United States Department of the Interior
National Park Service

National Register of Historic Places Multiple Property Documentation Form

This form is used for documenting property groups relating to one or several historic contexts. See instructions in National Register Bulletin *How to Complete the Multiple Property Documentation Form* (formerly 16B). Complete each item by entering the requested information.

X New Submission ____ Amended Submission

A. Name of Multiple Property Listing

Bridges of the Spokane, Portland & Seattle Railway Company, 1906–1967

B. Associated Historic Contexts

(Name each associated historic context, identifying theme, geographical area, and chronological period for each.)

1. The Spokane, Portland & Seattle Railway
2. Railroad Bridges and Bridge Engineering in the Era of the SP&S

C. Form Prepared by:

Name/title: Matthew Sneddon (Edited by DAHP Staff)
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D. Certification

As the designated authority under the National Historic Preservation Act of 1966, as amended, I hereby certify that this documentation form meets the National Register documentation standards and sets forth requirements for the listing of related properties consistent with the National Register criteria. This submission meets the procedural and professional requirements set forth in 36 CFR 60 and the Secretary of the Interior's Standards and Guidelines for Archeology and Historic Preservation.

[signature] _SHPO_____ 11-14-18
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I hereby certify that this multiple property documentation form has been approved by the National Register as a basis for evaluating related properties for listing in the National Register.

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Signature of the Keeper Date of Action

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Table of Contents for Written Narrative

Create a Table of Contents and list the page numbers for each of these sections in the space below.

Provide narrative explanations for each of these sections on continuation sheets. In the header of each section, cite the letter, page number, and name of the multiple property listing. Refer to *How to Complete the Multiple Property Documentation Form* for additional guidance.

SECTION E. STATEMENT OF HISTORIC CONTEXTS

E1. The Spokane, Portland & Seattle Railway

On an August day in 1905, representatives of two of the nation's largest railway companies, the Northern Pacific Railway Company (NP) and Great Northern Railway Company (GN), filed articles of incorporation with the State of Washington for a new line, the Portland & Seattle Railway Company (Portland & Seattle). The filing generated no news, as the new trustees, bankers without established ties to the GN or NP, requested it not be made public. The company's chosen name, the Portland & Seattle, added to the veil of secrecy by masking its true purpose: to build a line along the north bank of the Columbia River from Kennewick to Vancouver.[1] The deception gave the new railway company's true owners led by James J. Hill a final few weeks to prepare for the war that lay ahead, for building railroads in the United States often meant war of a kind, with surveyors, land agents, and attorneys in the vanguard, and rail barons acting as generals of campaigns fought with allies, armies, subterfuge, and even violence. Such was the language of the railroad business in the early twentieth century.

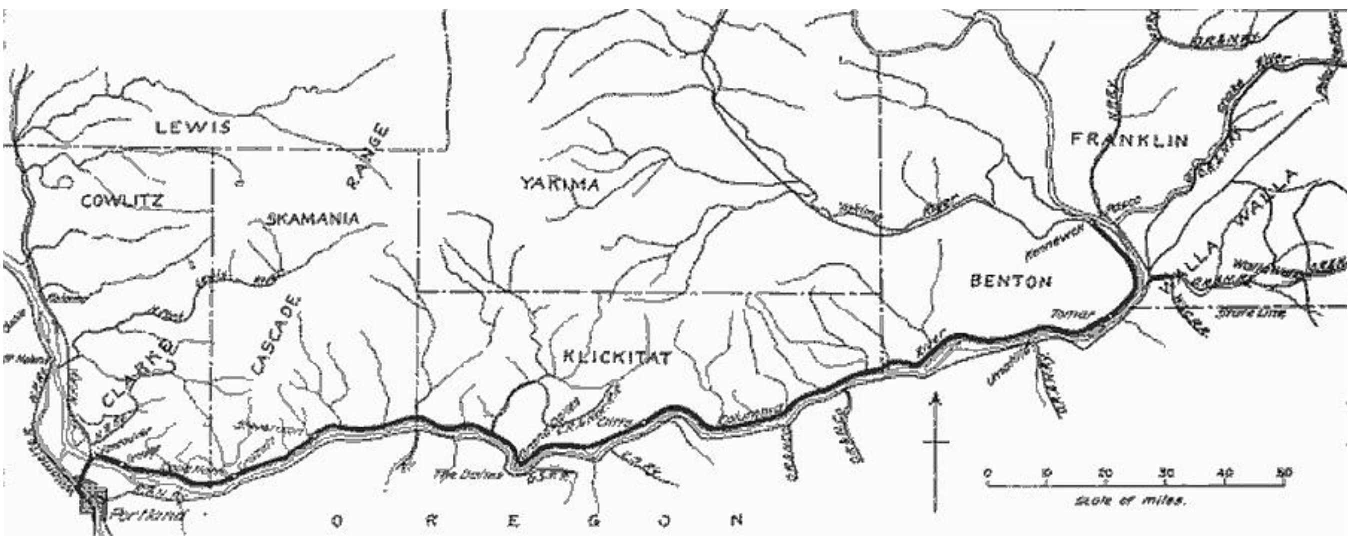

Figure 1. First phase of the Portland & Seattle Railway Company line—Portland to Kennewick.
Source: Estep, "The Portland & Seattle," 360.

The new railway would be built in part to compete with the rival line of the Oregon Railway & Navigation Company (OR&N)—controlled by Edward H. Harriman's Union Pacific Railway Company (UP)—on the opposite bank of the Columbia River, in places less than ½ mile apart. For many years, the OR&N and its predecessors had held a strong grip on rail and Columbia River traffic into Portland, the primary commercial hub of the Pacific Northwest. Hill, who had acquired a controlling interest in the NP in 1896, hoped to break into the Portland business with the so-called North Bank line. The project had been brewing in Hill's mind ever since he was unable to come to an agreement with Harriman over trackage rights and terminals a few years earlier.[2] In

[1] "Portland & Seattle Railroad Files Articles—Road Building War Is On," *Morning Olympian*, September 15, 1905.
[2] Don L. Hofsommer, *The Southern Pacific, 1901–1985* (College Station: Texas A&M University Press, 1986), 40.

moving forward with the North Bank project, Hill was carrying on a long tradition in the US railroad industry of building parallel lines, one that had often resulted in overextension and financial strain.[3]

Despite its competitive nature, the railroad industry also ran on cooperation, from gentlemen's agreements to formalized corporate collaborations such as the Portland & Seattle, later the Spokane, Portland & Seattle (SP&S). The strength of executive control and relative laxity of government regulation throughout much of the nineteenth century lent itself to business arrangements forged by a few men haggling face to face. Ultimately, the men that controlled the railroad industry sought consolidation and monopoly, whether through alliances, mergers, or stocks. After fending off a stock raid by Harriman in 1901, Hill attempted to protect his holdings from future takeover by forming the Northern Securities Company later that year.[4] Hill's holding company was blocked under the Sherman Antitrust Act by the Roosevelt administration, however nearly seventy years later, the federal government looked at the issue of monopoly differently, ultimately approving the Burlington Northern merger of the GN, NP, SP&S, and Chicago, Burlington, and Quincy Railroads.[5]

Born from competition, the SP&S provides one case study of collaboration between two major railway companies. Unlike many railroads built on speculation and land grants, construction of the SP&S had the substantial financial resources of the GN and NP to draw on and an experienced executive to lead the project. Although ostensibly established as an independent line, the SP&S's corporate history was one ultimately ruled by the tug-of-war between executives of the GN and NP.

The route planned for the SP&S would add to a transportation corridor of historic significance for the region. In 1805, Meriwether Lewis and William Clark reached the Columbia River and portaged around rapids and falls in areas that were later part of the SP&S grade. For thousands of westbound settlers on the Oregon Trail in the mid-nineteenth century, sighting the Columbia River meant their final destination was near. Steamships eventually started plying the river in 1850, establishing freight and passenger service that brought economic growth to the region and new settlement along the river. Similar to the railroad industry, private corporations sought singular control over river traffic, initially through the Oregon Steam Navigation Company, which the ON&R bought out in 1879.[6]

In 1851, just a year after the first steamer appeared on the Columbia, Francis Chenoweth was credited with building the first "railroad" in the northwest: an approximately 2- to 4-mile long wood-tracked portage road around the Cascade Rapids—roughly the same ground Lewis and Clark had traversed several decades earlier—over which a mule pulled a flatcar. After purchasing the road in 1863, the Bradford brothers converted it to steel rails and steam power.[7] Vital portages on both sides of the river came under control of the OR&N, which in the early 1880s completed a railroad from Celilo just east of The Dalles to Portland along the south bank to complement the steamer service.[8]

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[3] David M. Kotz, *Bank Control of Large Corporations in the United States* (Berkeley: University of California Press, 1978), 29.
[4] Michael P. Malone, *James J. Hill, Empire Builder of the Northwest* (Norman: University of Oklahoma Press, 1996), 212–14.
[5] Brian Solomon, *Burlington Northern Santa Fe Railway* (St. Paul, MN: MBI, 2005), 112.
[6] Peter J. Lewty, *To the Columbia Gateway: The Oregon Railway and the Northern Pacific, 1879–1884* (Pullman: Washington State University Press, 1987), 42.
[7] William L. Lang, "Oregon Steam Navigation Company," accessed May 18, 2016, http://www.oregonencyclopedia.org/articles/oregon_steam_navigation_company/#.V1ipNdkrJh.
[8] Lewty, *To the Columbia Gateway,* xiii, 48.

As construction of roads and railways proceeded on the Columbia's south bank, massive geologic formations at Cape Horn and Beacon Rock, steep slopes, several rivers and creeks, and dense forests presented significant challenges to similar such projects on the north bank. When the US Army investigated the prospects of building a military road to connect the forts at Vancouver and The Dalles in the mid-1850s, the officer assigned to survey the route estimated that cutting a road would take at least one million dollars, and recommended that the Army's best solution was to continue using the river for transportation and to portage where necessary.[9] Although some furtive efforts were made to build a line on the Washington side, including a survey conducted in 1890 for one unrealized project, little progress had been made until Hill became involved. Despite the obstacles, N. W. Bethel, an engineer charged with surveying a potential route for the Hill group, thought a line from Kennewick to Vancouver with 0.3 percent grade eastbound and maximum curvature of 4 degrees could be built for about $7.3 million.[10]

The prospect of a low grade and minimal curvature fit well with Hill's approach to railroad building, which valued minimizing the cost of running trains and maximizing traffic. Hill was willing to spend more money on a well-engineered line, even if it was longer, if it meant a given locomotive could pull more cars faster. The SP&S reflected this roadbuilding strategy in several ways. First, Hill lowered the already ambitious grade and curvature targets of Bethel's survey to less than 0.2 grade and 3-degree maximum curvature. Second, he raised the initial high-water mark of the line to 10 feet (ft) above the highest recorded value—that of the 1894 flood. Finally, he ensured all aspects of the line could handle a maximum speed of 60 miles per hour.[11] During one inspection trip, Hill boasted that "the Portland & Seattle Railway will be the best new road that was ever built in the United States. It will be a road of low grades and few curves, and it will be very expensive, but when it is built it will be the best construction ever undertaken in this country."[12] Hill would find his prediction about the expense of construction to be on the mark.

Although it was Hill's GN rather than the NP that had earned the reputation of a better-engineered intercontinental line, some aspects of the line reflected an NP cast. Bethel and William Darling, engineer in charge of construction, were NP men, and the bridges used on the line were from a standardized NP design.[13] The general contractor awarded the first stage of the project, grading the alignment from Kennewick to Vancouver, however, was a firm Hill had often used on GN work: Siems and Shields.

Siems and Shields would receive approximately $30,000 per mile for the job, equivalent to about $7,000,000. From its quarters at the Hotel Portland, Siems and Shields held "continuous reception with contractors of all kinds and descriptions," who were seeking the opportunity to secure portions of the big contract.[14] The contractors soon found the supply of labor below their hopes. By February 1906, some 1,500 men were on the job, but more were needed. In hopes of enticing additional workers from points east, Hill offered cheap rail fares from Chicago.[15]

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[9] "The Columbia River: A Photographic Journey," accessed May 10, 2016, http://columbiariverimages.com/.
[10] John T. Gaetner, *North Bank Road: The Spokane, Portland & Seattle Railway* (Pullman: Washington State University Press, 1990), 2–3.
[11] "Army of Men Working To Complete North Bank Road," *Oregonian*, September 1, 1907.
[12] "Best Ever Built, Says James J. Hill," *Oregonian*, July 14, 1906.
[13] "Hill Is Coming into Portland," *Oregonian*, September 13, 1905.
[14] "For the North Bank Road," *Oregonian*, October 10, 1905.
[15] "Railroads Can't Find Enough Men," *Tacoma Daily News*, February 7, 1906.

Part of Hill's haste in driving construction forward was to counter Harriman's efforts to halt or delay the project with every means at his disposal. Harriman held some old charters for sections of the north bank route and had his own gangs working on grading while rights-of-way were contested in the courts. On January 1, 1906, local newspapers reported that OR&N men had torn up disputed tracks and burned a bridge that the Portland & Seattle had constructed across their right-of-way.[16] The Harriman forces were also busy excavating a tunnel through Cape Horn (a massive basaltic cliff some 10 miles upriver of Washougal) from the west while the Portland & Seattle crews worked at the same task from the east. On January 7, 1907, after over a year of battle that the *Seattle Times* characterized as the "greatest warfare of its kind ever known in the Pacific Northwest," favorable court rulings ended the fight between Hill and Harriman. After employing 2,000 men and spending $350,000 on grades and tunnels, Harriman left the field of battle.[17]

With the rail war over, the Portland & Seattle could focus on the immense task still at hand, which labor shortages once again jeopardized. Sweetening his earlier deal, Hill offered free rail fares from Pittsburgh, Cincinnati, Chicago, St. Paul, and other Midwestern and eastern cities to induce men to come west. The result, according to the Oregonian, was "believed to have been the greatest immigration of its kind into the Pacific Northwest . . . employment agents estimate on a conservative basis that 40,000 workmen have been imported to this territory since work on the North Bank road was commenced."[18] Estimates of the labor force working on the project during 1907 ranged from 4,000 to 6,000, composed of largely Greeks, Austrians, and Bulgarians, who earned a day's wage of $2.50 and up for common labor.[19] Although progress by the "army" on tunnels, trestles (some over 1-mile long), and grading was carried out day and night, newspaper coverage doubted the mid-November target date for completing the section of line between Portland and Kennewick would be met—too many bridges were yet to be built and too many grades were yet unfinished.[20] When the completion date came and passed, Louis W. Hill, who had assumed the presidency of the GN after his father's retirement, reminded critics that this was "no small job . . . we are throwing more dirt every day on the North Bank road than is being moved from the Panama Canal."[21]

Although behind schedule, the board of directors felt enough progress had been made to file three supplemental articles of incorporation at the end of January 1908. The first article authorized the company to extend the line from Kennewick to Spokane—part of the plan from the start—and the second raised capitalization to $25,000,000 to fund the construction. The last article authorized changing the name of the company from the Portland & Seattle to the Spokane, Portland & Seattle (SP&S). Boosters in Spokane had urged the name change to promote business at the termination point in Spokane, and the railroad company obliged.[22]

Due to the phased nature of the project, the SP&S became operational on a rolling basis. On February 23, 1908, Vancouver and Kennewick crews met near milepost 50.5 without ceremony, but local pressure to commemorate the milestone resulted in a belated celebration a few weeks later on March 11.[23] Construction

[16] "Hill's Bridge Is Burned Up," *Grand Forks Daily Herald*, January 1, 1906.
[17] "Hill Wins Fight with Harriman," *Seattle Times*, January 7, 1907.
[18] "Workmen Sent to Coast, Fare Free," *Oregonian*, July 12 1907.
[19] "Workmen Sent to Coast, Fare Free."
[20] "Army of Men Working."
[21] "Trains into City Within 60 Days," *Oregonian*, December 15, 1907.
[22] "Important Articles Filed: North Bank Changes Name, Increases Capital and Will Extend," *Oregonian*, January 30, 1908, 11.
[23] Gaetner, *North Bank Road*, 17.

on the line was ongoing, including the connection between Vancouver and Portland and the line from Kennewick into Spokane. As of September 1, 1908, over $57 million had been spent on the line and more work still to be done—a good deal beyond the initial 1905 estimate of $7.3 million.[24] When trains finally began running on the last leg into Spokane in May 1909, local boosters boasted that the SP&S was "the most expensively and scientifically built road in the United States, having curves and grades reduced to a minimum, being, in fact, a continuous descent from near Spokane to tide-water. Its builders evidently expect stupendous traffic, and every feature of the line is adjusted to such expectation."[25]

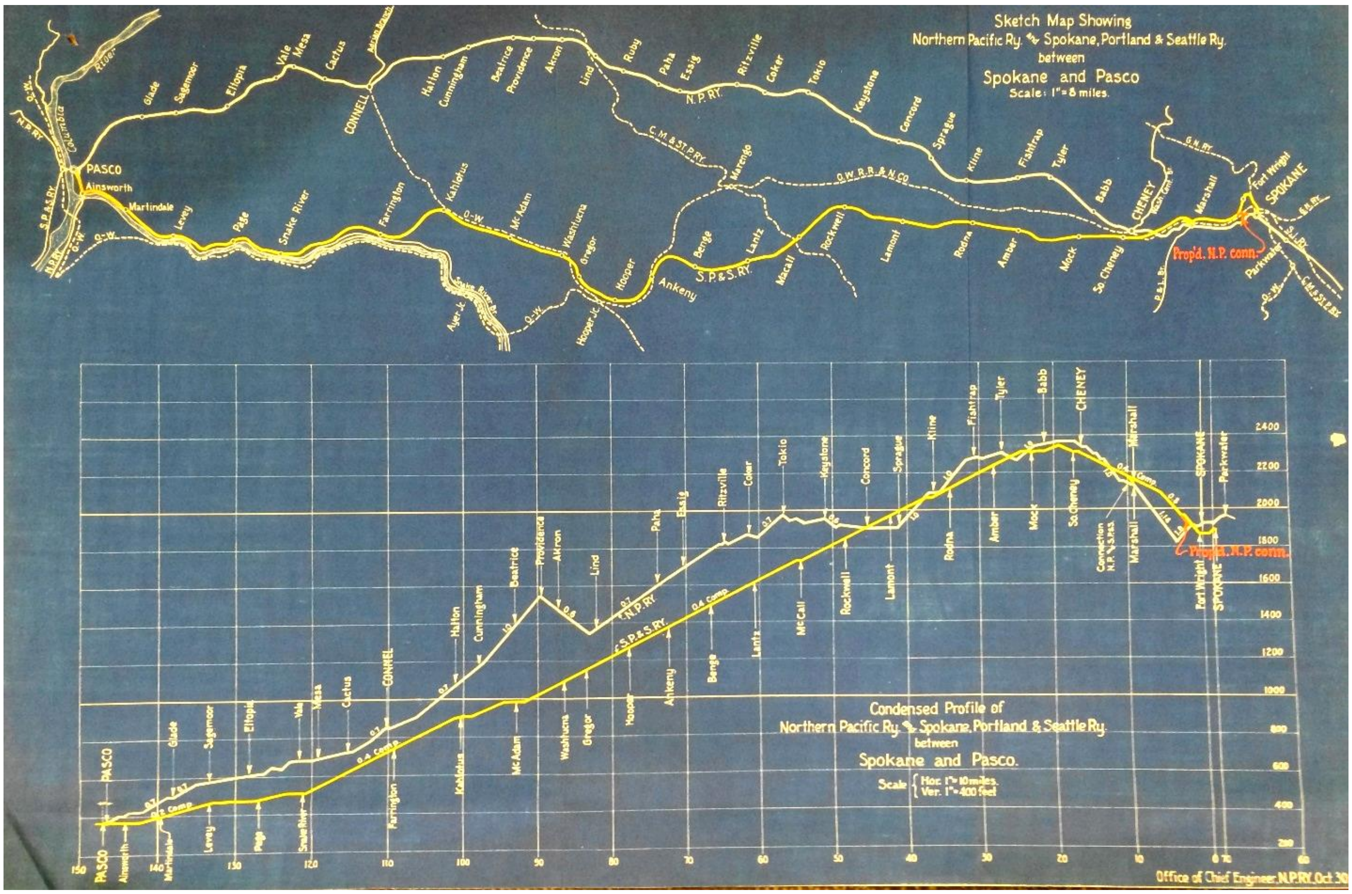

Figure 2. Map and profile comparing routes of the NP and SP&S from Pasco to Spokane, 1917.
Source: Minnesota Historical Society (MHS).

With construction finally complete, the GN, NP, and SP&S took up the next challenge: running the railroad. The two parent companies negotiated nearly every aspect of operations, including executive appointments, hiring crews, assignment of rolling stock, and trackage rights. Hill found traffic lighter than expected because NP and GN managers were still using established routes over the Cascades into the Puget Sound region. Throughout its

[24] Gaetner, *North Bank Road*, 20.
[25] William Denison Lyman, *The Columbia River: Its History, Its Myths, Its Scenery, Its Commerce* (New York: G. P. Putnam's Sons, 1909), 263.

existence, the SP&S had to factor NP and GN traffic into scheduling, lease equipment from the parent companies, and rely on their facilities for maintenance.[26]

The first twenty-five years of operations served as a referendum of sorts on whether the pseudo-independent SP&S offered any advantages to the parent companies. Weighed down by the heavy debt of construction, the SP&S faced a long struggle to gain profitability. During World War I when the US government nationalized control of the railroads, the line experienced high traffic, but in the 1920s, the rail industry in general began to feel the effects of the emerging competition from trucks and cars. The Great Depression made matters worse, and keeping the SP&S solvent demanded drastic measures. The GN and NP decided to take over the company in 1933. Nearly five hundred job cuts followed, and shops were closed whenever possible.[27]

One by-product of the joint ownership of the SP&S, identified by an Interstate Commerce Commission (ICC) study in 1933, was that the company did "comparatively little local business between Spokane and Portland, though it is the short and direct line between these cities." Instead, the study found, "its principal revenue is derived from through freight traffic furnished by the Great Northern Railway Company and the Northern Pacific Railway Company."[28] Consequently, the SP&S contributed more to the growth of established cities at major transportation hubs, such as Vancouver, Spokane, and the Tri-Cities (Kennewick, Pasco, and Richland), rather than smaller towns along the route. While smaller communities certainly benefited from the line, whether through spurs that served grain elevators and lumber industries or passenger service at depots and whistle-stops, many small towns along the north bank, such as Stevenson, White Salmon, Carson, Paterson, and Wallula, experienced modest growth at best.[29]

The Depression left its mark on the SP&S in more ways than one. To counteract the worst effects of the economic downswing, the Roosevelt administration sponsored massive public works programs and projects to provide employment and develop economic infrastructure. One such project, construction of the Bonneville Dam on the Columbia River, established the federal government as a major power producer in the region and reshaped the electric-utility industry in the Pacific Northwest. In addition to generating some freight business from the construction, the dam project required slightly shifting and raising a section of the railroad between mileposts 45 and 51 near Hamilton Creek.[30]

In 1936, despite the ongoing depression, the SP&S experienced an upswing in business, and its operating management decided to purchase nine new locomotives. That these were the first new locomotives placed in service in twenty-four years testified to the tendency of the GN and NP to provide the SP&S with outdated equipment.[31] The onset of World War II coincided with the first integration of diesel locomotives in the SP&S fleet, which was typical of the larger railroad industry.[32] Although conversion to diesel took about ten years, the move improved profitability, which combined with a dramatic increase in rail traffic brought by the war,

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[26] Gaetner, *North Bank Road*, 21–29, 42.
[27] Gaetner, *North Bank Road,* 44–47.
[28] Charles Luttrell, "A Cultural Resources Survey for Washington State Parks between Ice Harbor Dam and Snake River Junction, Franklin County, Washington," 1997, 10, submitted to Washington State Parks. Document available at the Department of Archaeology and Historic Preservation (DAHP), Olympia, Washington.
[29] US Bureau of the Census, *Fifteenth Census of the United States: 1930: Population*, Vol. 1 (Washington, DC: GPO, 1931), 1152.
[30] "Dam Bids Asked," *Oregonian*, May 18, 1934.
[31] Gaetner, *North Bank Road,* 49.
[32] Solomon, *Burlington Northern Santa Fe*, 50.

resulted in several good years for the SP&S.[33] During the war, the SP&S found labor so scarce that the company took the unusual step of hiring workers of Japanese descent and from Mexico.[34]

Another by-product of the war was an unprecedented demand for electricity.[35] Hydroelectric facilities in the Pacific Northwest generated electricity to power aluminum manufacturing, production of plutonium at Hanford, and other wartime industries. After the war, as demand continued to rise, the federal government planned to add generating capacity with several new dams on the Columbia River. The first project, McNary Dam, which was approved in 1948, required the relocation of 34.5 miles of SP&S tracks and the replacement of four bridges between Plymouth and Pasco, from milepost 188.5 to 223.[36] This was due to the rise in the water levels. Charged with the design, construction, and operation of the federal Columbia River dams, the US Army Corps of Engineers oversaw the line's realignment and the design and construction of the new bridges.[37] In 1958, six years after completion of McNary Dam, work began on the John Day hydroelectric project, which due to water rise caused the relocation of a 70-mile section of the SP&S, from milepost 108.5 to 188.5. As part of the project, the Corps replaced several bridges, and the SP&S installed continuous-welded rails, a relatively new technology intended to provide a smoother and quieter ride. Although the company had already experimented with continuous-welded rails in smaller sections, the railroad and Corps celebrated the completion of the new rail project—according to an SP&S executive "the longest new stretch of it found anywhere in the country."[38]

By virtue of its relationship with the GN and NP, the SP&S was at the forefront of two major developments in the postwar railroad industry: the merger movement and the decline of nationwide private passenger service. In 1956, discussions began among the SP&S, GN, NP, and Chicago, Burlington, and Quincy about a merger, later referred to as the "North Lines" merger.[39] Other rail companies, such as the Pennsylvania Railroad and New York Central, were doing the same. In 1964, an ICC examiner initially approved the North Lines merger, but objections by the US Justice Department; the Chicago, Milwaukee, St. Paul & Pacific Railroad Company (Milwaukee Road); State of Washington; and other states led to additional hearings on the matter. Washington state officials wanted more time to analyze the deal and expressed concern that "it would stifle competition and put some 1,284 men out of work with an annual loss of income for those men of $8 million."[40]

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[33] Gaetner, *North Bank Road*, 50–51
[34] Gaetner, *North Bank Road*, 59.
[35] US Energy Information Administration, *The Changing Structure of the Power Industry* (Washington, DC: US Department of Energy, 1996), 107.
[36] Gaetner, *North Bank Road*, 71.
[37] "Army to Pay for Most of New Track," *Seattle Times*, November 10, 1949, 11.
[38] "New Track Promises Quieter Train Rides," *Oregonian*, May 17, 1967, 19.
[39] Solomon, *Burlington Northern and Santa Fe*, 118.
[40] "Olympia Asks for Time to Complete Rail Case," *Oregonian*, September 11, 1964.

On April 27, 1966, the same day the ICC approved the Pennsylvania Railroad and New York Central merger—which was expected to save companies $80 million annually—rejected the Northern Lines merger by a 6-to-5 vote. Calling it the "first merger turned down in modern rail history," one newspaper reported the decision was "based solely on presumption that competition would suffer if the five-way merger went through." The examiners concluded that smaller lines like the Milwaukee Road would be "no match" for the new merger.[41] After revising their application to address ICC concerns, the Northern Lines merger was approved in 1967 but again delayed, this time by the Justice Department which "brought suit to block merger on the ground that the ICC had not shown that advantages of the merger outweighed anticompetitive effects."[42] The Justice Department finally allowed the merger to proceed in 1970, which created the Burlington Northern Railroad Company (BN). In contrast to the Pennsylvania Railroad and New York Central merger, which filed for bankruptcy two years after its creation (at the time the largest corporate bankruptcy in US history), the BN, later the Burlington Northern and Santa Fe Railroad Company (BNSF), succeeded and continues to use the original SP&S tracks from Portland to the Tri-Cities for freight service.[43]

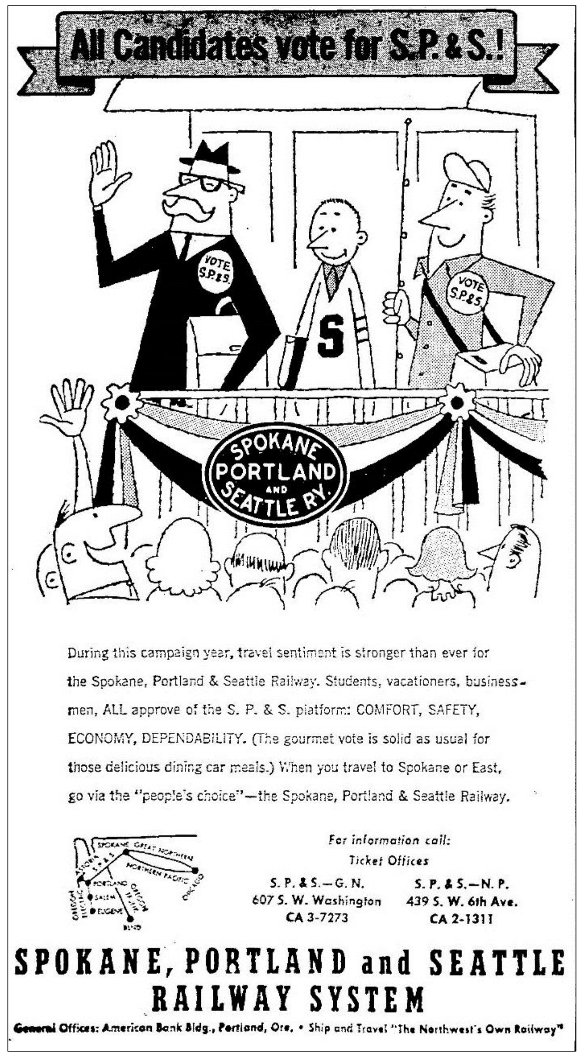

Figure 3. 1960 SP&S newspaper advertisement promoting its passenger service.
Source: *Oregonian*, August 9, 1960.

At the same time railroad executives were pursuing mergers, the profitability of passenger rail service was declining dramatically in the United States. By 1970, eroded by airlines and personal vehicles, passenger service totaled only 7 percent of railroad traffic. The railroads sought to drop the unprofitable sector of their business through various means, including neglect and limited service. In 1970, Congress formed the National Railroad Passenger Corporation, Amtrak, which took over passenger service on a nationwide basis in 1971.[44] Although the SP&S had run ads through the 1960s to boost passenger traffic, over sixty years of moving people along the north bank from Vancouver to points east ended with the BN merger and the creation of Amtrak.

Ultimately, the SP&S's legacy may be best represented by its physical remnant, a well-engineered railroad. One historian of the SP&S concluded that "in spite of the SP&S's slow start in the early twentieth century, and despite the massive debt incurred during the railroad's initial construction, the care taken at that time had a marked

[41] "Pennsy-Central Merger Okayed," *Evening Star*, April 27, 1966.
[42] "High Court Upholds North Lines Merger," *Omaha World-Herald*, February 2, 1970.
[43] US Congressional Budget Office, *The Past and Future of U.S. Passenger Service* (Washington, DC: GPO, 2003), 8.
[44] US Congressional Budget Office, *Past and Future of U.S. Passenger Service,* 6–8.

effect on the SP&S's operating ratio and was especially important after 1940 when traffic density increased dramatically."[45] The BNSF continues to benefit from James J. Hill's commitment to constructing the "best new road that was ever built in the United States," as part of his strategy to compete in the railroad wars of the early twentieth century.

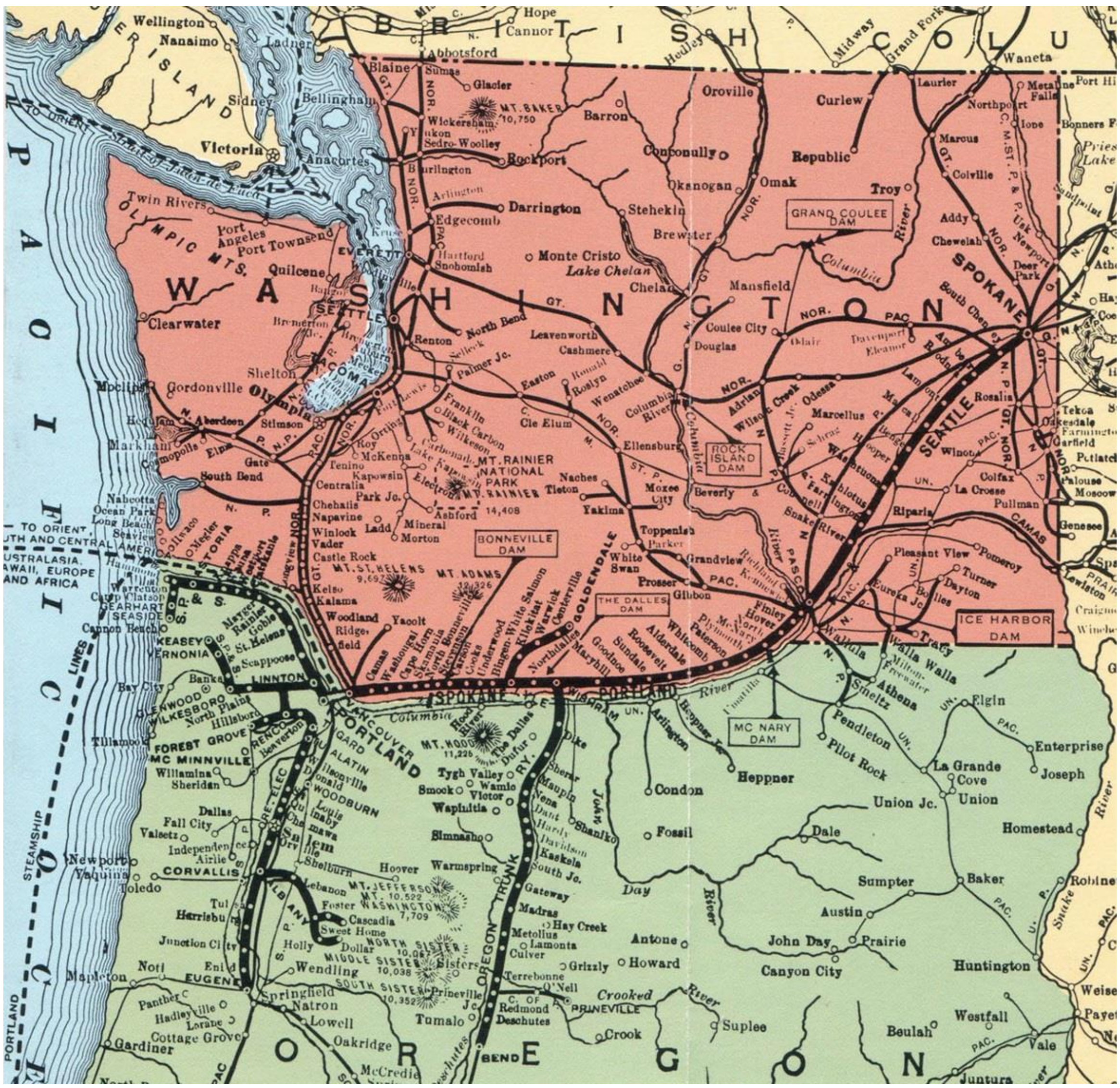

Figure 4. 1953 SP&S route map showing main line and stops between Portland and Spokane, and branch lines to Goldendale, WA and in Oregon.

[45] Gaetner, *North Bank Road*, 86.

E2. Railroad Bridges and Bridge Engineering in the Era of the SP&S

In completing its line along the north bank of the Columbia River and northeast to Spokane, the SP&S faced a problem that most railway companies with western networks encountered: the need for many bridges. By 1914, the SP&S had built 105 bridges of various types on the section between Portland and Spokane, from simple timber stringers to a cutting-edge, reinforced-concrete arch, one of the longest in the western United States when completed in 1907. The early SP&S bridges represented several aspects of the history of railroad bridges. With examples built from wood, metal, and concrete, the SP&S bridges also illustrate developments in materials and railroad bridge design over a span of some fifty years. Along the line are bridge types that are both generally rare or no longer built, such as the timber trestle and pin-connected truss, and types that remain standard selections for bridges of the twenty-first century, such as the prestressed concrete girder. Some SP&S bridges were designed in house by unnamed staff, others by one of the most renowned bridge engineers of his day, Ralph Modjeski.[46]

This historic context for the SP&S bridges is divided thematically by material, which roughly corresponds to a chronology of bridge engineering that moved from designs based on wood to metal to concrete. Use of all three materials overlapped during the SP&S era, but steel and concrete came to dominate railroad bridge construction by the end of the twentieth century. The context that follows is intended to provide a brief introduction solely to bridge types built by the SP&S rather than a comprehensive discussion of all bridge types built by railroad companies.

E2.1 Wood— Timber Trestle

Wood or timber trestles played an important role in the first hundred years of railway construction in the United States. During the nineteenth and early twentieth centuries, railroads in the United States primarily built two types of trestles: *pile* and *framed*. In the *pile trestle*, bents consist exclusively of piles and a cap, whereas in the *framed trestle*, the timbers composing the bents are squared and framed together, often resting on a pile foundation. As one historian of the railway industry found, trestles often factored in the evaluation of trade-offs between alignment, acceptable grade, and costs: “in many cases, the railroad company was willing to accept a longer route with heavier grades in order to avoid bridging; in others, they built wooden trestles rather than costly iron bridges.”[47]

Simple to build and ubiquitous, trestles were constructed in large numbers to support the westward movement of the US railroad industry. As Mark Aldrich points out in his study of the American railroad industry, whereas British railroad builders “turned from stone to iron bridge construction in the 1840s, in the United States, with wood cheap, familiar, and easy to work with, the early bridges were nearly all wooden trestles or Howe trusses.”[48] In 1887, prominent civil engineer Arthur Wellington called the wooden trestle “emphatically an American Institution,” noting that “few of the roads . . . west of Ohio use anything but wooden trestles for their structures in first

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[46] Reuben Hull, “Modjeski Hailed as World’s Leading Bridge Builder,” February 3, 2016, http://news.asce.org/modjeski-hailed-as-worlds-leading-bridge-builder/.
[47] Anthony J. Bianoulli, *Trains and Technology: The American Railroad in the Nineteenth Century*, Vol. 4 (Dover: University of Delaware Press, 2001), 68.
[48] Mark Aldrich, *Death Rode the Rails: American Railroad Accidents and Safety, 1828–1965* (Baltimore, MD: Johns Hopkins University Press, 2008), 148.

construction."[49] Timber trestles continued to fill a distinctive and important role in American railroads in the first decades of the twentieth century. In his 1913 treatise on wood trestles, bridge engineer Walcott Foster observed that "the great extent to which timber trestling has been adopted in this country is one of the principal factors in the economy of construction and rapidity of completion which have been characteristic of American railway work. The use of such temporary structures has been justified by the necessity of keeping the first cost of long lines as low as possible, and by the importance of putting the companies in a position to earn money by carrying freight as soon as possible."[50] By the mid-1930s, the use of timber for trestles was in decline both as concrete and other materials were becoming more viable substitutes and as fewer new railroad lines were being built.[51]

Two factors led to the extensive use of timber trestles during the initial construction of the SP&S railway. First, where the alignment followed uneven ground along the Columbia River and through the scablands of eastern Washington, many sections required long trestle spans across water and gaps to maintain the grade and curvature standards set by Hill for the line. Second, because of the need to open the line to traffic as soon as possible, trestles, which could be erected quickly, were used as a temporary solution to be followed by either a more permanent structures or fill at a later date. The SP&S kept records of trestle construction, noting the type and length of trestle, number of bents, height, depth of ground penetration, and estimation of safe loading. Trestle 589, for example, forming an approach to the east end of the Wind River Bridge, was 1,008 ft long with an average height of 53 ft, and piling penetrations ranging from 16 to 24 ft. The bridge engineer noted that "this trestle is across the former booming grounds of the Wind River Lumber Company. This trestle is menaced in the same manner as is the one at Washougal River and it should be filled at once so as to protect piling and bracing."[52] Trestle 589, partially shown in the photograph below, appeared to follow the standard GN design for a pile trestle over 19 ft high.[53]

Figure 5. Eastbound #2 crossing temporary bridge over Wind River, just west of Home Valley, ca. 1908.
Source: "Golden Spike Ceremony," *Dope Bucket* 20 (1958): 5.

[49] Quoted in Aldrich, *Death Rode the Rails*, 148.
[50] Wolcott C. Foster, *A Treatise on Wooden Trestle Bridges* (New York: Wiley & Sons, 1913), 4.
[51] Michael A. Ritter, "Timber Bridges: Design, Construction, Inspection, and Maintenance," 1990, 1-17, 2-13, US Forest Service, http://www.fpl.fs.fed.us/documnts/misc/em7700_8--entire-publication.pdf.
[52] W. C. Taylor, "Progress Reports for the Period between November 15, 1908, to February 5, 1910," January 1909, 4, Subject Files, 1871–1970, Minnesota Historical Society (MHS), Minneapolis, Minnesota.
[53] "Great Northern Standard Trestles," *Railroad Gazette* 34 (August 8, 1902): 618.

Later in 1913 when the SP&S replaced the section of trestle over the Wind River (between the concrete abutments shown in Figure 4) with a steel-truss bridge, a framed trestle on a pile foundation was built to temporarily provide an approach to the bridge.

Figure 6. Close up of frame on pile trestle, Wind River Bridge, 1913.
Source: Oregon Historical Society (OHS).

Other substantial trestles included one near the Little White Salmon River, 1,246 ft long consisting of 89 bents with a height ranging from 28 to 41 ft and penetrations ranging from 35 to 40 ft; and Trestle 789, 2,422 ft long consisting of 175 bents with minimum safe loading of 8.3 tons and a maximum of 43.9 tons per pile. The SP&S trestles typically used a spacing of approximately 14 ft between bents. Many of the original wooden trestles along the SP&S line are no longer visible, largely due to a thorough program of filling in gaps spanned by trestles. Between 1913 and 1914 alone, SP&S crews filled in 31,866 ft of trestles.[54] One "exceptionally large trestle fill" at Sprague Gulch even attracted coverage in *Popular Mechanics*. Built in 1907 with an average height of 75 ft and a length of 4,869 ft, the Sprague Gulch trestle required construction of an auxiliary trestle to support a small "dirt train" used to dump initial loads.[55]

[54] Office of the Chief Engineer, "Statement of Expenditures for Permanent Improvement Work on the S.P. & S. Ry. from November 1, 1912, to June 30, 1914," Subject Files, 1871–1970, MHS.
[55] "Exceptionally Large Trestle Fill," *Popular Mechanics* (March 1912): 327.

Figure 7. Trestle, looking east, 1 mile north of Lyle.
Source: OHS.

Figure 8. typical SP&S trestle, ca.1908. Unknown location.
Source: Minnesota Historical Society (MHS).

Figure 9. Sprague Gulch trestle, ca. 1908.
Source: MHS.

Figure 10. A pile driver work on a trestle during the construction of the SP&S.
Source: SP&S 700 Pacific Railroad Preservation Association.

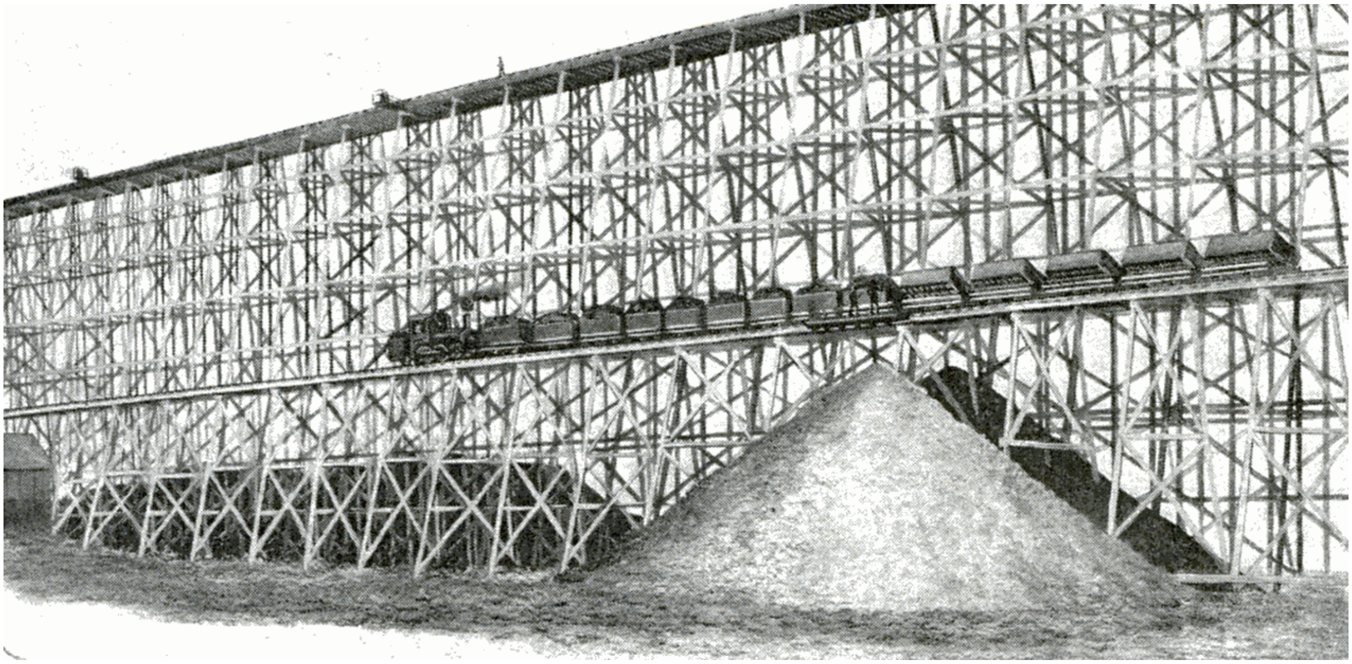

Figure 11. "At Work on First Lift, in Filling the Railroad Trestle across Sprague Gulch, Wash" (1912).
Source: "Exceptionally Large Trestle Fill," *Popular Mechanics*, 54.

E2.2 Steel

The development of railroads, bridge design, and the iron and steel industries were closely intertwined in the United States, and technological breakthroughs in one area often shaped the course of another. The introduction of the steam locomotive and iron railroad tracks in the 1830s, for example, required new bridges to handle the increased loads generated by trains' weight and movement. Bridge designers turned to trusses as the starting point for shorter span bridges, and men like William Howe (1840), Squire Whipple (1841), and James Warren (1848) submitted patent applications for designs that still bear their names. At the same time, metallurgists and foundries worked to better meet the demand for metal rails and other structural products. Innovation and incorporation of metal structural components became the hallmarks of early bridges specifically designed to handle railroad traffic. Some notable examples include James Millholland's "tubular" iron plate girder bridge for the Baltimore and Susquehanna Railway Company in 1846, Wendel Bollman's patent for the first all-metal bridge in 1852, John Roebling's suspension bridge across the Niagara River in 1855, and the Eads Bridge (a combined vehicular and railway bridge) across the Mississippi River in 1874—the first bridge in the United States built with an entirely steel superstructure.

Early metal bridges in the United States were built with either cast or wrought iron as steel was expensive and difficult to manufacture. Both had advantages, but cast iron's brittle character and wrought iron's malleability made them both less than ideal as structural elements in certain applications. In fact many of these early iron bridges failed, some with disastrous consequences. According to one account, fatigue in cast-iron structural elements had caused some 25 percent of the bridges in the American railroad inventory to fail between 1875 and 1888.[56] In one of the most horrific of these failures, ninety-two people died when a cast-iron Howe deck truss over the Ashtabula River collapsed in 1876. The tragedy spurred engineers and governmental agencies to find solutions to problematic past practices. Investigations into the epidemic of bridge failures found a lack of consistent specifications for design and materials, of sufficient knowledge of fatigue and stress, of regular inspections, and of testing.[57]

Another contributor to the problem was the nature of the railroad- and bridge-building industries in the mid-nineteenth century. Faced with the high cost of capital and cutthroat competition, many railroads built quickly, inexpensively, and sometimes shoddily. The many bridge companies established to meet demand also operated under these conditions, exacerbated by the high cost of skilled labor in America compared to Europe. In the mid-nineteenth century, railroad companies typically contracted with bridge companies by linear foot. Bridge design under this arrangement rested in the hands of the bridge companies, which often were formed to market and build a certain patented type.[58] This practice resulted in not only inadequate communication between railroads and bridge engineers on specific design conditions but also a temptation within bridge-company managers to economize cost or extend a specific design past its best application.[59] Although efforts to pass regulations or develop standardized specifications proved difficult, the practice of bridge design and manufacturing began to change in the wake of the Ashtabula River bridge disaster. A new generation of consulting engineers emerged as specialists, some with experience as railroad staff engineers that worked on a per-project basis.[60] Notable designers included Octave Chanute, George S. Morison, Alfred Boller, Charles C. Schneider, Theodore Cooper, and Ralph Modjeski. Railroads moved away from linear-feet contracts and toward in-house engineering departments for most bridges, developing specifications for bridge manufacturers to use. At the same time, work moved forward on a promising alternative to cast iron: steel.[61]

The most successful of the initial efforts to improve steel production—the Bessemer process, developed in the 1850s—proved useful for rails and some other items, but a lack of tensile strength made Bessemer steel poorly suited for structural applications. Only after the development of the open-hearth method of steelmaking in the 1880s did steel emerge as a viable replacement for iron in bridge design.[62]

The introduction of steel did not dramatically alter the existing forms of bridge design—bridge builders merely used steel in place of iron in plate girder and truss designs. As bridge engineers and steel producers gained greater familiarity working with and manufacturing steel and steel alloys, some efforts were made by individual railway companies and railway engineering associations to standardize railroad bridge designs in ways that maximized steel's structural properties.[63] Another factor behind the standardization movement was

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[56] John F. Unsworth, *Design of Modern Steel Railway Bridges* (Boca Raton, FL: CRC Press, 2010), 19.
[57] Unsworth, *Design of Modern Steel Railway Bridges*, 34–35.
[58] Llewellyn Nathaniel Edwards, *A Record of History and Evolution of Early American Bridges* (Orono, ME: University Press, 1959), 99.
[59] Aldrich, *Death Rode the Rails,* 135, 139.
[60] Edwin T. Layton, Jr., *The Revolt of the Engineers: Social Responsibility and the American Engineering Profession* (Cleveland, OH: Press of Case Western Reserve University, 1971), 10–25.
[61] Aldrich, *Death Rode the Rails,* 144.
[62] Thomas Misa, *A Nation of Steel: The Making of Modern America, 1865–1925* (Baltimore, MD: Johns Hopkins University Press, 1995), 75.
[63] Mansfeld Merriman and Henry Sylvester Jacoby, *A Text-book on Roofs and Bridges* (New York: Wiley & Sons, 1912), 192.

the increasing weight and speeds of the freight and passenger trains: adopting heavier rolling stock often necessitated the replacement of a large percentage of bridges along certain routes.[64]

The Northern Pacific (NP) Railroad provides one case study of the standardization effort. The company's initial attempt in the early 1890s to produce an in-house set of standard plans was suspended when the weight of rolling stock again increased, rendering the plans already obsolete.[65] At this point, the company turned to two of America's most prominent bridge engineers, George Morison and Ralph Modjeski, for a new standardized design.

Morison began his career as an apprentice to Octave Chanute on construction of the first railroad bridge across the Missouri River in 1867. Over the next three decades, Morison's work on railroad bridges made him one of the best-known bridge engineers of his generation.[66] Morison hired Modjeski in 1885. Modjeski had emigrated from Poland to the United States after obtaining a degree in engineering from the prestigious École Nationale des Ponts et Chaussées and built a distinguished career as bridge designer and consultant. Modjeski was a versatile designer, producing landmark designs for both truss (Rock Island and Quebec) and suspension bridges (Mid-Hudson, Benjamin Franklin, and San Francisco Bay).[67] The work on a standardized bridge design for NP between 1899 and 1901 was likely one of the last collaborations between the two engineers, as Morison died in 1903 after a brief illness.

Morison worked on two early NP railroad bridges in Washington, the Ainsworth Bridge and the Riparia Bridge—both across the Snake River—which were completed in 1884 and 1889, respectively. Only remnants of the Riparia Bridge piers remain.[68] Modjeski's legacy has been more lasting in the Pacific Northwest, including several notable bridges designed for the SP&S: the Columbia River Bridge linking Vancouver and Portland (1908) the first bridge of any kind to be built across the lower Columbia River; Celilo Bridge (1912) across the Columbia River near The Dalles; and Willamette River Bridge (1908) in Portland, Oregon, which incorporated the longest swing-span section in the world.

Morison let the younger Modjeski take the lead in the NP designs.[69] Between 1900 and 1902, Modjeski produced drawings for I-beam spans from 10 to 30 ft, deck plate girders from 25 to 100, through plate girders from 30 to 100 ft, deck lattice and pony lattice spans for 110 and 120 ft, and deck and through pin-connected truss spans from 130 to 200 ft. The bridge types associated with the distance of each span generally conformed to an industrial standard.[70] Modjeski's standardized plans would serve as the basis for the design of the SP&S steel bridges, including pin-connected trusses, I-beam, and deck plate girder bridges.

Modjeski presented the plans in a meeting of the Society of Western Engineers and defended various aspects of his designs during the discussion period, particularly the choice of a roller-type expansion bearing at one

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[64] Edward Godfrey, "Railroad Bridge Design in Europe and America Compared," *Journal of the Western Society of Engineers* 18 (March 1913): 200; and Ralph Modjeski, "Northern Pacific Railroad Standard Bridge Plans," *Journal of the Western Society of Engineers* 6 (January–December 1901): 51.
[65] Modjeski, "Northern Pacific Railroad Standard Bridge Plans," 51.
[66] Frank Griggs, Jr., "George S. Morison," *Structure Magazine* (February 2008): 56.
[67] Richard G. Weingardt, *Engineering Legends: Great American Civil Engineers* (Reston, VA: American Society of Civil Engineers, 2005), 60.
[68] Griggs, "George S. Morison," 55.
[69] Modjeski, "Northern Pacific Railroad Standard Bridge Plans," 51–52.
[70] American Railway Engineering Association, *Manual of the American Railway Engineering Association* (Chicago: American Railway Engineering Association, 1921), 744.

end of the truss bridge. When queried about the wisdom of standardized plans given the constant increase in loads, Modjeski stated that his spans could "safely withstand an increase of 50 per cent in loading without undue overstraining of metal, and it will take some time before such an increase rolling stock will take place."[71]

Modjeski's work on standardized bridges for NP coincided with a period of consolidation of heavy industries in the United States. In the late nineteenth century, industrialists and financiers like Andrew Carnegie, John Rockefeller, J. P. Morgan, and James J. Hill endeavored to control various sectors of the American economy with corporate acquisitions, mergers, and consolidations. One product of these efforts was the American Bridge Company, which J. P. Morgan formed from twenty-seven existing bridge companies in 1900. The original American Bridge Company had first been established in 1870 in Chicago and reorganized as the American Bridge Works in 1891 before being incorporated into Morgan's new company, which when formed commanded more than 90 percent of the US bridge construction market.[72] The American Bridge Company was folded into the United States Steel Corporation after its formation in 1901, and a major new bridge manufacturing plant was built in Pittsburgh. Over the course of the century, the American Bridge Company conglomerate, was associated with the design and construction of many large-scale bridge projects as well as the construction of iconic buildings nationwide, including the Chrysler Building (1929) and Empire State Building (1931) in New York City, the San Francisco–Oakland Bay Bridge (1932), and the Boeing 747 manufacturing plant in Everett (1968). The company constructed fourteen bridges over the Columbia River and its tributaries, and as a part of the United States Steel Corporation (from 1901–87), had roles in establishing railroads throughout the country and abroad.[73]

Although steel continued as the primary material of choice for beam, plate girder, and truss bridges for several decades, the introduction of prestressed concrete in the 1950s gave railroads a new option for bridging spans with relatively standardized components. By the early 1990s, 50 percent of bridges built in the United States were prestressed concrete types.[74] In response to the challenge posed by concrete, developments in high-strength steel, connections (friction-grip bolts), and welding helped make steel plate girders and box girders competitive for shorter spans.[75] As one bridge historian concludes, the steel plate girder and box girder types "share many of the advantages of their concrete counterparts: they are lightweight, simple, easily analyzed and rapidly erected."[76]

The I-beam, deck plate girder, Pratt truss, and steel tower viaduct types comprise the bulk of the steel bridges built on the original SP&S line. The subsections below provide a brief context for the evaluation of each of the SP&S steel bridge types.

E2.2.1 I Beam

The introduction of I-beam bridges resulted from developments in rolling mill technology in the second half of the nineteenth century. After Peter and Edward Cooper and Abram Hewitt opened a mill to roll beams and girders from wrought iron in 1847, an I-beam shape was quickly adopted as a structural component in

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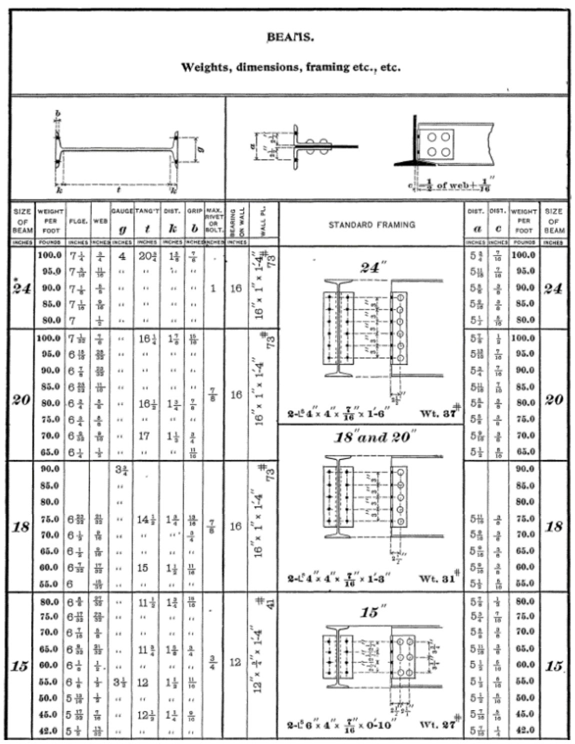
[71] Modjeski, "Northern Pacific Railroad Standard Bridge Plans," 65.
[72] J. Seymour Currey, *Chicago: Its History and Its Builders* (Chicago: S. J. Clarke, 1918), 16.
[73] American Bridge Company, "Timeline," accessed April 1, 2011, http://www.americanbridge.net/AboutUs/timeline.php.
[74] Transportation Research Board, "Concrete Bridges," 7, http://www.trb.org/BridgesOtherStructures/TRBCommittees.aspx
[75] Jonathan Clarke, "Material Concerns in the Pacific Northwest: Steel versus Reinforced Concrete in Highway Bridge Design in Washington State, 1910–1930," *Construction History* 16 (2000): 55.
[76] Clarke, "Material Concerns in the Pacific Northwest," 55.

"fireproof" building construction.[77] As other rolling mills took up I-beam production and steelmaking became more cost effective, railroad companies began to use the steel I beam for short bridge spans in the late nineteenth century. As early as 1879, Octave Chanute, chief engineer of the New York, Lake Erie & Western Railroad Company, published specifications for rolled beams for bridges up to 17 ft long.[78]

A 1914 SP&S bridge schedule shows a relatively small number of I-beam bridges on the line for spans that ranged from 13 ft to 27 ft long.[79] These bridges used I beams of standardized specification, typically called out by a combination of height and weight per pound as shown in the beam chart for the American Bridge Company below. The smaller 13 ft bridge employed eight 12-inch (in) tall, 40 lb (40 lbs per foot) I beams. If ordered from the American Bridge Company, the corresponding beam had a 5¼ in flange and 7/16 in thick web. Similarly, the longer 27 ft bridge used eight 24 in tall, 100 lb beams, which by American Bridge Company standards had a 7¼ in flange and a ¾ in thick web.[80] The I beams were connected with steel bolts and separators and bolted directly to concrete abutments with angle irons.



SIZE OF BEAM (inches)	WEIGHT PER FOOT (pounds)	FLGE. (inches)	WEB (inches)	GAUGE g (inches)	TANG'T t (inches)	DIST. k (inches)	GRIP b (inches)	MAX. RIVET OR BOLT (inches)	BEARING ON WALL (inches)	WALL PL.	DIST. a (inches)	DIST. c (inches)	WEIGHT PER FOOT (pounds)	SIZE OF BEAM (inches)
24*	100.0	7 1/4	3/4	4	20 3/4	1 5/8	7/8			16"×1"×1'-4" #73	5 3/4	7/16	100.0	24
	95.0	7 3/16	11/16	"	"	"	"				5 11/16	7/16	95.0	
	90.0	7 1/8	5/8	"	"	"	"	1	16		5 5/8	3/8	90.0	
	85.0	7 1/16	9/16	"	"	"	"				5 9/16	3/8	85.0	
	80.0	7	1/2	"	"	"	"				5 1/2	5/16	80.0	
20	100.0	7 1/32	7/8	"	16 1/4	1 7/8	15/16			16"×1"×1'-4" #73	5 7/8	1/2	100.0	20
	95.0	6 15/16	25/32	"	"	"	"				5 13/16	7/16	95.0	
	90.0	6 7/8	23/32	"	"	"	"				5 3/4	7/16	90.0	
	85.0	6 25/32	11/16	"	"	"	"				5 11/16	7/16	85.0	
	80.0	6 3/4	5/8	"	16 1/2	1 3/4	7/8	7/8	16		5 5/8	3/8	80.0	
	75.0	6 3/4	5/8	"	"	"	"				5 5/8	3/8	75.0	
	70.0	6 5/32	9/16	"	17	1 1/2	3/4				5 9/16	3/8	70.0	
	65.0	6 1/4	1/2	"	"	"	11/16				5 1/2	5/16	65.0	
18	90.0			3 3/4						16"×1"×1'-4" #73			90.0	18
	85.0			"									85.0	
	80.0			"									80.0	
	75.0	6 23/32	21/32	"	14 1/2	1 3/4	13/16	7/8	16		5 11/16	3/8	75.0	
	70.0	6 1/2	9/16	"	"	"	3/4				5 9/16	3/8	70.0	
	65.0	6 1/2	9/16	"	"	"	"				5 9/16	3/8	65.0	
	60.0	6 7/32	17/32	"	15	1 1/2	11/16				5 9/16	3/8	60.0	
	55.0	6	15/32	"	"	"	"				5 1/2	5/16	55.0	
15	80.0	6 5/8	27/32	"	11 1/2	1 3/4	15/16			12"×3/4"×1'-4" #41	5 7/8	1/2	80.0	15
	75.0	6 17/32	23/32	"	"	"	"				5 3/4	7/16	75.0	
	70.0	6 7/16	5/8	"	"	"	"				5 5/8	3/8	70.0	
	65.0	6 9/32	21/32	"	11 3/4	1 5/8	3/4				5 11/16	3/8	65.0	
	60.0	6 1/8	1/2	"	"	"	"	3/4	12		5 1/2	5/16	60.0	
	55.0	6 1/8	1/2	3 1/2	12	1 1/2	11/16				5 1/2	5/16	55.0	
	50.0	5 13/16	1/2	"	"	"	"				5 1/2	5/16	50.0	
	45.0	5 17/32	7/16	"	12 1/2	1 1/4	9/16				5 7/16	5/16	45.0	
	42.0	5 1/2	13/32	"	"	"	"				5 7/16	1/4	42.0	

Figure 12. Beams—weights, dimensions, framing.
Source: American Bridge Company, *Standards for Structural Details* (1901).

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[77] Charles E. Peterson, "Inventing the I-Beam: Richard Turner, Cooper & Hewitt and Others," *Bulletin of the Association for Preservation Technology* 12 (1980): 13.
[78] "Historical Sketch of the Development of American Bridge Specifications," *Proceedings of the American Railway Engineering and Maintenance of Way Association* 6 (1905): 212.
[79] "SP&S Bridge Schedule: Portland to Spokane," March 1914, 1–12, Great Northern Railway Company (U.S.). President, files, MHS.
[80] American Bridge Company, *Standards for Structural Details* (Pencoya, PA: American Bridge Company, 1901), 1; and "SP&S Bridge Schedule," 4, 7.

While the I-beam dimensions varied little among manufacturers, railroad companies differed in the number and size of the beams specified for various spans. The Atchison, Topeka & Santa Fe Railway Company, for example, used four 15 in 50 lb I beams for a 12 ft span (compared to eight 12 in 40 lb beams for the 13 ft SP&S span noted above); six 80 lb I beams for 24 ft spans (compared to eight 24 in 100 lb beams for the 27 ft SP&S span), and ten 24 in, 90 lb I beams for 34 ft spans on their lines in the early twentieth century. The I-beam spans had end plates riveted to angle brackets on webs of beams and intermediate diaphragm plates fitted between webs as braces or stiffeners.[81] Overall design was governed by loading, and other engineering calculations, but generally followed rules of thumb for spacing between beams, bracing, and connections.[82]

E2.2.2 Plate Girder

James Millholland is credited with the design of first plate girder bridge in the United States in 1847. His tubular design for the Baltimore & Susquehanna Railway Company was composed of iron boiler plates riveted together and cross braced with timbers. Millholland's bridge originally supported a single track but was reconstructed for double-track operation in 1864 and continued in service until 1882.[83]

Early versions of the plate girder bridge were built with iron until replaced by steel in the mid-1880s.[84] The plate girder type proved popular for its simplicity, ease of construction, and durability. As one bridge engineer explained, plate girders "are very solid and rigid, easily erected, economically manufactured, and never require adjustment after completion." Disadvantages, however, included a perception that such bridges were "sometimes unsightly, sometimes involved objectionable rivets, and when the spans are very long require special plant for riveting and handling them, are likely to be difficult to ship."[85]

According to one contemporary, in 1915 the American bridge industry typically used plate girder bridges for spans 20 to 100 ft long and almost exclusively for spans 30 to 60 ft long. The NP's standard plans for deck plate girder bridges fit within these larger patterns, with specifications 60 ft and 100 ft deck plate and through girder types that could be modified for other lengths.[86] The original SP&S plate girders were based on Modjeski's NP plans ranged from 17 to 75 ft long, the bulk of which were lengths of 35, 45, 50, 70, and 75 ft. A few through plate and deck plate girders were added later, largely due to dam construction projects that resulted in relocations of the line.[87]

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[81] "Standard Plans for Bridges on the Atchison Topeka & Santa Fe Ry.," *Engineering News* 49 (May 28, 1903): 483.
[82] John Alexander Low Waddell, *Bridge Engineering*, Vol. 2 (New York: Wiley & Sons, 1916), 1667.
[83] "First Plate Girder in America," *Engineering News* (October 20, 1888): 305. Millholland is sometimes erroneously spelled as Milholland, such as in Christina M. Zweig, "Creating New Bridges," February 19, 2014, http://csengineermag.com/article/creating-new-bridges/.
[84] Frank Woodward Skinner, *Types and Details of Bridge Construction* (New York: McGraw, 1906), 3–4.
[85] Skinner, *Types and Details of Bridge Construction,* 3.
[86] Modjeski, "Northern Pacific Railroad Standard Bridge Plans," 55.
[87] SP&S, "SP&S, Oregon Trunk, Bridge Records," binder on file at the Pacific Northwest Railroad Archive (PNRA), Burien, Washington.

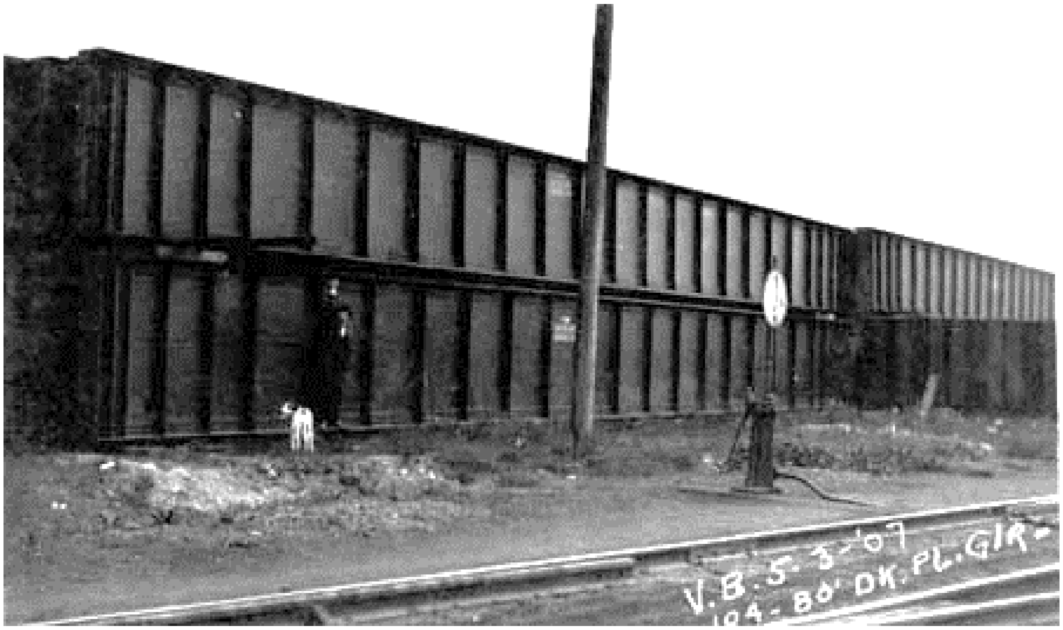

Figure 13. SP&S deck plate girder bridges stacked for future installation, 1907.
Source: Walt Ainsworth Collection, SPSHS.org.

E2.2.3 Truss

Medieval builders used wood trusses to support roofs, which provided the basic models for early bridge applications of trusses in Europe and the United States. In the US, the patent system proved influential in the development of truss and other bridge designs. Ithiel Town, who patented a lattice-type truss in 1820, established the practice of charging licensing fees for use of his design. Later, bridge companies were formed to market and supply bridges based on a particular patent.[88]

While early truss bridges were built with wood, in the United States the introduction of metal structural elements began with experiments in the 1830s. Massachusetts millwright William Howe patented an influential design in 1840 that clearly shows the attention these innovators were paying to joints and connections between structural components:

> Howe arrived at a simple, elegant solution to a problem that had confounded several generations of wooden bridge builders, the solution to joining in tension two wooden members. The classic weakness of a timber truss is not the individual members, but the connections. Tension connections proved particularly difficult to detail to insure minimum joint movement and maximum efficiency in transferring tensile loads to a joint. The genius of the Howe system is that the timber verticals, which pose the most difficult problem in forming an effective connection, were neatly replaced with an iron rod. Eliminating the complex mortise and tenon connection simplified the work of millwrights,

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[88] Parsons Brinckerhoff and Engineering and Industrial Heritage, "A Context for Common Historic Bridge Types," prepared for the National Research Council, October 2005, 3–15, http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/25-25(15)_FR.pdf

resulting in a truss that was not only easy to erect, but could be adjusted and parts replaced while remaining in service.[89]

Howe's truss put timber diagonals in compression and lighter iron rods in tension, exactly the opposite of another patent granted a few years later to Caleb and Thomas Pratt in 1844. The Pratt configuration proved longer lived than the Howe type as it was better suited to take advantage of the better compressive strength of iron (and later steel) compared to wood.[90]

Given the later classification of the Pratt type as a truss characterized by parallel top and bottom chords with bottom chords and diagonals in tension and top chords and vertical posts in compression (except the verticals adjacent to the inclined ends), the actual patentable claim the Pratts presented is often overlooked. The Pratts summarized the import and novelty of their design as "the combination of two diagonal tension braces and straining blocks, in each panel of the truss frame of a bridge; by means of which the camber may be regulated so as to increase or to diminish it, either in whole or in sectional part of the bridge," and envisioned a "longitudinally" curved upper chord as one possible configuration.[91] Like the Howe before it, the Pratt truss reflected the transition from wood to metal components in truss design and a concern for post-construction adjustments of joints. It was designed to be wood except for the diagonal braces "being a metallic rod or bar."[92] The original intent of the design—the ability to adjust the tension in the cross braces—faded, but the Pratt truss gained popularity in slightly modified form (some panels have only a single diagonal brace in tension) when iron and then steel became standard for truss fabrication for its economy of materials and simplicity of construction.[93] Nonetheless, as the design and materials of the truss changed in the years following the original 1844 patent, but the name stuck. Bridge engineers used several different types of structural elements in designing Pratt trusses, including cast-iron, wrought-iron, and later steel channels, tubes, beams, rods, and eyebars, depending on whether the elements were in tension or compression.[94]

Many bridge and railroad companies adopted some variant of the steel Pratt truss with pins used to connect the truss chords and eye-bar bracing for spans between 100 and 250 ft long. One advantage of the pin connection was in the analysis of forces: the pin-connected truss was statically determinate, that is, a structure where the reactions and forces could be determined from equations of static equilibrium, which were well known to engineers of the late nineteenth century. In contrast, riveted connections were statically indeterminate, meaning that engineers could only approximate force distributions. Pin-connected trusses in the United States became known as the "American system" of bridge design, favored for its facility of manufacture, ease of field erection, ability to be transported in pieces, and minimization of field riveting—all characteristics well suited to remote river or gorge crossings in the American west.[95]

Whereas Modjeski and NP chose to standardize on a Pratt design, GN favored the Warren truss. Although named for English patent claimant James Warren, the Warren truss had earlier European and American

[89] Parsons Brinckerhoff and Engineering and Industrial Heritage, "Context for Common Historic Bridge Types."
[90] Frank Griggs, Jr., "The Pratt Truss," Structuremag.org, June 2015, http://www.structuremag.org/?p=8600.
[91] Thomas W. Pratt and Caleb Pratt, "Truss-Frame of Bridges. Patent No. 3523, United States Patent Office, Washington D.C., 1844," 2, http://www.historicbridges.org/info/patents/3523.pdf.
[92] Thomas and Caleb Pratt, "Truss-Frame of Bridges," 1.
[93] Frank Griggs, Jr., "The Pratt Truss."
[94] Waddell, *Bridge Engineering*, 468.
[95] Dario Gasparini and David Simmons, "American Truss Bridge Connections in the 19th Century. II: 1850–1900," *Journal of Performance of Constructed Facilities* 11 (August 1997): 130–32.

antecedents. A benefit of the Warren truss was its simplicity—composed of equilateral triangles, the diagonals take both compressive and tensile loads and are typically the same shape and size, which simplified calculation of stresses, fabrication, and construction. For longer spans, engineers often added vertical posts to help minimize buckling loads in the top chords. Although the earliest forms of the Warren truss had pin connections, such bridges were rare by the late nineteenth century.[96] An early, extant example of a GN Warren truss built in 1887 to span the Minnesota River near Granite Falls, Minnesota, shows the railroad's preference for riveted connections that was continued in a 1907 bridge over Barclay Creek in Snohomish County, Washington, a 1913 bridge over Crow River in Hennepin County, Minnesota, and later Warren trusses built around the country in the 1920s and 1930s.[97]

In the 1920s, American engineers began to favor riveted over pin connections in trusses more generally. The pins, a bridge's most catastrophic point of failure, were difficult to inspect, and the introduction of portable riveting machines lessened the construction costs of riveted designs.[98] As an alternative to rivets and pins, experiments with welded connections led to the construction of the first all-welded through truss, a Warren type, which went into service over a power canal at Chicopee Falls, Massachusetts, for the Boston & Maine Railway Company in 1928. The Westinghouse Electric Company carried out the project to showcase the potential of electric arc welding for bridge construction.[99] Although the project engineers touted a 33 percent reduction in the amount of steel needed for the Chicopee Falls bridge, the US bridge industry as a whole was slow to adopt welded construction.[100] Only after WWII-era industries such as shipbuilding and airplane manufacturing expanded the use of welding on a massive scale did welded bridge construction become popular, especially in the deck plate girder type.[101] Unfortunately, due to insufficient study and testing of fatigue in welded connections, many of the early welded bridges were later found structurally deficient.[102]

The SP&S built its last truss bridge —a Warren deck truss design —on the line between 1931 and 1932 to cross the Oregon-Washington Railroad & Navigation's tracks near Washtucna, Washington. Although many of the truss types that proliferated in the nineteenth century lost favor, the construction of a polygonal Warren through truss for the Chicago, South Shore & South Bend Railroad in 2012 shows that Warren trusses remain viable options for bridge engineers.[103]

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[96] Frank Griggs, Jr., "The Warren Truss," structuremag.org, July 2015, http://www.structuremag.org/?p=8715.
[97] "Great Northern Railway," Bridgehunter.com, accessed October 22, 2016, https://bridgehunter.com/category/railroad/great-northern-railway/page3/.
[98] Brian Solomon, *North American Railroad Bridges* (St. Paul, MN: Voyageur, 2008), 52; and Jon Axline, *Conveniences Sorely Needed: Montana's Historic Highway Bridges, 1860–1956* (Helena: Montana Historical Society Press, 2005), 62.
[99] Jeffrey A. Hess and Robert Hybben, "Historic American Engineering Record, Benton Street Bridge," October 1989, 6, https://cdn.loc.gov/master/pnp/habshaer/ia/ia0100/ia0198/data/ia0198data.pdf.
[100] "First All-Welded Truss Railroad Bridge Is Put in Service," *Railway Age* 84 (March 24, 1928): 664–67.
[101] Hess and Hybben, "Benton Street Bridge," 10.
[102] Hess and Hybben, "Benton Street Bridge," 19.
[103] "South Shore–Torrence Avenue Overpass," bridgehunter.com, accessed November 4, 2016, https://bridgehunter.com/il/cook/bh61321/.

E2.2.4 Steel Tower Viaduct

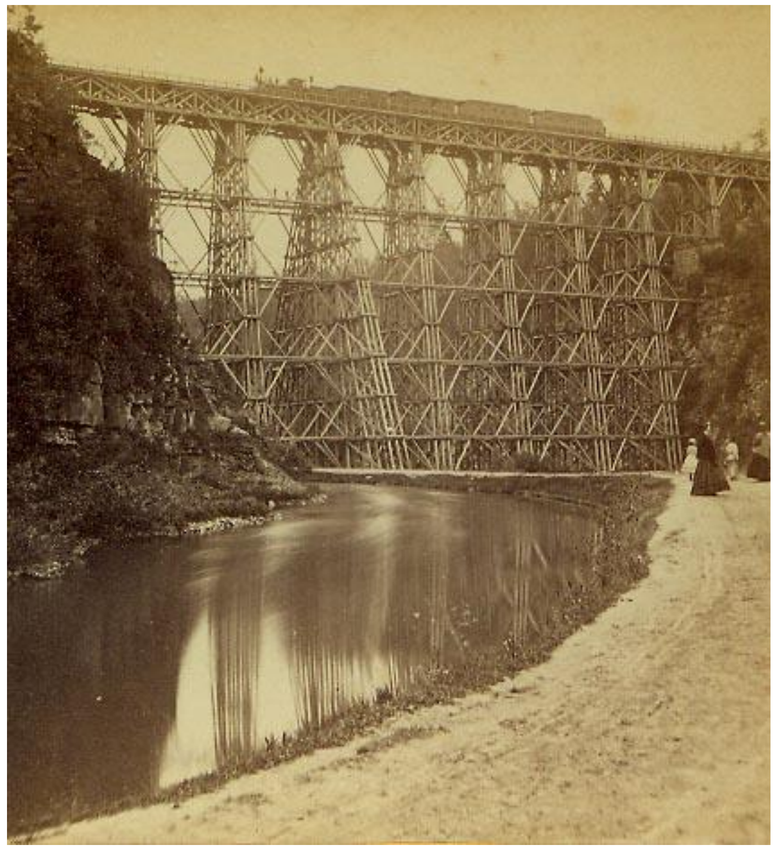

Figure 14. Portage R.R. Bridge, with Passenger Train, c. 1870.
Source: "Portage R.R. Bridge, with Passenger Train,"

Similar to the other steel bridge types, the steel tower viaduct traces its lineage to iron designs of the late nineteenth century. Railroad companies typically turned to metal tower viaducts for bridging long spans at tall heights, either to replace wood trestles or in new construction, resulting in some of the most celebrated and visually impressive railroad bridges of the day. The American Society of Engineers' exhibit at the 1878 Paris World's Fair, for example, included metal tower viaducts at Portage, New York, Harrisburg, Pennsylvania, and two locations near Cincinnati, Ohio.[104] The most common configuration paired metal tower supports with either deck plate girders or trusses, and occasionally a combination of both. The Portage crossing provides an interesting case study in the transition from wood to iron to steel as the weight of rolling stock increased in the late nineteenth century. The initial timber viaduct, called by one contemporary bridge engineer "one of the most remarkable timber viaducts ever erected," was completed in 1852 by the New York & Erie Rail Road. Some 800 ft long and 234 ft high at its peak height, the timber trestle contained over 1.6 million board feet of timber. After its destruction by fire in 1875, bridge engineer George S. Morison, in collaboration with Octave Chanute, designed a new iron bridge consisting of ten 50 ft long, two 100 ft long, and one 118 ft long Pratt deck trusses supported by iron towers.[105] The speed of construction and success of the bridge helped establish the braced four-post tower supporting either plate girder or truss spans as a basis for the most common metal viaduct design, albeit with heavier cross bracing.[106] In 1904, the railroad determined that the wrought-iron structure no longer met traffic and load requirements and replaced the iron trusses with steel deck plate girders and riveted Pratt deck trusses. Because the bridge had originally been designed to handle two tracks, the engineers determined that the existing foundations and towers could be safely retained.[107]

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[104] "American Engineering as Illustrated at the Paris Exposition—American Bridge Building," *Railway World* 23 (June 7, 1879): 532.
[105] "Railway Practice in America," *Scientific American* 62 (March 8, 1890): 152.
[106] Solomon, *North American Railroad Bridges*, 68.
[107] "The New Spans of the Portage Viaduct, Erie R.R.," *Engineering Record* 51 (February 4, 1905): 120. See also "Portage R.R. Bridge, with Passenger Train," c. 1870, Letchworthparkhistory.com, http://www.letchworthparkhistory.com/lpa14.html; and "New Iron R.R.

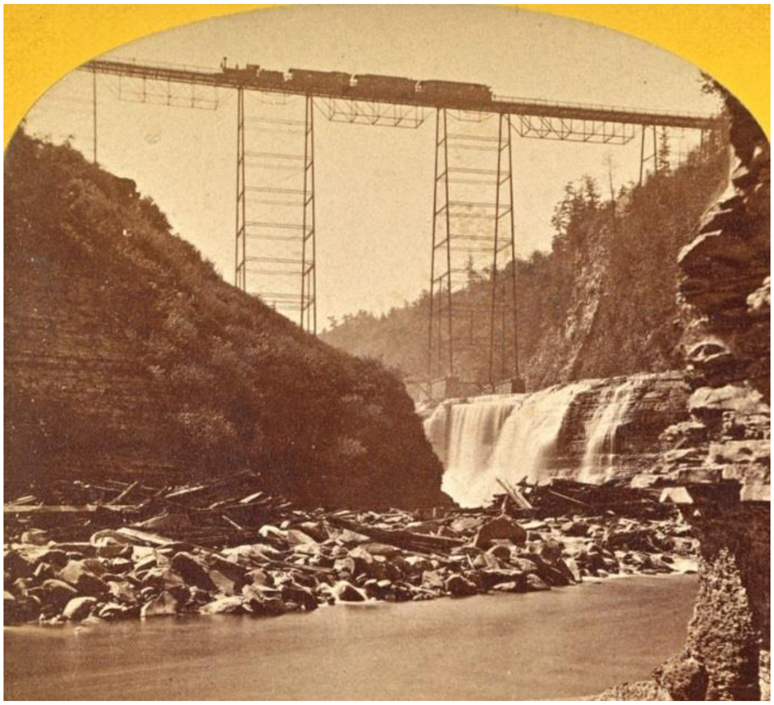

Figure 15.“New Iron R.R. Bridge and Genesee Falls, Portage, N.Y.,” c. 1875.
Source: “New Iron R.R. Bridge and Genesee Falls, Portage, N.Y.,” Letchworthparkhistory.com.

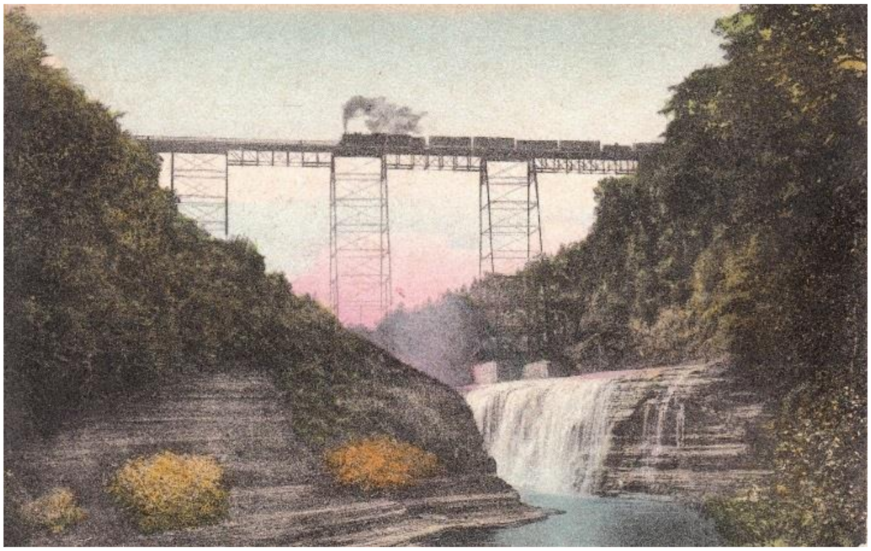

Figure 16. Portage Viaduct after replacement of original iron trusses with steel deck plate girders and trusses.
Source: “New Iron R.R. Bridge and Genesee Falls, Portage, N.Y.,” Letchworthparkhistory.com.

Bridge and Genesee Falls, Portage, N.Y.,” Letchworthparkhistory.com, October 4, 2016, http://www.letchworthparkhistory.com/Photo_Index.html.

From 1890 on, railroads built steel tower viaducts across the country to span canyons, rivers, and badlands. The typical tower design consisted of four battered posts composed of rolled steel structural elements, riveted and bolted connections, X-form cross bracing with either angle irons or laced channels, and web plate girders at top for mounting the individual spans—usually a deck plate girder between 30 and 80 ft long. One design challenge for engineers was pairing the number of tower supports with standard lengths of deck plate girder or truss. For example, in building a 3,700 ft long steel tower viaduct near Valley City, North Dakota, between 1906 and 1908, NP used thirty towers to support three lengths of deck plate girders, 45 ft, 75 ft, and 101 ft long.[108] For its two long crossings at the Nemadji River and Black River completed in 1911, the Minneapolis, St. Paul & Sault Ste. Marie Railway Company or "Soo Line" used combinations of 75 ft long, 90 ft long, and 100 ft long deck plate girders.[109]

To maintain the maximum grade set for the line, the SP&S built steel tower viaducts to bridge several canyons on the section of line between Pasco and Spokane. These viaducts were constructed between 1908 and 1909 (some fill and abutment work was carried out in the years after the bridges became operational), but all were based on a similar design with deck plate girders supported by steel towers set on concrete footings. The steel towers carried a 45 ft length from base to top and a width that varied with a battered slope of approximately 10 percent to the top where it met the deck plate girder. The towers were spaced 75 ft apart, thus conforming to the typical NP standard that used 45 ft and 75 ft deck plate girders in combination for the overall span. The lone exception was the Box Canyon Bridge, which originally spanned the gap between west abutment and the first tower structure with two approximately 60 ft deck plate girders supported by a steel bent.[110] Towers were composed of built-up riveted and laced channels for posts and beams, and X-form bracing in panels of various sizes. Lengthwise bracing used laced channels, riveted web plates, and a half-vertical post; and widthwise bracing used horizontally laced "ladder" bracing, also with half-vertical posts. Small safety platforms were added at roughly the center point of each 45 ft span.

Beginning in the early twentieth century, Steel faced increasing competition from concrete and was gradually phased out of use. After WWII concrete became the material of choice for most long-span railroad viaducts.

E2.3 Concrete

Experimentation with concrete as a bridge material in the United States began in the late nineteenth century as engineers, innovators, and manufacturers sought new ways to build during a period of massive growth. As railroads expanded, urban construction took off, and heavy industries proliferated, concrete held great potential for a range of applications from building foundations to railroad ties. This potential fueled the growth of the Portland cement industry in the United States. In 1890, the entire Portland cement production in the United States totaled 335,500 barrels for the year. Production in five-year intervals rose dramatically over the next twenty-five years, with 990,324 barrels produced in 1895; 8,482,020 barrels in 1900; and 35,246,812 barrels in 1905.[111] Production and the number of new plants in the United States continued to climb in the next decade.[112]

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108 "Railway Bridge at Valley City, N.D.," *Popular Mechanics* 10 (July 1908): 430.
109 "Twin City-Twin Ports Line of the Soo," *Railway Age Gazette* 52 (April 12, 1912): 844.
110 SP&S, "SP&S, Oregon Trunk, Bridge Records.
111 Robert W. Lesley, *History of the Portland Cement Industry in the United States* (Chicago: International Trade Press, 1924), 257–69.
112 Lesley, *History of the Portland Cement Industry*, 275–81.

At same time, the development of reinforcement technologies in the late nineteenth and early twentieth centuries aimed to solve one of concrete's limitations. Unreinforced concrete has great strength in compression but is weak in tension. Reinforcement—typically with steel bars or rods inserted in forms prior to pouring—addressed this weakness by imparting steel's excellent tensile performance to concrete, opening up new possibilities for structural design. The steel rods or "rebar" within the concrete functioned as a "passive" method to handle various loads, such as dynamic loads applied by a train crossing over a reinforced concrete bridge and static loads associated with the weight of the bridge itself.

Although European bridge engineers had begun building with concrete in the mid-nineteenth century, in the United States, concrete bridges began to appear in earnest around the turn of the twentieth century.[113] Most of these early bridges were purpose-built arch bridges, typically single spans or a series of spans between 30 and 100 ft long. Some employed reinforcing, others were built with unreinforced concrete. Early arch designs were largely based on stone precedents, but as the quality of concrete and reinforcement improved, engineers began to pursue open spandrel designs and other means of reducing the amount of concrete to both lower costs and the loads imposed by the weight of the structure itself. Early examples of open spandrel designs include the Illinois Central railroad bridge over the Big Muddy River (1903) and the Salt Fork Bridge near Danville, Illinois (1906).[114]

Figure 17. SP&S Klickitat River Bridge, reinforced-concrete arch.
Source: MHS.

[113] Henry G. Tyrrell, *History of Bridge Engineering* (Chicago: G. B. Williams, 1911), 396.
[114] "Excursion of the Western Society of Engineers," *Railway Age* 36 (November 6, 1903): 618; and "Concrete Arch on the Big Four at Danville," *Railroad Gazette* 41 (July 13, 1906): 30.

The arch design was considered aesthetically superior to most other types and was frequently chosen for park settings.[115] When completed in 1908, the Walnut Lane Bridge in Philadelphia, a concrete arch bridge with a 233 ft long main span, was considered one of the most beautiful bridges in the country.[116] For a project at Niagara Falls, New York, bridge engineer R. S. Buck recommended a three-span concrete arch bridge to replace an "excessively ugly bow-string truss bridge entirely out of keeping with the scenic beauties of this famous pleasure resort."[117] Later masterpieces by Robert Maillart took the concrete arch to perhaps its most elegant form through a unique synthesis of engineering analysis and artful design.[118]

Less beautiful but undeniably practical, the concrete-slab type also began to see use over smaller spans—typically between 10 to 25 ft—in the early twentieth century. Initial designs used I beams or even rails as reinforcement in the slab; others explored beamless systems, such as the "mushroom" columns developed during the first decade of the twentieth century by C. A. P. Turner in the United States and Maillart in Europe.[119] By the mid-1910s, several state highway departments had developed standardized plans for short-span concrete slabs and other types.[120] For spans longer than about 25 ft, engineers developed concrete slab designs supported by beam and girders. Some early beam bridges simply entailed encasing steel I-beams or other structural elements in concrete; later beams and girders were composed of concrete with reinforcing elements. Concrete also found use during this period in designs for trestles, viaducts, and culverts. Early box designs for concrete culverts were later applied to bridge spans with great success. Homer Hadley, for one, used the box girder as the basis three innovative bridges in Washington, the Puyallup River Bridge (completed in 1934), Purdy Bridge (completed in 1937), and Donald-Wapato Bridge (completed in 1948).[121]

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[115] Tyrrell, *History of Bridge Engineering,* 427.
[116] Ken Finkel, "The Walnut Land Bridge: Poetry in Poured Concrete," Phillyhistory.org, October 2, 2016, http://www.phillyhistory.org/blog/index.php/2016/10/the-walnut-lane-bridge-poetry-in-poured-concrete/.
[117] "The Green and Goat Island Concrete-Steel Bridges at Niagara Falls, N.Y.," *Engineering News* 44 (December 6, 1900): 382.
[118] David P. Billington, *The Tower and the Bridge: The New Art of Structural Engineering* (Princeton, NJ: Princeton University Press, 1985), 155–70.
[119] D. A. Gasparini, "Contributions of C. A. P. Turner to Development of Reinforced Concrete Flat Slabs 1905–1909," *Journal of Structural Engineer*ing (October 2002): 1243.
[120] Maryland Department of Transportation, "Concrete Bridges in Maryland," https://www.roads.maryland.gov/OPPEN/IX-CBMD.pdf; M&H Architecture, Inc., "Indiana Bridges Historic Context Study, 1830s–1965," February 2007, 90, https://www.in.gov/indot/files/INBridgesHistoricContextStudy1830s-1965.pdf.
[121] Craig Holstine and Richard Hobbs, *Spanning Washington: Historic Highway Bridges of the Evergreen State* (Pullman: Washington State University Press, 2005), 87.

Figure 18. SP&S reinforced-concrete viaduct.
Source: MHS.

Figure 19. SP&S reinforced-concrete culvert.
Source: MHS.

As use of concrete grew more widespread, concrete bridge designs moved toward more efficient, durable, and economical use of concrete. Some factors influencing the path of concrete construction development included the cost of wages and materials, aesthetics, and demand for certain products. In the 1920s and 1930s, important innovations included air entraining to counteract the effect of water freezing within a concrete mass, thin shell designs, and more significant for bridge design, prestressed and precast technologies.[122]

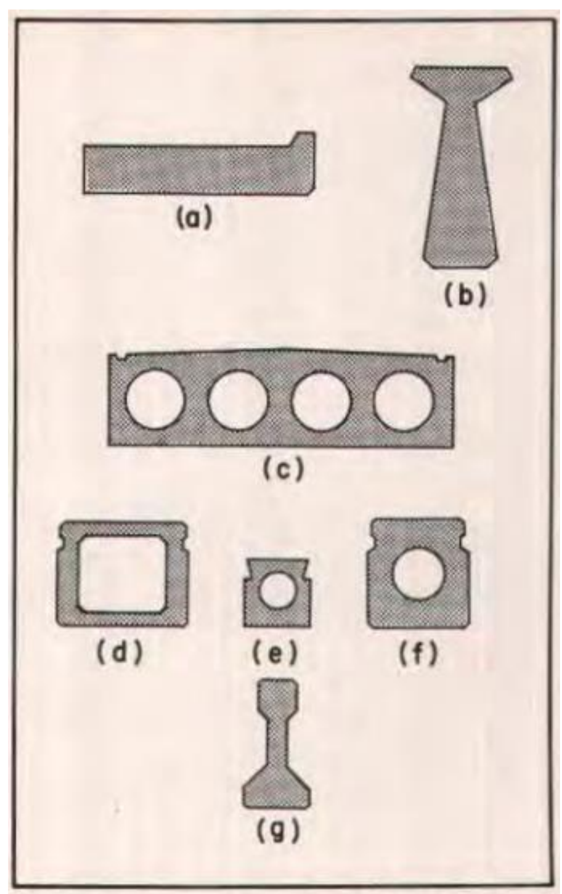

Figure 20. Cross sections of various prestressed-concrete railroad bridges in the late 1950s.
Source: Goldberg, "Thirty Years of Prestressed Concrete Railroad Bridges," 80.

Prestressed concrete originated from experimentation with "active" methods that induced an internal load on concrete—that is, methods to create a continuous state of compression in the concrete to counteract potential tensile loads. Although engineers tried various approaches to "precompress" or prestress concrete, imperfect understanding of shrinkage and creep and a lack of high-tensile steel limited the success of these early efforts. The work of French engineer Eugene Freyssinet and Belgian Gustave Magnel proved vital to the development of practical methods of prestressing concrete. Mangel's design for the first prestressed concrete bridge built in the United States, the Walnut Lane Bridge in Philadelphia (1950), illustrated the basic concept of prestressing: high-tensile-strength steel wires were stretched and anchored (using the patented Mangel-Blaton system) within the concrete deck

[122] Eric M. Hines and David P. Billington, "Anton Tedesko and the Introductio *of Structural Engineering* (November 2004): 1639–41.

girder before the concrete dried to apply a compressive load to the girder. Another variant on this concept, posttensioning, allowed engineers to adjust the internal tension in the structural element during or after installation. Prestressed concrete, which historian David Billington has called "the single most significant new direction in structural engineering of any period in history," became the basis both for the mundane (standard highway concrete girders) and the extraordinary (Ganter Bridge, Brig-Glis, Valais, Switzerland; and Lusitania Bridge, Mérida, Badajoz, Spain) in bridge design.[123]

As prestressing and posttensioning gained acceptance in the United States in the 1950s, it was combined with another approach to concrete construction: precasting. Although the concept of precasting dates from the late nineteenth century, the modern approach developed roughly concurrently with prestressing. In precasting, concrete is cast in a reusable mold or "form," which is then cured in a controlled environment, transported to the construction site, and lifted into place. Typically, precasting was used for modular or sectional elements.[124] The economies of scale and materials gained by precast, prestressed methods were showcased in the construction of the 24-mile long Lake Pontchartrain Causeway near New Orleans, Louisiana, which at the time of its completion (one of two current spans) in 1956 was the longest precast, prestressed concrete bridge in the world.[125]

Prestressed and precast technologies found application in several types of railroad bridge designs, such as girders, box girders, slabs, and arches. After test results by the Association of American Railroads proved promising, the Chicago, Burlington & Quincy Railroad built one of the first prestressed-concrete slab railroad bridges near Hunnewell, Missouri, in 1954. Other railroads followed suit and developed a number of different concrete types utilizing prestressing in the late 1950s.[126]

The US Army Corps of Engineers incorporated developments in prestressed concrete in their own design program, and in the mid-1950s considered how the technology might inform the construction of bridges, buildings, and airfields.[127] In 1958, when the construction of the John Day Dam project on the Columbia River required relocation of 1-mile section of the SP&S line, the Corps turned to prestressed-concrete girder and box-girder designs for the bridges.

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[123] David P. Billington, "Historical Perspective on Prestressed Concrete," *PCI Journal* (January–February 2004): 14.
[124] Amy Slaton, *Reinforced Concrete and the Modernization of American Building, 1900–1930* (Baltimore, MD: Johns Hopkins University Press, 2001), 17, 144; and J. L. Peterson, "History and Development of Precast Concrete in the United States," *Journal of the American Concrete Institute* 50 (February 1954): 477–96.
[125] Peter S. Joselin, "Lake Pontchartrain Causeway," *Civil Engineering* 52 (Spring 1957): 1371.
[126] Donald Goldberg, "Thirty Years of Prestressed Concrete Railroad Bridges," *PCI Journal* 28 (September–October 1983): 78–111.
[127] Cedric Stainer, "Prestressed Concrete Progress and Costs," *Military Engineer* 47, no. 315 (January–February 1955): 22–27.

SECTION F. ASSOCIATED PROPERTY TYPES

The following section provides a guide for evaluating the eligibility of railroad bridges built by SP&S in Washington for listing in the National Register of Historic Places (NRHP). Bridge construction on the SP&S occurred in two primary stages: initial construction between 1905 and 1915; and bridge replacements associated with the relocation of the alignment due to dam projects on the Columbia River between 1934 and 1967. A few bridges were replaced or constructed at various crossing points between these years for other reasons as well, such as a 52 ft long steel girder bridge over Columbia Street in Vancouver, Washington, ordered by the US Maritime Commission in 1943.[128]

F1. General NRHP Evaluation

Bridges built by the SP&S are classified under six categories or property types: trestles; beam, slab, and girder; truss; arch; viaduct; and culverts. Organization and format of the evaluation framework follows NPS guidelines, with a description, statement of significance, and registration requirements for each type.

Description

Descriptions of the various bridge types use the following general terms, as defined by prominent bridge engineer J. A. L. Waddell:

Abutment: *a structure sustaining one end of a bridge span and at the same time supporting the embankment, which carries the track or roadway.*

Batter: *an incline from vertical.*

Beam: *a member the principal function of which is to carry a transverse load*.

Bearing: *the support for a shaft, axle, or trunnion; the shoes for a span.*

Bent: *a supporting frame consisting of posts or piles with bracing, caps, and sills*.

Deck: *the flooring of a bridge.*

Pile: *a long, heavy post or pole of timber, concrete, or steel driven into the ground to compact the soil, to shut out water, to carry a vertical load, or to resist a horizontal force.*

Pin-connected: *a term applied to the method of joining the members of a truss by pins instead of using riveted connections.*

Plate Girder: *a girder built of structural plates and angles*.

Superstructure: *the portion of the bridge or trestle lying above the piers, pedestals, and abutments.*

Substructure: *the piers, pedestals, and abutments of a bridge or trestle*.[129]

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[128] SP&S, "SP&S, Oregon Trunk, Bridge Records."
[129] Waddell, *Bridge Engineering*, 1893–2089.

Statement of Significance

The bridges may have significance associated with either of the two historic contexts in Section E. A short general statement of significance is provided for each bridge type as a brief preface to evaluation under the NRHP criteria. The period of significance for this MPD runs between 1906 when the first bridge construction began, and ends in 1967 when the last bridges were built on the line as part of a relocation project necessitated by the construction of the John Day Dam on the Columbia River. Individual bridges can be nominated under one or more criteria.

Registration Requirements

National Register Criteria for Evaluation

The criteria for evaluating and listing properties in the NRHP require that a historic property be at least 50 years old; possess integrity of location, design, setting, materials, workmanship, feeling, and association; and meet at least one of the following criteria:

A. *Property is associated with events that have made a significant contribution to the broad patterns of our history*.

   The former SP&S railway alignment eligible for the NRHP under Criterion A for its association with:

   1. the history of the railroad industry, both as a unique example of collaboration between two major railway companies and as an exemplar of the role high engineering standards played in the SP&S's fortunes; and

   2. the regional transportation and economic history of the counties along the alignment.[130]

   A bridge will likewise be eligible under A if it has a significant association with some aspect of the collaboration between the Great Northern and Northern Pacific, such as a design based on Great Northern or Northern Pacific standards; or it significantly exemplifies the commitment to low grade and minimizing curvature, such as long or high bridge over a canyon, body of water, or the channeled scablands; and it possesses sufficient aspects of integrity (discussed in Section F3) to convey the associations.

B. *Property is associated with the lives of persons significant in our past*.

   Bridges eligible under Criterion B are unlikely but must fulfill all of the following requirements:

   1. persons associated with the bridge must be demonstrably important within the SP&S historic context and have a specific tie with the specific bridge being nominated;

   2. the bridge must illustrate a person's important achievements; and

   3. a person's association with the bridge must fall within the period of significance, 1906–1967.

[130] Margaret L. Dryden, " Spokane, Portland & Seattle Railway, Property #97784," May 11, 2009; James McNett and Marcia Montgomery, "Spokane, Portland & Seattle Railway Bridge, Property #672899," April 2, 2014; Alex McMurry, "Spokane, Portland & Seattle Railway 3rd Subdivision, Property #488414," April 8, 2015, https://fortress.wa.gov/dahp/wisaardp3/.

Note that bridges associated with a person's contribution to engineering or architecture will be evaluated under Criterion C per National Park Service guidelines.

C. *Property embodies the distinctive characteristics of a type, period, or method of construction or represents the work of a master, or possesses high artistic values, or represents a significant and distinguishable entity whose components lack individual distinction*.

NPS guidance emphasizes establishing the importance and significance of properties when evaluating the distinctive characteristics of a type, period, or method of construction:

> A structure is eligible as a specimen of its type or period of construction if it is an important example (within its context) of building practices of a particular time in history. For properties that represent the variation, evolution, or transition of construction types, it must be demonstrated that the variation, etc., was an important phase of the architectural development of the area or community in that it had an impact as evidenced by later buildings. A property is not eligible, however, simply because it has been identified as the only such property ever fabricated; it must be demonstrated to be significant as well.[131]

Because the significance of the bridges vary by type, eligibility requirements relating to the distinctive characteristics of a type, period, or method of construction will be addressed for each bridge type individually in the sections below.[132]

NPS guidelines characterize a master "as a figure of generally recognized greatness in a field, a known craftsman of consummate skill, or an anonymous craftsman whose work is distinguishable from others by its characteristic style and quality." Properties eligible for associations with a master "must express a particular phase in the development of the master's career, an aspect of his or her work, or a particular idea or theme in his or her craft." Several prominent engineers were associated with bridge construction on the SP&S including William L. Darling, Chief Engineer of the Northern Pacific in 1906 and in charge of the initial construction of the SP&S line, Harold E. Stevens, Bridge Engineer for the Northern Pacific from 1907 to 1916, Ralph Budd, one of the early chief engineers of the SP&S, Alexander M. Lupfer, who replaced Budd in 1913 and was in turn succeeded by A.J. Witchel, and consulting engineers Ralph Modjeski, and Harold U. Wallace and Frank R. Coates of Wallace-Coates Engineering Company, the firm engaged for construction of the reinforced-concrete arch bridge over the Klickitat River. Most of these engineers, however, achieved prominence as railroad industry executives—only Modjeski, whose significance is outlined in the historic context, stands apart as a figure of generally recognized greatness in the field of bridge engineering.[133] Therefore only SP&S bridges associated with Modjeski are potentially eligible under Criterion C as representing the work of a master.

[131] U.S. Department of the Interior, National Park Service, "National Register Bulletin: How to Apply the National Register Criteria for Evaluation," https://www.nps.gov/nr/publications/bulletins/nrb15/nrb15_2.htm.
[132] Parsons Brinckerhoff and Engineering and Industrial Heritage, "A Context for Common Historic Bridge Types," prepared for National Cooperative Highway Research Program, October 2005, 1-6.
[133] "Memoir of Alexander McClure Lupfer," *Transactions of the American Society of Civil Engineers* 84 (1921): 878-80.

While the bulk of the utilitarian bridges built by the SP&S on the line between Vancouver and Spokane generally fall into a class that contemporaries regarded as aesthetically deficient, the arch bridge over the Klickitat River was another matter. Celebrated as a union between latest developments in bridge engineering and aesthetics, the Klickitat River Bridge was seen as adding to the beauty of the Columbia River gorge and a signature statement of the SP&S line.[134] Of the SP&S bridges, only the Klickitat River Bridge is significant under Criterion C for sufficiently representing high artistic values in bridge design.

The overall design of the original SP&S line is significant as an engineering achievement that contributes to understanding the history of railroad industry, particularly given the challenging terrain and many water crossings encountered along the surveyed route. The WA DAHP has previously determined the SP&S railway alignment eligible for the NRHP under Criterion C (and Criterion A, as noted above). As such, individual bridges are significant as part of the larger line which represents a significant and distinguishable entity whose components in some cases lack individual distinction. While some bridges may be individually eligible for the NRHP under Criterion C, others that lack sufficient individual distinction may nonetheless qualify as contributing resources to the historic railway alignment. The distinction between the two categories of eligibility will be addressed in the individual bridge type subsections.

D. *Property has yielded, or is likely to yield information important in prehistory or history*.[135]

Although the section of the former SP&S line between Vancouver and Pasco still operates as an active railway, the section between Ainsworth Junction and Spokane converted to a trail functions more as an archaeological resource. Over the bulk of the trail, bridges, where extant in some form (many trestles, for example, underlie sections of fill, such as at Sprague Gulch) constitute some of the last remnants of the former railway and may contribute to answering important research questions regarding the engineering of the line, particularly in comparison to other lines in the vicinity such as those built by the NP and UP. Eligibility under Criterion D depends on building a sufficient case for both the importance of the research question, and that the bridge constitutes the principal source of information for research.

[134] "Modern Bridge," *Morning Astorian*, August 14, 1097, 4.
[135] National Park Service, "National Register Bulletin: How to Apply the National Register Criteria for Evaluation."

F2. Individual Bridge Type Evaluations

F2.1 Trestle

Description

The trestle, a design with ancient roots, was one of the first types adopted by the early railroad industry in the 1830s.[136] The design's simplicity is captured by its definition in one railway manual, as "a bridge composed of relatively short spans of simple horizontal members or beams, supported on caps resting on upright members, placed transversely to the axis of the structure and forming bents or trestles used as load applied to the horizontal members."[137]

Figure 21. SP&S framed trestle at Wind River.

During the nineteenth and early twentieth centuries, railroads in the United States primarily built two types of trestles: pile and framed. In the pile trestle, bents consist exclusively of piles and a cap, whereas in the framed trestle, the timbers composing the bents are squared and framed together, often resting on a pile foundation. Several methods of attaching caps to piles were used, including mortise and tenon connections, drift bolts, or dowels. A variety of different types of wood were used, with cedar and oak among the most durable. Round piles were typically 12 to 15 in in diameter where cut, and squared piles were commonly 12 in across each face. Bents were cross braced and connected in parallel with stringers and additional cross bracing. Cross ties were laid across the stringers that in turn supported the tracks (Fig. 21).[138]

The length and height of trestle spans varied widely depending on the application, from low, short spans over a section of swampy ground to long, high spans over canyons. Some very long, low timber trestles were built in the late nineteenth and early twentieth centuries, including the New Orleans & Northeastern Railway trestle across Lake Pontchartrain, purportedly the longest bridge in the world at 22-mile long when originally built in 1883, and the Southern Pacific's 11-mile long, 15 ft high trestle over the Great Salt Lake completed in 1903.[139]

Aside from its basic function to carry tracks across a span, trestle design also often incorporated maintenance and safety features such as refuge bays for personnel encountering trains and fire protection measures such as barrels of water or sand mounted on extended ties and sheet metal attached between railroad ties and stringers to protect from errant sparks or ashes. Due to the vulnerability of timber trestles to rot, wear, and fire, one railway engineer recommended "never-ceasing watchfulness" when it came to trestle inspections.[140]

Although the basic design of timber trestles moved toward standardization during the nineteenth century (an effort assisted by the various railway associations that investigated and reported on best practices in trestle design and construction), individual railroads followed internal standards that varied as to the number of piles

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[136] Tyrrell, *History of Bridge Engineering*, 365.
[137] E. T. Howson, E. R. Lewis, and K. E. Kellenberger, eds., *Maintenance of Way Cyclopedia* (New York: Simmons-Boardman, 1921), 279.
[138] Foster, *Treatise on Wooden Trestle Bridges*, 5–7.
[139] J. G. Van Zandt, "Outline History of Railway Bridge Building in the U.S.," *Railway Engineering and Maintenance of Way* 8 (October 1912): 451; and J. Cecil Alter, "Water-Level of the Great Salt Lake," *Engineering News* (August 6, 1914): 281.
[140] Walter G. Berg, ed., *American Railway Bridges and Buildings: Official Reports, Association of Railway Superintendents, Bridges, and Buildings* (Chicago: Roadmaster and Foreman, 1898), 9.

in a bent, distances between bents, angle of batter, type of connections, dimensions of caps and stringers, length of cross types, and type of decking, depending on the height of and expected loads on the trestle. The GN, for example, had a standardized pile trestle design for four categories of height (Fig. 22).

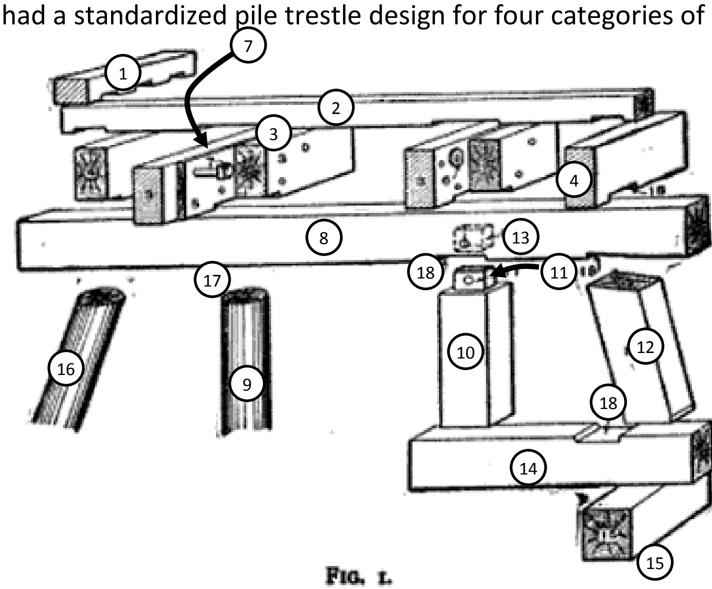

FIG. 1.

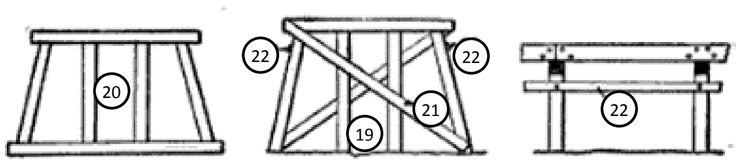

FIG. 2.

Bent, Framed, 20.
Pile, 19.
Cluster.
Bent Brace, see Sway-brace.
Block, see Sub-sill.
Bolster, see Corbel.
Cap, 3.
Chord, see Stringer.
Corbel, Bolster.
Cross-tie, 2.
Cut-off, 17.
Dapping, see Notching.
Fender, Guard-rail, 1.
Gaining, see Notching.
Girt, see Longitudinal Brace.
Girder, see Stringer.
Guard-rail, Fender, Ribbands, 1.
Jack-stringer, see Stringer.
Longitudinal Brace, Girt, Waling-strip, 22.
Mortise, 13.
Mud-sill, see Sub-sill.
Notching, Gaining, Dapping, 18.
Outside Stringer, see Stringer.
Packing-block, Packing piece, 5.
Packing-bolt, 7.
Packing-piece, see Packing-block.
Packing-washers, see Separator.
Piles, Batter, Inclined Brace, 16.
Vertical, Plumb, Upright, 9.
Posts, Batter, Inclined, 12.
Vertical, Plumb, Upright, 10
Ribbands, see Guard-rail.
Separator, Packing-washer, **Thimble Spool, 6.**
Sill, 14.
Spool, see Separator.
Stringer, Chord, Girder.
Track, 3.
Outside, Jack, 4.
Sub-sill, Mud-sill, Blocks, 15.
Sway-brace, Bent Brace, 21.
Tenon, 11.
Thimble, see Separator.
Track-stringer, see Stringer.
Waling-strip, see Longitudinal Brace.

Figure 22. Technical terms, names, and definitions—wooden trestles. Source: Foster, *Treatise on Wooden Trestle Bridges*, xvii.

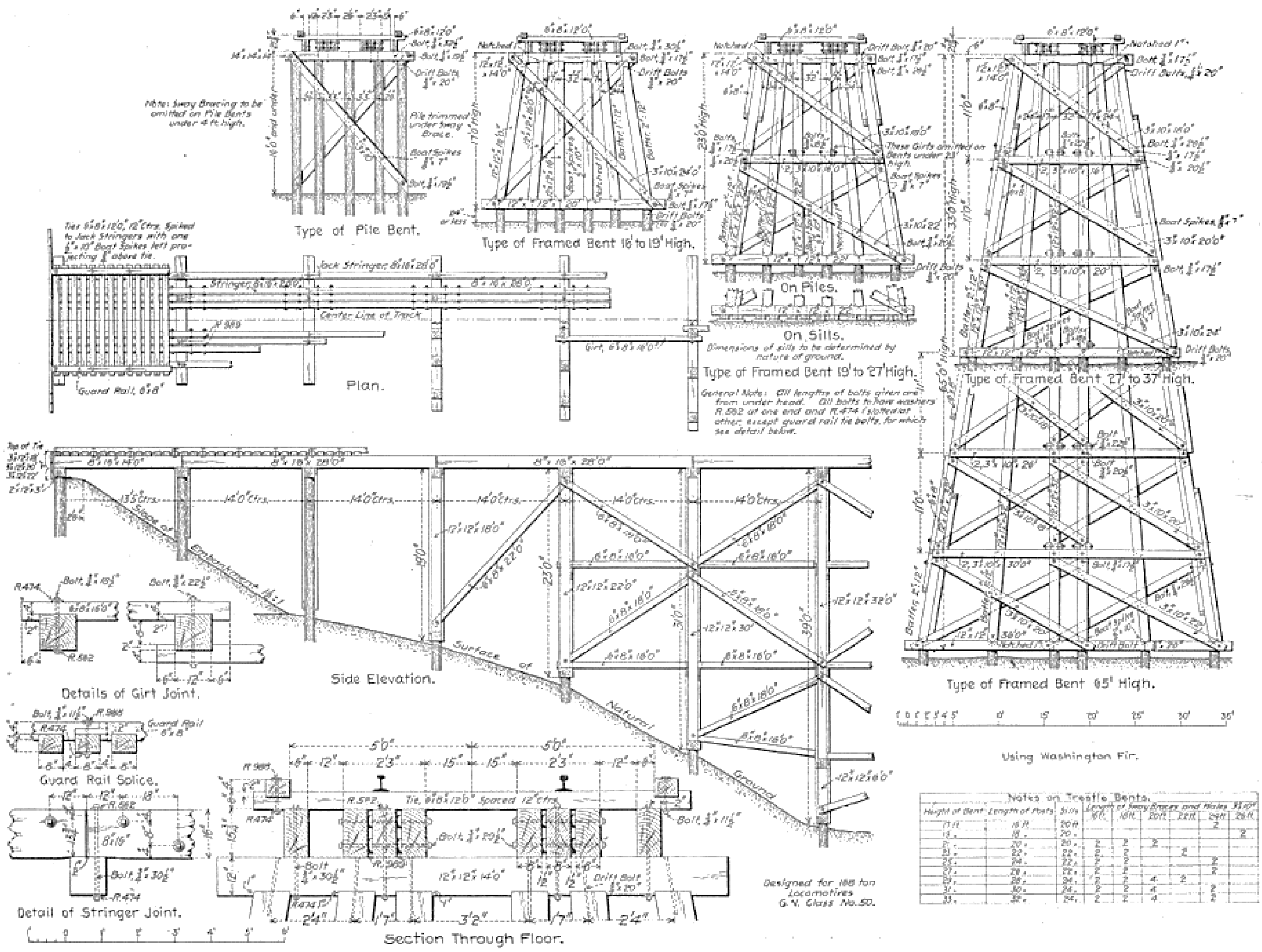

Figure 23.Great Northern standard trestles.
Source: *Railroad Gazette* (August 8, 1902): 618.

A 1902 *Railroad Gazette* article describing the new GN standard noted that the railroad changed the trestle span length from 16 ft to 14 ft.[141] The railroad also used other designs depending on class of the line: a branch line or second-class line, for example, might have a five- rather than six-post design. The NP 1907 timber trestle showed the slight variance in standards between railroads. While the NP standard used the same 12 x 12 in posts, the batter of the outside posts at 3 in per ft and inside posts at 1 in per ft, size of the six deck stringers at 9 x 18 in, and 13 ft 9 in spacing between bents differed slightly from the GN standard.[142]

[141] "Great Northern Standard Trestles," 618.
[142] "Formulas for Estimating the Quantities of Materials in Timber and Pile Trestles and Hints on Estimating Costs," *Engineering-Contracting* 29 (February 12, 1908): 104.

Significance

The extensive use of trestles on the SP&S line is significant in that it represents an American approach to railroad building, especially in the western United States. Built largely as temporary structures and then either filled in or replaced with more permanent structures later, trestles reflected the competitive nature of the railroad industry in the early twentieth century that forced railroad companies to rush projects to completion. While exact numbers on the SP&S line are unknown, early surveys indicate that few wood trestles remain. Several of the SP&S trestles were substantial structures, especially the Sprague Gulch trestle, which at 4,869 ft long and with an average height of 75 ft was one of the tallest and longest in the nation. With an aggregate length well over 6 miles, the SP&S trestles were an important component in achieving the high standards for grade and curvature James Hill set for the line.

Character-defining features of the trestle type include wood bents (either pile or framed), bracing, and stringers.

Registration Requirements

Trestle types may be eligible under Criteria A–D as described in Section F.1 above. Trestles may also be individually eligible under Criterion C for representing a specific period, type, and method of construction if they:

1. represent an NP standardized design from original period of construction of the line (1906–1915);
2. represent a GN standardized design from original period of construction of the line (1906–1915); or
3. represent the high engineering standards set for the line in terms of grade and curvature. For example, a long viaduct over a canyon may illustrate a decision to maintain a steady grade rather than a lower path that avoided the need for a trestle but introduced a section of descent and climb.

In addition, trestles not meeting requirements for individual eligibility are considered contributing resources to the SP&S historic railway alignment if constructed during the period of significance (1906–1967), and the trestle retains sufficient integrity to convey that association.

F2.2 Beam, Girder, and Slab


Figure 24. SP&S "deck-plate" girder span, Fish Lake Bridge.

Description

A beam is a structural element capable of withstanding load primarily by resisting bending. One of the simplest forms of a beam bridge is a log across a stream. Girders are a form of beam, typically composed of a rolled metal structural element such as an I beam or Z beam, a built-up structural element such as a metal web plate with top and bottom flanges, or a box-shaped element. In bridges that contain both girders and beams, girders are usually the main load-carrying elements and are aligned in the direction of the traffic the bridge carries.[143] A slab is also a form of beam, consisting of a monolithic or composite block of material that typically serves as the bridge deck. Mesopotamian bridge builders used shaped stone slabs for small spans as early as 3500 B.C.[144]

In the era of the SP&S between 1906 and 1970, a beam bridge referred to a deck supported by several beams, either timber or rolled-metal structural elements such as I beams. Girder bridges consisted either of steel-plate girder types—deck, pony, or through—composed of sections of steel plates and flanges riveted together with an I-shaped cross section, or concrete deck types supported by either solid or hollow girders. Slab railroad bridges were built with reinforced concrete. While early concrete bridges were typically cast in place, prefabricated and prestressed technologies were widely used in concrete bridges built in the 1960s.

The NP standard deck-plate girder bridge used by the SP&S consisted of two parallel girders, each built up with riveted web, top, and bottom plates, and bracing elements. Although defined by the girders that carried the main loads, structurally the deck-plate girder formed a rectangular box, typically 6 ft 6 in wide from centerline to centerline of the girders, 6 ft tall, and of various lengths. The girders, which formed the two solid sides of the box, were connected together by Warren truss lateral bracing at the top and bottom, and internal cross bracing at regular intervals. Railroad ties were bolted directly to the top of the girders.

Through-plate girder designs were somewhat similar, but featured rounded end plates, cross beams connecting the two girders, and X-form lateral bracing at the bottom. Railroad ties were bolted to the top of two stringers riveted between cross beams.

Both specifications called for different end bearings depending on whether the bridge would be attached to wood or masonry abutments. In general, bearing systems were divided into two types: fixed and expansion. Longer spans often called for a fixed


Figure 25. SP&S "through-plate" girder span, Paxton Bridge.

[143] George C. Lee and Ernest Sternberg, *Bridges: Their Engineering and Planning* (Albany: SUNY Press, 2015), 40.
[144] Ian McNeil, ed., *An Encyclopedia of the History of Technology* (London: Routledge, 1990), 462.

bearing at one end, such as a pin hinge bearing bolted to a steel shoe, and an expansion bearing at the other, such as a roller type. The bearings were often bolted to the abutment with a cast-steel shoe or pedestal.

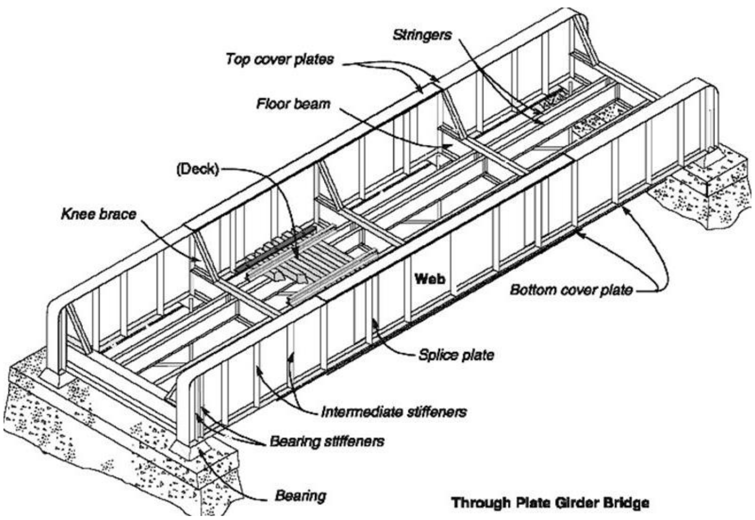

Figure 26. Typical “through-plate” bridge.
Source: AREMA. https://slideplayer.com/slide/4613095

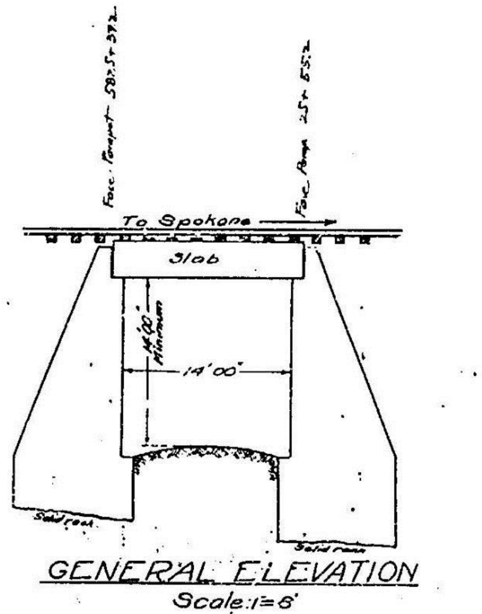

Figure27. SP&S reinforced-concrete slab bridge (1911).
Source: PNRA.

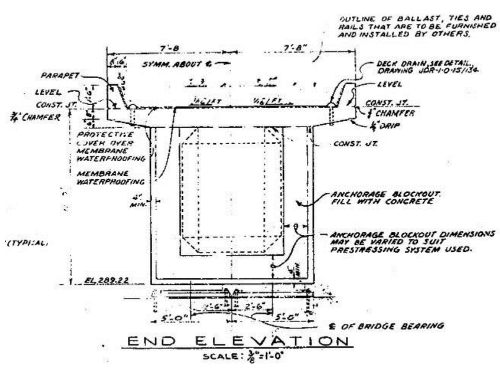

Figure 29. Pre-stressed concrete box girder bridge, US Army Corps of Engineers for SP&S (1962).
Source: PNRA

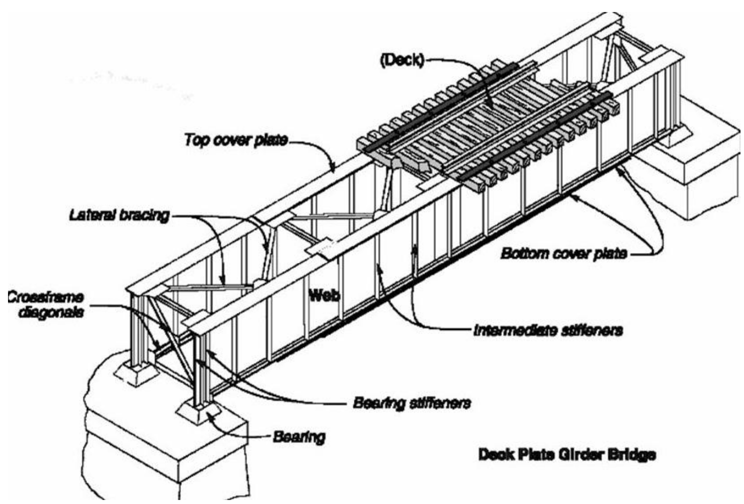

Figure 28. Typical “deck-plate girder” design.
Source: AREMA. https://slideplayer.com/slide/4613095/

Significance

Railroads have widely used slab, beam, and girder type bridges since the nineteenth century. While slab and beam bridges are better for relatively short spans, girder types are well suited to spans between 30 and 100 ft long. While use of these bridges types was not confined to the United States, certain aspects of their development reflected the American context. For example, whereas in Great Britain the early plate girder bridges tended to be larger, purpose-built, individual designs made of iron, bridge engineers in the United States moved toward prefabricated, standardized plans and quickly adopted steel.[145]

The SP&S bridge schedule reflected this larger national pattern. As part of the original construction of the line, the railroad built several I-beam bridges for shorter spans and heavily used the steel deck-plate girder type for individual spans less than 50 ft long, as approaches for longer truss spans and in steel tower supported viaducts. Later, as part of the line's relocation to accommodate the John Day Dam project, the US Army Corps of Engineers replaced a few of the original bridges with prestressed-concrete box girders.

The original deck-plate girder bridges provide a physical marker of SP&S's origins as a corporate collaboration between the GN and NP. As discussed earlier, although standardization efforts in the late nineteenth and early twentieth centuries steered railroad companies toward similar designs, each railroad maintained internal standards that varied in the details. The NP standard used for deck-plate girder bridges on the SP&S line built between 1907 and 1915—developed by prominent bridge engineer Ralph Modjeski—both shows the connection to the parent railroad and represents an era when steel dominated railroad bridge construction.

Character-defining features of the slab railroad bridge type includes monolithic, reinforced-concrete deck of uniform thickness and abutments; of the beam type includes beams of various types (rolled structural elements, timber stringers, or concrete), the deck, and bridge supports; and of the girder type includes the girder (whether built-up of metal plates, flanges and rivets or concrete), deck, and supports.

Registration Requirements

Beam, girder, and slab types may be eligible under Criteria A–D as described in Section F.1 above, and individually eligible under Criterion C for representing a specific period, type, and method of construction that meet the following conditions:

1. deck-plate girders that represent Modjeski's standardized design for the NP.

In general, the design of SP&S I-beam and concrete slab bridges followed established rules of thumb and lack sufficient distinction in terms of engineering achievement. Furthermore, due to the shortness of these spans, compared to other bridge types the I-beam and slab types do not best represent the high engineering standards set for the line in terms of grade and curvature.

Evaluation of the concrete box girder and prestressed girder types built by Corps during the relocation efforts associated with the McNary Dam and the John Day Dam projects is informed by the Advisory Council on Historic Preservation's Program Comment on Post-1945 Concrete and Steel Bridges. Although the program comment applies to highway rather than railroad bridges, the Corps bridges designed for the SP&S fall into categories identified as "well-documented standardized designs that lack individual distinction."[146] Both the

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[145] Solomon, *North American Railroad Bridges*, 117.
[146] "Program Comment Issued for Streamlining Section 106 Review for actions Affecting Post-1945 Concrete and Steel Bridges," *Federal Register* 77 (November 16, 2012): 68794.

concrete box and prestressed girder types were well established and ubiquitous in bridge engineering when completed for the SP&S in 1952 and 1967, respectively. Early work with concrete box girders began in Europe during the 1920s, and as noted in the historic context, appeared in Washington in the 1930s and 1940s in the work of Homer Hadley. By the 1950s, box girder type widely used in bridge building throughout Washington and the United States.[147] Similarly, prestressed concrete bridges in the United States dated to 1948, and became widely adopted in the mid-to-late 1950s. No specific importance related to engineering design, analytical techniques, materials, or developmental transitions were identified to suggest significance under Criterion C.

However, any beam, girder and slab types not meeting requirements for individual eligibility may still qualify as a contributing resource to the SP&S historic railway alignment if constructed during the period of significance (1906–1967) and possessing sufficient integrity to convey that association.

Figure 29. SP&S Pratt truss bridge near Stevenson, WA.

F2.3 Truss

Description

Truss bridges share a basic superstructure consisting of two or more (typically two) bridge trusses connected by a system of bracing and flooring (typically beams or girders) that transfer loads to bearings. The bearings are typically affixed to bridge abutments or other supports. Truss bridges are distinguished by the bridge truss type, which in most cases are named after a patent claimant or developer such as Howe, Warren, or Pratt. The bridge truss itself is usually built up with a regular pattern of straight structural elements connected in a triangular configuration, commonly defined by top and bottom chords, end posts, and web members. Web members are further divided into hip verticals, intermediate posts, and diagonals. A flooring system of stringers, cross beams, and braces supports a deck to which cross ties and tracks are affixed. Depending on type, bridge trusses are stiffened with a variety of different types of bracing, including portal, sway, and knee braces. Connections between various elements are usually made with rivets, pins, and bolts. Common structural elements of a metal bridge truss include rolled beams, forged eyebars, laced or lattice channels, plate girders, and cast-iron bearings and shoes.

Truss bridges are further categorized as either *deck, through,* or *pony types*. In a *deck truss*, the deck rests atop the bridge trusses; in a *through truss*, the flooring system and deck are connected to the bottom of the bridge trusses, which are braced at the top with overhead portal and sway bracing; *pony trusses* are similar to through trusses but rise only a few feet above the deck and lack overhead bracing.

Between Vancouver and Spokane, the SP&S relied on the Pratt through truss for all truss spans with the exception of three Howe trusses and a single Warren deck truss. The diagrams below illustrate the basic components and configurations of the various truss bridges.

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[147] Robert H. Krier, J. Byron Barber, Robin Bruce, and Craig Holstine, “Donald-Wapato Bridge,” National Register of Historic Places Registration Form, 8-1, 1991, https://npgallery.nps.gov.

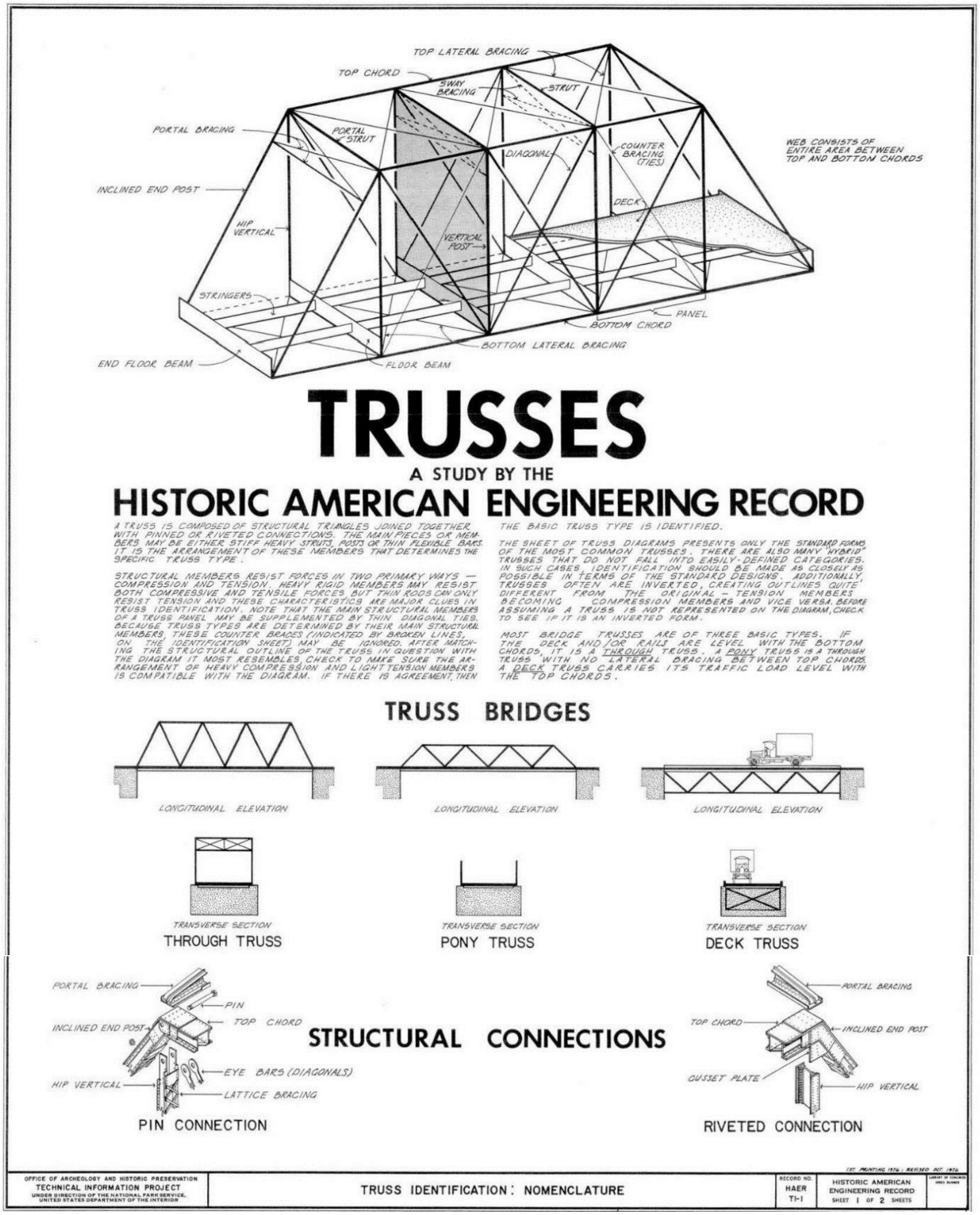


Figure 30. Bridge truss types and connections.
Source: Adaptation of Historic American Engineering Record, Library of Congress

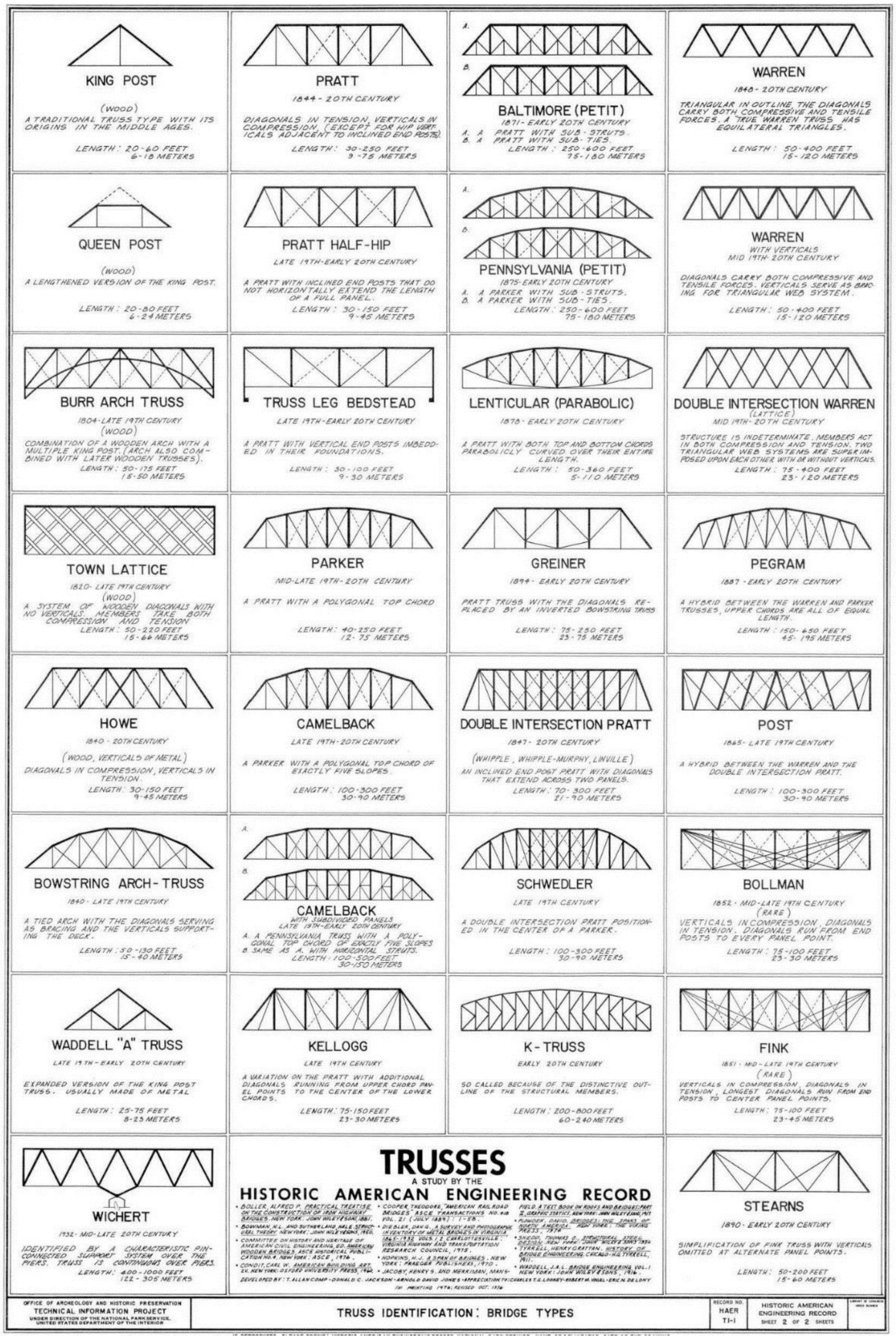
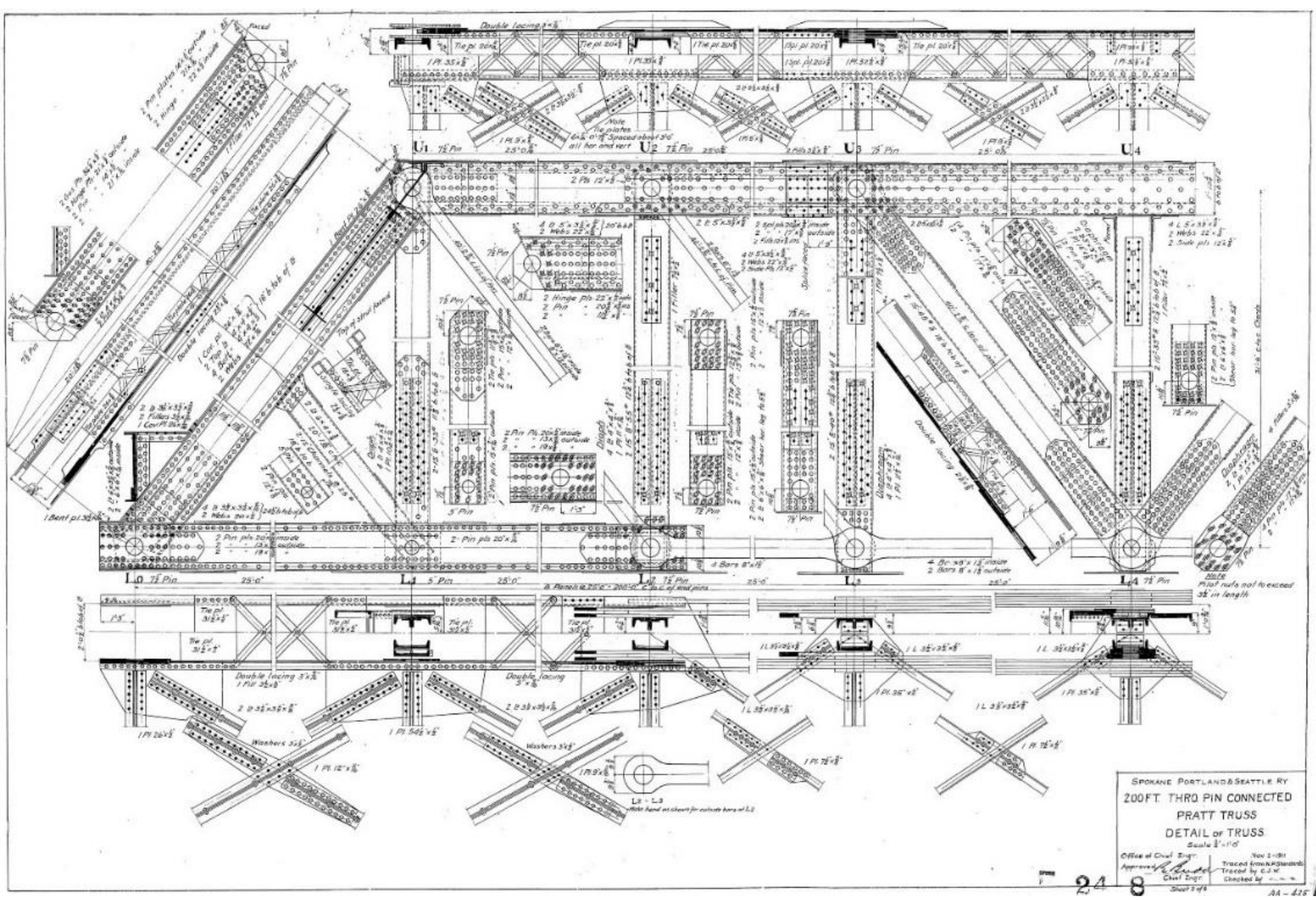


Figure 31. Truss configurations.

Source: Historic American Engineering Record, Library of Congress

The SP&S Pratt truss bridges generally represent Modjeski's standardized design developed for the NP. They typically ordered Pratt trusses in two lengths: 150 ft and 200 ft. The basic design consists of two Pratt trusses connected by girders beneath the bridge deck and portal bracing between the top chords. For the 200 ft long bridge—measured from center to center of the end pins in the bearing supports—each truss is composed of six full panels, each 25 ft long and 32 ft 9 in high, and a half panel at each end divided by the inclined end post. The bridge is symmetrical along the two axial centerlines. Panel configurations are of three types: end (half) panels have hip struts to brace the inclined ends; the next two sets of panels from each end have diagonal eyebar stays; and the two center panels have cross bracing consisting of laced channel diagonals sloping up from the center of the bottom chord to the top chord. The center panel cross bracing differed from the standardized design, which specified two eyebars. The heavier laced channels used instead of eyebars for the diagonal stays likely reflected the high-speed design requirement for the line. The primary connection points between panels are made with pins, a common feature of truss bridges designed between 1880 and 1915.[148] Shop and field riveting were used to join other structural elements.



[148] Gasparini and Simmons, "American Truss Bridge Connections in the 19th Century," 132.

Figure 32. 200 ft pin-connected Pratt truss.
Source: BNSF Railroad Co.

The bridge deck is supported by a substructure divided into units by the panel configuration; that is, the trusses are connected widthwise by a girder or web plate riveted to the vertical posts, and two stringer girders running lengthwise are in turn riveted to the web plates. Timber railroad ties bolted across the top of the stringer girders support the rails. The substructure is braced in an X pattern on the bottom between web plates and in a W pattern between the stringer girders under the railroad ties. Cross braces also extend between the pin-connection brackets at the bottom of the vertical posts to further stiffen the bottom chords of the truss.

Significance

Trusses figure prominently in the history of bridge engineering in the nineteenth and twentieth centuries, showing important developments in the transition from wood to metal in bridge construction; in analytical concepts of force, stress, strength of materials, and fatigue; and in the nature of the bridge industry itself. More specifically for the SP&S, the trusses built on the line represent a standardization effort based on the “American system,” one that differed from earlier standards developed by bridge-patent companies and among railroad companies themselves. Similar to the deck-plate girder type, the truss bridges constructed as part of the original alignment provide a physical marker of the SP&S’s origins as a corporate collaboration between the GN and NP. Modjeski’s standard truss developed for the NP and used on the SP&S built between 1907 and 1913 both shows the connection to the parent railroad and represents an era when steel dominated railroad bridge construction.

Character-defining features of the truss type includes triangular configuration of structural elements defined by top and bottom chords, end posts, and web members and connected by a flooring system, deck, and bracing. Common structural elements of a metal bridge truss include rolled beams, forged eyebars, laced or lattice channels, plate girders, and cast-iron bearings and shoes, and connections made with rivets, pins, and bolts.

Registration Requirements

Truss types may be eligible under Criteria A–D as described in Section F.1 above, and individually eligible under Criterion C for representing a specific period, type, and method of construction if it:

1. represents Modjeski’s standardized design for the NP;
2. represents the pin-connected, “American System” design; or
3. represents the high engineering standards set for the line in terms of grade and curvature; or
4. represents an innovative or otherwise important aspect of bridge engineering.

Any truss type not meeting requirements for individual eligibility may still qualify as a contributing resource to the SP&S historic railway alignment if constructed during the period of significance (1906–1967) and possessing sufficient integrity to convey that association.

F2.4 Arch

Description

Figure 33. SP&S reinforced-concrete arch bridge over Klickitat River.

The arch bridge relies on the shape of a curved span to distribute compressive loads to its supports, typically piers or abutments, and to minimize tension loads. For this reason, arch bridges are built with materials that perform well in compression, such as stone, concrete, and steel. An important design element of the arch bridge is the curvature of the arch, which can range from a semicircle to low curvature segmental arches. One 1915 bridge-engineering manual pointed out that as arch designs were inferior to trusses in terms of stiffness, they were better adapted to highway rather than railroad applications. However, under certain conditions, such as crossings over deep ravines that offer natural abutments of sufficient quality, the manual advised that the arch bridge could be economical.[149]

Figure 34. SP&S short-span concrete arch.

Similar to truss bridges, arch bridges can be classified by deck configuration. The deck arch, one of the more common forms of arch bridge, refers to a bridge where the deck is above and supported by the arch. In the deck arch, the area between the arch and the deck is known as the spandrel. Whereas “closed” spandrels are solid, usually the case in a stone arch bridge, an “open” spandrel either is open or supported by a number of vertical columns rising from the arch. Some arches are hinged at the apex or abutments to better determine stresses and accommodate movement from thermal expansion or foundational settling.[150] Through-arch designs with the two arches connected at the bottom by the deck and at the top by overhead bracing and tied-arch types that suspend the deck from the arch are rarely used in railroad applications.

In some cases along the SP&S mainline, short-span arch designs were used to pass vehicular traffic underneath the tracks (Fig. 33). These “bridges” resemble tunnels, but differ from tunnels in that the loading was primarily from trains rather than overburden, and the structures were built to carry the rails over an existing obstacle, typically a road.

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[149] F. C. Kunz, *Design of Steel Bridges* (New York: McGraw-Hill, 1915), 347.
[150] Kunz, *Design of Steel Bridges*, 347.

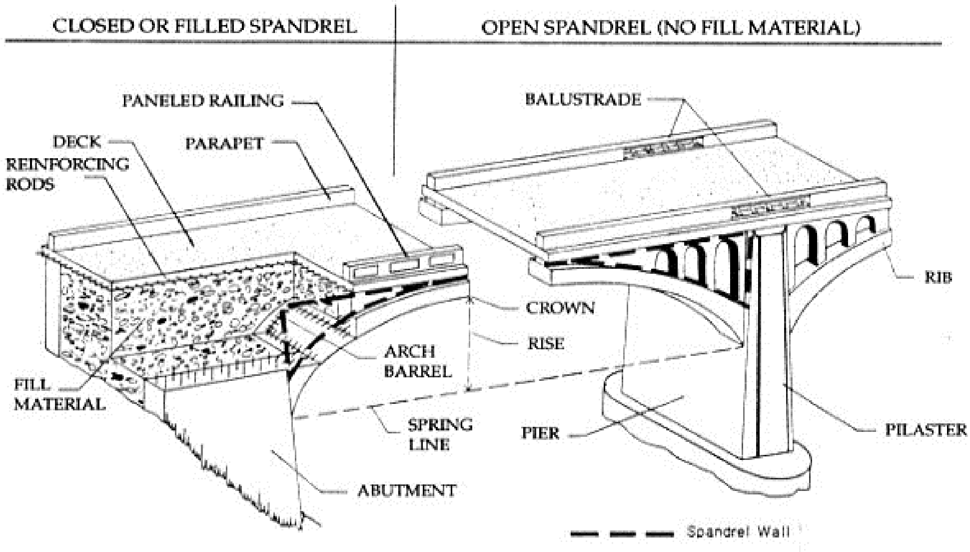

Figure 35. Concrete arch bridge diagram.
Source: Connecticut's Historic Highway Bridges, http://www.past-inc.org/historic-bridges/Gloss-concretearch.html.

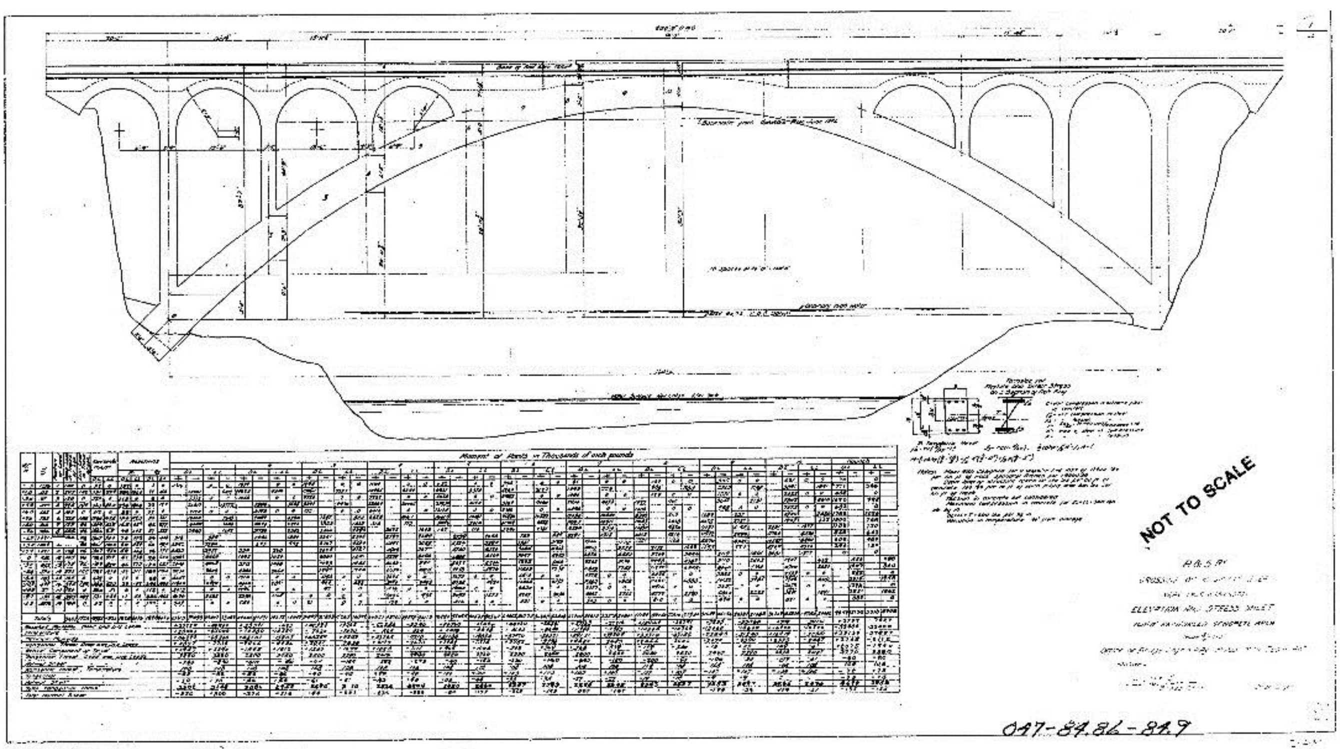

Figure 36. Klickitat River Bridge, reinforced-concrete arch.
Source: PNRA.

Significance

The arch form has resulted in some of the most celebrated engineering achievements worldwide. Another ancient bridge type, the arch span was a subject of early analytical study in Europe. As bridge builders sought to increase the length and strength of arch spans, use of stone gave way in the nineteenth century to metal and concrete. From an engineering standpoint, the significance of an arch bridge can be evaluated in terms of its contribution to design innovation, analytical developments, and new methods of bridge construction. Longer-span, purpose-built, individual designs will likely have greater significance than shorter spans based on well-established designs and materials.

The most notable arch bridge on the SP&S line was the 160 ft long bridge over the Klickitat River, one of the earliest long-span, reinforced-concrete arch railroad bridges built in the western United States. This example of cutting-edge bridge engineering in a remote location is a case study of how railroad companies used bridges to promote “technological tourism” and market their lines, a strategy that began at Niagara Falls after construction of the Roebling suspension bridge in 1855. Railroad companies’ completion of engineering marvels, notes one historian, “conferred credit on the line that used or owned it,” and suggested financial strength, forward thinking, and a technologically advanced operation.[151] The Klickitat River Bridge is currently listed in the Washington Heritage Register.

Although use of reinforced concrete for short-spans was widespread when bridge construction began on the SP&S, experimentation in the early years of concrete bridge construction with different types of reinforcement, concrete mixes, and methods of construction led to innovative designs that sought reductions in material and construction time by opening spandrels, introducing ribbed arches, flattening arches, and inventing reusable forms.[152] With their relatively high arches and solid barrel form, the shorter span bridges built by the SP&S represent one of the earliest stages of concrete bridge engineering in the railroad industry.

Character-defining features of the arch railroad bridge type include arch ribs (ring or barrel), deck, bearings, abutments, material, and spandrels.

<u>Registration Requirements</u>

The Klickitat River Bridge has significance under Criterion C for representing:

1. an early example of a long-span reinforced concrete arch designed for rail traffic; and
2. an aesthetic ideal, specifically the arch form regarded as the most beautiful bridge shape when built; and the idea of marketing technological achievement in railway engineering.

Other concrete arch types may be eligible under Criteria A–D as described in Section F.1 above, and individually eligible under Criterion C for representing a specific period, type, and method of construction if it:

1. represent an NP standardized design from original period of construction of the line (1906–1915);
2. represent a GN standardized design from original period of construction of the line (1906–1915); or
3. represent the high engineering standards set for the line in terms of grade and curvature; for example as part of a large section of fill needed to maintain gradual grade; or

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[151] William Irwin, *The New Niagara: Tourism, Technology, and the Landscape of Niagara Falls, 1776–1917* (University Park: Pennsylvania State University Press, 1996), 60.
[152] M.S. Troitsky, *Planning and Design of Bridges* (New York: John Wiley & Sons, Inc., 1994), 33.

4. represents an innovative or otherwise important aspect of bridge engineering.

Any arch type not meeting requirements for individual eligibility may still qualify as a contributing resource to the SP&S historic railway alignment if constructed during the period of significance (1906–1967) and possessing sufficient integrity to convey that association.

Figure37. SP&S steel tower viaduct at Wilson Canyon.

F2.5 Viaduct

<u>Description</u>

In its first usage in the early nineteenth century, *viaduct* referred to "an extensive bridge consisting, strictly of a series of arches of masonry, erected for the purpose of conducting a road or a railway over a valley or a district of low level, or over existing channels of communication, where an embankment would be impracticable or inexpedient; more widely, any elevated roadway which artificial constructions of timber, iron, bricks, or stonework are established."[153] At the close of the century, metal deck-plate girder and truss spans were often used in place of arches, but the basic form of a viaduct composed of a series of spans supported by piers or towers remained. Reinforced concrete became a popular material for viaduct construction in the early twentieth century. Concrete viaducts have different substructure designs, typically supporting the superstructure with single piers of various shapes or two-pier bents.[154]

Figure 39. SP&S concrete viaduct, milepost 17.4.

<u>Significance</u>

Over the course of the nineteenth century, viaducts transitioned from older forms based on stone and brick construction to those built with metal and concrete. The railroads made widespread use of steel tower viaducts in the American west to maintain grades over canyons, valleys and urban crossings, a light, spindly contrast to some of the heavy arched masonry viaducts of the east. Because of their height and length, viaducts are one of the best representatives of the high engineering standards set for the SP&S line in terms of grade and curvature. Long viaducts over canyons along the Snake River, for example, illustrate a decision to invest in the engineering and cost to build steel tower viaducts to support a steady grade rather than follow routes that necessitated sections of descent and climb.

Character-defining features of the railroad viaduct type include supports or piers, abutments, and individual spans, whether masonry or metal.

<u>Registration Requirements</u>

[153] Online Etymology Dictionary, "Viaduct," accessed November 20, 2016, http://www.etymonline.com/index.php?term=viaduct.
[154] Goldberg, "Thirty Years of Prestressed Concrete Railroad Bridges," 78–100.

In 2015, DAHP determined five SP&S steel tower viaducts at Burr Canyon, Bouvey Canyon, Wilson Canyon, Box Canyon, and Cow Creek—all on the inactive section between Pasco and Spokane—eligible for the NRHP under Criteria A and C for representing the railway's high engineering standards. The NRHP evaluation found that "the viaducts in the Snake River Canyon area are the highest and among the longest viaducts remaining in the state," and that "the construction of these major viaducts, and the tunnels between Pasco and Kahlotus resulted in construction costs that represented the most expensive stretch of railroad construction ever known in Washington at $250,000 per mile."[155] The requirements below incorporate the previous eligibility determinations under Criterion C.

Viaducts may be eligible under Criteria A–D as described in Section F.1 above, and individually eligible under Criterion C for representing:

1. Modjeski's standardized design for the NP;
2. represent a GN standardized design from original period of construction of the line (1906–1915); or
3. an innovative or important design in the development of bridge engineering; or
4. the high engineering standards set for the line in terms of grade and curvature.

Any viaduct not meeting requirements for individual eligibility may still qualify as a contributing resource to the SP&S historic railway alignment if constructed during the period of significance (1906–1967) and possessing sufficient integrity to convey that association.

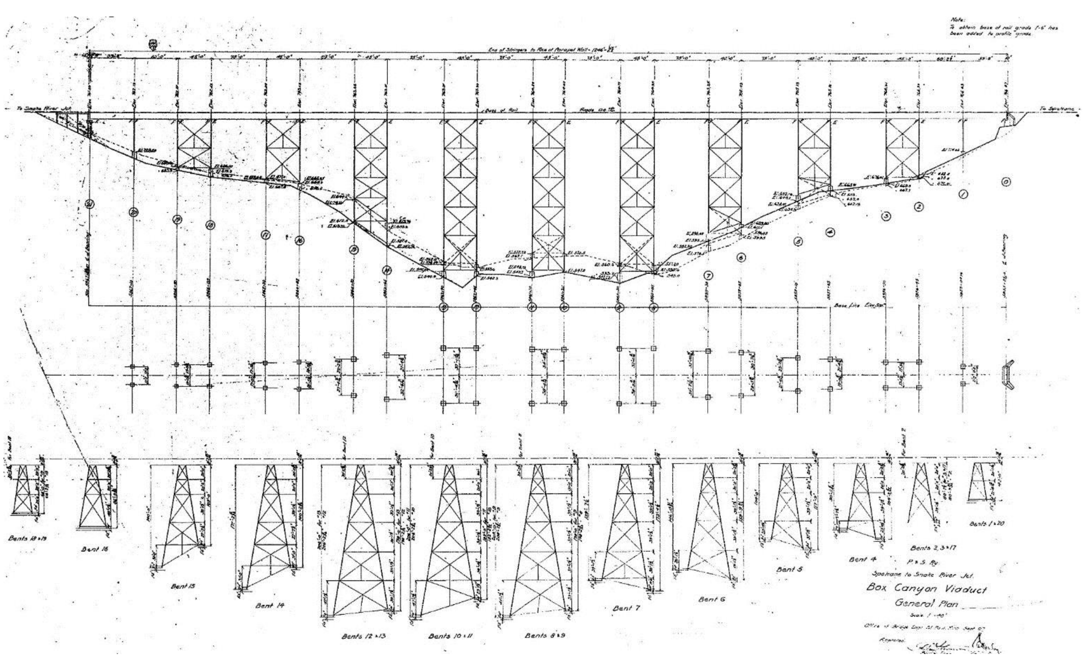

Figure 40.Box Canyon Bridge, steel tower viaduct.
Source: PNRA.

155 McMurry, "Spokane, Portland & Seattle Railway 3rd Subdivision."

F2.6 Culvert

Description

By common definition, a culvert is a drainage or tunnel structure that that allows water to flow under a road, railroad, or embankment.[156] Culverts come in several forms, ranging from simple pipes to more elaborate and substantial concrete structures with wing walls to hold back the surrounding railroad embankment (Fig. 41). Some SP&S standardized culvert structures were later converted to permit passage underneath the tracks by vehicular traffic. Common drainage culverts built during the SP&S era included corrugated metal pipes, concrete pipes, stone and masonry arches, and reinforced-concrete boxes. Only culverts that reflect greater consideration of train loads in the design, the reinforced-concrete box or arch designs, are considered under this MPD. Pipe culverts (Fig. 42), although necessary components of the line, better represent drainage features rather than bridges.

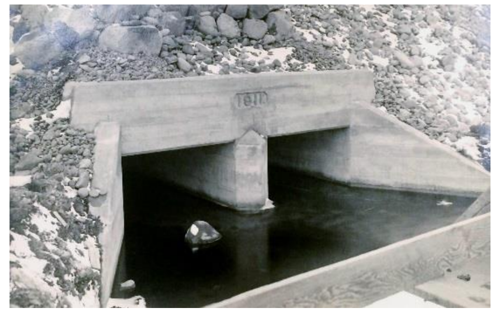

Figure 41. SP&S two-chamber concrete culvert.

Figure 42. SP&S metal pipe culvert.

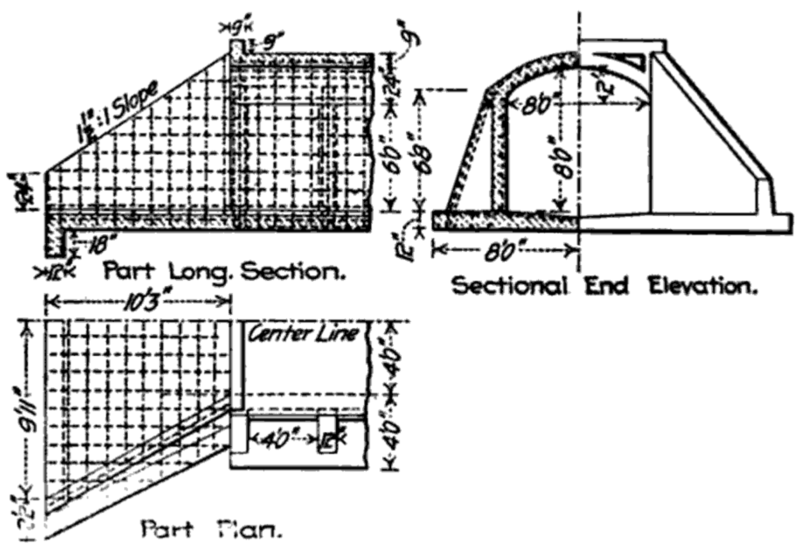

Figure 25. Standard Great Northern arch culvert.
Source: Homer Reid, *Concrete and Reinforced Concrete Construction* (New York: Myron Clark Publishing Company, 1907), 812.

Significance

Culverts fulfilled a pedestrian yet vital role for railroads. Typically less complex than bridges and easier to construct or install, culverts nonetheless offered some lessons that could be applied to bridge engineering. For example, US railroads were building culverts with concrete several years before it was used for bridges. One railway engineer lamented in 1885 that “while concrete culverts and drains are now quite common and very

[156] American Railway Engineering Association, *Manual of the American Railway Engineering Association*, 19.

satisfactory, concrete bridges are hardly known in this country."[157] Early use of concrete in culverts contributed to a better understanding of the performance of concrete box structures, knowledge that engineers later applied to the development of concrete box girders. Due to the proximity of the SP&S grade to the Columbia and Snake Rivers, the railroad made extensive use of culverts to allow small creeks and streams to pass under embankments.

Character-defining features of the culvert include the culvert structure (whether box or arch), short span, and reinforced-concrete construction.

Registration Requirements

Culverts, if the design reflected consideration of loads imposed by trains, may be eligible under Criteria A–D as described in Section F.1 above, and individually eligible under Criterion C for representing:

1. an NP standardized design from original period of construction of the line (1906–1915);
2. a GN standardized design from original period of construction of the line (1906–1915); or
3. the high engineering standards set for the line in terms of grade and curvature; for example as part of a large section of fill needed to maintain gradual grade.

Any culvert not meeting requirements for individual eligibility may still qualify as a contributing resource to the SP&S historic railway alignment if constructed during the period of significance (1906–1967) and possessing sufficient integrity to convey that association.

F3. Integrity

As outlined in National Register Bulletin 15, listing in the NRHP requires that a resource both possess significance under National Register criteria and sufficient integrity to convey its significance. Integrity is defined in terms of the seven aspects or qualities listed below. To retain historic integrity a property will always possess several, and usually most, of the aspects. Essential questions to consider when evaluating the seven integrity aspects of each bridge type include:

Location

The place where the historic property was constructed or the place where the historic event occurred.

Does the bridge lie within the original SP&S alignment? For bridges eligible under Criterion A, association with the original alignment is important. Some bridges are located within sections that significantly departed from the original alignment due to dam-related relocation projects. For evaluations of eligibility under Criterion C, the issue of location is less important.

Design

The combination of elements that create the form, plan, space, structure, and style of a property.

If the bridge represents either the NP or GN standard design commonly used in the original period of construction, are key aspects of this design still extant? For deck-plate girders, do the spans retain their original bracing, girders, and rivets? Are the important aspects of the American-system Pratt truss still evident,

[157] "Concrete Bridges," *Journal of Railway Appliances* 6 (October 17, 1885): 441.

including pin connections, steel eyebar chords, portals, stringers and beams, bracing, and bearings? Do concrete arches, slabs, and girders represent significant aspects of original design, such as open spandrels or reinforcement?

Minor modifications that do not significantly alter the basic design, such as additional tensioners, railings, and catwalks, may acquire historic significance in their own right and should be considered minimal losses of integrity.

Materials

The physical elements that were combined or deposited during a particular period of time and in a particular pattern or configuration to form a historic property.

Does the bridge retain original or replaced in-kind materials? For bridges, all materials that factor in the bridge design are especially important. For example, significant trestle materials include wood piles, framed bents, railroad ties, stringers, bracing and metal fasteners. For steel deck-plate girders, significant materials include steel web plates, flanges, and rivets.

Because railroad lines are often working entities that require periodic maintenance, replacement of features such as rails, railroad ties, deck ties, and guard rails does not necessarily constitute a significant loss of overall integrity, especially if those items were replaced in-kind.

Workmanship

The physical evidence of the crafts of a particular culture or people during any given period in history or prehistory.

Are the signs of original methods of construction evident? Important aspects of workmanship represent historic aspects of bridge design or construction, such as methods of forming connections (field rivets, pin connections) and pouring concrete, or an approach to aesthetics. The lack of ornamentation on many railroad bridges reflects the utilitarian priorities of the railroad companies at the turn of the twentieth century and a standardized design often intended for rural and remote locations. Earlier truss bridges sometimes featured decorative portal bracing, manufacturer's plates centered atop the portal bracing, and ornamental finials on vertical posts, but such elements are harder to find in railroad truss bridges built after 1900.[158]

Setting

The physical environment of a historic property.

Does the physical environment in the vicinity approximate the topography, vegetation, and built environment during the period of significance (1905–67)?

Feeling

A property's expression of the aesthetic or historic sense of a particular period of time

[158] See for example the F Street Bridge, Willapa River Railroad Bridge, Anamosa Bridge, Bauer Road Bridge, Bertram Road Bridge, Mead Avenue Bridge, accessed October 13, 2016, https://bridgehunter.com/.

How well does the bridge express the aesthetic or historic sense of the SP&S construction and operation between 1906 and 1967?

Association

The direct link between an important historic event or person and a historic property.

How direct is the link between the bridge and the historic construction and operation of the SP&S between 1906 and 1967?

Loss of Tracks

In the inactive section of the line between Pasco and Spokane now owned by the Washington State Parks, some segments have been abandoned or converted to paved trail, resulting the loss or removal of ties, rails, ballast and other track-related materials. In the case of bridges, the loss of tracks diminishes integrity to some degree but typically has minimal effect on the bridge’s ability to convey significance through its other materials, design, and workmanship. Loss of tracks may have greater effect on the integrity of setting, feeling, and association if no remnant of the alignment is visible. Evidence of the alignment such as grading, ballast, and signal equipment in most cases is sufficient to convey a connection between the bridge and the abandoned or converted railway, particularly if the design reflects the purpose to convey rail traffic, such as width and lack of road surface.

SECTION G. GEOGRAPHICAL DATA

The geographic area covered by the MPD follows the main alignment of the former SP&S line (currently partially owned and operated by BNSF (from Vancouver to Pasco) & WA State Parks (Pasco to Spokane) in Washington State that begins at milepost 9.88 in Vancouver, Washington and terminates at milepost 379 in Spokane, Washington, as shown in the map provided. The alignment passes through Clark, Skamania, Klickitat, Benton, Franklin, Adams, Whitman, and Spokane Counties.

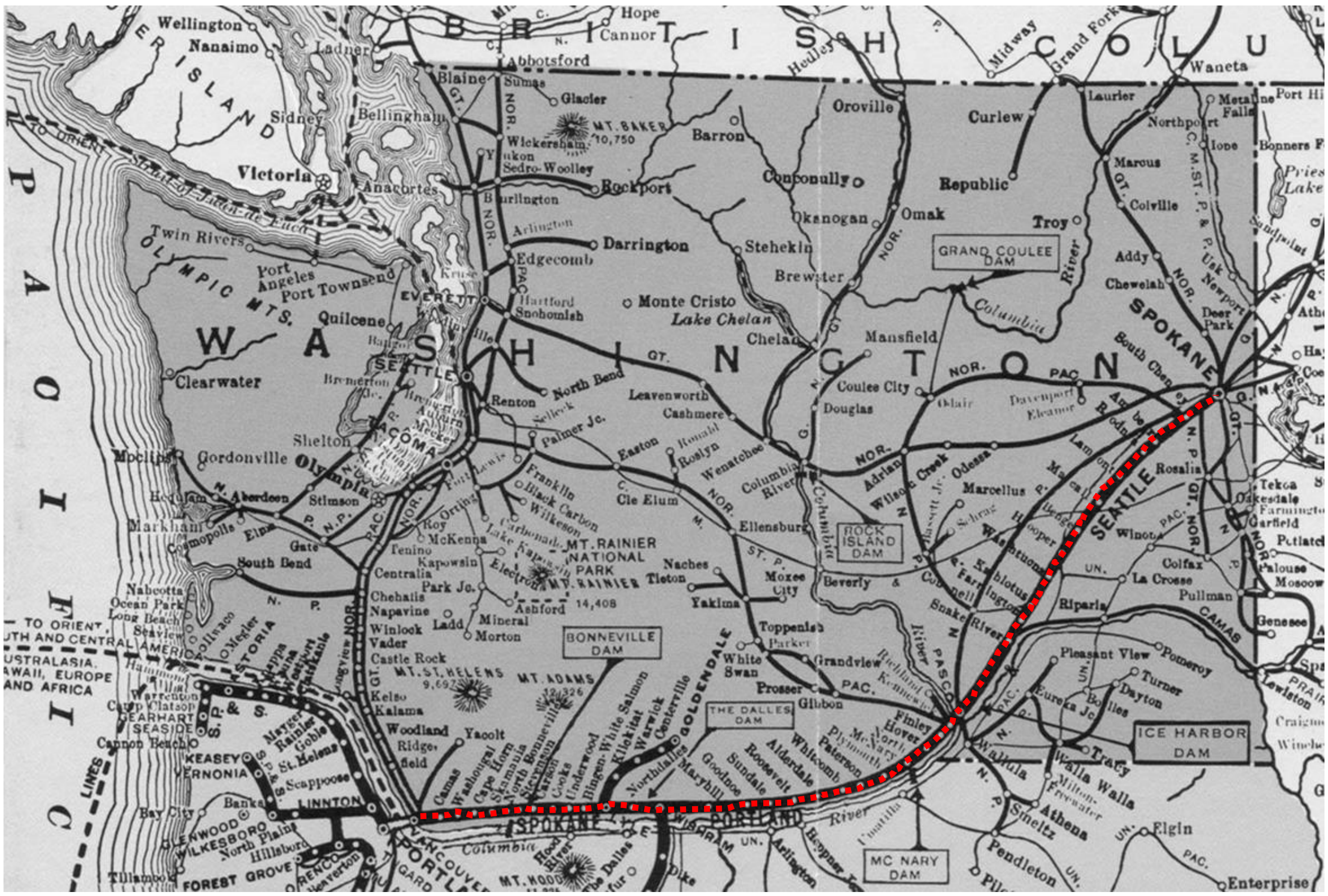

Figure 263. 1953 SP&S route map showing main line and stops between Vancouver and Spokane. Geographic area of MPD is the main line (highlighted in red).

SECTION H. SUMMARY OF IDENTIFICATION AND EVALUATION METHODS

The Bridges of the SP&S MPD project was initiated as partial mitigation for the replacement of the BNSF Washougal River Bridge, a combination deck-plate girder and pin-connected truss railway bridge built by the SP&S in 1908 that was determined eligible for the NRHP in 2015. As specified in the memorandum of agreement (MOA) among BNSF, the US Army Corps of Engineers, and the Washington State Historic Preservation Officer, the MPD provides a historic context for evaluating railroad bridges on the former SP&S

line in Washington for the NRHP, and serves as a cover document for an NRHP nomination form for the Klickitat River Bridge, a reinforced-concrete arch bridge near the town of Lyle.

The original SP&S main line ran from Portland, Oregon to Spokane, Washington and included a short branch line from Lyle to Goldendale. Later the SP&S added other branch lines in Oregon, including the Oregon Trunk, Oregon Electric Railway, and Portland, Astoria & Pacific Railroad. In the late 1980s, BNSF, formed from a merger of several rail lines and the SP&S, terminated use of the section of former SP&S track between Pasco and Spokane, and ultimately turned over the abandoned line to the State of Washington for conversion to a trail. Per the MOA, the MPD only covers main-line bridges in Washington, which represents the bulk of the original construction. Bridges between Oregon and Washington, and those used by the SP&S but owned and built by other railroads are not included.

Development of the MPD followed two parallel tracks: one focusing on the history of the SP&S; the other on the history of railroad bridge engineering as it related to the bridges SP&S built. To identify the range of bridge types built by the SP&S, the project team conducted research at the Minnesota Historical Society, Oregon Historical Society, and Pacific Northwest Railroad Archives, and reviewed secondary and primary sources. BNSF provided additional historical materials on specific bridges as well.

Research helped refine the definition of bridge and classification according to type used in the MPD. Although the MPD is organized in terms of "bridge types," the types are best considered as spans in the SP&S context, where bridges often contained two or more spans. For example, the Wind River Bridge near Carson, Washington, originally included wooden approach trestles, two deck plate girder spans, and a central Pratt truss span. Although trestles typically are not designed to allow traffic to pass underneath—a central design element of some bridges—they are included in this MPD as a common railway structure intended to carry the tracks over obstacles such as water and uneven ground. The MPD also includes culverts of a certain type, those that carry the line over named bodies of water or vehicular or pedestrian traffic, but exclude pipe culverts, which better represent drainage features rather than bridges.

After compiling a preliminary list of bridges and spans constructed by the SP&S, the project team conducted reconnaissance field survey between Vancouver and Spokane to better study the various bridge types. Because of the remote location of sections of the abandoned line, site inspection of some bridges was not feasible. The intent of the fieldwork was to gain a more complete understanding of each bridge type rather than comprehensive inventory.

Following the reconnaissance survey, work focused on identifying significant historical themes to pair with developments in bridge design and construction during the SP&S era. Two distinctive themes emerged from the research. First, because the SP&S was formed by the GN and NP, it served as an important case study of corporate collaboration in the railroad industry. Second, the commitment to high engineering standards (low grade, minimal curvature, high speed) on the line provided another comparative line of analysis. Hill invested significantly in a well-engineered railway in hopes of gaining a competitive advantage but at the cost of debilitating debt. In its early years, the SP&S had a difficult time gaining profitability, and ultimately, BNSF abandoned the section between Pasco and Spokane, despite its better engineering standards, for an older, parallel NP line. In this respect, the engineering standards themselves are a significant aspect of the SP&S history, and the history of the larger railway industry. Evaluations of bridges for the NRHP are thus considered primarily in terms of these two themes.

Evaluation of the bridges also considers significance relative to the larger history of railroad bridge engineering. The historic bridge context is organized by bridge material, which provides a chronology based on the transition from wood to steel and the emergence of concrete in railroad bridge design, to provide a backdrop for the types of bridges built by the SP&S and a basis for assessments under NRHP Criterion C.

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