(*Paper No. 2673.*)

**"The Chinipas Aqueduct and Mineral Railway,
North-West Mexico."**

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THE district in which the works described were carried out lies on the eastern border of the "Tierra Caliente," or torrid lowlands of the Pacific coast. It is actually in the State of Chihuahua, though remote from the capital city and the central parts of that State. It is drained by the river of Chinipas, which unites with the larger river of El Fuerte about 90 miles from its mouth in the Gulf of California. The town of Chinipas lies 1,250 feet above sea-level and is surrounded by mountains, some of which attain an elevation of 7,000 feet. The climate is semi-tropical and dry, the annual rainfall averaging probably less than 30 inches. In the surrounding country are numerous mineral veins, and some well-known mines are in operation, producing chiefly silver, with a variable quantity of gold. The mine of Palmarejo, about 8 miles east of the town, was opened at the beginning of the present century (Fig. 1, Plate 6).

The construction of an aqueduct and a narrow-gauge railway in connection with this mine was undertaken in 1888 and actively commenced in March, 1889.

AQUEDUCT.

The aqueduct was intended to supply water-power to a new crushing-mill, and the preliminary surveys were made and the scheme worked out in principle by Mr. Arnold Lohsé, the engineer of the Palmarejo Mining Company. Between the site of the mill and the point selected for the commencement of the aqueduct, the river has a length of about 12 miles and a fall of 117 feet. The length of aqueduct required was 10 miles, so that, assuming an inclination of 2 feet per mile, there would remain an effective head of 97 feet at the mill. It was estimated that, except in periods of extreme drought, the river would supply 4,000 cubic feet of

water per minute, which quantity, at the head obtained, would correspond with 733 HP. The estimated requirement for a completely equipped dry-crushing mechanical roasting and amalgamating-mill, with one hundred stamps, was 505 HP. from the motors, and the margin provided thus appeared to be sufficient.

The nature of the ground required that a considerable part of the aqueduct should consist of bridges, flumes, lined channels and tunnels, and a rectangular section was adopted as the basis of calculation. With dimensions of 6.5 feet in width by 4.5 feet in depth of water, the cross-sectional area was 29.25 square feet; and, in order to discharge 4,000 cubic feet per minute, the velocity required was 2.28 feet per second. The hydraulic radius of the section being 1.8871 foot, and the surface inclination 2 feet per mile, the value of c in the equation $v = c\sqrt{mi}$ must be 85.25. The value of the coefficient of roughness in Kutter's well-known formula is required to be $n = 0.019$, the value lying between those applicable to rubble-masonry linings and firm gravel, subject to some irregularity of cross-section, viz., 0.017 and 0.020. Enlargement of the cross-section, by giving to the sides of the cut the slope necessary for stability would, it was believed, meet the case where no lining was employed, and some irregularity, either at first or subsequently, might be unavoidable.

The intake, *Figs. 2*, is a wooden trunk 15 feet long by 8 feet wide and 6 feet deep, composed of seven rectangular frames of pitch-pine, 8 inches by 6 inches in scantling, covered with 3-inch planks. The upper timbers project horizontally on the side next to the rock, and are built into masonry on a shelf cut out for that purpose. On the other side, the lower timbers project similarly, and are built into a mass of rubble, bound together by mortised-and-keyed timbers, and capped by masonry in mortar continuous over the top of the trunk. This bulwark projects towards the centre-line of the stream, and behind it the trunk is ranged in line with the open cut of the aqueduct below, diverging from the stream at an angle of about 30° . There are no sluice-gates, as the first $\frac{3}{4}$ mile of aqueduct are drowned in an ordinary summer freshet; whilst in heavy floods nearly 2 miles are covered, and the intake is practically inaccessible.

The open cut, *Fig. 3*, passes partly through a gravelly shoal, and partly through a bed of detritus and boulders brought down by a side torrent; this is now allowed to discharge into the cut, which has here an ample section. The sides are sustained by close piling of round timbers, and immediately outside them runs a low semicircular mound carefully built with heavy stones. Alongside

the main channel of the river, crossing the intervening space diagonally, are groynes of stakes and brushwood in double rows; the object of which is to favour the deposition of gravel and silt between the channel and the aqueduct. The open cut continues on a curve along the foot of the bluffs till the latter again approach the channel at a bend of the river, where the floods set strongly against them. Here the aqueduct is carried in a series of tunnels 8 feet square, driven through the solid rock

ELEVATION.

for 350 feet, the short intervals being strongly walled up. As far as the commencement of the tunnels, the calculated water-level of the aqueduct, fixed in accordance with the lowest known level of the channel, is below the general level in the river, so that it was unnecessary to make the work water-tight, as is the case from this point onwards. The tunnels terminate about half-a-mile from the intake, and the next half mile is cut partly in rock and partly in gravel, *Figs. 4 and 5*. The hollows in the rock are filled in up to

the bottom of the cut with concrete in bags, forming a foundation for a strong masonry wall which completes the section. In the gravel, which is compacted with silt, the side next the river is protected by a concrete wall, with a batter of $\frac{1}{4}$ to 1, surmounted by a semicircular stone mound. The bottom and the inner side of the cut are natural ground cut to a suitable profile.

At the end of the first mile of aqueduct the cut is entirely faced with concrete for about 150 yards, *Fig. 6*, until the first regulating-gate is reached, placed beyond the reach of ordinary floods. This is a simple drop-gate of planks let down horizontally in lateral grooves, one above another, so as to limit at will the

Fig. 3. *Fig. 5.* *Fig. 4.* *Fig. 6.*

Scale, 1 inch = 16 feet.

quantity of water passed, or to stop the flow altogether (Figs. 7, Plate 6). Before the gate, the aqueduct is deepened 2 feet, to form a collecting-box for silt. In the enclosing masonry are fixed four sluices at the lowest level, each opening being 3 feet wide by 1 foot high. These can be lifted singly for scouring purposes, or used conjointly for passing off the whole flow from above when the stop-gate is entirely closed. The sluices are placed two on each side of the chamber, discharging upon curved aprons of masonry leading to a natural watercourse which here passes underneath the aqueduct through three low arches. Above this place all the small streams flowing off the precipices are allowed

to run into the cut; but below it, all watercourses of importance pass under arches or flumes, while a few small torrents are passed over the aqueduct by rough shoots made of round timbers placed close together and floored with heavy stones.

The greater part of the aqueduct is formed on a shelf or chase cut out of the precipitous bluffs which border the river bed; a wall being built near the outer edge to confine the water. Where a sound foundation is afforded by the rock, or by indurated clay, the upper part of the wall is 2 feet thick, forming a pathway on the top. Below $4\frac{1}{2}$ feet from the top, the wall is strengthened by counterforts against the internal pressure of water. The total length of this wall is over $6\frac{1}{2}$ miles. It is built of half-coursed rubble in mortar, with one through binder in every square yard of face. All the mortar is made with good hydraulic lime procured in the district, gauged 1 part of slaked lime to 5 parts of sharp sand. Catch-pots, sluices and stop-gates are provided at intervals, where some natural water-course affords an opportunity of discharging the scour. There are in the length of the aqueduct 12 such sets of gates, including the first above mentioned and the terminal sluices.

There are in all eighty arches, of which fifteen are at the crossing of a hollow near the end of the eighth mile. The parapets over all arches are similar in dimensions to the upper part of the long wall with which they are continuous. At all spans of $6\frac{1}{2}$ feet and upwards, tie-rods are set at the level of the floor, with wrought-iron bearing-plates outside the walls, so as to bind the work securely together at two points over each arch (Figs. 8, Plate 6). The 4 arches first built were turned in stone; but it was afterwards found cheaper to use brickwork. The larger hollows and ravines (with the exception of that last mentioned) and a stretch of crumbling hillside are passed by means of timber flumes supported upon masonry piers. When the height does not exceed 20 feet, these are 23 feet apart from centre to centre; when between 20 and 50 feet high, the distance is $34\frac{1}{2}$ feet. The water-trough is designed in bays of $11\frac{1}{2}$ feet, to bring the timbers within dimensions convenient for transport (Figs. 9). The upper work of the flumes is uniform, but the mode of intermediate support by strutting from the piers is different in the larger and smaller spans. The bottom of the trough is 2 inches thick, and the two lower strakes of the sides, which serve as beams, are 4 inches thick, the upper boards being only 1 inch thick. The aggregate length of flume is 2,600 feet. As, however, the length of one flume never exceeded 600 feet, it was thought

unadvisable to contract the sectional area of waterway over so short a distance, notwithstanding the diminished resistance to flow offered by the planking as compared with other materials. At each end of every flume, lateral grooves are provided to receive stop-planks, so as to retain water when the adjacent portions of the aqueduct are laid dry. It was found that even partial drying left the planks so warped and shrunk that no amount of caulking would prevent leakage; while, if kept filled, the flumes were water-tight. No ironwork, except nails and some $\frac{1}{2}$ -inch carriage-bolts, was used in these flumes, the parts being so framed together as to hold one another in place. Besides the tunnels near the intake, there are three of short lengths on the bluffs lower down. The longest tunnel passes behind the town, and is for nearly its whole length of 920 feet driven through greenstone. The clear dimensions of this tunnel are 7 feet wide by 6 feet high. Side-walling was only introduced where required to obviate leakage in some fissured lengths. Another tunnel, 880 feet long, on the last mile of the aqueduct passes through soft and treacherous ground, containing inclined beds of shaly rock and a few veins of greenstone. The excavation was timbered throughout with "mauto," the wood reputed to be the best adapted for underground work in damp situations, the props and caps being round timber, not less than 8 inches in diameter, and the polings being round sticks, 3 inches to 4 inches in diameter. After the whole length had been driven (from two shafts as well as the open ends) and timbered, masonry side-walls were built in place of the props, the roof-timbering being permanently retained. The aggregate length of tunnelling is 2,265 feet.

The town of Chinipas is now supplied with water from the aqueduct, in accordance with an agreement embodied in the concession of water-power and rights of way. A $2\frac{1}{2}$ -inch wrought-iron pipe, galvanized, with screwed ferrule-joints, is led through the side-wall, and furnished with a stop-valve immediately outside and with a scour-valve at the lowest part of its course. Branches of $1\frac{3}{4}$ -inch diameter lead to 1-inch stand-pipes in the public places of the town. The maximum calculated delivery is 15 cubic feet per minute—a quantity insignificant in relation to the flow of the aqueduct, but sufficient for the wants of a population far exceeding that now supplied with water. The previous supply was drawn direct from the river, or from a few private wells; and the distribution, being effected by means of bucket-carriers or animals carrying water-bags, was both inadequate and costly.

The aqueduct terminates about 300 yards from the mill, the supply being conveyed to the motors through an inclined steel-plate pipe 28 inches in diameter at the bottom but bell-mouthed to 4 feet in diameter at the upper end (Figs. 10). It was found that the empty pipe expanded and contracted through a range of about 4 inches; and provision was therefore made for its expected contraction on the admission of water, by a short leather sleeve placed between the end of the pipe and a surrounding ring of brickwork in which the pipe was free to move. The pipe passes through three such rings in the outer and the partition walls of a double chamber filled with puddle. The upper part of the bell-mouth is set so as to be well covered by a depth of only 2 feet of water in the aqueduct. In the front wall of the inlet-chamber are set two pen-stocks of cast-iron, each giving when fully open a clear waterway of $4\frac{1}{2}$ feet high by $3\frac{1}{2}$ feet wide, the top of the opening coinciding with the terminal water-level. The bottom of the chamber slopes down to the pipe in one direction and in another down to the silt-box, from which the chamber is separated by a grating. On the surface of the water floats a board with short vertical pegs both above and below, as an additional preventative against the entry of rubbish, and the chambers are boarded over. Immediately beyond the entrance of the inlet-chamber is a set of sluices for scouring purposes; and the aqueduct terminates with a waste-weir, the crest of which is at the top water-level and of sufficient length to pass the whole flow with a rise of 6 inches above it. The waste water is led off by a paved channel to a natural water-course at the foot of the knoll upon which the aqueduct terminates.

Experience having shown that some lengths of the aqueduct were liable to obstruction by falls of *débris* in the rainy season completely blocking the waterway and producing discharge over the top of the wall upon the foundations; several adjustable overflows were provided in places where such lateral discharge would not be prejudicial, so as to render unnecessary the opening of sluices to prevent the topping of the wall by pent-up water. By inserting planks to regulate the level of escape, the volume of flow can be increased to the full capacity of the aqueduct, if required by the extension of the mill or for other purposes. Some trouble was occasioned by leakage through natural fissures in the rocks or cracks caused by blasting, and a considerable length of aqueduct was at last lined or paved with pitching and puddle, or with concrete in places where such expense had not at first been thought to be called for. Considerable loss of water occurred also

at first by leakage through the masonry, some sections of the long wall appearing to be very permeable. This was, however, after examination attributed to imperfect setting of the work, owing to the mortar having lost its moisture too quickly in the dry seasons; and in a short period after water was run into the aqueduct this leakage perceptibly decreased and at last became insignificant in quantity—owing probably to the requisite moisture being supplied, thus enabling the mortar to set.

The cost of the aqueduct was approximately:

Materials and stores from England (including freight)	£ 680
" " " other than the above	14,600
Transport from the coast to Chinipas	600
Wages and local transport	58,221
General charges (preliminary survey, superintendence, &c.)	7,820
Total cost of 10 miles of aqueduct	<u>81,921</u>

RAILWAY.

The railway, the gauge of which is 2 feet 6 inches, begins 90 feet below the end of a tramway from the mine. The ore, on arriving there, is tipped through a shoot into a bin capable of holding 300 tons, from which it is drawn into the railway wagons. The down gradient of the railway commences about 200 feet from the bin. The maximum gradient is 1 in 25 on straight portions of the line, a reduction being made on curves according to their radii, so as to equalize the resistance to traction. The average gradient of the first $6\frac{1}{2}$ miles of line is 1 in 32.

The greater part of the line consists of a succession of sharp curves with short intervening straight lengths; the minimum radius, used on two curves only, is 115 feet; while 127 feet, corresponding with a central angle of 45° for an arc of 100 feet, is the most common radius.

At about 200 yards from the bin, two level sidings give facilities for passing the full and empty trains and for the locomotives to run round them. Water-supply at the commencement of the line is afforded by a spring. At 500 yards from the bin the railway crosses the gorge, on the left side of which the works above mentioned are situated. The bridge has two spans, one of 65 feet from a rocky bluff to a pier springing from the foot of the opposite slope, and another of 52 feet (Fig. 11). The abutments and the pier are built of coursed-rubble masonry in mortar, and the wing-walls of dry random-rubble, the foundations in each case being upon rock.

The super-structure is a pair of timber trusses, spaced 7 feet apart and braced together vertically and horizontally both at the top and bottom. The trusses are framed in bays of 13 feet, with wrought-iron verticals in tension, adjustable by screws. The depth between the centres of the top and bottom booms is 13 feet on the smaller span and $14\frac{1}{2}$ feet on the larger one; the main transverse bearers are on the top, bolstered to suit the gradient. The bridge crosses the gorge at an angle of about 70° , and a curve of 127 feet radius commences on the smaller span, but as the un-symmetrical loading affects only the end bay it has been neglected in designing the trusses. The height from stream to rails is 62 feet. The line follows the ravine in a succession of short deep cuttings, and banks supported by dry-stone retaining-walls, with occasional tunnels, bridges, and culverts. All the culverts are built of dry-stone. The largest are double 4-foot openings, with the upper courses of the side-walls sailing over; the openings so reduced being spanned by the largest and heaviest stones available, the mere mass of which gives considerable stability to the work.

Only two masonry bridges with timber super-structures, in addition to that already described, occur within the first mile, and no others for $5\frac{1}{2}$ miles beyond. As, however, they are generally at some deep gorge crossed by the railway on a sharp curve, the general design was a succession of 25-foot spans, with piers built tapering so that the opposite sides of each span were parallel near the top (Figs. 12, 13 and 14). The super-structure consists of 3 parallel timber trusses, carrying transverse and longitudinal bearers, the latter being laid to the curve so as to support the ordinary cross-sleepers under the rails. There are on the $12\frac{1}{4}$ miles of railway, 17 spans of 25 feet, and 10 of 7 feet, besides the 65-foot and 52-foot spans first described. There are also two arched bridges, one of 29 feet and the other of $6\frac{1}{2}$ feet; and 45 dry-stone culverts, with numerous catch-water channels. On this upper part of the railway there are 7 tunnels, varying between 96 feet and 315 feet in length, and aggregating 1,114 feet. Nearly all are curved for the whole or some part of their length, and are driven through hard greenstone or hornblende porphyry, only two of the faces requiring to be timbered.

The total descent of the railway is 1,406 feet, of which 1,100 are made in the first $6\frac{3}{4}$ miles. A reverse gradient adds some 82 feet to the upward climb.

The station or dépôt is about $\frac{1}{2}$ mile short of the termination of the line, at the foot of the incline above mentioned. The work-

shop and engine-shed is a brick and adobe building 65 feet by 35 feet, provided with an engine-pit on one side, while the other side of the building is occupied by the work-bench and machine-tools. Attached to the shop are a forge, a carpenter's yard and a store 40 feet by 20 feet. The roof is of galvanized corrugated iron, supported by timber principals and purlins. The men's quarters are also built with brick and adobe, but have a flat roof in the native style, covered with bricks and clay. On the north side is a wide verandah. The railway, which is level through the station-yard, falls beyond it, rising again to the same height behind the mill. Here the loaded wagons are traversed sideways, to discharge into the ore-bins under cover.

The rails are steel, of two sections—35 lbs. to a yard, and 25 lbs.—the latter being, however, light for the traffic. The weight was reduced to the lowest limit on account of the expense of transport from the coast. About one-third of the total weight consisted of the heavier rail-section in lengths of 12 feet, the lighter in 12-foot lengths and also in 18-foot lengths. The first and last lengths, weighing 140 lbs. and 150 lbs. respectively, were reckoned as two to a mule-load, or three of the second lengths. The practicability and cheapest method of transport were discussed with experts before the rails were ordered; and one object in view in so varying the weights was to utilize the varying powers of the animals comprised in ordinary mule-trains. Half a load or "carga" (of 300 lbs.) is the usual limit of weight, but certain parts of the rolling-stock weighed necessarily more than a full load. These, up to a maximum of 450 lbs. for a small number of pieces only, were transported by relays of the strongest mules, each animal carrying the load for a short distance at a time. Some parts of the road approaching the summit west of Chinipas were so steep, and the zigzags so short, that the rails were more conveniently carried up and down on men's shoulders; and a few bulky and light packages were so carried over the whole length from the end of the practicable wagon-road, a distance of 45 miles. The cost of transport from the coast to Chinipas, including landing-expenses, storage, agency and all charges between the ship and the station-yard, was \$75 (Mexican) per ton (2,000 lbs.) for the rails and rolling-stock, \$60 for the sleepers, and \$56 for the remainder of the material and stores; being thus between twice and three times the freight of the same from Liverpool to New Orleans or Galveston, thence by rail to Guaymas on the Gulf of California, and by small coasting steamers or sailing craft to Agiabampo, distant 150 miles from Chinipas.

Steel sleepers were obtained from England, partly because of the scarcity of timber suitable for sleepers in the immediate vicinity of the railway; and also from the apprehension that all facilities for transport would for two entire seasons be maintained on the Alamos road only and be difficult to divert elsewhere. 20,000 sleepers were supplied, of inverted trough section, $3\frac{1}{2}$ feet long and $6\frac{1}{2}$ inches wide, having outside clips raised by stamping, to confine the rails, and holes for screw-bolts which secured pinch-plates resting on the inner side of the flat-footed rail. 5,000 sleepers were for the 35-lbs. rails, and are $\frac{1}{6}$ -inch thick; the rest are $\frac{1}{4}$ -inch thick only; the weights, including fastenings, are 33 lbs. and 26 lbs. respectively. The sleepers are all straight and hold the rail without giving any inward cant or providing for any alteration of gauge. Owing to the short dimension adopted, there was some deficiency of bearing-surface outside the rail, in consequence of which the road proved expensive to maintain. For the sharper curves and heavy gradients, wooden sleepers procured in the district are on this account preferable. These are 4 feet 3 inches long and of 6 inches by $4\frac{1}{2}$ inches scantling. Oak was chiefly used, only a few other timbers being laid experimentally. All were very hard and the machine-boring and spiking proved costly.

The locomotives, two in number, were built by Messrs. Manning, Wardle and Co. of Leeds. They are six-coupled tank-engines, with wheels 2 feet 6 inches in diameter, and cylinders 9 inches in diameter by 14 inches stroke, to carry 120 lbs. per square inch working pressure. The weight of each in running order is nearly 18 tons. They were specially sectioned for transport and were erected at Chinipas by mechanics recommended by the makers. The workmanship was excellent; but the design is not, in all its details, appropriate to the conditions of working. The fire-boxes are small for wood-burning, and in order to keep steam at very moderate speeds on the heavy inclines a special class of fire-wood and careful stoking are necessary. Each engine was at first provided with two injectors, but in view of the great summer heat and the scarcity of water along the railway, an independent steam-pump was afterwards substituted for one of the injectors. Without this alteration, the irregular work during construction could hardly have been carried on. Another defect in the design was the rigid parallelism of the three axles, on a wheel-base of 9 feet 6 inches, for curves of 95 feet radius on the original route. Side-play was allowed to the extent of $\frac{1}{2}$ -inch each way from the centre on the trailing axle, and the flanges of the centre wheels were thinned, but great wear of both tyres and rails was soon

observed. As it appeared that the cylinder-power corresponded with the adhesion of four-coupled wheels only, it was then decided to dispense with the extra coupling-rods and to fit the leading-axle with radial boxes. By this modification the life of the tyres was greatly increased and the wear of the rails on curves diminished, whilst the tractive power showed a decided improvement. The brake-power was, however, reduced, as the rigging had to be removed from the radially-fitted wheels.

The wagons supplied for the permanent working, twenty-five in number, are entirely of steel and were manufactured by the Metropolitan Carriage Company of Birmingham. They have a wheel-base of 6 feet, with wheels 1 foot 6 inches in diameter. The bodies are hopper-shaped, with bottom doors to discharge between the rails; the somewhat large wheel-base was necessary to give clearance for the counter-weights to these doors. The capacity was stated at $3\frac{1}{2}$ tons, but when fully loaded with ore they hold $4\frac{1}{2}$ tons. Five of the number are fitted with brakes to all the wheels, worked by a hand-wheel and chain, a seat being provided for the travelling brakesman. These wagons weigh $1\frac{1}{2}$ ton. It was calculated that two 5-ton brake-wagons, in a train of ten or eleven, would assist the engine effectually to control a descending train, even after the alteration the engines underwent; but so far trains of that length have not been brought down loaded. Additional brake-wagons are now fitted, and as, owing to the climate, the rails are never greasy, the up and down trains should be equalized and power should be economized.

The Author was appointed in January 1889 to the post of General Manager in Mexico and Chief Engineer of the Mexican Mineral Railway Company, Limited, and was succeeded in February 1892 by Mr. Thomas Fitzgerald, who had been engaged as Chief Assistant Engineer from July 1889, under whom the works were completed in May 1892.

The cost of the railway was approximately—

	£.
Materials and stores from England (including freight)	16,544
„ „ other than the above	10,450
Transport from the coast to Chinipas	13,634
Wages and local transport	48,145
General charges (preliminary, survey, superintendence, &c.)	7,820
Total cost of $12\frac{1}{4}$ miles of railway	<u>£96,593</u>

The Paper is accompanied by 6 tracings, from which Plate 6 and the *Figs.* in the text have been prepared.

[APPENDIX.

APPENDIX.

NOTES ON MATERIALS AND LABOUR.

Sand and gravel for concrete were obtained from the river-bed. The sand deposited near the highest flood-range is too fine for building purposes, but clean sharp sand was easily obtained from pits sunk in the shingle.

The river-bed also furnished a quantity of stone suitable for rubble masonry on the first 3 miles of the aqueduct; but, where the work was only a little retired from the river, or situated at a much higher level, it was cheaper to open small quarries on the hill-side, when the rock from the cutting proved unsuitable.

Limestone exists in many places, but generally in thin beds, so that extraction soon becomes expensive. The bulk of the lime used on the aqueduct was supplied from kilns erected about 7 miles away, where a large outcrop of stone was found naturally denuded, alongside the main pack-road. This lime, which is strongly hydraulic and was, owing to careful burning, of uniform quality, cost, delivered on the middle portion of the aqueduct, \$2.00 (Mexican) per "carga" of 300 lbs., and \$2.50 at places which lay more than a day's pack-journey from the kilns. The price rose somewhat after the first contract was completed. For the railway-works a somewhat inferior lime was obtained from several other places at about the same cost.

The bulk of the mortar was mixed at convenient points for subsequent distribution—when possible, in or near to the river-bed, where the materials could be cheaply assembled. During the dry months lime did not suffer by being heaped in the open air; but the stock for the rainy seasons was put under sheds roofed with palm-leaves, or a skin of mortar was run over exposed heaps. The average cost of making the mortar was 90 cents per cubic yard of rubble masonry.

Bricks made in the native fashion are generally of poor quality. As the sun's heat cracks any strong clay before it is possible to move the bricks to the kilns, a very light loam is commonly used, and fire-wood being a serious item of expense, the burning is often inefficiently performed. Three sizes were made: the "jaboncillo," useful for engineering works but not often employed in house-building, is $10\frac{1}{2}$ by $5\frac{1}{4}$ by $2\frac{1}{4}$ inches, and costs from \$12 to \$15 per thousand; the "lozeta," $10\frac{1}{2}$ inches square and most commonly used for paving and for the quoins and dressings of "adobe" buildings, costs \$18 to \$22; and the "adobon," $15\frac{1}{2}$ by $7\frac{1}{2}$ by $2\frac{1}{4}$ inches, used for roofing and paving, costs \$25 to \$28 per thousand. The last-mentioned were largely used on the works for quoins of rubble piers, and cost less than the most roughly-dressed stone. All bricks are moulded on an earthen floor and left in place to dry, so that, unless they are specially cleaned before being burned, one side of each brick is soft.

The sun-dried "adobe" is chiefly used for house-walls above the ground-line. It is made of loam mixed with straw or grass to prevent cracking. The standard size is 1 foot 10 inches by 11 inches by $3\frac{1}{2}$ inches to $4\frac{1}{2}$ inches thick. It is always laid as a header, making a wall 2 feet thick, including the subsequent plastering, which, however, is not added until the wall has settled and seasoned, and is often dispensed with altogether externally.

Water for tempering or mixing is carried in leather or canvas bags slung across an animal. A full-sized pair of these bags, in good condition holds

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20 gallons of water, but generally one-half of it is lost on the way, through leakage or collisions.

The timber used for constructional purposes is almost invariably pine, all other woods being comparatively scarce, small, or unsound. The pine is a solid, heavy, durable wood, generally containing much turpentine. The natives often use the lighter and inferior kinds, for which they need not go far into the hills; and these not being so well grown or durable as the red pine grown at considerable elevations, give rise to some distrust of the wood generally.

Oak is generally small, but there is a kind called "encina robe," having large cup-shaped leaves, which grows about the lower pine boundary and attains a considerable size. Twelve sleepers, 6 by $4\frac{1}{2}$ inches, have been sawn out of the trunk sections. This wood is very heavy and scarcely floats in water. Sleepers cut from small timbers cost from 70 to 90 cents apiece, according to distance from the point of delivery; but the best, sawn from the large trees above-mentioned, where a large number were found in one place fully seven leagues from the railway, cost 80 cents each (delivered).

For tunnel-timbering and foundation-piling "mauto" was always used; this is a sort of acacia having a dark heart-wood, tough throughout, but not difficult to work. A much harder description called "tepeguaje," was advantageously used for small cleats, pulleys and rubbing-pieces. The low grounds furnish a variety of timber, the most valuable being ebony, sabine, logwood and lance-wood.

All other building materials are imported.

The wages of unskilled labourers range ordinarily from \$0.75 to \$1.0 per day; and of lumbermen \$1.25; masons receive from \$1.25 to \$2.50, according to their experience and skill; good foremen, \$3.0 to \$4.0; quarrymen and stone-hewers, \$1.0 to \$1.50; carpenters, \$2.50 to \$3.0; and smiths rather more than this.

Miners receive from \$1.50 per day for ordinary drill-hands to \$2.50 or more for experienced men who can prepare and set timbers underground. These prices are for outside work or for tunnelling when mines are shut down or slack.

The cost of rock-tunnelling varies with the amount of blasting required. Short tunnels in hard rock, 6 to 7 feet square, can be driven for \$5 to \$6 per lineal foot; longer tunnels, in which the disposal of the stuff is more expensive, or which are driven from shafts, may cost double as much. On the railway, tunnelling in hard rock, 13 feet by $11\frac{1}{2}$ feet in main dimensions, equal to about $4\frac{1}{2}$ cubic yards per lineal foot, cost from \$15 in the short tunnels to \$20 and \$22 in the two longest tunnels (208 and 315 feet respectively) per foot run. Excavation in the open cost from a minimum of 7 cents (contract price) to a maximum of 25 cents per cubic yard in deep trenches for foundations; hard gravel or rock requiring no blasting up to 50 cents per cubic yard. The hardest rock cost \$1.25 per cubic yard, including explosives; and some work amongst heavy boulders under water cost as much as \$2.50. The highest contract price on any large cutting was 94 cents per cubic yard, all labour, tools, steel, and explosives included.

Masonry cost, for all labour, except mortar-mixing, in the most favourable situations, \$2.50 per cubic yard of rubble-walling. Bridge-abutments and high walling, \$3.75 to \$4.75, and lofty piers, \$8.50 per cubic yard. Brick-arching up to 15 feet span, including centreing and mortar of a special quality, \$12 per cubic yard. Concrete rammed in moulds, with large stones interspersed, cost \$2.50 per cubic yard; laid in bags under water, \$6 per cubic yard. Dry-stone building in culverts and retaining-walls on the railway, quarrying included, cost \$1.60 to \$2.50 per cubic yard.

The hire of a mule and pack-saddle averages 50 cents per day; the wages of a driver, who can load and attend from four to six animals, is \$0.75 to \$1 per

day. Donkeys could be hired, including drivers, for 25 to 35 cents a day, the higher figure being paid for those carrying the "bote" or water-bags. In the rainy season of July and August all animals run loose, and it is scarcely possible to hire them at any price. Oxen are little used except for ploughing, as, to give good results, they require careful feeding, which the natives grudge to any animal.

The native generally labours only when compelled by necessity to do so. His favourite occupation is agriculture, which, if successful in the summer, ensures him an indolent existence for several months. Slavery has long been abolished by law; but the lower classes readily incur debt which practically binds them to service; as they are liable to be prevented from working otherwise than as their creditors may determine. The employer-creditor is in a position, during the slack season of agriculture, to furnish working gangs to any undertaking that makes it worth his while to do so. These gangs return to their fields in summer, and may not become again available until near the end of the year, though some of them offer service after the sowing-season.

CHINIPAS AQUEDUCT AND RAILWAY.

Fig: 1.

SECTION ON A.A.

Figs: 7.

PLAN

Figs: 8.

Figs: 10.

Scale 1 Inch = 16 Feet, Figs: 7, 8, 9, 10, 12, 13 & 14

Fig: 12.

Fig: 13.

Figs: 9.

PLAN

Fig: 14.

Fig: 11.

Scale 1 Inch = 32 Feet, Fig: 11.