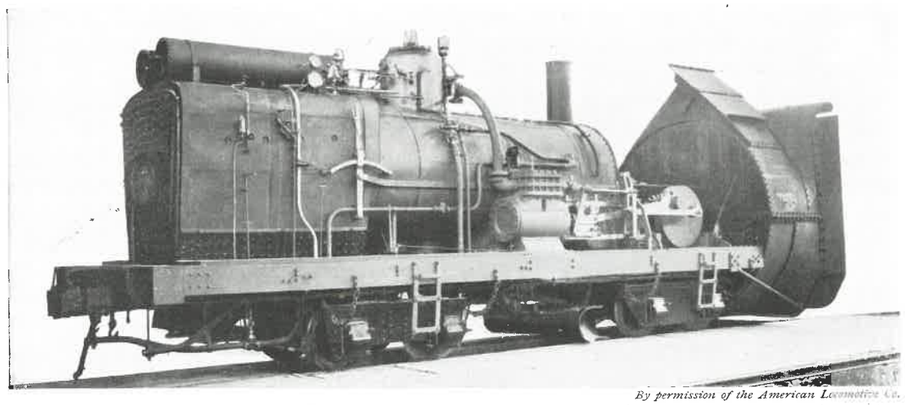
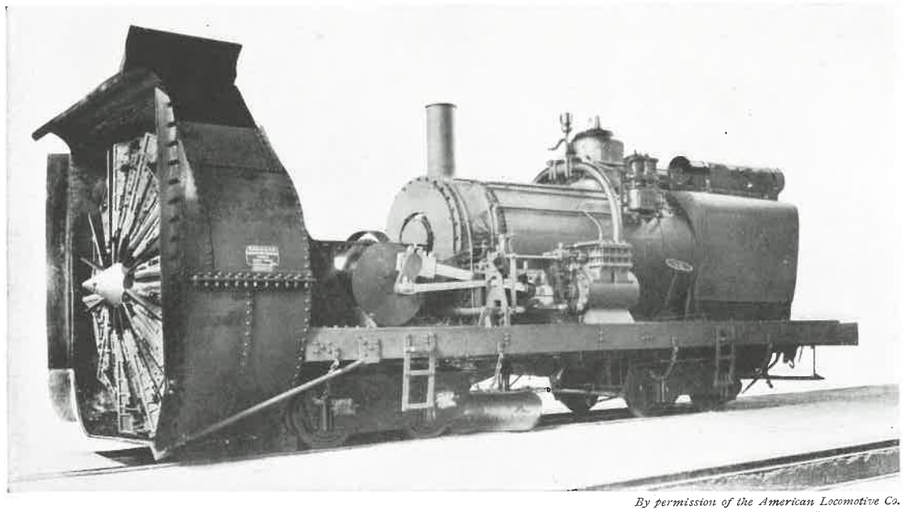
and carries 16 tons of coal and 7,000 gallons of water, so that the total length over frames of this machine is over 80 feet.



By permission of the American Locomotive Co.

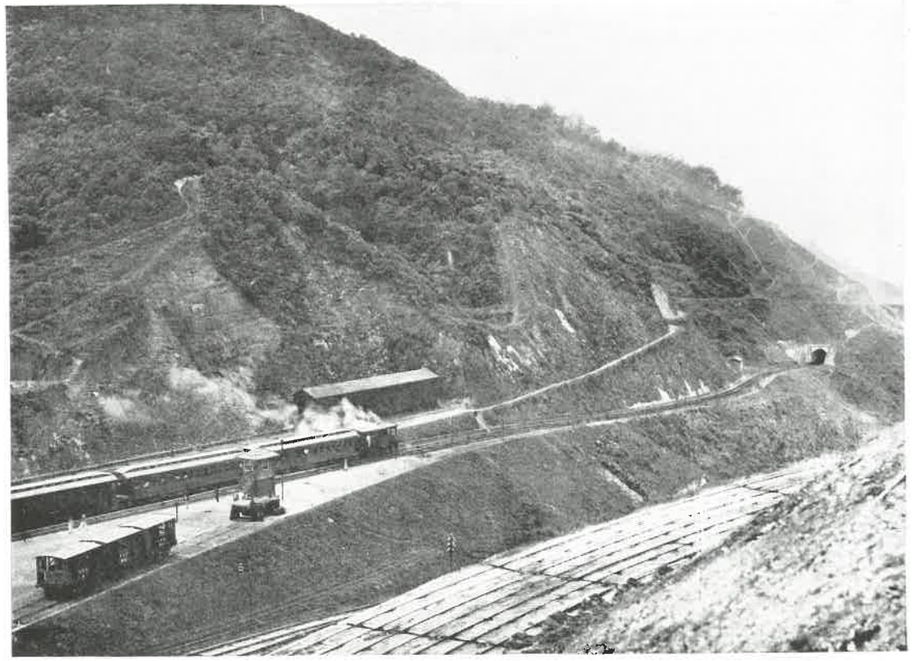
THE ROTARY UNHOUSED, SHOWING BOILER AND ENGINE FOR DRIVING THE SCOOP WHEEL.

Two of these powerful ploughs were built as a first instalment and were dispatched to the mountains immediately upon completion in January, 1911. Although the winter was not so severe as those experienced in previous years, and consequently an opportunity did not arise to submit the machine to a most exacting test to ascertain its capabilities, yet the work which was carried out therewith served to indicate that the forces controlling the mountain section of this railway had secured a plough such as they desired. With the aid of only one locomotive instead of two, drifts of packed snow and ice 250 yards in length were forced with ease, speed being maintained from one end of the cut to the other. Ability to tackle the avalanche with its concealed trees was demonstrated also, because trunks 4 inches in diameter were cut up by the knives as if they were straws.



By permission of the American Locomotive Co.

FRONT VIEW OF UNHOUSED ROTARY, SHOWING SCOOP WHEEL AND ITS DRIVING GEAR.



A BANKHEAD ON THE INCLINE SECTION OF THE SAN PAULO RAILWAY.

A Wonderful Brazilian Railway

THE STORY OF AN ENGLISH ENGINEER'S STRUGGLE WITH PRIMEVAL NATURE

IN the early days of 1856, a number of distinguished Brazilian gentlemen, among whom was Baron de Mauá, received a concession from their Government for the construction of a railway from the seaport of Santos to the town of Jundiahy on the great inland plateau. The connection was required urgently as the fertile tableland and its commercial centres were cut off from the seaboard. In point of length the projected enterprise was not particularly striking, seeing that, as the crow flies, Jundiahy is barely 72 miles from Santos, but, nevertheless, the provision of a steel link offered as teasing a puzzle in railway engineering as could be conceived. As far back as the early thirties the establishment of such a line had been urged and considered, to afford an outlet for the coffee crop, and the scheme had been referred to Mr. Robert Stephenson for his opinion and advice. Nothing came of that attempt, as the year 1839, in which it was advanced, was too early for such an enterprise.

Baron de Mauá, however, was more aggressive. He was resolved that the line should be built, and he even had preliminary

surveys run from Jundiahy towards the coast under his own initiative. But his engineers only ran their lines roughly to the eastern edge of the plateau. There they stopped, not from lack of funds, but because they were baffled. The plateau tumbles precipitously into the sea, presenting a staggering cliff some 2,500 feet in height.

A British Engineer Engaged.

Thereupon Baron de Mauá sent to England to enlist the services, knowledge, and skill of the eminent British railway engineer, James Brunlees. But the Brazilian concessionaires had no intention of permitting the engineer to solve his difficulty as he pleased. Nothing but a locomotive line would be accepted; there were the two points which were to be connected with the shortest possible link of steel, and there were £2,000,000 available for the work. It either had to be completed for this figure, or the Brazilian concessionaires would go elsewhere. And for this sum no pioneer railway would be accepted, it had got to be a first-class line in every respect.

The British engineer, though aware of the severe stumbling-block which the Serra do Mar, as the granite cliff is called, offered to construction, accepted the onerous terms. His first question was the selection of an engineer to determine the route of the line. The circumstances demanded an engineer who had a railway eye for the country, was accustomed to working in mountainous districts, and thus qualified to grapple with the peculiar difficulties which were certain to crop up. The eminent engineer remembered one of his former pupils, Mr. Daniel Makinson Fox, who had been connected with some most difficult undertakings. At the time he was only twenty-six years of age, but he had demonstrated his ability in no uncertain manner, having assisted, among other enterprises, in laying out and constructing a narrow gauge railway in North Wales. There was another recommendation in this young engineer's favour. He was conversant with Spanish, having mastered this language while spying out the land for railways among the mountains of the Pyrenees.

Accordingly, the young engineer was summoned to London, where the conditions of the undertaking were explained, and he was instructed to proceed to San Paulo to make the surveys for a locomotive line the cost of which was not to exceed £2,000,000.

Mr. Fox vividly recalls that Brazilian expedition. His knowledge of Brazil was somewhat hazy, but he did not worry his head about his pending work during the tedious sea journey, feeling sure that all anticipations would be shattered. It was a fortunate circumstance that he embarked upon his task in this spirit, because when he reached Santos, and came face to face with the Serra do Mar, he gave way to as severe a fit of despondency as could be imagined. The cliff appeared to be as impossible of conquest by a locomotive line as the Himalayas, and he conjured up visions of the £2,000,000 which had been set down for the whole 88 miles to Jundiahy going in the climb up that escarpment. Nor did his spirits rise when he pursued the first task of an engineer who is dropped into a strange country. He questioned all those in Santos who penetrated the inland plateau as to the trails, paths and watercourses cutting through the Serra, but the information thus vouchsafed was of a meagre description.

A Depressing Start.

The abortive result of these preliminary investigations proved only too conclusively that he would have to find out everything for himself. There were no maps to guide him, so he had to become an explorer as well. He got together a small party of trusted natives to act as carriers, and to perform other varied tasks. Equipped with a good supply of axes and other tools, he

An Exploration Trip.

plunged into the dense forest which clothes the cliff from base to crest. The going was hard and slow. The virgin forest was dense and tangled—so much so that no sun ever penetrated the foliage to strike the ground. The rainfall was terrific, and, added to this, the Serra is torn in all directions by deep precipitous ravines, among which one had to scramble nimbly at the imminent risk of a fall and broken limbs. There was a heavy demand upon axe-work, and advance under such conditions was slow.

The exceedingly arduous conditions which prevailed demanded special arrangements. It was impossible to drive straight ahead through the forest from point to point, remaining in this timber prison until the opposite side was reached, owing to the difficulties pertaining to the commissariat, and the serious risk to health which it involved. So the engineer resorted to what might be described as periodical dives into the bush. He would load up his pack train with a large stock of provisions of a strictly limited variety—the prowess of the canner's art still remained to be revealed—making doubly sure that a goodly supply of tobacco was in the packs, and then would strike his route. At a suitable point in the bush a clearing was made, and a few huts of palmetto leaves run up for shelter from the rains and to offer a more or less inviting couch at night. From this camp narrow headings, virtually Indian trails, were driven in various directions, and the levels, and distances taken roughly. As a rule, three weeks were spent at a time in the jungle, which, owing to the absence of sunlight, generally was sufficient to bleach him like a stick of sea-kale. Then camp would be broken and a return made to Santos or some other convenient point, where he sojourned for about a fortnight, devoting his time unravelling the work and notes collected during the excursion into the jungle. On one occasion he was immersed longer in the forest than he had anticipated, and when he emerged he was so pallid, thin, and drawn that his companions in Santos at once jumped to the conclusion that he had been stricken down with fever.

A Noisome Jungle.

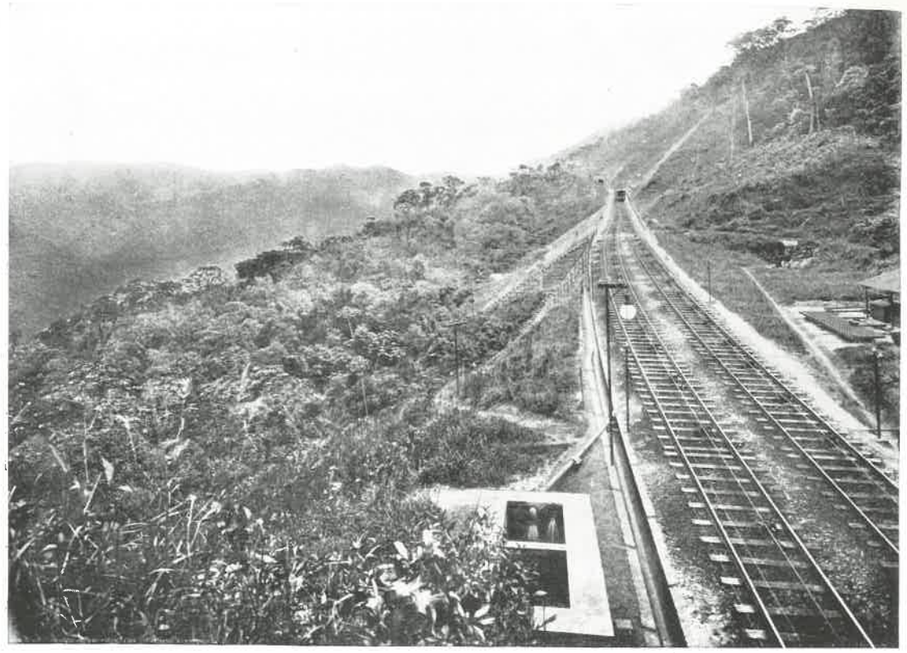
In this manner the engineer tramped up and down the Serra do Mar for month after month, but the discovery of a pass through the rampart appeared to be as far off as upon the day he first landed. One morning he descried through the trees a big fissure in the ridge, and at last he thought he had met success. The party struggled to the big, rugged V, and then disappointment hit them hard. It was a waterfall, and a sheer cliff on the inner side. However, it was a beautiful glimpse of rugged and wild Nature, and the engineer, dropping all thoughts of his railway for the time being, determined to examine the fall at close quarters. With infinite labour he scaled one of the perpendicular side walls and took a breather to enjoy the view unfolded from the top of the waterfall. The surveyor was sitting down smoking placidly, when his eye, idly following the valley spread beneath him through which the Rio Mugy flows, saw that the floor of the valley rose gradually to the north-east. He had trudged that valley previously, but from the bottom of the depression was unable to see what was now revealed. In a flash, he espied the only feasible route for the line.

A Way Out.

The party hurriedly regained the valley, and then carefully drove a way along the route which the engineer had taken in with his eye from the edge of the waterfall. As he expected, it brought him to the top of the Serra, where a gap swinging through the mountain in a north-westerly direction brought him on to the plateau. Following this up, he gained a point on the highlands to which the Brazilian surveyors had brought their lines some years previously.

When the engineer had committed the results of his investigations to paper, and

had evolved his location, he found that he could negotiate the Serra within a distance of 5 miles. This in itself was a distinct achievement, inasmuch as previous computations had indicated the necessity for a tortuous line of about 26 miles to overcome the cliff. But in this short length of 5 miles a difference in level of 2,550 feet had to be overcome. Such a sharp rise was dead against a continuous adhesion track, unless zig-zagging, V-switches, and other intricate solutions were incorporated. But they were impossible from motives of cost. As those were pre-rack-rail days, the engineer was thrown dead up against it. But as he was convinced that there was no easier path through the Serra, he decided to stick to his location.



PASSING PLACE ON THE INCLINE, SHOWING UP AND DOWN TRACKS AND CABLES.

Desperate situations demand drastic means of escape. So, foiled in the effort to get a grade not exceeding 1 in 40, the engineer conceived a unique means of overcoming the steep ascent, which stamps the San Paulo as one of the most remarkable and interesting railways in the world. He divided the ascent into four sections. In this way the trains would ascend and descend the mountain side in steps. As adhesion working was out of the question, he conceived a cable-hauling system. Each section or incline is topped by a short length of line 250 feet in length, falling downwards at 1 in 75, which is termed a bankhead, and at each of these points the stationary winding engines were to be placed. In this manner, four inclines, 6,388, 5,842, 6,876, and 7,017 feet in length respectively, were provided, each having a gradient of 1 in 9·75.

Fifteen months were occupied in the preparation of these plans, and then the engineer returned to England with his proposals. They were scrutinised minutely by the master-hand, and as the cost of building the railway upon these lines would not exceed the £2,000,000, Brunlees gave the ingenious solution of the problem his wholehearted support.

The project received the approval of the company which had been formed to build the road, and construction was commenced. The young engineer, when he produced his surveys, did not fail to point out the fact that heavy excavation and development work would be unavoidable in scaling the Serra, and his statements proved to be not a whit exaggerated. When the railway builders appeared upon the scene, they found themselves faced by conditions which has to cross an arm of the sea and two formidable rivers, both of which are subject to heavy and sudden fluctuations in level. For the first 8 miles a low embankment had to be raised to receive the metals laid on the 5-feet 3-inches gauge, the location paralleling the Government road laid across the marshes. A 500-feet bridge swings the line across the arm of the sea which separates the island on which Santos stands from the mainland; four 75-feet spans carry it across the Cubatao River, while three 66-feet spans lift it over the Mugy River.

But it was the incline division which seldom had been equalled in such operations previously. Although the going for the first 13½ miles out of Santos runs through practically level country for a greater part of the way, the land is marshy, and before it reaches the foot of the cliff worried the builders. In the first place they had to drive roads through extremely rough country and dense forest to reach the camps scattered along the location, for the haulage of supplies and material. As the region was uninhabited, and for the

THE TWO INCLINES ON THE SAN PAULO RAILWAY.
The original line is in the foreground and shows the viaduct, 705 feet in length by 185 feet high.

most part unexplored, reliance had to be placed upon the rough maps which the engineer had drawn up in preparing his surveys.

Overcoming Landslides.

The railway in its climb to the plateau ascends the spur forming the east bank of the Mugy River. The sides of these mountains are torn and riven by gullies, chasms, couloirs, and rifts in the most fantastic manner, and as these run at right angles to the railway their negotiation offered many opportunities for ingenious thought, as did also the overcoming of the spurs and shoulders of treacherous rock forming the walls of these gaps. Some of the cuttings are of great magnitude, running up to 75 and 95 feet in depth. The trials of the builders were aggravated by the severity of the landslips and rock-slides, precipitated by the heavy rainfall. Time after time an embankment when completed for the rails was demolished. As a rule the earth could only be prevented from slipping by throwing up massive retaining walls varying from 10 to 60 feet in height.

After the line had been opened, one heavy landslip completely blocked a cutting, but it was removed in an ingenious manner. A mountain torrent was diverted so that it rushed into the cutting. Gangs of men were crowded on to the work, moving the soil, and the water, assisted by the heavy fall of 1 in 9·75 represented by the grade, scoured away the loose detritus effectively, economically, and expeditiously, leaving behind the heavier stone, which was utilised for building purposes.

Bridge-building.

At the foot of the fourth incline a deep chasm had to be crossed by means of a viaduct 705 feet in length, divided into ten 66-feet and one 45-feet spans, with the rail level, in the centre, 185 feet above the floor of the valley. Owing to the difficult character of the situation, the simplest means of erection had to be employed. A wire rope was stretched across the rift, along which ran a block and tackle whereby the vertical members of the piers were placed. The spans were set by means of a crane, one by one, commencing from the south side, to which material was brought.

Grades and Curves.

Although the railway traverses undulating country for 68 miles from the top of the inclines to Jundiahy, it is not free from extensive work. Heavy cut-and-fill prevailed for the first 12 miles from the Serra summit, with a maximum grade of 1 in 50, and curves of 1,320 feet radius, though that at the Serra summit, where the line swings sharply from the north-east to the north-west, is of 792 feet radius. On the inclines themselves the curves vary in radius from 1,980 to 5,280 feet. The hardest section of the plateau division is the 38 miles from San Paulo to the inland terminus, owing to the country being more broken. From a point 7 miles out of the first-named city the line cuts at right angles across a succession of rifts and ridges, entailing heavy cuttings, embankments, and bridging. Sharp grades were found unavoidable, the stiffest being 1 in 40, while in order to overcome the Belen summit a tunnel 1,950 feet in length had to be driven. On the north side of the tunnel a serious landslide menaced the safety of the line for a considerable time, and it was not until the treacherous earth was removed from beneath the metals in favour of a solid invert of stone 12 feet deep, made up in 8-feet lengths, that stability was secured.

The inclines are laid out upon an ingenious principle. Being worked upon the counterbalancing system, wherein one load descends while another ascends, a crossing has to be provided at a half-way point. On the lower part of each lift, an ordinary single track is laid, branching out into two tracks at the passing point, which are of sufficient length to accommodate the longest trains. But above the crossing there are three metals, the centre rail being common to both up and down traffic. This arrangement permits of two lines of cable pulleys—one on each side of the centre rail—one for each load, while below the crossing only a single line of pulleys is necessary.

BANKHEAD SHOWING POWER HOUSE FOR DRIVING THE CABLES.

At each bankhead a pair of non-condensing horizontal engines of 150 nominal horse-power are installed to drive the winding machinery. The cylinders have pistons of 26 inches diameter by 60 inches stroke, and run at 22 revolutions per minute under a steam pressure of 30 pounds per square inch in the cylinders. The rope pulleys, 10 feet in diameter, are driven through friction gearing. A special brake wagon operating a clip brake is attached to every train running in either direction, and the train averages about four vehicles. The time occupied in the negotiation of each incline is about 15 minutes, or one hour for the ascent of 2,550 feet from the foot to the summit of the Serra. Four trips per hour thus can be made, though, if necessary, the journey could be accelerated by 15 minutes.

Although the railway has been in operation for nearly half a century, the incline system never has proved wanting, nor has an accident occurred. A few years ago, when the coffee traffic had outgrown the capacity of the older line, a new track was laid, roughly parallel to the first road, and also built upon the cable system. This line is laid somewhat higher up the mountain-side, the shoulders and spurs being tunnelled, while the rifts are spanned by heavy steel bridges.

Mr. D. M. Fox succeeded completely in keeping within the estimates, and the contractors completed the task ten months in advance of the specified time (eight years), for which they received a bonus of £43,750 from the Brazilian Government.

Photograph by courtesy of the San Paulo Railway.

HOW THE SERRA DO MAR OF BRAZIL IS CONQUERED BY THE RAILWAY.

The location of the San Paulo line over this formidable obstruction so as to enable trains to be lifted vertically 2,550 feet within a distance of 5 miles constitutes one of the cleverest feats in railway engineering. It is a unique trunk road because the vehicles are hauled by cables over the mountain range. To the left is the original line, while to the right is the new road which became necessary to cope with the increased traffic