years after ground was broken, some 3,000 well wishers gathered on the shoulder of Grandfather Mountain for the parkway's official dedication ceremonies. Just to the south, a ribbon had been cut on the last stretch of the parkway to be completed.[79] Visitors could now travel the entire length from Shenandoah's Skyline Drive

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[77]"Viaduct Built from the Top Down," 22.

[78]"Viaduct Built from the Top Down," 25.

[79]Marily Nixon, "After 52 Short years: The Blue Ridge Parkway Takes a Bow," *Courier*, November 1987, 12.

to Great Smoky Mountain's Newfound Gap Road along an uninterrupted parkway presenting some of the most beautiful vistas in the eastern United States.

Awards

The Linn Cove Viaduct received several awards recognizing both the challenge of designing and building the project and its state-of-the-art technology and aesthetic characteristics.

The Linn Cove Viaduct won two federal awards. The most impressive award is the 1984 President's Design Award. This program was "the first government-wide effort to recognize and foster excellence in federal design efforts." Linn Cove was one of just 13 projects chosen for this award out of nearly 700 entries. The FHWA selected Linn Cove for first place in the "Highway Improvements in Federally Owned Lands" category of its own Biennial Awards Program for excellence in Highway Design (1984).

The Linn Cove Viaduct was the recipient of numerous awards from engineering societies. The Post-Tensioning Institute presented the project with its 1983 PTI Award of Excellence. The jury stated that "the complex geometry and environmentally sensitive area posed an unusual challenge to designer and builder. The beautiful solution is a curving post-tensioned box girder, built entirely from overhead. The bridge fits harmoniously with the site and demonstrates a mastery of pre-cast technology." The Prestressed Concrete Institute presented the Blue Ridge Parkway its Award of Excellence and the American Society of Civil Engineers presented its National Award of Merit. The National Society of Professional Engineers deemed the viaduct one of the Ten Outstanding Structures in the United States in 1984. The Linn Cove Viaduct also won first prize in the Florida Institute of Consulting Engineers Engineering Excellence Awards competition. In the national competition of the American Consulting Engineers Council the project was given a Honor Award.[80]

The Jury Citation of the 1984 Presidential Design Awards sums up the viaduct nicely.

> The designers of the Linn Cove Viaduct were confronted with the difficult problem of creating a road over a rugged terrain of exceptional beauty without interfering with the environment. Their solution is technically innovative and respectful of the environmental situation.
>
> From an engineering point of view, construction of the roadway by pre-cast, segmental concrete elements set from above on segmental piers is elegant, economical, and new. These techniques can be used in the service of the

[80]Figg and Muller, Inc., "Linn Cove Viaduct: Apex of Bridge Design," 1.

environment; they provide accessibility by animal life both below and around the structure and do not damage the forest land, trees, or streams.

The roadway results in an elegant curving ribbon that caresses the terrain without using it as a support. It gives the motorist the sensation of driving tantalizing on air while the earth goes by.

For their sensitivity and high technical expertise, the designers and the authorities who supported them well deserve this citation.[81]

[81]Figg and Muller, Inc., "Linn Cove Viaduct: Apex of Bridge Design," 1.

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