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(*Paper No. 4068.*)

“The Transandine Railway.”

By BRODIE HALDANE HENDERSON, M. Inst. C.E.

THE idea of connecting the railways of Argentina with those of the countries on the western slope of the Andes was first brought to the notice of the public as long ago as 1854, when a suggestion was put forward to connect the Caldera-Copiapó line with the Argentine railways at, or near, Córdoba. Nothing came of this project, and another scheme was brought forward about 1870, the originators being Messrs. Juan and Mateo Clark, who were also the originators and constructors of the railway from Buenos Aires to Mendoza. The 1870 project was to connect the Cuyo provinces of Argentina with Chile by means of a railway from Mendoza via the Uspallata Pass to Santa Rosa de los Andes, a station on the Chilian State Railways (Figs. 1 and 2, Plate 3). The Cuyo provinces of Argentina had drawn their supplies from, and carried on trade with, Chile over the Uspallata and other passes for many years.

Other projects for joining the two countries are still under consideration, most of which, however, are for crossing the Andes at considerable distances to the north or south of the Transandine Railway. To the north, the main range of mountains is, generally speaking, divided into several subsidiary ranges and, to the south, it is also split up into various ranges or ridges, the passes in the south being generally at considerably lower elevations than the Uspallata Pass, which was the one adopted for the Transandine Railway after investigation of many alternative routes. Since

the Uspallata Pass was selected, studies of the different passes in the Andes have been continued and much exploration work has been carried out, but no pass offering greater advantages has been discovered anywhere in the neighbourhood of the Transandine Railway.

The railway passes to the south of the Aconcagua mountain, 22,500 feet high, which has a great attraction for mountaineers from all parts of the globe. To the south of the railway is the less famous Tupungato Peak, 22,040 feet high.

The Transandine Railway, starting from Mendoza, runs along a valley formed by the rivers Mendoza and Cuevas, which presents many difficulties to railway-construction owing to its tortuous course, its narrowness in many places, and the steep rise of the valley-bed. There are numerous side streams, and the slopes of the mountains on either side of the valley are at such an angle that location work was exceedingly difficult. Many avalanches and mud-slides of a more or less permanent nature are encountered.

On the Chile side the railway runs along the valley of the River Aconcagua; here the bed of the valley is steeper than on the Argentine side, but, owing to its greater width, there was more scope for development.

About 1883 the railway from Buenos Aires to Mendoza was completed, thus paving the way for the commencement from the latter town of the Transandine Railway, the construction of which was started in 1887.

Mendoza is 2,520 feet above sea-level and 1,048 kilometres (651 miles) from Buenos Aires. Santa Rosa de los Andes, the terminus of the Transandine Railway in Chile, is 2,723 feet above sea-level and 144 kilometres (89½ miles) from Valparaiso, the sea-port on the Pacific Ocean for this part of Chile. The distance from Mendoza to Los Andes is 249·68 kilometres (155 miles). Thus, the distance from Buenos Aires on the Atlantic Ocean to Valparaiso on the Pacific Ocean, via the Transandine Railway, is 1,441·68 kilometres (895½ miles).

The highest point on the Transandine Railway is in the Summit Tunnel, under the Uspallata Pass, where a height of 10,521 feet is reached; this is about 6,700 feet higher than the St. Gothard summit, but is considerably lower than other railways in South America, e.g., the summit of the Galera tunnel of the Central Railway of Peru, which is 15,583 feet above sea-level. The height of the Uspallata Pass above the tunnel is 2,000 feet.

Although the construction of the railway was commenced in 1887, for financial reasons the work was not pushed on with, and the line was only completed throughout in 1910. During all these

years the climatic conditions were studied, so that a considerable amount of knowledge regarding the avalanches, mud-slides, snow-fall, etc., was gained. The first idea was to put the railway as far as possible in tunnels, to avoid such dangers; but as it has been found in Canada, Switzerland, and other countries, that railways constructed more or less in the open and protected by sheds can be operated successfully, the location of the Transandine Railway was changed and many of the projected tunnels were eliminated.

It was found that the snow-fall amounts to about 21 feet in a severe winter, whereas on the Canadian Pacific Railway the highest recorded fall is 45 feet. The severest cold recorded at the summit tunnel is 20° F. below zero, but this is exceptionally low; in ordinary winters the temperature probably does not fall much below -7° F.

The gauge of the railways from Buenos Aires to Mendoza and from Santa Rosa de los Andes to Valparaiso and Santiago, the capital of Chile, is 5 feet 6 inches. The gauge of the Transandine Railway is 1 metre (3 feet $3\frac{3}{8}$ inches).

It was found impossible to locate an adhesion railway for the whole length of the line, and therefore it became necessary to employ a rack, the Abt system being adopted. The total length of rack on the Argentine side—divided into seven different lengths—is 15,381 yards, and on the Chile side—divided into six different lengths—23,316 yards, a total on the whole line of 38,697 yards = 21.93 miles (Figs. 2, Plate 3). The maximum rack gradient is 8 per cent., or 1 in $12\frac{1}{2}$, with a minimum curve of 200 metres (10 chains) on the rack. The radius of the minimum curve on the adhesion portion is 120 metres (6 chains), and the maximum adhesion gradient is 2.5 per cent., or 1 in 40. The division of a rack section into different lengths is to be avoided where possible; but in the case under consideration it was necessary, owing to the configuration of the country, to divide the rack into the sections indicated above.

On leaving Mendoza the railway consists of rising adhesion gradients, the maximum being 2.5 per cent., or 1 in 40, as far as kilometre 137.345, at which point it has risen 1,502 metres (4,927 $\frac{1}{2}$ feet), an average rise of 59 feet per mile. Here the first rack gradient is encountered, 1.4 kilometre in length, with a maximum gradient of 6.1 per cent., or 1 in 16.4. As will be seen from the longitudinal section (Fig. 3, Plate 3), the gradients, except where the rack is employed, are not particularly severe for a mountain railway.

On the Chilian side the rack commences at a point 34.940 kilo-

metres from Santa Rosa de los Andes, in which length the line has risen by adhesion gradients 690 metres (2,264 feet), an average rise of 104 feet per mile.

No reverse gradients on the rack are employed, as they cause difficulty in maintaining the water in the locomotive-boilers at a proper level. At the foot of each rack incline it is advisable to lay a short length of rack-rail so that the cog-wheels on the locomotives may fully engage with the teeth of the rack before commencing hard pulling up the steep gradient.

On the Argentine side there are nine tunnels, with a total length of 575 yards. On the Chile side there are twenty-six tunnels, with a total length of 3,481 yards. The summit tunnel, partly in Argentina and partly in Chile, is $3,463\frac{1}{2}$ yards long. Thus, the total length of tunnels on the whole line amounts to $7,519\frac{1}{2}$ yards.

Most of the tunnels are unlined, being in rock. The sections adopted are shown in Figs. 4, Plate 3. The summit tunnel was the only one that presented difficulties in construction, due chiefly to climatic causes and to the distance at which the work was situated from the base whence supplies, men, etc., were drawn. All material on the Chile side had to be brought a considerable distance on mule-back, but on the Argentine side the railway had reached the mouth of the tunnel before the latter was commenced. During the winter the tunnel was cut off from the outer world, and materials, food-stuffs, etc., for several months had to be laid in. The contractors for the summit tunnel were, in the first instance, a construction company formed for the purpose: after commencing the work, they sub-let it to Messrs. C. H. Walker and Company, who employed up to a maximum of 1,200 men on the works. The tunnel is in rock, with the exception of about 600 metres at the Argentine end, where obviously there has been, at some remote period, a slip on the face of the mountain, the material in this length being composed of rock and earth saturated with water. Towards the Chile face the rock in the tunnel is friable and the strata are nearly vertical. The summit tunnel is lined throughout with Portland-cement concrete in mass, of the following proportions: 1 of cement, 2 of sand, 4 of shingle. On the Argentine side the tunnelling was carried out at first by means of a bottom heading, and on the Chile side by means of a top heading. The adoption of different methods was due to the fact that the contractors had different men in charge, who were doubtless influenced by the material they had to work in; that on the Chile side was rock, while on the Argentine side the entrance was in soft material. Afterwards Messrs. Walker continued

in the same manner. Water of a very low temperature was met with during the boring of the tunnel, but not in sufficient quantity to hamper the work very much, although it considerably affected the health of the workmen. For rock-boring, Ingersoll-Sergeant drills were employed, compressed air being obtained by means of Diesel engines, which were also used to generate electric current for lighting. It is interesting to note that, owing to the elevation at which they were working, the Diesel engines were calculated to develop only about 70 per cent. of their ordinary powers, which were 120 HP. and 80 HP., there being five of the former size and two of the latter. They were used for working the drills, driving electric generators, and charging two compressed-air locomotives.

The difficulties in setting out the summit tunnel correctly were considerable, owing to the difficult light and strong winds. On completion of the tunnel, the difference in the centre-lines was found to be $2\frac{3}{4}$ inches, and the level was only 0.67 inch incorrect: these results reflect great credit on the engineers, working as they were under adverse conditions.

The bridgework on the railway does not call for particular comment, the longest span being 247 feet.

At numerous points along the line snow-sheds, built of timber and galvanized iron, have been constructed (Figs. 5, Plate 3). Avalanche-sheds have also been built at various points, the usual form being a masonry wall on the upper side, with timber supports on the lower side carrying a timber roof covered with sheet iron. Every winter discloses the fact that more snow-sheds are needed: this will probably continue for some years, and it may be that the construction of snow-sheds will never cease entirely.

The permanent way consists, on the adhesion line, of a 50-lb. rail on timber sleepers laid at the rate of 1,810 per mile. On the rack a 55-lb. rail is employed, on steel sleepers weighing, with fastenings, 119 lbs. each, laid at the rate of 1,828 per mile. The rack consists of three vertical plates, each 20 millimetres (0.787 inch) thick, made in lengths of 8 feet 8 inches, and laid so that the teeth break joint. The material employed is open-hearth steel giving 25 tons per square inch tensile strength, with not less than 18 per cent. elongation. The teeth are slotted from the solid bar. At the entrance to each rack section there is a rail, 10 feet 9 inches long (Figs. 6), with teeth of special shape, and laid on springs to facilitate the engaging of the teeth of the locomotive cogs with the teeth of the rack-bars. The rack-bars are laid in cast-iron chairs, which in turn are bolted on to steel sleepers.

expected in connection with engines of this class. When the line was completed and through traffic had to be carried, more powerful engines were required, and two types were adopted. One was built by the Maschinenfabrik Esslingen, and is of the articulated class, being a modification of the Mallet type (Figs. 7, Plate 4). Its leading dimensions are :—

Adhesion cylinders, $15\frac{1}{2}$ inches in diameter by 19 $\frac{1}{2}$ inches stroke.	
Rack cylinders, $21\frac{1}{4}$ inches in diameter by 17 $\frac{3}{4}$ inches stroke.	
Heating-surface :—	
Fire-box	115 square feet.
Tubes	2,068 „ „
Total	2,183 „ „
Grate-area	35 „ „
Working-pressure	215 lbs. per square inch.
Weight in working order	87 tons.

These engines have three rack-pinions coupled together by connecting-rods. The adhesion engine has eight wheels coupled, the wheels being 36 inches in diameter. The total length of the engine over buffers is 45 feet 9 $\frac{1}{2}$ inches.

The other type of articulated engine in use was built by Messrs. Kitson and Company, of Leeds, and is a modification of the Meyer type of engine. It consists of two bogies, one for adhesion purposes and the other for carrying the rack-wheels (Figs. 8, Plate 4). The general particulars of this engine are :—

Heating-surface :—	
Fire-box	140 square feet.
Tubes	1,900 „ „
Total	2,040 „ „
Grate-area	34 „ „
292 tubes, 1 $\frac{1}{2}$ inch in diameter outside.	
Water-capacity	2,100 gallons.
Fuel „	3 $\frac{1}{2}$ tons of coal.
Cylinders :—	
Adhesion, 16 $\frac{1}{2}$ inches in diameter by 19 inches stroke.	
Rack, 18 $\frac{1}{2}$ inches in diameter by 19 inches stroke.	
Boiler-pressure	200 lbs. per square inch.
Coupled wheels	3 feet in diameter.

The locomotives made by the Maschinenfabrik Esslingen and Messrs. Kitson and Company, are probably as powerful as any that have been designed for a rack-railway. Up an 8 per cent. (1 in 12 $\frac{1}{2}$) gradient they haul 140 tons total load, in addition to their own weight, at a speed of about 8 miles per hour; and they have been known on occasions to haul even more than this. They are designed

for the rack mechanism to run in front when ascending inclines, so as to clear the track as much as possible of snow and ice in advance of the adhesion wheels. They are equipped with Westinghouse automatic and non-automatic brakes and hand-brakes applied to the driving and carrying wheels. Also, repression brakes are fitted for applying to both rack and adhesion cylinders, and band-brakes on all rack-pinions. Arrangements are provided for turning exhaust steam into the tanks when working in tunnels.

The Esslingen engine develops a tractive effort of 47,000 lbs. by means of the rack mechanism, and 20,000 lbs. by means of the adhesion engine, the corresponding figures for the Kitson engine being 34,600 lbs. and 20,000 lbs.

With engines of this power and weight the proper maintenance of the rack is a very important matter, as inequalities in the rack will cause undue wear of the pinions on the engine, and may cause excessive pressure on the teeth. The rack-pinions on the engines are fitted with springs so as to deal with small inequalities in the track; it is found that these springs are very necessary, and they should always be in good working order.

The rack engine should always be at the lower end of the train, that is, it should push the train up-hill; but it has been found difficult to adhere strictly to this rule owing to the fact that when, during the winter months, there are snow-drifts on the line, the vehicles at the head of the train are liable to be derailed, whereas the engine, if placed in front, is not so liable to derailment, owing to its weight. It remains to be seen whether it would not be safer and better to have two lighter engines, one at each end of the train.

The question of brake-power has been carefully studied in connection with these engines. It is found that care has to be exercised in applying the rack brake; the rack-pinions are necessarily somewhat concentrated, and therefore, if the rack brake is applied suddenly and severely, there is a danger of damaging the rack rails, particularly when running down-hill.

The carriage and wagon stock, of which examples are illustrated in Figs. 9 and 10, Plate 4, does not call for special comment. It will be noted that the safety-chains are particularly strong and heavy, and that the Westinghouse automatic brake is fitted throughout.

Push snow-ploughs of various designs and also rotary steam-ploughs are used for keeping the line free from snow in winter.

The Paper is accompanied by sixteen tracings, from which Plates 3 and 4 have been prepared.

Discussion.

The PRESIDENT, in moving a vote of thanks to the Author for his Paper, remarked that it was a matter for congratulation that this important connection of the two coast-lines of the South American continent had been designed and carried out by British engineers and, he understood, British contractors. The President.

The AUTHOR pointed out that the Paper was almost entirely a record of facts. To give in words an idea of the exceedingly rough nature of the country through which the railway passed was almost impossible; the photographs on the table and some lantern-slides which he had would show this better than any verbal description. He believed that in the original surveys, before mule-tracks were made, the engineers had to be let down by ladders and ropes to various observation-points. He also wished to point out that numerous features of the railway were settled many years ago, when, for instance, the rack-railway was not as well known as it was at present, although even in those days the Abt system was undoubtedly the best. The rack rail, as stated in the Paper, consisted of three plates, but since those days two plates had become what might be termed more fashionable. Whether two plates had any advantages or not was quite open to question. Three plates were adopted in the railway under consideration, but the latest rack-railway under construction used only two plates. There was a natural bridge which was of great interest at a place called Puente del Inca on the Argentine side. The slide which he would exhibit showed that this bridge was in the form of an almost perfect arch. In 1906 a very severe earthquake occurred in Chile, destroying Valparaiso, which was the largest port on the Pacific coast. The path of the earthquake followed the route of the Transandine Railway, but the damage done to the railway was represented by only a few thousand pounds. He believed that those who had had experience of railways in earthquake-countries would confirm his statement that usually earthquakes did not do very much damage to railways. The Author then exhibited several lantern-slides illustrative of the railway and of the country through which it passed. The Author.

Mr. JOHN CARRUTHERS remarked that, while the Paper was very interesting, he thought there was little in it for discussion beyond the question of the main design of the railway and the employment of rack inclines. No one who did not possess a great deal of Mr. Carruthers.

TRANSANDINE RAILWAY.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

PLATE 3.
TRANSANDINE RAILWAY.

Fig^s 7.

ESSLINGEN ENGINE.

Scale to Fig^s 7 and 8 1 Inch = 4 Feet.
Inches 12 11 10 9 8 7 6 5 4 3 2 1 0 10 15 20 Feet.

TRANSANDINE RAILWAY.

Fig^s 8.

KITSON ENGINE.

Scale to Fig^s 9 and 10 1 Inch = 8 Feet.
Inches 12 11 10 9 8 7 6 5 4 3 2 1 0 10 15 20 Feet.

PLATE 4.
TRANSANDINE RAILWAY.

Fig^s 9.

Fig^s 10.