XIII.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INCORPORATED 1852.

TRANSACTIONS.

TUNNELS OF THE PACIFIC RAILROAD.

A Paper read before the Society Jan. 5, 1870, by JOHN R. GILLISS, Civil Engineer, Member of the Society.

During the past summer the track has been completed across this Continent, and so much sooner than was thought possible, that the difficulties overcome are apt to be underrated. Some account of a single item in the great work may therefore be interesting.

Between Omaha and Sacramento there are nineteen tunnels. Four of these are on the Union Pacific, and fifteen on the Central. The latter, having been completed before those on the Union Pacific were commenced, will be spoken of first.

Central Pacific Tunnels.—The tunnels of the Central Pacific are nearly all near the summit, where it crosses the western range of the Sierra Nevada. The line here lies on steep hill-sides, in some cases being, for long distances, on a face of bare granite, more or less broken by projecting ledges and boulders, but with an average slope often greater than 1 to 1. In such places embankments were almost impracticable; the hills were too steep to catch the slopes, and most of the rock from cuts was thrown far down hill by heavy seam blasts. On these accounts

the line for two miles east of Donner Pass was thrown further into the hill than on original location, thus adding to the depths of cuttings and increasing the number of tunnels, but saving retaining walls, and where tunnels were made enabling the work to be carried on in winter. Another important object was the saving of snow-covering where tunnels were made, and giving a good foundation for it where they were not. It is within these two miles that seven tunnels are crowded.

A detailed account of each tunnel would be tedious. Their characteristics have therefore been condensed into a table. See Appendix A.

Commencement of Work.—Tunnels 1 and 2 are both west of Cisco, a small track ninety-two miles from Sacramento, and within thirteen of the summit. They were both finished in 1866. During the fall of that year the track reached Cisco, and as fast as the gangs of Chinamen were released they were hurried to the summit to be distributed among the tunnels in its vicinity. The year before, some gangs had been sent to summit tunnel No. 6, and commenced the cuts at its extremities; winter set in before the headings were started, and the work had to be abandoned. To avoid a repetition of such delay, the approaches to all the tunnels were covered with men, and worked night and day in three shifts of eight hours each. Thus time was saved, and the tunnel organization started at once. As an illustration of the hurry, I may mention walking two miles over the hills after dark, and staking out the east end of No. 12 by the light of a bonfire; at nine o'clock the men were at work.

In November and the early part of December there were several snow-storms, just enough to stimulate without delaying the work. The rough rocky sides of Donner Peak soon became smooth, slopes of snow and ice covering the trail that led from tunnel 8 to 9; it remained impassable until spring, and communication had to be kept up by the wagon-road, five or six hundred feet below. This, the Dutch Flat and Donner Lake wagon road, was opened soon after it was decided to adopt this route. From the Pass the descent toward the lake was over very rough ground, requiring heavy side cuts and retaining walls with numerous zig-zags to gain distance.

From this road the scene was strangely beautiful at night. The tall firs, though drooping under their heavy burdens, pointed to the mountains that overhung them, where the fires that lit seven tunnels shone

like stars on their snowy sides. The only sound that came down to break the stillness of the winter night was the sharp ring of hammer on steel, or the heavy reports of the blasts.

Winter of 1866–7.—By the time winter had set in fairly the headings were all under ground. The work was then independent of weather, except as storms would block up tunnel entrances, or avalanches sweep over the shanties of the laborers. Before tracing the progress of the work underground, it will be well to see the character of weather outdoors.

A set of meteorological instruments was furnished by Colonel Williamson, of the United States Engineers, consisting of barometer wet, dry, maximum and minimum thermometers. These, with wind, clouds, etc., were recorded three times a day, and hourly during ten days in each month. From this record the table of storms given in Appendix C was made.

Snow-storms.—These storms, forty-four in number, varied in length from a short snow squall to a two-week gale, and in depth from a quarter of an inch to ten feet—none less than the former number being recorded, nor had we occasion to note any greater than the latter. This, the heaviest storm of the winter, began February 18th, at 2 P. M., and snowed steadily until 10 P. M. of the 22d, during which time six feet fell. The supply of raw material was then exhausted, but the barometer kept low and the wind heavy from the south-west for five days more, by which time a fresh supply of damp air came up from the Pacific, and then, as the machinery was still running full speed, this was ground up without delay. It snowed steadily until March 2d, making ten feet snow and thirteen days storm. It is true that no snow fell for five days, but it drifted so furiously during that time that the snow-tunnel at east end of tunnel No. 6 had to be lengthened fifty feet.

These storms were grand. They always began with a fall in the barometer and a strong wind from the south-west, hurrying up the tattered rain-clouds or storm-scud in heavy masses. The barometer, which averaged twenty-three inches, would drop sometimes as low as twenty-two and a half. The thermometer was rarely below twenty degrees at the beginning of a storm, and usually rose to thirty-two degrees before its close, so that the last snow would be damp and heavy,

sometimes ending in a rain. The storms ended, and clouds were scattered by cold winds blowing over the eastern range of the Sierra Nevada; these raised the barometer and dropped the temperature at once. The lowest temperature of the winter was from a wind of this sort, five and a half degrees above zero.

Our quarters were at the east end of Donner Pass, but still in the narrow part. About the second or third day of a storm the wind would be a gale, sometimes ten pounds per square foot; and would plough up the new fallen snow to heap it in huge drifts beyond the east end of the pass. About thirty feet from our windows was a large warehouse; this was often hidden completely by the furious torrent of almost solid snow that swept through the gorge. On the cliff above, the cedar trees are deeply cut, many branches of the thickness of a man's wrist being taken off entirely by the drifting snow-flakes.

No one can face these storms when they are in earnest. Three of our party came through the pass one evening, walking with the storm—two got in safely. After waiting a while, just as we were starting out to look up the third, he came in exhausted. In a short, straight path between two walls of rock, he had lost his way and thought his last hour had come.

Road-breaking.—Of course these storms make the road impassable even for sleighs. They are opened by gangs of men kept there for the purpose with heavy ox sleds. The snow when new fallen is very light, so that a man without snow-shoes would sink to his waist or shoulders. Into this the oxen would flounder, and when they lay down, worn out, be roused by the summary process of twisting their tails. I saw three in one team so fortunate as to have had theirs twisted clear off, none left to be bothered with. The men were as regardless of themselves as of their animals. They took life easily in fine weather, but were out nearly all the time when it stormed. Late at night they could be seen shovelling on a bad drift at the corner of the warehouse, where the wind heaped in the snow faster than they could dig it out, and then a denser mass of flying snow would hide them altogether.

Snow-shoes.—We started with Canadian snow-shoes, but soon abandoned them for the Norwegian, each a strip of light wood ten to twelve feet long, four inches wide, and an inch and a quarter thick in the centre;

they taper in thickness towards the end, are turned up in front, and grooved on the bottom.

There is a broad strap in the middle to put the foot under, and a balancing-pole to steady, push, and brake with. The latter will be seen all-important, as a speed of twenty-five to thirty miles an hour is often attained on a steep hill side. During several winters the mails were carried across the mountains by a Norwegian named Thompson, on these shoes. It is said he made sometimes forty or fifty miles a day on them.

Snow-slides.—Snow-slides or avalanches were frequent. The storm winds being always from the south-west, form drifts or snow-wreaths on the north-east crests of hills. When these become too heavy, which is generally towards the close of the storms, they break off, and in falling start the loose snow below. This slides on the old crust. I never knew of a slide from the ground.

Near the close of one storm, a log-house with board roof, containing three Scotchmen, brothers, and sub-contractors with their gang, some fifteen or sixteen men in all, was crushed and buried up at day-break. The storm ended at noon Towards evening, a man coming up the road missed the house and alarmed the camp, so that by six o'clock the men were dug out. The bulk of the slide had passed over and piled itself up beyond the house, so that it was only covered fifteen feet deep. Only three were killed; the bunks were close to the log walls and kept the rest from being crushed. The snow packed around the men so closely that only two could move about; they had almost dug their way out; over the heads of the rest little holes had been melted in the snow by their breath. Most of them were conscious, and, strange to say, the time had passed rapidly with them, although about fourteen hours under the snow.

This event startled us, for at the top of the cliff, in front of the camp, was a snow-wreath forty or fifty feet long, projecting twenty feet, and of about the same thickness. We were uncertain when it would come down and where it would stop. A keg of powder was put down behind it next morning and fired. A white column shot up a hundred feet, and then the whole hill-side below was in motion; it came down a frozen cascade, covered with glittering snow-dust for spray. It was a rare sight, for snow-slides are so rapid and noiseless that comparatively few are seen.

They were so frequent across the trail leading to tunnel No. 9, that it had to be abandoned for some months. At tunnel 10, some fifteen or twenty Chinamen were killed by a slide about this time. The year before, two road repairers had been killed, and buried too, by a slide, as their bodies were not found until spring.

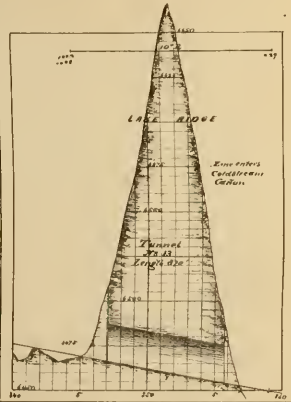
The name given to pass, peak, and lake, is itself the record of a tragedy. In the fall of 1846, the Donner party of emigrants from the East delayed crossing until too late. Nearly all died of starvation; the few survivors had prolonged their lives by cannibalism.

Snow-tunnels.—Before the snow had acquired depth enough to interfere much with the work, the headings were all started. The cuts at their entrances soon filled up with snow, but drifts were run through them, in some instances large enough for a two-horse team. Through these snow-tunnels, whose lengths varied from 50 to 200 feet, the material excavated was hauled in carts or on sleds to the waste banks. These snow-tunnels kept settling at the crown, so that they had to be enlarged from time to time, otherwise they were perfectly satisfactory.

The most remarkable snow-tunnel was made to connect the two ends of tunnel 8. The spur through which this is made terminates in a vertical bluff of granite a hundred feet high. To get around it during the fall, a rope was fastened to the rocks at a point where there was a steep descent of thirty or forty feet. During the early part of winter a snow-drift formed on the face of this bluff, descending in a steep slope from its top to the wagon road, two hundred feet below. On this slope a trail was cut and used for a month or two.

Later in the winter, when the accumulation of snow made it practicable, a snow-tunnel was excavated through the drift, and around the face of the bluff. Windows were made at short intervals for light, and to throw the material out in excavating, and steps cut where a descent was necessary. One flight of these led down to the blacksmith's shop, buried still deeper in the snow, while the main passage led into one already excavated at the east end of tunnel 8. The snow kept settling down hill and away from the bluff, so that there was an open space of three or four feet between it and the rock towards the close, which was far from inspiring much confidence in the route.

Between tunnels 7 and 8 there is a deep ravine, in crossing which the



PROFILES

OF TUNNELS 6 TO 13

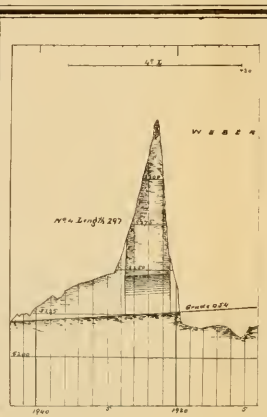
CENTRAL PACIFIC RAILROAD

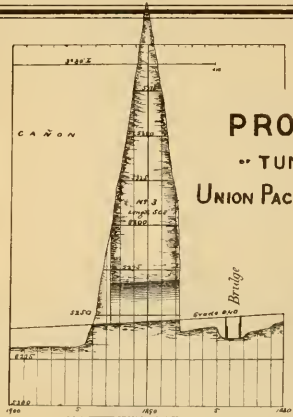
From Summit of Sierra Nevada

Eastward

Vertical lines 100' apart.

Horizontal „ 5' „ .

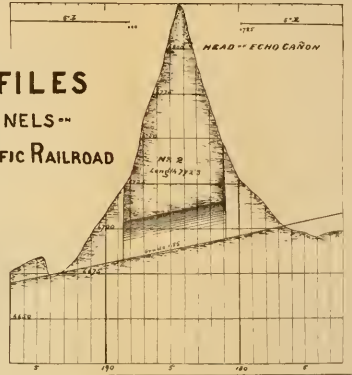


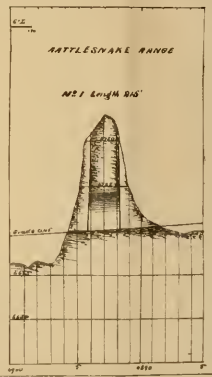


PROFILES

OF TUNNELS ON

UNION PACIFIC RAILROAD





Photohth by the N.Y. Lithog. Eng & Printg Co. 16 & 18 Park Place

road has a 4x5-feet box culvert, and a retaining wall on the lower side of 75 feet extreme height. The foundation was begun in fall, but stopped by winter, and the ravine filled with snow. Next spring a snow-tunnel was commenced about two hundred feet down the ravine, and run in to strike the unfinished foundation. Smaller tunnels were run to quarry stone got out in fall, and a cave dug over the foundation large enough to work in. The culvert was built, and by the time it was finished the depth of snow overhead had decreased to twenty-five or thirty feet; this was excavated by a stream of water, and the retaining wall commenced.

Snow-cuts.—In spring, when the road has begun to be bare, so that sleighs can no longer be used, there are very heavy banks of snow to cut through to make the road passable for wagons.

In June I measured one of these cuts through the end of a snow-slide, and found it twenty-five feet deep. A week later the road was dusty in the centre, but the snow banks were not all gone until July, so that we had at that place the strange spectacle of sprinkling-wagons watering a road between two walls of solid snow.

Alignment.—As soon as each heading became sufficiently advanced, the centre line was secured, generally by small holes drilled in the roof, with wooden plugs and tacks. These points were placed as far apart as length excavated would permit, and from them the line produced as the work advanced. In most cases the entrances were afterwards so blocked up with snow that it was impossible to recur to the line outside, and the tunnels were completed from the points first put in.

In running lines outside during the winter, it was generally necessary to make deep cuts, and sometimes tunnels, through the snow, to get at the original transit points.

Most of the tunnels are on curves, No. 13 being on one of 573 feet radius, with 87 degrees of curvature inside the tunnel. In this, as in No. 11, the usual difficulties of working with instruments by candle-light were much increased by the numerous temporary timbers in the headings. The lines met in the centre of the tunnel, parallel to each other, but two inches apart. In the other cases the discrepancies were too slight to notice.

Dimensions.—Most of the work was through solid rock, which did not require lining, and the following dimensions were adopted: Bottom, a rectangle, 16x11 feet; arch, a semi-circle, 16 feet in diameter; grade at centre of tie, and one foot three inches above sub-grade.

Tunnel 11 was partly, and tunnel 13 wholly, lined with timber in the following manner: 12"x12" sills were placed on each side, and posts 12"x16" morticed into them. The latter support arches, each composed of three thicknesses of 5"x12" plank, breaking joints, and bolted with ¾-inch iron bolts, thus making a solid arch of 180 square inches sectional area. The distance from centre to centre of arches varies from one and a half feet to five feet, according to material. Over the arches, and, where the material required it, on the sides also, split lagging about two and a half inches thick was put in. The width at sub-grade inside of posts is seventeen feet; at springing line inside of arches, nineteen feet; giving a batter of one foot on each side. Height of crown above grade, nineteen feet nine inches, thus leaving room for masonry inside the temporary wooden lining.

Tunnels 1 and 2 were lined in a similar manner, except that the batter of side posts was only six inches.

In these tunnels, through soft material, the heading was supported by temporary timbers. Chambers were then excavated at the sides to below sub-grade, for the sills, and the central core left to support the shores which held the material above in place. As the timbering advanced, the core and false work were removed.

In tunnel No. 12, a short distance in the centre was found to be decomposed granite, and after the tunnel was excavated a light set of timbers was put in. They consisted of arches, each composed of seven pieces of 10x10-inch timber, with side-posts and sills similar to those already described.

In all the tunnels on curves, allowance was made for elevation of outer rail, so that top of cars would remain in centre of opening.

Laborers.—With the exception of a few white men at the west end of tunnel No. 6, the laboring force was entirely composed of Chinamen, with white foremen—the laborers working usually in three shifts of eight hours each, and the foremen in two shifts of twelve hours each. A single foreman, with a gang of thirty to forty men, generally constituted

the force at work at each end of a tunnel; of these, twelve to fifteen worked on the heading, and the rest on bottom, removing material, etc.

When a gang was small, or the men needed elsewhere, the bottoms were worked with fewer men, or stopped so as to keep the headings going.

The Chinamen were as steady, hard-working a set of men as could be found. They were paid from $30 to $35, in gold, a month, finding themselves, while the white men were paid about the same, but with their board thrown in. The force at work on the road probably averaged from six to ten thousand, nine-tenths of them being Chinamen.

Progress.—Records were kept of weekly progress, and number of working days in tunnels 3 to 13 inclusive, from which the accompanying table, Appendix A, is principally taken. The headings were worked steadily until they were through; the force was then crowded on the bottoms, which had, by that time, fallen behindhand. The progress made on them, under these circumstances, is shown in the last column.

Cost, etc.—An approximate estimate of cost of excavation of tunnel No. 6 is given in Appendix D, showing it to have been about $14.80, gold, per cubic yard with powder, and $10 with nitro-glycerine.

Tunnel No. 6.—This, the longest tunnel of the road, is parallel to and about four hundred feet north of Donner Pass. Its length is 1,659 feet, and greatest depth below the surface, 124 feet, measuring from grade. The material is granite, of a medium quality, crossed by seams in every direction.

To expedite the work a shaft was sunk about the middle of the tunnel, its dimensions being 8x12x72.9 feet.

Work was commenced on the shaft August 27th, and for the first thirty feet it was sunk at the rate of a foot a day, after which its progress slackened, from delay in hoisting the material with a common hand derrick.

Meanwhile a house was being built over the shaft, and the hoisting engine was put up. The latter consisted of an old locomotive, the Sacramento, and, by an interesting coincidence, the first engine run in the State. This was geared to a drum six feet in diameter. The house was fifty feet square, containing, in addition to the hoisting apparatus, forges, fuel, tamp-

ing, etc., so that when snowed in, these articles would be close at hand. The shaft was divided by planking into two compartments, each five feet square; over these were two "jiggers" or transfer tables. The buckets were first of wood, then two additional ones were made of boiler plate, four feet nine inches square by two feet six inches high, outside dimensions, and fitted for side dumping. They were loaded at the face of the work below, run on trucks to the bottom of the shaft, hoisted and transferred to other trucks to run out on the waste bank.

Total days' work on shaft, 85; average progress, 0.85 feet in twenty-four hours. Nitro-glycerine had not yet been introduced; with it the progress would probably have averaged 1.5 feet.

Nitro-Glycerine.—This was introduced on the work early in 1867, to expedite progress of the summit tunnel. It was made on the spot by Mr. James Howden, and used in the four headings of tunnel No. 6 from Feb. 9th, and to some extent in tunnel No. 8, but not enough to give data for comparison. After the headings of these tunnels were through, it was used in the bottoms.

In the headings of summit tunnel the average daily progress with powder was 1.18 feet per day, with nitro-glycerine, 1.82 feet, or over 54 per cent. additional progress.

In bottom of summit tunnel, average daily progress with powder, full gangs, was 2.51 feet; with nitro-glycerine, 4.38, or over 74 per cent. in favor of nitro-glycerine. The same number of men were used with both explosives.

The additional progress in heading was due, principally, to the use of one and a quarter inch drills instead of two and a half inch, as required by powder.

In the bottoms the difference was principally due to fewer holes being required, and to the granite being broken into small pieces that seldom needed new holes to split them on. In both headings and bottoms less time was found to be required to clear the tunnels of smoke with nitro-glycerine than powder.

The cost of nitro-glycerine made at Donner Pass, according to Mr. Howden, was about 75 cents per lb.

It was considered there to be about eight times as powerful as the

same weight of powder, which would make it the cheapest, viewed simply as to expense of producing a given effect.

Wherever practicable, I have no doubt that it is safest to manufacture nitro-glycerine on the site where it is to be used, and from day to day as required. At Donner Pass I only recollect two accidents, and those would have happened with powder.

The conclusion we may safely come to, from the Central Pacific work, is, that in hard rock tunnels, with the same number of men, over fifty per cent. additional progress can be made by using nitro-glycerine in place of powder, and the expense will be reduced proportionately.

Since papers have been read before this Society on the subject by Messrs. North and Chester, it is unnecessary to speak of the details of manufacture and use of this agent.

Tunnels of the Union Pacific Railroad.—A detailed list of these tunnels will be found in Appendix F.

Tunnel No. 1 is on St. Mary's Creek, about 680 miles west from Omaha, and 12 miles east of second crossing of North Platte River. It was commenced April 30th, 1868, and continued from each end until June 8th. At that time the two headings were in 86 and 87 feet respectively, the progress having averaged 2.22 feet per day. A soft spot was then found in the west end, and there being no means of lining without delay, the open cut was extended to cover the place, and the length of tunnel reduced to 215 feet.

This delayed the work, so that a temporary track had to be built around it.

Tunnel No. 2 is at the head of Echo Cañon, in Utah, about 972 miles from Omaha. Its length is 772.3 feet, being the longest of the Union Pacific. The approaches were started in July, 1868; they are heavy cuts through clay. Rock was struck about the end of August, and found to be like the prevailing formation in the vicinity, an indurated clay, with occasional streaks of soft sandstone. Most of it drilled very easily, but required as much powder in blasting as ordinary rock. While damp it stood firm, but after sufficient exposure to the air to dry out the moisture, it cracked and crumbled like lime in slacking. These qualities made the work very expensive; rock prices had to be paid, and earth slopes taken out.

In starting the headings they had to be supported the same day the excavation was made; but on getting fairly in, the roof would stand well a week or two.

There was an irregular streak of blue sandstone which ran completely through the tunnel near the springing line.

The headings were started at the west end August 29th, and at the east end September 5th; they met January 30th, 1869. The tunnel was finished April 3d, 1869.

When work was commenced on the tunnel the track was still three hundred miles east, and all the available transportation required to haul tools, materials, and provisions over this gap; it was useless even to think of getting cement in time. There was no suitable stone near the work, and the clay had too much lime to make brick. On these accounts the tunnel had to be lined with timber.

While waiting for the latter to be sawed, the headings were secured temporarily by bents framed as shown on Plate 2.

The permanent timbers consist of arches placed four feet apart, centre to centre, and similar to those already described on the Central Pacific Railroad. (See Plate 2.)

They differed from those of the Central Pacific in having a longitudinal stringer on each side at the springing line. This guards against the effects of unequal lateral pressure, and enabled the excavation to be taken out more economically. Instead of chambering to sub-grade and building up from the bottom sill, the chambers were cut only to the springing line, the stringers laid, and the arches raised and lagged. The bottom was then taken up, leaving a bench to support stringers. When the bottom was all out, the stringers were under-pinned, the benches cut away, and the lower timbers put in.

The roof was lagged throughout; the sides, for about two hundred feet at each end, and the remainder left to be finished after the track was laid. For lagging, round and split poles were first used, but afterwards two and a half inch plank.

The excavation of the tunnel was let by contract to Miller & Patterson; their expenses in timbering were paid as extra work. The detailed cost is given in Appendix F. The excavation required two pounds powder and two and seven-tenths feet fuze per cubic yard. The heavy work on each side of the tunnel was not ready for the track, and a tem-

porary line of eight miles in length was built around it This line started about a mile west of Wahsatch—descended into the cañon by two Ys, and followed the main ravine to near Castle Rock station, where it regained the main line. The latter was finished May 25, 1869.

Tunnels Nos. 3 and 4. These are in the Weber Cañon, Utah, three-quarters of a mile apart, and about one thousand and five miles west from Omaha.

They were started under the direction of Thomas H. Bates, Division Engineer. When about one-third done, he was relieved by E. P. North, to whom I am indebted for the details of their construction. In January, 1869, it was feared these tunnels would not be through in time for the track, and Mr. North was directed to run temporary lines around them. Instead of that, he suggested hastening the work by using nitro-glycerine; which was done with very satisfactory results, as will be seen.

Tunnel No. 3.—This tunnel is through a sharp spur of black limestone and dark blue quartzite, two hundred and sixty-six feet of the former and two hundred and forty-two feet of the latter, total length five hundred and eight feet, on a 3 deg. 30 min. curve to the left. The headings were commenced about September 1, 1868, and met April 4, 1869. Until December 27th the work was part of Brigham Young's contract, and sub-let to Sharp and Young. It was then carried on as company work, and let to Daniel McGee, a "Gentile," February 9th. Not being finished in time for the rails, a temporary track was built around it, partly on a 22 deg. curve, two hundred and sixty feet radius, around which trains of twenty-three cars were taken.

Nitro-glycerine was fairly introduced into the tunnel by February 23d. About twenty per cent. of the tunnel men struck on account of its use, and were not replaced as two shifts on the bottoms were found enough to keep them up with the headings, notwithstanding the additional progress they too were making; three shifts had been required with powder. The progress of this tunnel, under various circumstances, is given in Appendix E. It will be seen that, after allowing for the smaller force employed, about twice as much work was done per man, with nitro-glycerine as with powder. The use of nitro-glycerine in tunnel No. 3 saved the Company nearly $40,000.

Tunnel No. 4.—Length two hundred and ninety-seven feet; alignment

4 deg. to left; material, quartzite, similar to that in tunnel No. 3. Headings were commenced about September 10, 1868, and tunnel finished January 29th; nitro-glycerine was used to take up the last one hundred and eighty feet of bottom, which it did in eleven days; making the remarkable progress of 8.18 feet per day from each end. In tunnel No. 4, one thousand nine hundred and sixty cubic yards were taken out with powder, requiring two hundred and eighty-nine kegs and seven thousand feet of fuze, or three seven-tenths pounds powder and three six-tenths feet fuze per cubic yard.

Comparison between the two roads.—The total length of tunnelling on the Central Pacific is six thousand two hundred and thirteen feet, on the Union one thousand seven hundred and ninety two. The cross sections of tunnels on the two roads are practically identical.

The circumstances and materials varied too much to make an accurate comparison of progress in tunnels of the two roads. The greatest average daily progress of heading on the Central Pacific, through granite with nitro-glycerine, was 3.29 feet. On the Union Pacific, through quartzite about as hard as granite, 4 62 feet. Each road has done over eight feet per day at a single face in taking up bottom.

The laborers on the Central Pacific were mostly Chinamen, paid $30 to $35 gold per month, working three shifts per day in tunnels, and twelve to fifteen men in a heading. On the Union Pacific the laborers were white men, paid $3 to $4 per day currency, generally working two shifts per day, and eight to twelve men in a heading on tunnels 1 and 2, and three shifts of fourteen to sixteen on tunnels 3 and 4.

The Central Pacific Railroad was built under the direction of S. S. Montague, Chief Engineer. The location and construction across the Sierra Nevada were in charge of L. M. Clements, Resident Engineer. The account of tunnels on that work is principally compiled from a report on the subject written for the latter by the author, while engaged on tunnels 6 to 13 of that work.

The Union Pacific Railroad was built, and its location revised, under the direction of S. B. Reed, Engineeer and Superintendent of Construction. The accounts of tunnels 1 and 2 are from personal observation, and of tunnels 3 and 4 from data furnished by Edward P. North, Resident Engineer of work in Weber Cañon.

Appendix A.

Tunnels of Central Pacific Railroad.

S. S. MONTAGUE, *Chief Engineer.* I. M. CLEMENTS, *Resident Engineer.*

Number.	Distance in miles from Sacramento.	Locality.	Alignment.	Material.	Length.			Greatest depth.	No. of faces worked.	Heading.		Bottom.		
					Not lined.	Lined.	Total.			Total work'g days 24 hours.	Average daily progress.	Total working days.	Average daily progress.	Daily progress, full gauge.
1	77	Grizzly Hill	..	Conglomerate	226	232	498	..	..	..	..	..	..	..
2	84	Emigrant Gap	..	"	..	271	271	..	..	..	..	..	..	..
3	92	Cisco	9° R	Hard trap	280	..	280	..	2	354	0.79	280	0.89	1.43
4	93	Red Spur	8° R	" "	92	..	92	..	1	128	0.72	101	0.91	1.63
5	97	Crocker's Spur	8° R	Granite	128	..	128	.	1	213	0.60	144	0.89	1.48
6	105	Summit	T	"	1659	..	1659	124	4	396	1.18	621	1.42	2.51
"	"	"	"	"	..	..	..	..	..	*a*655	*a*1.82	*a*178	*a*4.38	*a*4.38
7	105	"	T	"	100	..	100	41	1	113½	0.88	63½	1.57	2.00
8	106	Black Point	T	"	375	..	375	169	2	399½	0.94	260½	1.44	*a*3.82
9	106	Donner Peak	T	"	216	..	216	46	1	171½	1.26	152	1.42	2.29
10	107	Cement Ridge	8° L & T	Conglomerate	509	..	509	67	2	202½	2.51	143	3.56	4.91
11	107	Tunnel Spur	T & 8° R	Granite, partly	325	252	577	74	2	356	1.62	494½	1.17	*b*2.19
12	107	" "	8° R	Decomposed	262	80	342	78	2	268	1.28	184	1.97	1.97
13	112	Lake Ridge	10° R	Conglomerate	..	870	870	210	2	389	2.24	335	2.59	3.15
14	134	Alder Creek	..	Trachyte	200	..	200	..	..	..	..	..	..	..
15	137	Quartz Spur	..	Soft granite	96	..	96	..	..	..	..	..	..	..
		TOTAL			4508	1705	6213							

a. Using nitro-glycerine; all others with powder. *b.* In east end—hard granite.

Appendix B.

Abstract of preceding Table—Average Daily Progress in different Materials. The bottom progress is for full gangs.

Material.	Explosive.	From Tunnels	Heading.	Bottom.
Hard Trap.....	Powder.....	3 and 4.....	0.76	1.53
Hard Granite	"	5, 6, 7, 8, 9 ..	0.97	2.09
" "	Nitro-Glycerine	6.....	1.82	4.38
Conglomerate..... ..	Powder.....	10 and 13....	2.38	4.03
Hard Granite	"	Shaft in No. 6	0.85	..

Appendix C.

Snow Storms at Donner Pass, California, Winter of 1866–67, *during which most of the preceding work was done.*

Month.	Number of Storms.		Depth of Snow.		
	1′ and over	Under 1′.	Fallen during Month.	Average Depth.	Maximum Depth.
			′ ″	′ ″	′ ″
November, '66.....	3	..	4 6	1 0	1 6 Nov. 4.
December, '66.....	4	5	10 10½	5 0	9 0 Dec. 20.
January, '67.....	3	7	11 00½	8 0	10 6 Jan. 24.
February, '67.....	3	5	10 3½	10 0	12 8 Feb. 22.
March, '67.....	2	9	4 2¼	12 6	14 4 Mar. 2.
April, '67.....	1	1	3 6	13 0	15 1 Apr. 13.
May, '67.....	....	1	3	8 6	11 0 May 1.
June, '67.....	....	..	....	3 0	6 0 June 1.
Sums and means ...	16	28	44 7¾	7 0½	

Appendix D.

Estimated Cost of Excavation in Tunnel No. 6, Central Pacific Railroad (Granite with Powder); average progress, 35′ per month.

Cost of each heading and bottom per month:

100	men per day (in 3 shifts)	at	$31 00	$3,100 00
2	foremen; pay, $90; board, $30	"	120 00	240 00
3	horses	"	50 00	150 00
3	blacksmiths; pay, $85; board, $30	"	115 00	345 00
3	helpers; pay, $50; board, $30	"	80 00	240 00
40	kegs powder	"	4 00	160 00
150	lbs. candles	"	40	60 00
400	bushels charcoal	"	20	80 00
1,500′	fuze	"	3 00	45 00
	Superintendence, tools, etc.	20 per cent.		884 00
				$5,304 00

Or $14.80, gold, per cubic yard. With nitro-glycerine the cost must have been about $10 per cubic yard.

Appendix E.

Tunnels of Union Pacific Railroad.—S. B. Reed, Eng. and Supt. Construction.

No. of Tunnel.	REMARKS.	Distance from Omaha in Miles.	Length.	Alignment.	Depth.	No. Faces worked.	Average Daily Progress.	
							Heading.	Bottom.
1	Soft sandstone.....	680	215	Straight,	64	2	4.	6.
2	Clay rock.....	972	772	"	135	2	4.	9.
3	Limestone and quartzite..	1,005	508	3° 30′ L	178	2		
"	Mormons with powder....	..	..	....		..	1.03	0.57
"	Gentiles "	..	..	....		..	2.70	3.17
"	" with nit. gly.....	..	..	....		..	4.62	4.62
4	Quartzite.....	1,006	297	4° L	108	2		
"	Mormons with powder....	..	..	....		..	1.38	0.92
"	" " nit. gly....	..	..	....		..	...	8.18
			1,792′					

Note.—Progress in tunnels 1 and 2 is when working full gangs.

Appendix F.

Estimated Cost of Tunnel No. 2, Union Pacific Railroad.

Excavation of tunnel—12,410$\frac{1}{2}$$\frac{1}{0}$ cubic yards, at $11.50			$142,715 57
Carpenter work	$11,434 20		
Blacksmith	1,711 50		
Teams hauling timber at tunnel	2,053 50		
Laborers on timbering	17,334 50		
Lights "	340 10		
Miscellaneous	206 55		
Cost of putting in timber	$33,080 35		33,080 35
Loading and hauling timber	$18,543 00		
Timber used in tunnel—304,114 ft. Bm., at $30	18,246 84		
Iron in bolts—8,032 lbs., at 20c.	1,606 40		
Cost of materials	$38,396 24		38,396 24
Total cost of tunnel			$214,192 16
Cost of excavation to contractors:			
Foremen 1,188 days at $7 00	$8,316 00		
Mechanics 2,640 " " 5 00	13,200 00		
Teams 1,604 " " 10 00	16,040 00		
Laborers 16,846 " " 3 50	58,961 00		
Powder 1,064 kegs " 10 00	10,640 00		
Fuze 33,200 ft. " $3\frac{1}{4}$	1,079 00		
Candles 3,450 lbs. " 45	1,552 50		
Lamp oil 310 gals. " 3 50	1,085 00		
Steel 1,798 lbs. " 30	539 40		
Superintendence, tools, coal, buildings, etc., at 20 per cent	22,282 58		
		$133,695 48	
Deduct timbering expenses paid by Company		31,026 85	
		$102,668 63	
Cost of work on timbering per lineal foot			42 83
" materials for " " "			49 72