Verrugas Viaduct and its Reconstruction, Peru, South America

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ABSTRACT: Henry Meiggs of San Francisco, a fugitive from the U.S. Government, signed a contract with the Peruvian Government in 1869 to build a 136 mile railroad connecting Callao (main port of Peru) and Lima (the Capital about 7.5 miles away) with Oroya (a small town close to the mining district of Cerro de Pasco) in six years for U.S. $25,875,000. Mr. Meiggs was the biggest employer of U.S. engineers next to the U.S. Army at that time. The Verrugas Viaduct was 51.8 miles from Lima and 5,850’ above sea level in the Andes mountains. The wrought iron viaduct was designed, fabricated and shipped by the Baltimore Bridge Company via land and sea to Callao from where it was transported to the site on rail and mules. The viaduct consisted of four Fink truss spans, three of 100’ in length and one 125’ long. The three piers were 146’, 252’, and 179’ in height; and were all 50’ wide. The total length of the viaduct was 575’. The fabricator had planned to frame the spans in the bed of the gorge and lift them bodily into place. However, Leffert L. Buck, the Resident Engineer, devised an ingenious erection scheme, and the viaduct was opened to traffic on January 8, 1873. In March 1889, heavy floods and rock slides in the gorge pushed the central pier causing collapse of the bridge. Mr. Buck was retained for the replacement bridge and he designed a cantilever bridge with two piers, two side spans of 140 ft. each, and a central opening of 235 ft. The existing abutments were used with the same span of 575 ft. Construction started on July 1, 1890, and the bridge was completed on January 1, 1891. This paper describes details of both bridges, difficulties encountered during their constructions, and people connected with them.

1 INTRODUCTION

In December of 1869, Henry Meiggs, an American entrepreneur and railroad contractor, signed a U.S. $25,875,000 contract with the Government of Peru in South America to design and build a 136 mile railroad between Callao, Lima and Oroya through the Andes Mountains, generally known as Oroya railroad (Figure 1). The contract was to be completed in six years. Callao was the port city, Lima was the Capital of Peru, and Oroya was a small town in the mining district of Cerro de Pasco.

Table 1 (New York Times, 1873b) conveys some idea about the magnitude and difficulty of the work where the grades were limited to a maximum of 4 percent, and the minimum radius of curves to 352 ft. (Rand and Owen).

The Verrugas Bridge or Viaduct was oriented east-west and situated 51.8 miles from Callao. The mean elevation above the sea level was 5,836 ft. The gorge which it crossed was for a very small stream which discharged into Rimac River, about 800 ft. north of the bridge. The width of the gorge was 525 ft. and the depth at the center was 252 ft.

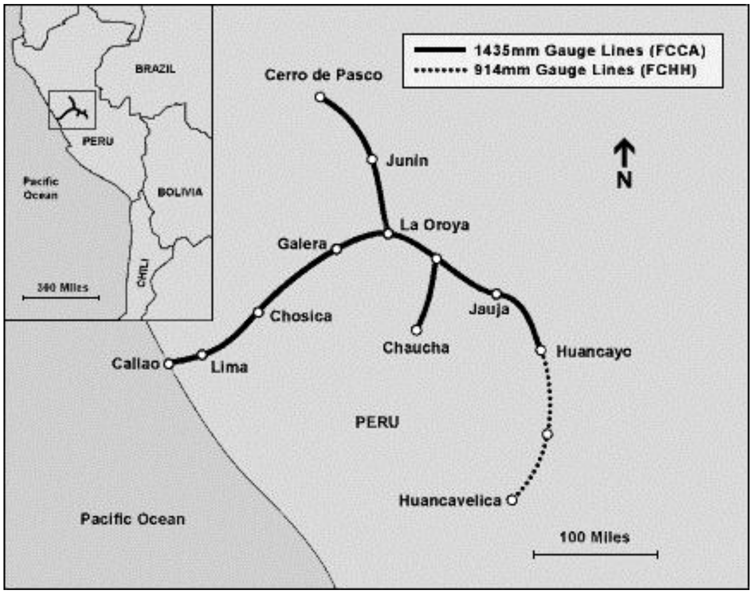

Figure 1. Map showing route from Callao to La Oroya

Table 1. Distances and Elevations along the railroad.

From Callao to	Miles	Elevation, Feet.
1. Lima	7.50	448
2. Quiroz	11.75	808
3. Santa Clara	18.50	1,312
4. La Chosica	33.50	2,800
5. Cocachara	44.75	4,588
6. San Bartolome	46.75	4,905
7. Verrugas Viaduct	51.75	5,840
8. Surco	55.75	6,655
9. Matucana	62.25	7,788
10. San Mateo	77.50	10,530
11. Summit Tunnel	104.50	15,645
12. Yauli	119.00	13,420
13. La Oroya	136.00	12,178

Meiggs selected Baltimore Bridge Company (BBC) of U.S. to design and fabricate the bridge. Because of the difficulties in designing and erecting a bridge in a remote location, he requested assistance from Walton White (W.W.) Evans of New York who was a consulting engineer to the Peruvian Government. Charles H. Latrobe was Assistant Engineer of BBC in charge of design.

Evans was familiar with the wrought iron viaducts being built in the U.S., and was sure that such a viaduct would work for Verrugas. He prepared several schemes, and asked for plans and cost estimates for these schemes from the BBC. To reduce the span lengths of trusses, he designed 50 ft. long trestle piers. The final scheme that was accepted by both Evans and BBC for fabrication had four Fink trusses (3 of 100 ft. span and one of 125 ft. span) and 3 piers (each 50’ long) making a total bridge length of 575 ft. The heights of three piers were 179 ft., 252 ft., and 146 ft. starting from west to east (Figure 2, Railroad Gazette, 1873).

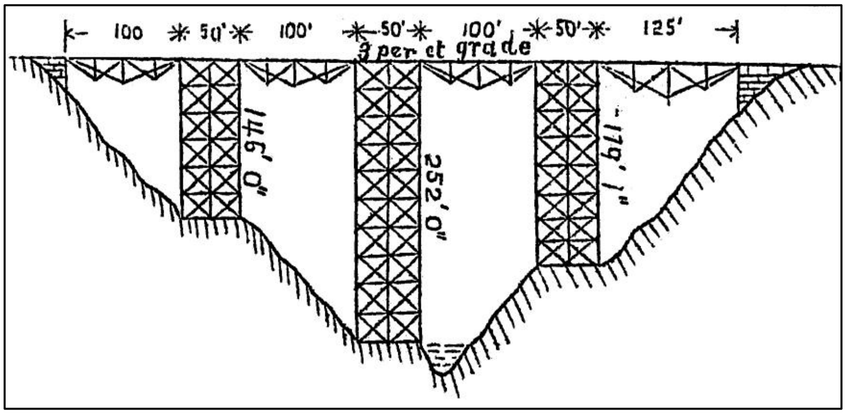

Figure 2. Verrugas Viaduct Elevation.

2 ORIGIN OF IRON RAILWAY VIADUCTS IN U.S. (GREINER, 1891)

It is interesting to note that Benjamin H. Latrobe, father of Charles H. Latrobe, was the first person in the U.S. to promulgate the use of iron viaducts for railroad bridges. He was associated with the Baltimore & Ohio Railroad; and two of his assistants Wendel Bollman and Albert Fink developed distinct iron trusses that bear their names.

It was in 1851 that Bollman designed Carey Street trestle over B&O RR tracks in Baltimore that had iron diagonals connecting successive bents. Albert Fink designed the first cast iron viaducts for the B&O RR in 1852 known as the Buckeye and Tray Run viaducts, and they were built in early 1853 (Figure 3, Greiner, 1891).

3 VERRUGAS VIADUCT

3.1 *Site*

The earth in the vicinity of the bridge was sort of concrete. The westside was the hardest, and was composed of water-washed granite, boulders, cobblestones, and closely packed pebbles. It required blasting for its removal. The eastside was not quite so hard, but had a texture resembling of "blue stone" of which curbs were made in New York City around 1870s. It was very compact, and provided a good foundation in a dry climate at Verrugas. The sides of the gorge were very rugged.

People working in this area were getting sick with a mysterious disease called "Verrugas" which covered the body of its victims with painful blood boils. It was found that this disease

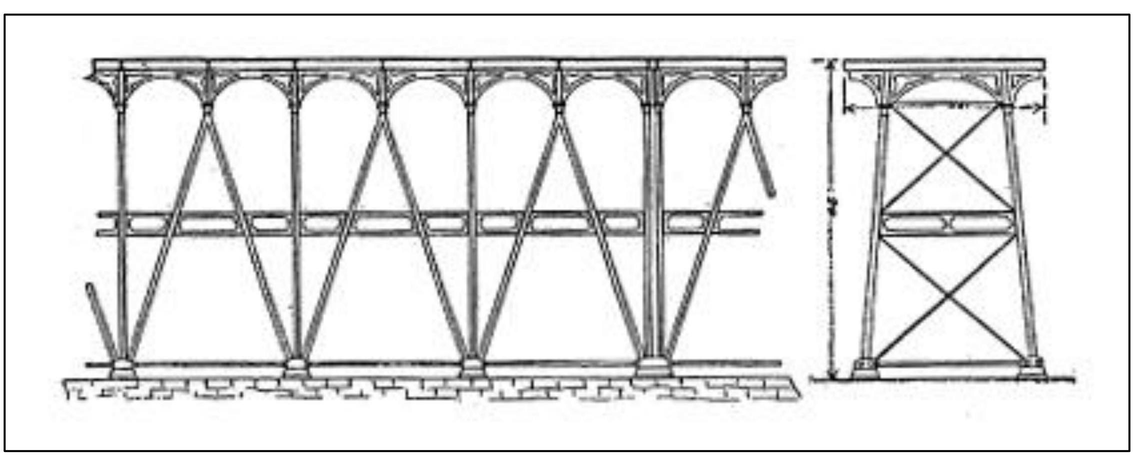
Figure 3. The first iron viaduct in the U.S. (1853)

was active between the height of 3,000 ft. and 6,600 ft. above sea level. Foreigners to this locality were more susceptible to catching the disease if they stayed for more than 24 hours; and if it was not attended to in a timely manner, it was causing deaths of some patients. Meiggs had provided extensive quarters and accommodation for his staff and workers at great expense so that men got immediate medical attention at the first sign of the disease, but there was no sure cure (Bogue, 1876/7).

Skilled labor was difficult to obtain at this location as no similar bridge and tunnel projects were built in Peru up to that time. The labor turnover was great due to death or injuries. Most of the unskilled workers were Chinese, Chileans, and Peruvian Indians. Between 1860 and 1872, more than 80,000 Chinese workers were shipped from Macau to Peru in 192 vessels (New York Times, 1873a). About 30 percent of these workers died in shipwrecks, or due to sickness or suicides. The best labor that could be made available or used was that of runaway sailors who were good at climbing and rigging, but not skilled as mechanics or ironworkers for erecting bridges.

3.2 *Bridge Dimensions*

The bridge had three wrought iron piers, four wrought iron spans, and two stone abutments which were 42 ft. wide. The description of four spans is already given before.

Each pier was composed of three transverse bents with four columns in each bent. Thus, there were 12 columns in each pier. Each column was provided with a cast iron shoe supported on a granite pedestal. The height and area of each pedestal were calculated based on the load and the foundation material. The piers were built up in sections of 25 ft. height, and connected by cast iron joint boxes to which the columns were bolted.

The piers at the grade measured 15 ft. x 50 ft. All 12 column legs battered transversely one half in and one half out, as they descended. The outward batter was 1 in 12, but the inward batter was variable to bring the converging legs together at their feet. Each group of four columns formed an inverted M transversely. Longitudinally, the piers were vertical, holding their size of 50 ft. from top to base. The pier legs were covered by heavy cast iron shoes, planed to a true surface, and were anchored to the rock or base blocks. All bearing surfaces were planed and truly dressed (Engineering, 1872a).

At each joint there was a casting with a tenon on each end. This casting formed the joint connecting the pieces of the column, and intersections of the column with the longitudinal and transverse struts, and the tie rods by which the pier was braced. All horizontal struts consisted of double channels. All columns were proprietary “Phoenix” columns.

The bridge was on a 3 percent grade rising from west to east. However, with the use of shim plates, all wall plates, bridge seats, and roller beds were made level.

3.3 *Erection of the Bridge*

The Baltimore Bridge Company had planned to erect the 125 ft. span on the western end using wooden falseworks. It intended to bodily raise the two center spans of 100 ft. each through a height of 252 ft.

This meant that BBC had to erect the 252 ft. high pier first by means of derricks, which would rest on the top of a 25 ft. section, and raise the pieces to their proper places, the derricks being shifted to the top of each section when completed, to serve similarly on the section above. This method would have involved the lowering of each piece to the bottom of the valley, which would then be raised on the pier. Since all the bridge components were delivered by railroad cars at the top of the bridge, this procedure did not make much sense.

Figure 4 shows side elevation of erection work in progress along with cables, temporary span, and temporary bents, at the two abutments, etc. Figure 5 is a transverse view of the top section of one of the piers, showing end view of temporary span (Buck, 1876/7a)

BBC had sent two foremen, Mr. W.H. Tipton and Thomas Flanagan from the U.S., who were employed by Meiggs to manage the erection, with Tipton being in control of the erection. BBC plan of erection was given up, and a new plan developed by the Resident Engineer L. Lefferts Buck was adopted in consultation with Tipton. Buck presented a paper to the American Society of Civil Engineers (ASCE) in December 1875 describing the erection of the Verrugas Bridge

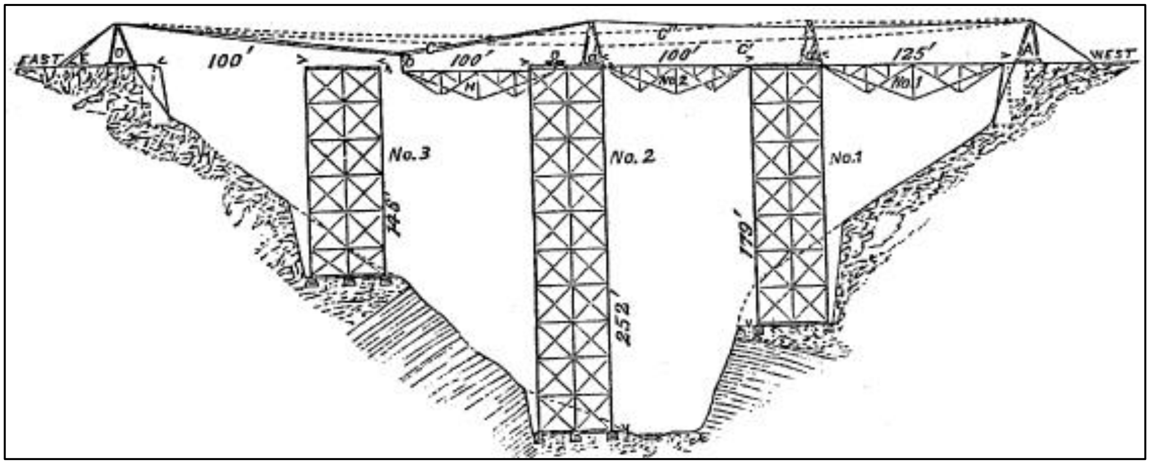

Figure 4. Erection of Piers 2 and 3 and Spans 2, 3, and 4.

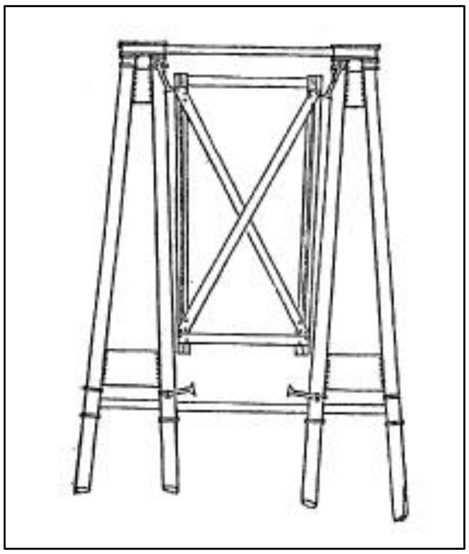

Figure 5. Transverse View of Pier

(Buck, 1876/7-a). The procedure described below is compiled from four different sources (Latrobe, 1873; Cleemann, 1873; Buck (1876/7a and 1876/7b)).

Two 30 ft. high wooden bents or towers A and D were erected on the road bed beyond the abutments; and between them were suspended two sets of wire cables sufficiently high for the lowest point of the curve to clear the top of the bridge, one set vertically over each truss line. The ends of the cables were secured into the ground. Each cable was supplied with a traveler ‘b’.

3.3.1 *Erection of Piers:*

Two columns with struts and diagonal rods connecting them were put together on the graded roadbed at the western end where the railroad cars delivered the pier components. They were attached to travelers on the cables by means of tackles, so that they could be raised or lowered. Once the columns assemblies were launched into the air, a rope attached to the traveler served to regulate their position so as to be directly over the point of the pier where they were to be lowered by means of the tackle. Connections were made with the other columns so that a 25 ft. high section of pier with 12 Phoenix columns was completed. The same procedure was repeated for each pier so that it reached its design height. The maximum design pressure on the base plates of pier columns was 121 pounds per square inch (Engineering, 1872).

To facilitate unloading and error-free erection, each pier was painted with a different color. Pier 1 was painted red, Pier 2 black, and Pier 3 green. The piers were assembled with screws and nuts to avoid riveting due to the lack of skilled labor. After the initial learning curve, the piers were constructed in 42 days.

3.3.2 *Column Stresses:*

There were two types of "Phoenix" columns, six-segment and four-segment. The six-segment column had a cross-sectional area of 20 sq.in. and when fully loaded, had a stress of 4,612 pounds per square inch (psi). The four segment column had a cross-sectional area of 13 sq.in. and a design stress of 3,127 psi under full load (Latrobe, 1873).

3.3.3 *Erection of Truss Spans:*

This was the most difficult and tricky operation in erection of the bridge. In the bottom of the gorge where the 252 ft. high middle pier was planned, there was a large quantity of loose material thrown down in making deep cuts in mountainside to the made the roadbed at each end of the bridge. He was concerned about the difficulty of supporting any falsework on this material for the iron truss spans on either side of this middle pier. This prompted him to turn his attention to development of a scheme using a temporary span to erect the three identical 100 ft. span Fink Trusses.

On completion of all three piers, and the 125 ft. span, the cables were strengthened by additional wires to prepare them to support heavier loads. Towers or bents, a' and a", were placed on Piers 1 and 2 to reduce the span of the cables as shown in Figure 3. c' and c" are the respective positions of the cables. Two temporary or auxiliary Fink trusses made from wood and iron were built to support the permanent iron trusses while they were being put together. H represents the two temporary Fink trusses. They were braced together at such a distance apart so that when the permanent iron trusses were put outside of them, the latter would be in their final position.

The temporary trusses were then attached to the wires at the middle points and at ends, and swung over their intended positions, lowered, and connected to the piers. Thus, they became the falsework for the permanent iron spans.

When the iron trusses had been put together, so as to support themselves, the upper bracing of the middle pier was taken out, and the temporary truss pushed through (suspended from the cables) to serve in a similar manner for the next span, the diagonal bracing of the permanent span being put in as rapidly as the progress of the wooden one left the space clear.

It took only two days to move the wooden span from one opening to the next, and only 16 hours to complete the iron one afterwards.

3.4 *Erection Time*

Pier No. 1, 179 ft. in height was erected in 18 days. Pier No. 2, 252 ft. in height in 12 days, and Pier No. 3, 146 ft. in height in 12 days. In the meantime, Span No. 1, 125 ft. in length was erected on scaffolding in 5 days, and two strong wooden Fink trusses to act as temporary trusses were fabricated which were then going to be used for the erection of three 100 ft. spans.

Span No. 2 was raised, and swung into position in 22 hours. The wooden tower was moved from Pier 1 to Pier 2, and Span No. 3 was swung into place in 16-1/2 hours. Span No. 4 between Pier No. 3 and the east abutment was swung into place in 18 hours.

It took few days to lay the floor and the permanent tracks. The total time consumed in the erection of Verrugas Viaduct, including all preparations, was 3-1/2 months. The actual time used in raising operations was 55 working days.

No one was seriously injured. One piece of column broke loose from the strap, fell down, and it was badly damaged. It was taken to Lima for repairs, and reused in such a way as not to have any effect on its structural strength or properties.

3.5 *Weight of the Bridge (Table 2)*

The bridge members were made of wrought iron and the joints in compression were made of cast iron. The connections were made using screws and nuts to avoid riveting.

Table 2. Weight of individual bridge components

Member	Height or Length in feet.	Weight in pounds Wrought Iron	Cast Iron	Total weight in pounds	Weight per linear feet.
Pier 1	145	250,724	37,112	287,836	1,985
Pier 2	252	442,494	52,261	495,755	1,962
Pier 3	178	295,397	39,338	334,735	1,880
Span 1	125	62,195	7,037	69,232	N.A.
Span 2	100	42,776	7,055	50,831	N.A.
Span 3	100	42,776	7,055	50,831	N.A.
Span 4	100	42,776	7,055	50,831	N.A.
	Total	1,182,138	156,913		

Total weight of the bridge = 1,339,051 lbs or 670 U.S. tons (Latrobe, 1873).

3.6 *Cost of the Bridge*

The cost was estimated at U.S. $360,000 including fabrication, shipping, sending of 2 foremen to Peru, and labor and other costs (Engineering News, 1889).

3.7 *Opening of the Bridge*

A rendering of the bridge with a train on it is shown in Figure 6 (Engineering, 1872). On January 8, 1873, a train pulled by a locomotive named “Matucana” was sent from Lima with a number of excursionists and company officials and it crossed the bridge safely and without any incident. Many officials, not sure of the strength of the viaduct to support a locomotive with railroad cars, decided not to participate. The entire entourage crossed the viaduct again, and made the return trip to Lima safely. President Pardo of Peru accompanied by members of the Peruvian Congress and representatives of foreign nations living in Lima visited the Verrugas Viaduct, and they were treated with great hospitality by John G. Meiggs, brother of Henry Meiggs (Engineering, 1873).

4 COMPARISON OF VERRUGAS VIADUCT WITH OTHER VIADUCTS

In 1875, Ernest Pontzen, an Austrian Engineer wrote a paper comparing the Verrugas Viaduct with other prominent viaducts of Europe. At that time, the European bridges used riveting to

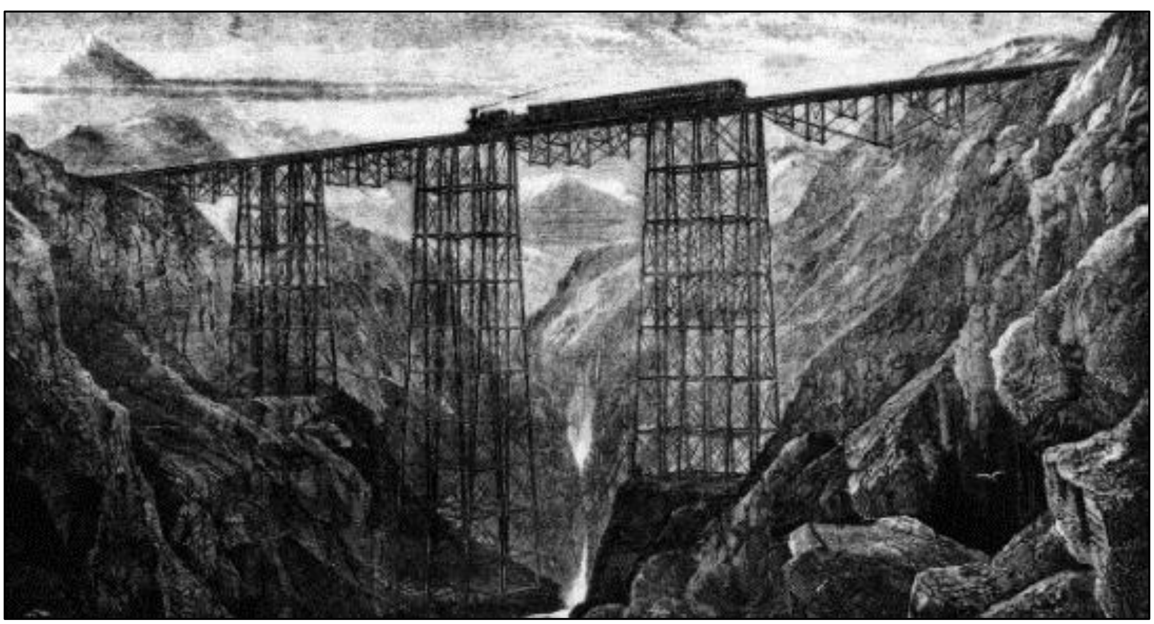

Figure 6. Rendering of Completed Verrugas Viaduct

connect truss members. American practice of that period used pins instead of rivets, and then used bolts and screws to make the connection. Field riveting in a remote location such as the Andes Mountains without riveting equipment and trained labor force was almost impossible or extremely costly.

He noted that the workmen that Mr. Buck employed to erect the Verrugas Viaduct were mostly deserted sailors and not blacksmiths or machinists. They were good at climbing and hoisting. Even though the work was at a considerable height on unsteady scaffolding, they were very efficient in putting the bridge together under proper guidance.

Mr. Pontzen cited several examples to demonstrate superiority of pin-connected bridge over riveted and latticed bridges (Pontzen, 1876).

Mr. F. de Garay, a Mexican engineer, read a paper at a meeting of the Societe des Ingenieurs Civils at Paris in 1889, and compared European versus American bridges using Verrugas Viaduct as an example. He said that three 100 ft. spans of Verrugas Viaduct were erected in 16 hours each by a gang of 50 men at a height of 250 ft. above the ground (Engineering, 1891b).

On the same Lima-Oroya Railroad four other bridges of 100 ft. spans were constructed. Two were erected by Englishmen, and the erection lasted over two months. When test load was put on them, one bridge fell to the bottom of the ravine, the second one gave way during the trial and rested on the scaffolding below which was kept as a precaution. The third bridge was a riveted girder bridge of French construction. It took one-month of erection time and passed the load test without any problem. The fourth bridge of Fink Truss System was an American bridge. It took five days of erection time and passed the load test.

The European bridges each weighed 125 tons for a 100 ft. span, the American weighed only 67 tons for the same span.

5 DESTRUCTION OF THE VERRUGAS VIADUCT

The destruction of the Verrugas Viaduct took place on March 23, 1889. The summer season was an especially rainy one in the mountains along the line of the Oroya Railway. As a result of torrential rains on that day, the narrow ravines became raging streams, and tore away loose materials such as trees, stones, boulders, earth, etc. and came rushing down into the main valley of the Rimac River sweeping before them everything they encountered.

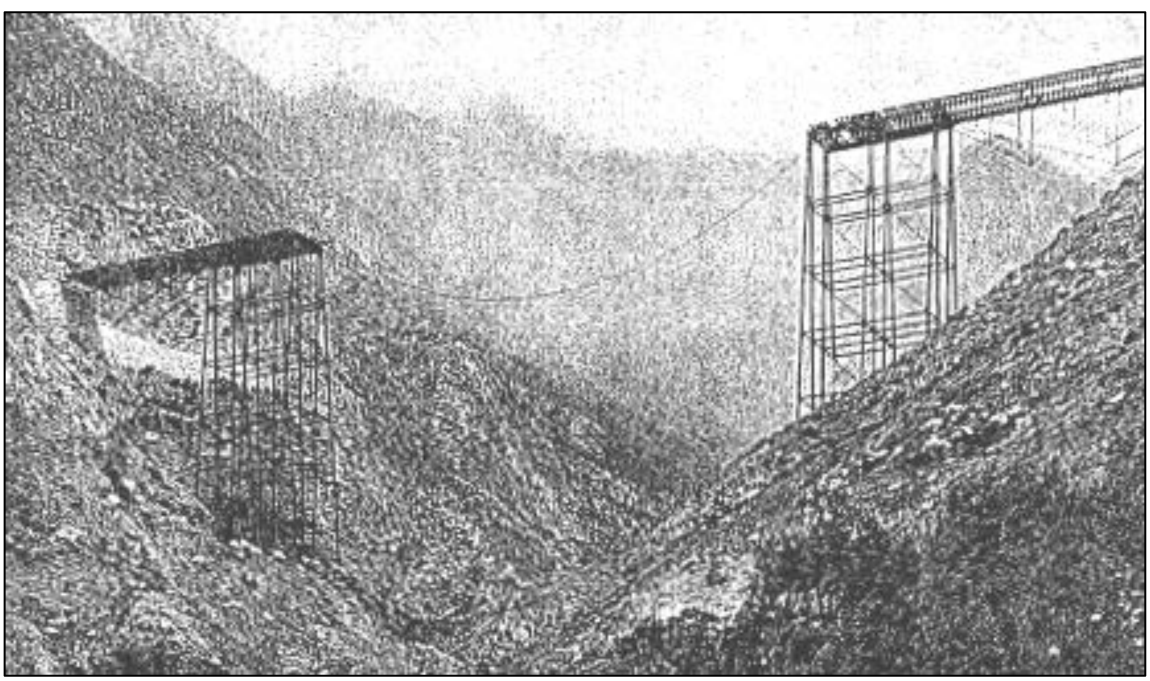

Figure 7. Unsupported rail spanning between Piers 1 and 3 after the accident.

This mass estimated at 8,000 tons pushed out the central pier in its path (Engineering and Building Record, 1889). The wall that was built to protect the central pier offered no resistance. The two 100 ft. adjoining spans that were resting on the central pier also collapsed. The central pier and the two spans were found one-fourth mile downstream after the floods subsided. Figure 7 shows the unsupported rail in the form of a catenary spanning between piers 1 and 3 (Engineering, 1891a). The masonry work for the piers was not damaged when the center pier was washed away.

6 BANKRUPTCY OF PERU AND FORMATION OF SYNDICATE OF DEBTORS

In July, 1875, Mr. Meiggs wrote a letter to President Pardo of Peru summarizing the status of his 7 contracts to build railways in Peru stating that because the Peruvian government had not succeeded in raising funds for the railroad construction, it was impossible for him to continue in such a ruinous and disastrous position (Engineering, 1875).

Since 1876, Peru had failed to pay any interest on its external debt to bondholders in England. The war with its neighbor to the south, Chile, between 1879 and 1883, bankrupted the country. Peru also lost about 775 miles of railroads already built by cession of the territory containing them to Chile (Engineering News, 1887b). The railroads were built by the Peruvian government with money obtained by the sale of bonds in England.

A syndicate of bondholders was formed to assume the national debt of Peru in return for huge concessions. The general principle of this arrangement was that Peru was unable to meet its financial obligations, and had agreed to hand over to its foreign creditors certain properties to administer for their own benefit (Engineering News, 1887c). The syndicate included Michael P. Grace of W.R. Grace & Co. of New York and two other Englishmen, Sir H.W. Tyler and G.A. Ollard. Michael Grace’s brother William R. Grace was a Mayor of New York from 1881-1882, and a partner in the firm of W.R. Grace & Co. Peru assigned to the bondholders for a term of 66 years some 769 miles of railways, telegraph and telephone facilities so that these bondholders and their representatives may extend and maintain them (Engineering News, 1887a).

The foreign debt of Peru when the bondholders’ contract was approved on October 25, 1889 was $160 million. The internal debt consisted of $100 million with interest. The bondholders’ contract had nothing to do with the internal debt (New York Times, 1890).

7 RECONSTRUCTION OF THE VERRUGAS VIADUCT

At the time of the collapse of the Verrugas Viaduct, the Oroya Railway was being managed by the Syndicate headed by the Grace brothers – William R. and Michael P. Grace. The latter obtained approval from the bondholders’ consulting engineers in England, Messrs. Levesey and Son, to select Leffert L. Buck to design the new replacement bridge because of his reputation and familiarity with the site (Engineering, 1891a).

Buck designed a cantilever bridge with two piers, the end spans acting as anchor spans and the center span as a suspended span. He also used the existing piers to support the new work. In Figure 8 the full lines show the elevation of the new Verrugas Viaduct, and the dotted lines the position of piers of the old viaduct (Engineering News, 1891). The new bridge was symmetrical about the centerline.

7.1 *Bridge, Dimensions and Details*

The Center span was 235 ft. between piers, the two side spans were 140 ft. each, and the length over piers 30 ft., making a total length of 575 ft. between end pins. The cantilevers were 30 ft. deep at the piers, and 15 ft. at the ends. The bearings for the end pins were anchored to the masonry abutments by four 1-3/4 inch diameter 12 ft. long bolts with anchor plates at the ends. The piers consisted of four columns braced together, and were 17 ft. x 30 ft. at the top. The upper piers had two legs of unequal heights (109’-6” and 122’0”), and the lower pier was 142’-6” high. The height from the lowest point of the gorge to the top of the rail was 250 ft. The

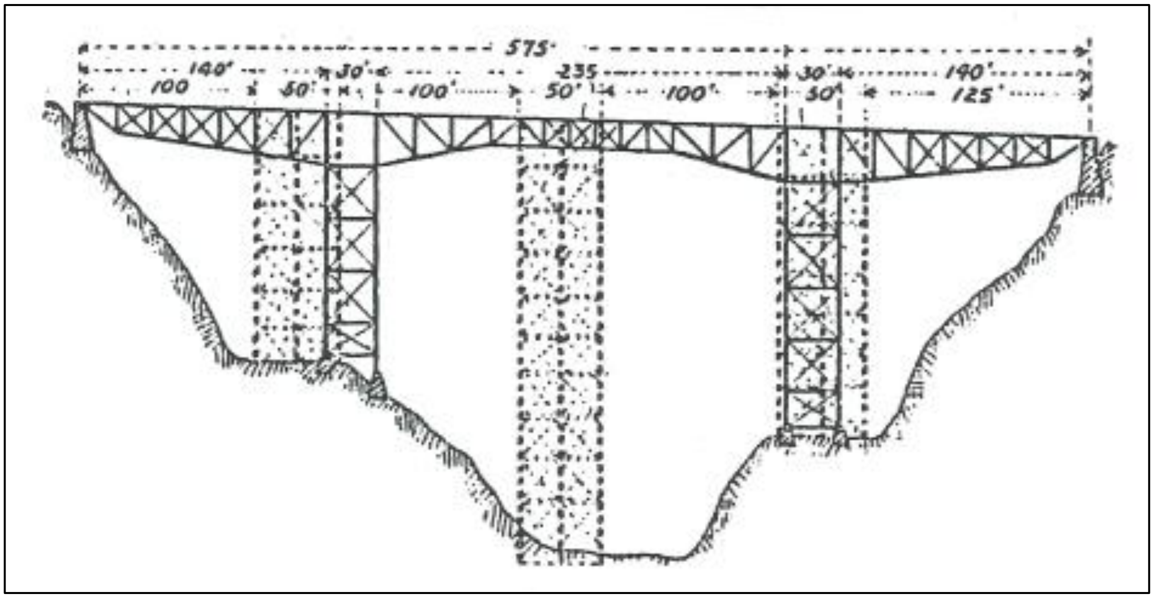

Figure 8. Comparison of Piers of new Verrugas Viaduct (solid lines) and old viaduct (dotted line).

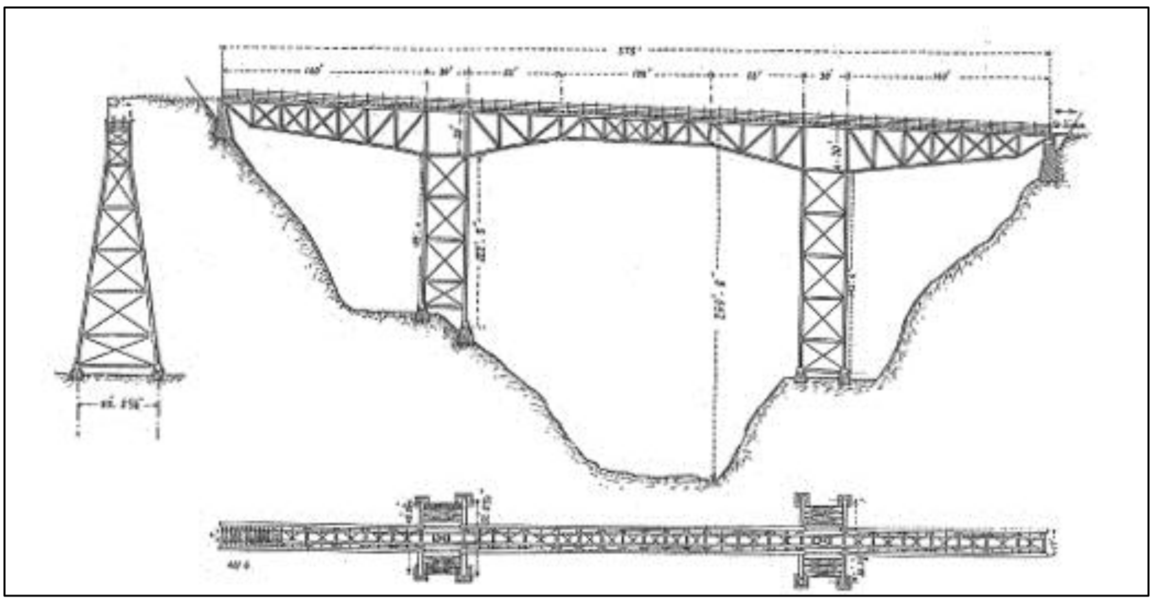

Figure 9, Plan, elevation and transverse view of new Verrugas Viaduct.

width was 17 ft. center to center of girders. There was a single track over the bridge, and a handrail was fitted on each side to prevent anyone from accidentally falling down.

Because the railroad was on a 3% grade, the westside (Lima and the coast) was at an elevation of 5826.16 ft. and the Aroyo side (or the eastside) had an elevation of 5,845.41 ft. above sea level.

Figure 9 shows the plan, elevation, and transverse view of the new Verrugas Viaduct (Engineering, 1891b). The details of shore arm with abutment, and of tower with lower arm of cantilever are presented in Figure 10 (Engineering News, 1891).

7.2 *Award of Fabrication and Erection Contracts*

Michael P. Grace invited bids from fabricators in the U.S. based on the drawings prepared by Buck. The fabrication contract was awarded in April 1890 to the New Jersey Steel and Iron Company, Trenton, NJ. A separate contract for shipment of the bridge components, and

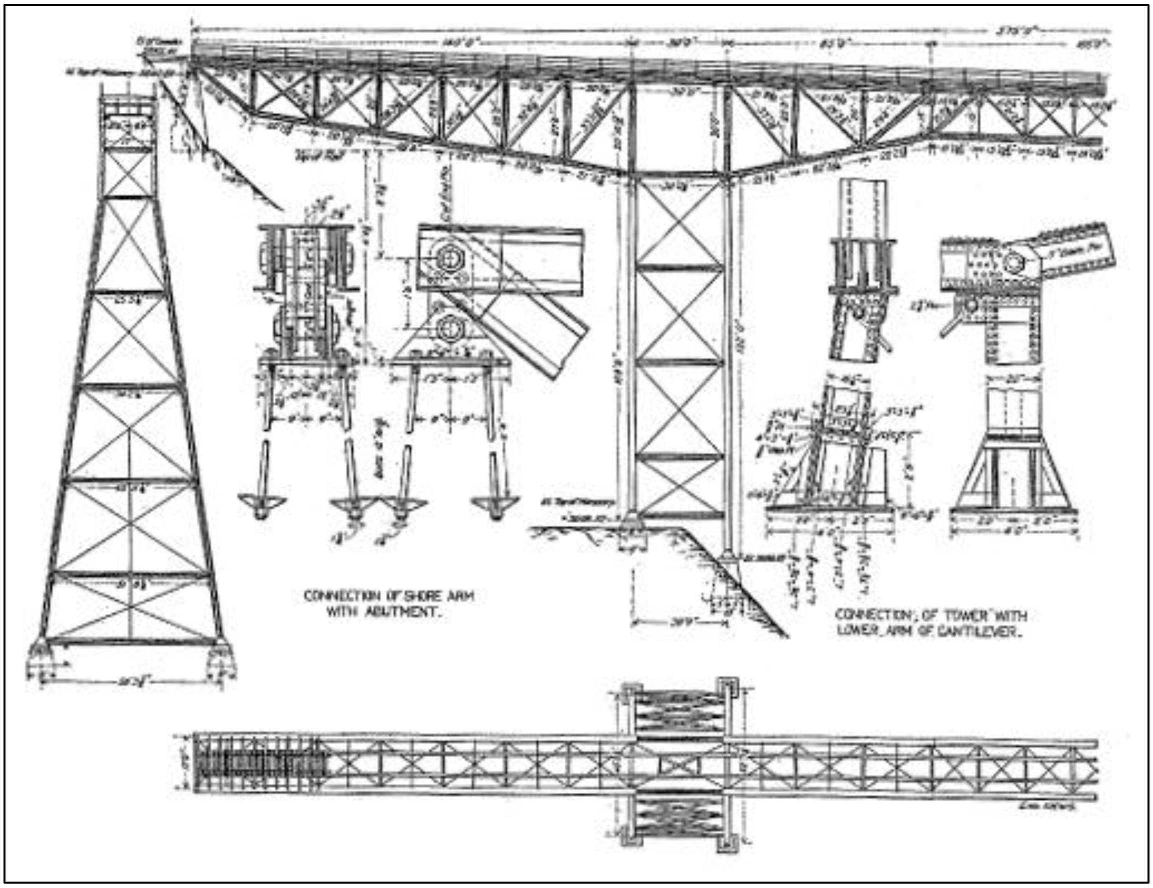

Figure 10. Details of new Verrugas Viaduct.

erection of the bridge was awarded to Cooper, Hewitt & Co. of Trenton, NJ (Engineering News, 1890).

7.3 *Bridge Erection (Engineering, 1891)*

The first shipment of bridge iron members and plant arrived at the site on July 1, 1890. This new bridge was riveted as opposed to the original bridge which was pin connected and bolted. Cooper, Hewitt & Co. sent from the U.S. riveting and erection crews to assemble and erect the bridge. Additional help was provided by runaway sailors of all nations who were picked up at the port city of Callao, and sent to the Verrugas Viaduct site by train. There was a high turnover of these sailors.

L.L. Buck had sent two of his men to supervise the construction; Albert S. Riffle was Engineer-in-Charge of construction, and H.H. Dougherty, the foreman. Mr. P.A. Frazer acted as the Superintendent of Oroya Railroad, and he represented the owner, Michael P. Grace, at the job site.

Engineering work related to the preparation of new foundations, and erection of new towers, and anchor and suspended spans was supervised by Riffle and Dougherty. There was no cure found for Verrugas sickness or fever in 1890. Riffle stayed on the ground during the period the construction work was going on. Both Riffle and Dougherty took the risk of getting infected by the Verrugas sickness.

Seventeen of the 20 staff members were stricken with the Verrugas sickness, and 9 of these 17 men died. During the six month construction period there were 100 to 200 workers on payroll, and many of them either left or fell victim to the sickness.

The following procedure for bridge erection was adopted.

1. The scaffolding was built between the old piers and the abutments, and the new towers were constructed around the old piers. The pedestals of masonry on which the towers rested were built of granite laid in Portland cement (Figure 11).
2. The old Fink trusses with deck spans were removed, lowered, and disposed of.
3. The shore arms (anchor spans) of the cantilever bridge were then built and anchored to the abutments.
4. Using a traveler on each side, the cantilever arms of the middle span were built towards the center of the bridge (Figure 12), and the final connection made (Figure 13).

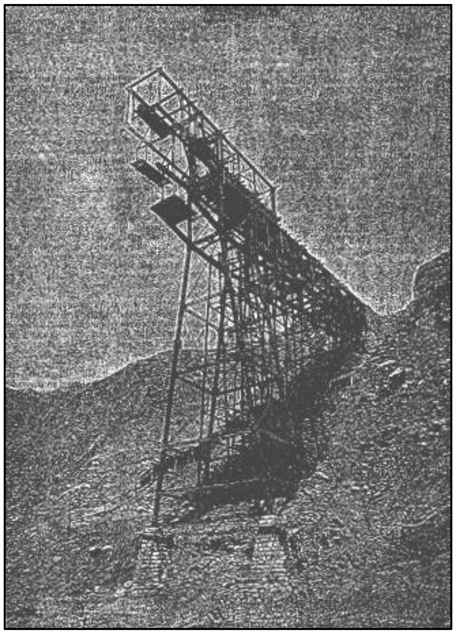

Figure 11. View showing newly built west pier and use of traveler to build out cantilever span.

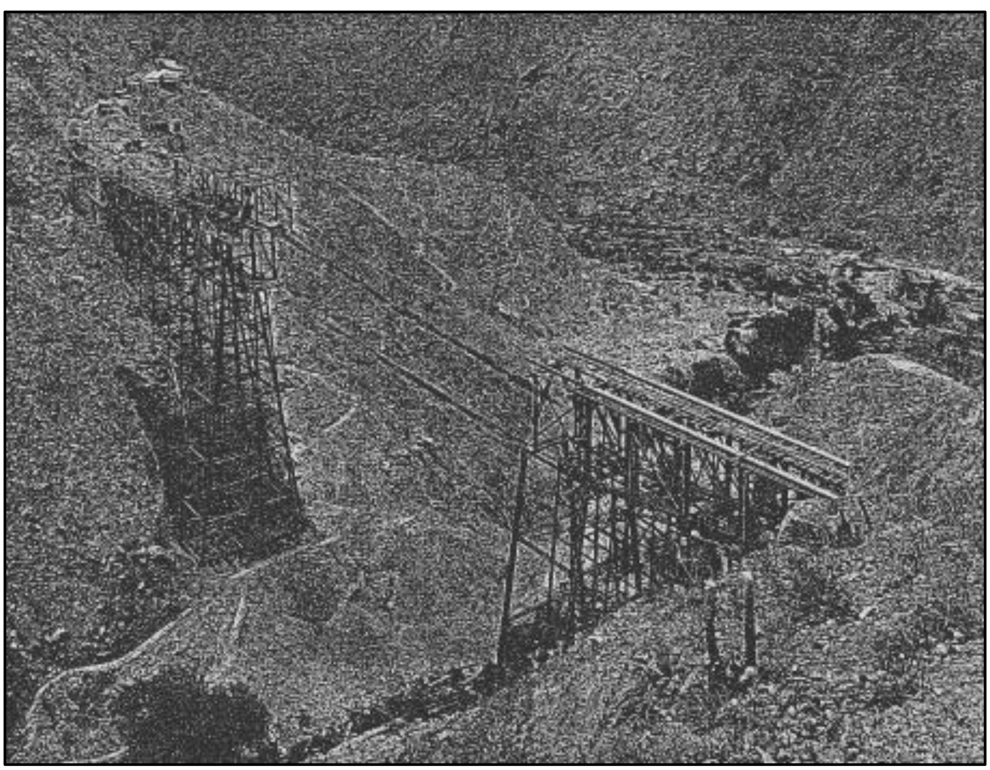

Figure 12. Aerial view of on-going new construction of cantilever span on Lima side (left).

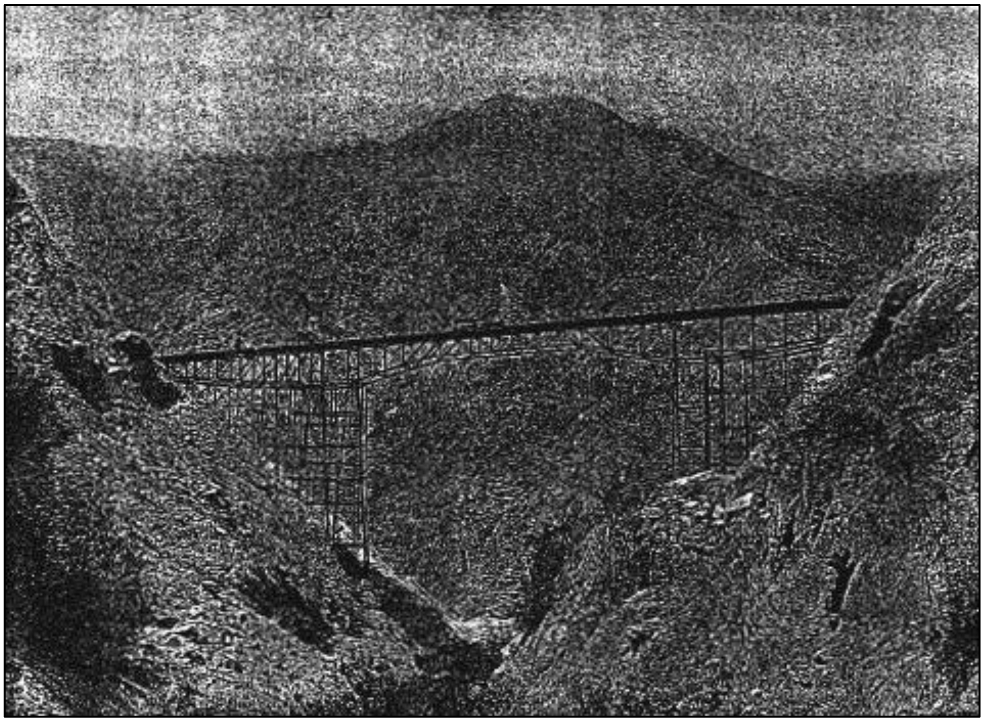

Figure 13. View of the new viaduct, completed January 1, 1891.

7.4 *Erection Time (Engineering, 1891)*

The erection time is summarized below:

1. Erection of false work or scaffolding .... 16 days
2. Erection of iron work for east pier.. 16 days
3. Erection of iron work for west pier .... 16 days
4. Transferring of iron work of half bridge across
   the gorge .... 17 days
5. Demolition of the west span of the old bridge............................. 5 days
6. Erection new west span .... 11 days
7. Demolition of the east span of old bridge................................... 3 days
8. Erection of new east span .... 10 days
9. Erection of west half cantilever and center .... 13 days
10. Erection of east half of cantilever and center span.................. 7 days

   .... 114 days

7.5 *Weight of the Bridge (Engineering, 1891)*

The total weight of the bridge was about 700 U.S. tons

7.6 *Construction Cost (Engineering News, 1889)*

The construction cost of the bridge was about U.S. $2 million.

7.7 *Load Test and Bridge Opening (Engineering, 1891)*

The test train had 3 engines and 10 American cars of rails and other construction materials, weighing about 350 tons. This train ran over the bridge at 20 miles an hour, and the deflection of the center span was measured at 1-¼ inches. This was less than L/2000 (or 1.41 inches). The bridge was opened to traffic on January 1, 1991.

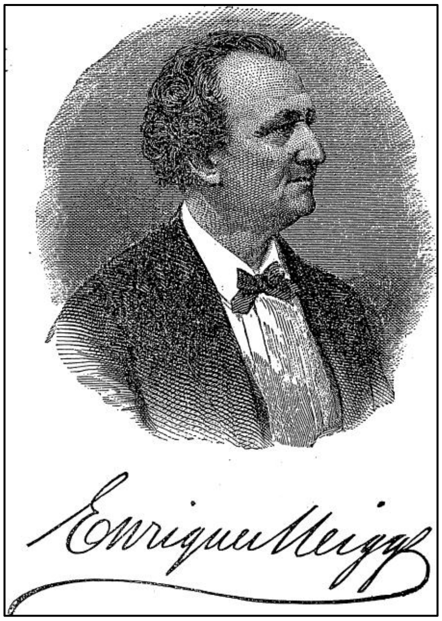

Figure 14. Henry Meiggs (Engineering and Mining Journal, 1878)

8 PEOPLE CONNECTED WITH VERRUGAS VIADUCT

8.1 *Henry Meiggs*

Henry Meiggs was born in Catskill, Green County, New York State in 1811. At age 20, he went to Boston and made some money by speculation in the lumber business. He came to New York in 1835, made a lot of money in the same business. However, in the financial panic of 1837, he lost his fortune. He recovered a year later, but then again became insolvent in 1842. When gold was discovered in California, he and his brother John loaded a ship with lumber, travelled around the Cape, and arrived in San Francisco in July of 1849. He sold his lumber for a profit of $50,000.

He prospered in the lumber business, but the financial crisis of 1854 ruined him financially. He committed forgeries of over $900,000, and realizing that he will be caught eventually, he sailed with his family to Chile in South America. In 1861, he took a contract to build 33 miles of railroad on Valparaiso and Santiago Railroad, with a rise of 4,800 ft. and completed the work in three years (instead of four) for $12,000,000 and earned a profit of $1,320,000. He stayed in Santiago, Chile until 1867, and then relocated to Lima, Peru.

In 1868, Henry Meiggs undertook the study for the construction of the Callao, Lima, Oroya railroad with the help of a Polish engineer Ernest Malinowski who proposed the route to be taken through the Andes Mountains for a distance of about 136 miles. On this route was located the Verrugas Viaduct. On December 18, 1869, the Peruvian Government signed the contract with Henry Meiggs for U.S. $25,875,000, to build one of the most difficult and challenging engineering works.

Meiggs had $126 million in contracts with the Peruvian government to build 1,013 miles of railroad on seven lines as follows (Engineering, 1874):

Table 3. Total cost of railroad projects

Name of Railroad	Length	Completion Date	Cost
Mollendo-Arequipa	107 miles	1870	$11,250,000
Callao-Oroya	136 miles	1876	$25,875,000
Ilo-Moquegua	63 miles	1872	$6,781,250
Arequipo-Puno	222 miles	1873	$30,000,000
Pacasmayo-Cajamarca	83 miles	1873	$6,656,250
Chimbote-Huaraz	172 miles	1876	$22,500,000
Puno-Cuzco	230 miles	1874	$23,437,500
	1,013 miles		$126,000,000

At the peak of Andean railroad construction, it is said that Meiggs had 14,000 workers, and he was probably the second biggest employer of the U.S. engineers after the U.S. Army, and the largest foreign purchaser of American railroad materials (Railroad Gazette, 1877). In 1875, the government ran out of money, and stopped paying interest on its bonds. This virtually stopped all of Meiggs' operations.

In his desperation to generate cash, he committed forgeries which initially helped him, but in the end he was caught. He suffered paralytic strokes, and it is believed that they caused his death. He died in Lima on September 30, 1877 (New York Times, 1877a).

8.2 *William H. Cilley*

He was Meiggs' most loyal and trusted employee, and second in command to build the Aroyo railroad. He was born in Northfield, New Hampshire on May 26, 1839. At a young age, he joined one of the railroads in New Hampshire and rose quickly from a fireman, engineer, roadmaster, to chief of traffic. Then, he joined Boston Gas Works and rose to the position of Manager. Attracted by opportunities in the west, he moved to California where he met Henry Meiggs for the first time, and learned mining operations of California. He returned to Boston with a modest fortune, but lost it due to poor investments.

In 1861 Meiggs signed a contract with the Government of Chile to build a railroad from Valparaiso to Santiago in four years. A short link of Valparaiso to Quillota was completed in about a year. In 1862, Meiggs wrote a letter requesting Cilley to join him. His contract called for the completion of Quillota to Santiago road in 3 years with a bonus of $10,000 per month for early completion, and like penalty for delay. Meiggs and Cilley completed the project in two years.

Based on Meiggs' success in building mountain railroads in Chile, Col. Balta, President of Peru, invited him to undertake construction of Arequipa and Oroya railroads – the two most difficult and daring engineering works ever undertaken in the history of railroad construction. Meiggs again called Cilley, who was working on a small railroad in the U.S., to come to Peru to join him, and run the operation with full control.

In his role as Superintendent of construction, Cilley hired some of the best, brightest, and enthusiastic American engineers who upon their return to the U.S. were instrumental in building railroads and major bridges, and opening up the western U.S. for development.

Some of the engineers that Cilley hired were Roswell E. Briggs, who later became Chief Engineer of Denver and Rio Grande Railroad; Virgil G. Bogue who was consultant for the foundation of the Brooklyn tower of the Williamsburg Bridge, and later became the Chief Engineer of Union Pacific; Leffert L. Buck, who was a classmate of both Brigss and Bogue at RPI, and later reconstructed Roebling's Railway Suspension Bridge over Niagara Gorge and became Chief Bridge Engineer of New York City and designed the Williamsburg Bridge; Othniel F. Nichols, who was also an RPI graduate, later became Chief Bridge Engineer of New York City from 1904-1906 and consulting engineer thereafter until his death in 1908, and was responsible for the design and construction of the Manhattan and Queensboro Bridges.

Cilley was a pallbearer at Henry Meiggs' funeral, and one of the executors of his will (New York Times, 1877b). He was for 27 years prominently connected with building of railroads in South America, and generated goodwill and respect for the U.S. business and technical acumen. He died in October 1889, and was buried at his home in Leominster, Massachusetts (Railroad Gazette, 1889b).

8.3 *Leffert L. Buck (Nason and Young, p. 386)*

Leffert Lefferts Buck was the resident engineer, and one of the first to use principle of suspension bridge in erection of the Verrugas Viaduct where it was difficult or impractical to use false work (New York Times, 1909). He was born in Canton, New York in 1837. Before completing high school, he served an apprenticeship to the machinist's trade. In 1859 he entered St. Lawrence University but left two years later at the outbreak of the civil war to enlist as a private in the 60th New York State Volunteers unit, and actively fought in the war. For his bravery, he was promoted to the rank of captain. Following his release from the army, he joined

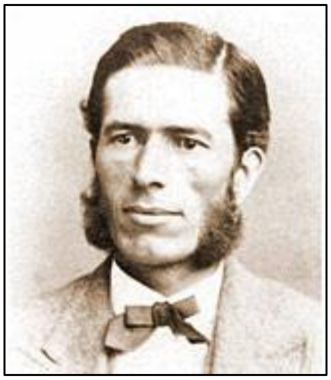

Figure 15. Leffert L. Buck (Circa 1875)
(Photograph Collection, Institute Archives & Special Collections, RPI, Troy, NY 12180)

Rensselaer Polytechnic Institute in Troy, New York, as a sophomore, and graduated in the class of 1868 (Engineering News, 1909).

He gained some experience running the first Adirondacks railway, and went to Peru, South America where he built a difficult tunnel section of the Lima & Oroya Railroad and constructed the Verrugas Viaduct on that line.

He returned to the U.S. in 1873 and joined the mechanical department of the Illinois Central Railroad. In 1888, he prepared plans for sinking pumping wells of Erie Dry Dock at Brooklyn Navy Yard. He was selected to rehabilitate the Roebling's first railway suspension bridge over the Niagara Gorge (Gandhi, 2006).

In 1891, he was appointed by the President of Peru, a Commissioner to represent Peru in the engineering congress at Washington, D.C., convened to study plans for an international railroad to connect North and South America (Engineering Record, 1891).

In 1895, he was appointed Chief Engineer of the Williamsburg Bridge. The bridge, when built in 1903, was exceeded in size only by the Firth of Forth Cantilever bridge in Scotland. He died on July 17, 1909 at his home in Hastings, NY due to apoplexy.

8.4 *Anthony Walton White (W.W.) Evans (Nason and Young, pp. 213-214)*

He was responsible for the design of the Verrugas Bridge as a Consulting Engineer to the Peruvian Government. He was born in New Brunswick, New Jersey in 1817. He dropped "Anthony" from his name early in life. After attending local schools and Rutgers College he entered Rensselaer Polytechnic Institute in Troy, New York in 1834, and graduated with a degree of Civil Engineering in 1836. He joined the Erie Canal project as an Assistant Engineer upon his graduation. In 1845 he became Assistant to Allan Campbell to building an extension of the New York and Harlem Railroad to Albany. In 1850, he resigned to join Campbell in building the Copiapo Railroad in Chile, South America, which he completed in 1853. While in Chile, he built the first pier on the coast of South America.

In 1853, he moved to Peru as Chief Engineer of Arica and Tacua Railroad, and completed the construction in 1856. He returned to the U.S. in 1856, got married, and went back to Chile with his wife in the fall of 1856 to build 50 miles of Southern Railroad which was completed in 1860. He then spent two years in visiting, studying, and examining public works, and opened an office as a consulting engineer in New York.

In 1862, he was appointed engineer of harbor defenses of the port of New York, and stayed in that position until the close of the civil war. In 1866, he went to England, Germany, and Russia to see and report on the railways and qualities of iron used.

For the Lima and Oroya Railroad, he was Inspecting or Consulting Engineer to the Government of Peru, and assisted Meiggs and Baltimore Bridge Company in the design and fabrication of the Verrugas Viaduct. In the 1860s and 1870s, European engines and rolling stock were considered superior to their American counterparts. He prodded foreign governments to buy American engines and rolling stock, and compare their performance using controlled tests. Using these tests results, Evans proved that the European products were

Figure 16. Walton White Evans (Circa 1875)
(Photograph Collection, Institute Archives & Special Collections, RPI, Troy, NY 12180)

overrated and did not perform as claimed (Evans, 1870 and 1877). He acted as agent for a number of foreign railways to purchase equipment and recruit staff; and in that capacity he promoted American products and engineers. Up to 1878, he was supplying, designing, and exporting a large quantity of railway plant and iron bridges to Peru, Australia, New Zealand, and Mexico. He died at his home in New Rochelle, New York on November 28, 1886.

8.5 *Charles H. Latrobe*

He was the design engineer for the Baltimore Bridge Company, the fabricator of the Verrugas Viaduct. He worked very closely with Evans in developing several truss and pier systems and preparing their cost estimates. He was born in Baltimore in 1833. His father Benjamin H. Latrobe was the first person to survey the Allegheny Mountains to establish a railroad route; and a member of the committee that reviewed John Roebling's scheme to built the Brooklyn Bridge and approved it, which made it possible for Roebling to obtain funding for the bridge. His grandfather rebuilt the Capitol in Washington, D.C. after its destruction by the British.

Charles Latrobe designed beautiful bridges spanning Jones Falls and for grade-elimination in Baltimore. The Baltimore Bridge Co. also fabricated all parts, assembled them into a viaduct structure, and disassembled for shipping to Peru. When Latrobe read about the destruction of the Verrugas Viaduct, he sent a letter to the Engineering and Building Record, and one of his comments was, "What the Revolutionists tried in vain to blow up, the water, in a rainless region, has carried away…" (Latrobe, 1889). He died in Baltimore on September 19, 1902 (New York Times, 1902).

8.6 *Thomas M. Cleeman (Nason and Young, p. 360)*

He was born in Philadelphia in 1843. He graduated from Rensselaer Polytechnic Institute in Troy, NY with a Civil Engineering degree in 1865. After graduating, he joined Pennsylvania Railroad as Assistant Engineer. After working for a few years, he became Assistant Engineer for the Allegheny Valley Railroad in Pennsylvania. Then he moved to Peru, South America. During the construction of the Verrugas Viaduct, he was the Division Engineer of the Callao, Lima and Oroya Railroad, and responsible for the layout of the route which was then built by thousands of workers employed by Meiggs. In 1873 he returned to Philadelphia. He was the author of the "Railroad Engineers' Practice" which went through several editions. He also taught the Railroad Engineering and Route Survey course at RPI in 1892. He died at Guayaquil, Equador, S.A. in 1893.

8.7 *Ernest Malinowski*

He was born in Poland in 1818 and came to Peru in 1852 to work on public works projects. He was instrumental in establishing the feasibility of the Lima-Oroya route. In 1868, when Henry Meiggs undertook the study for the construction of the Oroya Railroad, he sought assistance from Malinowski to lay out the proposed 136 mile route through the Andean Mountains. A commission of engineers, that included Federico Blume, Felip Arancivia, and Walter F. Morris, approved the project. In December of 1869, Meiggs signed a contract with the Peruvian government to build the Oroya Railroad for $27,600,000 in six years starting on January 1, 1870 and delivering the completed railroad on or before January 1, 1876. Malinowski died in Lima in 1899.

9 CONCLUSIONS

1. There was a lot of goodwill for American engineers and know-how in South America in the late 19th century.
2. When the railroad building program started in Peru in the 1860s, England and France were the major suppliers of locomotives, rolling stock, rails, bridges, and other supplies. However, with documented superior performance of comparable American products, all these items were purchased in the U.S. and shipped to South America, thus helping and developing the American economy. Most of the credit goes to engineers like W.W. Evans and American manufacturers and suppliers for maintaining very high standards.
3. It is amazing how the Verrugas bridge was designed and fabricated so that no part weighed more than 300 pounds. It was fabricated at Phoenixville, Penn; all parts were assembled on the ground in Baltimore, their positions numbered and the parts of the three piers color-coded; and shipped from New York around the Horn. The shipment arrived at the port of Callao in Peru, and it was put on a train for delivery near the bridge site. The bridge was built precisely as designed, thousands of miles away with mostly untrained labor.
4. These South American railway projects in mountainous countries were instrumental in training American engineers to take more responsible positions in building America after they returned home. For example, Virgil G. Bogue became Chief Engineer of Union Pacific, Leffert L. Buck and Othniel F. Nichols became Chief Bridge Engineers of New York City. Buck designed the reconstruction of Roebling's Niagara Railway Suspension Bridge, and the new Williamsburg Bridge in New York City. Nichols was in charge of Manhattan and Queensboro Bridges in New York from 1904 to1906 as Chief Bridge Engineer. Roswell E. Briggs became the Chief Engineer of the Denver & Rio Grande Railroad.

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