THE MAGNET TRAMWAY.

By R. F. WALLER, Assoc. M. Inst., C.E.

PERHAPS the most important problem in the development of many of our Tasmanian mines, and more especially in the case of those on the West Coast, is that of transit. So many of our mines are situated in inaccessible locations that, before economic development becomes a possibility, the problem of getting plant to the mine, and ore to market, becomes of vital importance, and in many cases must be either boldly attacked by shareholders themselves, or all hope of remunerative operations abandoned. This was notably the case at Mt. Lyell and Mt. Read, and some note of the solution arrived at in the case of the Magnet Mine may be of interest.

The Magnet Mine is situated some four miles south-west of Mt. Bischoff, on a spur of the Magnet Range, and is separated from Mt. Bischoff by the deep gorge of the Arthur River. The Corinna Road passes within two miles of the mine to the south, and avoids the Arthur Gorge by crossing that river near its source at an altitude higher than the mine.

When mining operations were commenced, the obvious route to market lay in a connection with this road, which is well constructed, and with fairly easy gradients. This was first accomplished by means of a pack-track along the leading spur between the mine and the road. With further development at the mine this proved quite inadequate, and was replaced by a tramway for horse-traffic of 2¾ miles in length. This tramway took about £28,000 worth of ore to market, and enabled the company to open up their mine in a systematic manner, which thoroughly demonstrated the fact that such a means of transport was utterly incompetent to deal with the ore available, and that, unless better facilities were provided, only the richest portions of the ore-body could be dealt with, and very large masses of moderate-grade ore would have to be left in the mine.

The Magnet Mine contains some very fine bodies of first-class gossan and sulphide ores, which in themselves would be payable under very adverse circumstances; but alongside of these ores lie very large bodies of lower-grade gossan ores, of excellent quality for fluxing purposes, containing, as they do, some 35 to 40 per cent. of iron and manganese, and about 6 to 10 per cent. of silica, and of values in lead and silver ranging from very little up to 30, 40, and 50 ozs. of silver per ton, with 7 to 15 per cent. lead. The amount of these ores has been variously estimated from 40,000 to 200,000 tons, according to the grades of ore included in the estimate. The lower figure may be taken as a conservative estimate of the quantity of ore now awaiting shipment. With present facilities and prices of metals, any improvement in metal prices, and a demand from Smelting Works for iron flux, will largely increase the amount available for export.

Surveys were accordingly put in hand, for the purpose of finding a route for a steam tramway of 2 feet gauge, to put the mine in direct communication with the Emu Bay Company's railway at or near Waratah. The principal obstacle is the gorge of the Arthur River. To head this gorge would mean a line of certainly over 15 miles in length, though construction would be easy; and many other routes, varying in distance and gradients, might be chosen, crossing the gorge lower down at various points. When the author was asked to undertake the construction of the tramway, one route had been partly surveyed, crossing the Arthur River near the top of the gorge; its length was about 13½ miles, and it had to negotiate some exteremely heavy country. Another route, over which a flying survey had been run, had a length of 9½ miles, and passed through easier country throughout; the grades, however, being heavier. This route was finally adopted, and lengthened to ten miles to avoid a short piece of very heavy work.

Permanent survey was started on 22nd January, 1901, by the author and Mr. F. K. Pitt, Authorised Surveyor. A party of about ten men was employed, as it was an object to get as good a start as possible during the summer months. The system adopted was to run a carefully-levelled and traversed trial line, with frequent cross-sections, plotting to a scale of 1 inch to the chain, and putting 10 feet contours to aid in the location of the line. By this method it is possible to draw a very closely approximate trial section before the centre line is laid down, and to locate the line to the best advantage. This procedure gives accurate data of a narrow strip of country, say 100 feet wide, within which limits it is possible to locate a line with a reasonable certainty that the best, and cheapest, location, as far as earthworks are concerned, has been secured. The best proof of this is in the fact that usually very trifling deviations indeed are found necessary during construction; it is, however, most desirable that the cross-sections be taken frequently, carefully, and with judgment. A careful system such as this is especially essential where it is attempted to compensate the gradient for curvature, which was done throughout on all grades against the load.

This matter of curve-compensation is a most important one in laying out any railway with heavy grades, as the maximum grade (of any length) limits the train-load, and therefore fixes the minimum carriage-cost. As a rule, on the West Coast, the grades must generally be long, and, with a view to shortening the length of line, it is usually desirable to make them as steep as practicable. The idea of curve-compensation is to make the total train resistance, uphill, approximately equal on curves and on the straight. To give some idea of the importance of the point, I may note that train resistance is approximately equal on a straight grade of 1 in 25, and on a combination of a curve of 1½ chains radius with a grade of 1 in 42·5.

The formula used in this computation was that given in Molesworth's Pocket-book, page 236. The train resistance on curves (for trains of normal length) is a junction of the radius of curve, gauge of line, and wheel-base of stock. In the present case the gauge is 2 feet, and the wheel-base was taken as 4 feet 6 inches. This value is rather in excess of the length of wheel-base subsequently employed, and as a matter of fact I find that traction on curves is generally rather easier than on straight road.

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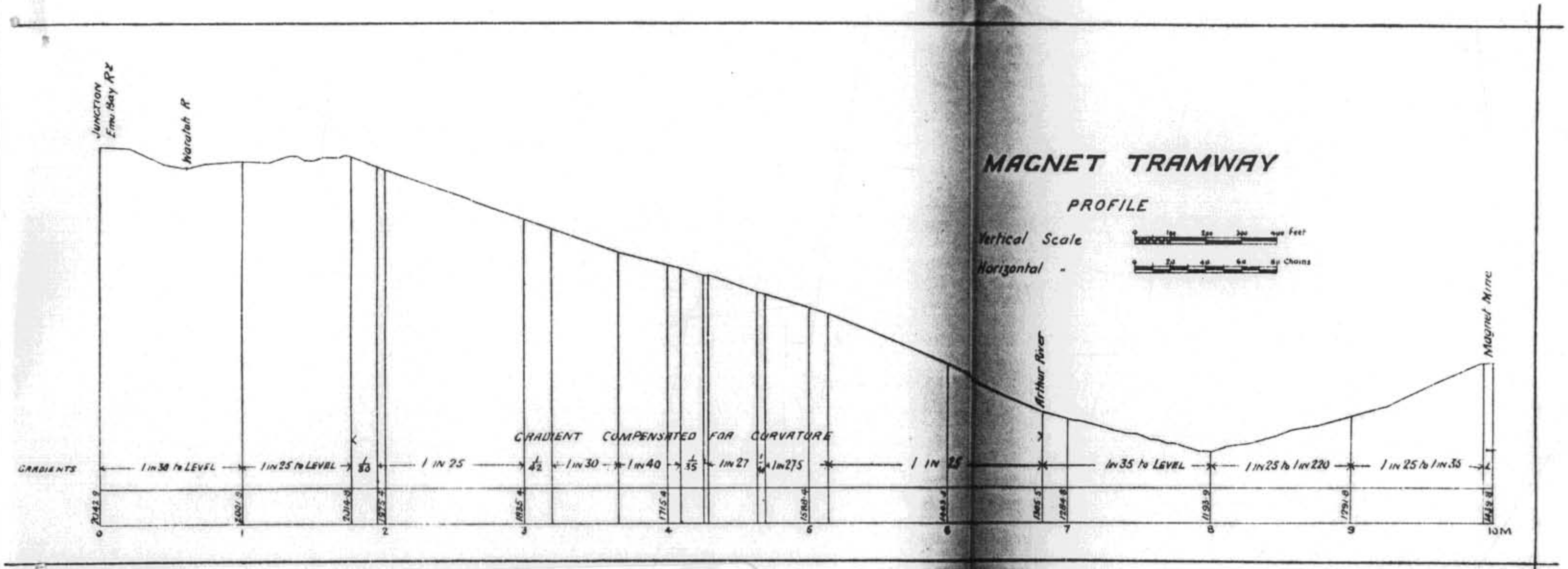

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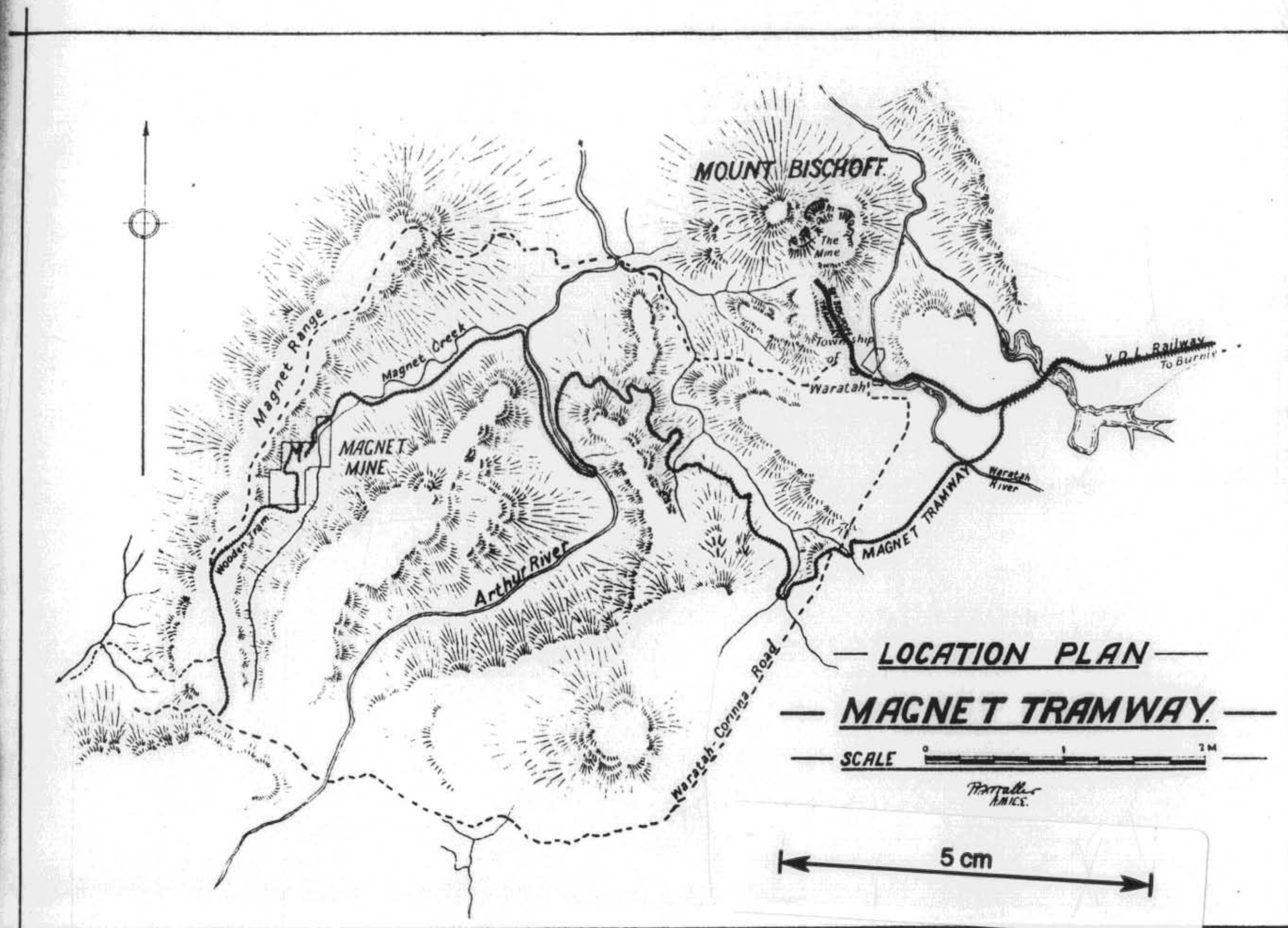

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The ruling gradient was fixed at 1 in 25, and the grade on curves works out as follows, the total resistance for each combination being approximately 1 in 25, or 4 per cent. :—

Combinations of curvature and gradient equivalent to straight road, 1 in 25 grade.

Radius of Curve. Links.	Gradient.	Feet rise per chain.
1000	1 in 25 ·	2 ·64
500	28 ·5	2 ·32
400	30 ·	2 ·20
300	31 ·5	2 ·10
250	33 ·	2 ·
225	35 ·	1 ·88
200	36 ·	1 ·83
175	38 ·	1 ·74
150	42 ·5	1 ·55

A similar calculation was made and tabulated for all the grades likely to be used. In actually grading the section these tables were adhered to as closely as possible, making the change of gradient at the nearest chain, or sometimes half-chain, to the end of the curves. In practice, I find that, as stated above, the curves are slightly over-compensated, the engine travelling over curves rather more easily than on straight road; this is particularly noticeable in wet weather, but on the whole the result is extremely satisfactory, and the engine takes its maximum load up the grades and curves at a steady uniform pace.

As to curvature, the sharpest curve was originally fixed at 150 links, or 99 feet radius; but after the type of locomotive was decided on, I determined to try the effect of a curve of even sharper radius, with its due compensation in the gradient. This was only done in a very few places, where there was a very large saving in first cost by sharpening the curves, and where altering the line afterwards would not entail much additional expense. The rolling-stock works round these curves of 125 links (82 feet 6 inches) radius quite easily; but, except in positions where the saving in first cost is exceptional, I cannot recommend the adoption of curves sharper than 150 links radius. The objection to them is solely on the score of increased wear and tear to rails and stock. I hope to be able to alter these curves to a wider radius during the course of next summer, at small cost, by the employment of the line-repairing gangs, who by that time will have the line in good solid running order, and will be able to effect the necessary alterations without the employment of any extra hands.

I think, however, that their introduction here has demonstrated the fact that, under suitable conditions, the employment of such sharp curves is a perfectly justifiable practice, and that where trouble is experienced with sharp curves on a 2-feet line it is not due to the curves themselves, but to a selection of rolling-stock which is not suitable for working such a line.

All curves of 150 links radius (and under) are transition curves; that is, they are put in with a length of 50 links at each end, with radii gradually increasing from the minimum to infinity, the curve at each end being a cubic parabola. The train enters and leaves the curves without the jerk usually felt in negotiating such sharp curves.

Speed of travelling on the curved sections of the line is limited to eight miles per hour, but during construction we frequently travel the worst parts of the line at a speed of over twelve miles per hour; and, except for the danger of encountering a fallen tree, the practice was absolutely safe, and the travelling was smooth and easy. This, I think, is impossible except on a line with compensated gradients and transition curves.

Transition curves present no difficulties in setting out, and when platelayers are used to them the extra trouble in construction is trifling; speed of platelaying is necessarily somewhat reduced, as the rails at ends of curves have to be curved on the ground by a "Jim-crow," but the slight extra trouble and still slighter extra expense is more than repaid by the smoothness of the road when built.

Survey work was started on 22nd January, 1901, the first clearing contracts were let in the middle of February, and earthworks were put in hand on 4th March: platelaying was started on 8th August, finished on 5th December, and ballasting was finished and construction hands paid off on 23rd January, 1902.

The line junctions with the V.D.L. Company's line to Waratah, now leased to the Emu Bay Railway Company, just outside the township of Waratah, and about 1½ mile from the terminus of that line. Here a running-shed for two locomotives is erected, with goods-shed, platform, coal-stage, shelter-shed for transhipping ore to Emu Bay Company's trucks, houses for engine-driver, stationmaster, &c. From this point the line traverses very easy country to the crossing of the Corinna Road, at 1m. .0c. The Waratah River is crossed at 0m. 46c., and on this section earthworks are easy, and grades, though stiff in places, are short. From 1m. 70c. to 6m. 70c. may be called the "mountain section" of the line. The grade is heavy and continuous, and the route is along steep and broken sidelings. The Arthur River is crossed at 6m. 65c., and from there to 8m. the line runs down the flats of the Arthur River to its junction with the Magnet Creek, thence up the flats of the Magnet Creek to 9m. 30c. This section is the easiest on the route; straights are long, curves are easy, and earthworks very light. The last 50 chains is another stretch of steep sidelings, with heavy grade and sharp curves.

The attached profile shows pretty clearly the nature of gradients on the line. The curvature works out as follows:—Taking first the portions 0m. to 1m. 70c., and from 6m. 70c. to 10m., which amounts to just half the total length of line, we find that these sections contain 53 curves, totalling 1m. 36c., leaving 3m. 44c. of straight road. On the "mountain section," from 1m. 70c. to 6m. 70c., on the contrary, we find 142 curves, totalling 3m. 21c., with only 1m. 59c. of straights. It must also be noted that the vast majority of sharp curves occur on this section; in fact, there are but five curves of under two chains radius on the other parts of the line. On the "mountain section" there are 71 curves with radius less than two chains.

The whole of the line is through heavy myrtle forest; indeed, on the first two miles the myrtles are the largest I have seen, running up to 5 and 6 feet in diameter. Clearing was done by contract, and was let in lengths of about 40 chains, as fast as the survey was completed. The line was only cleared to a width of 20 feet, except under seats of banks, which were fully cleared out. Culverts were let to the clearing contractors, and fixed and put in well in advance of the earthwork-gangs. Clearing cost about 16*s.* 6*d.* per chain, on an average; this includes grubbing all stumps over 12 inches diameter, except where covered by over 2 feet of embankment. Log culverts were used throughout, and in all steeply-inclined gullies were put in near formation level, with contour drains cut to intercept the water.

The formation width originally proposed was 8 feet; this was found to be rather too narrow. Eventually cuttings were taken out to a base of 8 feet 6 inches, to allow of a drain, and banks were made not less than 9 feet. This is quite narrow enough, and with banks any narrower the loss of ballast is serious.

Earthworks were almost entirely done by day labour; an attempt was made early in the job to sub-let some cuttings, but the prices demanded were in all cases much higher than the work was subsequently done for.

I regret that I am unable to give figures for the quantities of earthworks, as the staff available had no time to devote to earthwork measurements. Although it is most desirable, as a rule, that the work of the various gangs be checked by the cost per cubic yard of the work done fortnightly, I think that, if reliable gangers be employed, as good results may be got by cultivating a spirit of emulation between the respective gangs, and comparisons of the length of line formed fortnightly.

As the country was rough, it was decided to employ no construction trams for earthworks, as carrying the plant along is a serious matter where no road or track exists; besides this, on a 2-feet line the leads are generally so short that the work can be done almost as cheaply with barrows.

There are four small bridges on the line, the largest (seven spans) being over the Waratah River. Simple beam-bridges of 16-feet span were adopted, with skeleton road. The timber was all hewn locally, and is myrtle, gum, and leatherwood, all of excellent quality.

The question of sleepers received early attention. An attempt was made to procure them hewn alongside the line, of myrtle, which here is of unusually good quality, but it failed. Subsequently a careful examination of the district resulted in the discovery of a belt of gum country, from which nearly all the sleepers were drawn. It was, however, necessary to construct a mile of wooden tramway to connect with the Corinna road, along which the sleepers had then to be carted to the line. Sleepers were cut 5 feet by 8 inches by 4 inches, and cost 1*s.* each on the line. About 2200 sleepers to the mile were used; they were spaced 12 to the rail-length of 30 feet on straights, and 13 on curves of two chains radius and under. Sleepers were adzed by hand, a contract being let for adzing and boring for one rail only, which reduces the boring to be done while platelaying materially.

The rails employed were of American manufacture, supplied by Orenstein and Koppel, of Berlin; they weighed 30 lbs. to the yard, and were in 30-feet lengths; rails slightly shorter, to allow for lead on curves, could not be procured, so to keep square joints in platelaying necessitated cutting and re-punching rails by hand, which should have been unnecessary.

Rails were all curved in the yard, in a hand-press designed on the job, and made in Launceston. The press works with a screw, and is practically an enlarged "Jim-crow" made of cast-iron, and bolted to a stump. The screw acts horizontally, on the web of the rail, and the clips for holding the rail are so arranged that the rail may be put in the press with its head either up or down, so that either right or left hand curves may be pressed without the necessity of turning the rail end for end. I prefer this press to a roller-press, and think that both cheaper and better work may be done in it. Our rails were pressed by two men, at the rate of about 18 pairs per day, or at the cost of about 1s. per pair, and the results left nothing to be desired; the crow was never used on the road, except at the ends of curves, and more particularly of transition curves. I may mention here a new type of fishing-up spanner that was used throughout, made after the idea of the alligator-wrench; but as it was only required to take one size of nut, only one tooth was put in the jaw. These proved very fast and efficient.

The road was ballasted from two pits, the first situated at 2m. 42c., so that no ballast could be put on the road until this was reached. As much of the road was soft, and the work was done in the winter months, this was a troublesome piece of work, rails and sleepers disappearing under the weight of the engine in soft spots. The greater portion of the ballast came from the second pit at 3m. 70c., and was of excellent quality—a decomposed igneous rock, soft, but which never turns to mud. This ballast was taken right through to the mine, a distance of over six miles. About 900 cubic yards were put on to the mile, at an approximate cost of 3s. per yard laid and packed in the road.

The rolling-stock at present in use consists of two locomotives, both by Orenstein and Koppel, of Berlin; two 15-ton double-bogie ore-trucks, built in the Government Railway workshops in Launceston; a guard's van, and a rail and timber waggon, built on the job. Two 15-ton trucks of similar type are under order in America, and shortly expected.

Of the locomotives, No. 1 is a compound-engine, with articulated under-frame, on the Mallet system; attached is a diagram showing the leading features. It will be seen that, while the total wheel-base is 10 feet, the greatest rigid wheel-base is only 4 feet 3 inches. The long total wheel-base ensures steady running, and the short rigid base enables the engine to traverse sharp curves with great facility. The following are the leading dimensions :—

Cylinders, 8 inches and 12 inches diameter x 12-inch stroke.
Wheels (8 four-coupled), 25 inches diameter.
Rigid wheel-base, 4 feet 3 inches.
Total, 10 feet.
Boiler pressure, 170 lbs.
Heating surface, 418 square feet.
Grate area, 9 square feet.
Water-tanks (side), 500 gallons.
Weight in steam, 18 tons.
Approximate tractive force at 65 per cent. steam pressure in h.p. cylinders, 5940 lbs.
Adhesion ($\frac{1}{6}$), 6720 lbs.

The engine will take a load of 30 tons of ore and two trucks, which tare four tons each, up the 1 in 25 grade, and practically it takes a daily load of 35 tons (gross) up that gradient quite comfortably. This is its regular working load, and is taken daily up the six-mile stretch of heavy grade in all weathers without the slightest hitch or trouble. The engine is very economical in fuel. I think that a fair average of fuel used per trip of 20 miles is from 50 to 80 cubic feet of wood, and about $1\frac{1}{2}$ cwt. of coal. The firewood used is myrtle, cut in 2 feet 6 inch lengths, and a little coal is used to fill up the spaces at the ends of the wood, the firebox being a little over 3 feet long.

Wood is very much cheaper than coal here, costing about 5*s.* per ton of 80 cubic feet. The best determination of the relative values of wood and Newcastle coal I know of is the result of observations at Mt. Lyell, which gives a ratio of 1 ton coal to 2·4 tons wood. This makes wood equal to coal at 12*s.* per ton, whereas it costs about 40*s.* per ton here. However, if it is necessary to get the best work out of a locomotive, and more particularly the fastest work, coal must be used; and, having regard to wages cost, as well as fuel cost, I think that, provided the traffic is heavy enough to warrant it, it would pay to use coal exclusively.

The only other point I need allude to in regard to this locomotive is that of repairs. The engine has now made some 5000 miles of running, and the repair bill has hitherto been almost nil, with the exception that we have had some trouble with the tubes. These were rather too light in metal, and we have now replaced some three dozen of them with a stouter make; the rest will be renewed as necessity arises.

The general question of selection of a locomotive for narrow-gauge, and lines with sharp curves, seems to me to very largely depend on wheel-base. A long wheel-base is very desirable to give steady running, and a short rigid wheel-base is a necessity where sharp curves have to be negotiated. For light locomotives the four-coupled engines with a base of about 3 feet 3 inches to 4 feet, such as our No. 2 engine (6¾ tons) and the well-known Krauss engines (7½ tons), are excellent; and it is still a moot point whether such engines are not the most economical generally for 2-feet lines.

Engines a size larger are usually built six-coupled, and can be got up to about 14 or 15 tons, and with a wheel-base of about 5 feet 6 inches. This is a type I do not much care about, as the length of base is hardly long enough to give steady running; while it is decidedly too long to give the best results on curves of less than two chains radius. The addition of a bogie, or, worse still, of a pony-truck, or two-wheeled bogie, certainly helps as far as steadiness on the road is concerned, but is open to the serious objection that some of the weight which it is so important to utilise for adhesion is carried on idle wheels. The pony-truck is all right if the engine can be turned at each end of the journey, but runs so badly backwards that turn-tables or Ys are a necessity at terminal stations. The 20-ton engines in use on the North-East Dundas tram are of this type, though with four-coupled driving-wheels.

Of engines of a heavier type, I think the Mallet system compound locomotive that we have at present in use is about the best now in the market. The wheel-base is satisfactory, and if coal were burnt in a shorter firebox, the maximum rigid wheel-base of 4 feet 3 inches might be still further reduced. The only previous engine with a flexible wheel-base, and all the weight on driving-wheels, that I know anything about is the double Fairlie engine. This engine was troublesome, on account of the difficulty of keeping the steam connections tight. The trouble arose from the fact that there was a high-pressure connection, and also an exhaust, to each bogie, all of which had to be flexible. These flexible joints were made with ball-and-socket joints and a sliding gland. It was found exceedingly troublesome to keep these joints good, the difficulty being much accentuated with the high-pressure joints. I believe that later types of these engines have largely overcome the trouble by the use of flexible metallic tubing for steam connections. These troubles are largely overcome in the Mallet system by the adoption of compound working and its arrangement. The boiler is rigidly attached to the frame at the firebox end, and the high-pressure cylinders are situated under the footplate. This gives a rigid connection for the high-pressure steam. The pipe connecting high and low pressure cylinders is a large one, lying under the firebox, along the centre of the frame, and acts as an intermediate receiver. The frame is articulated, as shown in plan, but the amount of angular motion is small, and in the pipe is amply and efficiently allowed for by a short length of flexible metallic tubing. The whole pipe is well logged, and supplied with steam-traps, and a reheating arrangement with live steam, which, however, we use very little. Condensation in this intermediate pipe is very insignificant. The low-pressure cylinders are on the leading bogie, directly under the smoke-box, into which they exhaust through a pipe with a ball-and-socket on the upper end, and a ball-and-socket combined with a sliding gland with packing rings at the lower end. It will be noticed that by this arrangement we have a rigid connection for high-pressure steam, a very simple flexible joint, with a small amount of motion for the steam after its first expansion; and the only joint of a character at all likely to give trouble is the exhaust, where it can do least harm. There has certainly been no trouble hitherto, nor do I anticipate any.

The advantages of the compound system are, therefore, I think, much as follows :—

1. Long total and short rigid wheel-base.
2. Simplicity in steam connections as compared with non-compound engines with flexible frames.
3. The engine runs equally well forward and backward.
4. Economy in fuel.

The disadvantage, as far as I can at present see, is that the repair-bill must necessarily be higher in the long run, as many parts are duplicated.

Our No. 2 locomotive is a small four-coupled engine, weight in steam 6¾ tons. This engine is a good and efficient machine, and does excellent work for its size. At the worst of times it pulls comfortably a gross load of 15 tons up the five-mile stretch of heavy gradient.

The following are the leading dimensions, with those of the well-known similar engines by Krauss, of Munich, for comparison :—

	Orenstein and Koppel.	Krauss.
Cylinders, diameter.........	6½ inches	7⅛ inches
,, stroke...........	12 ,,	12 ,,
Wheels, diameter...........	22¾ ,,	24⅜ ,,
Wheel-base	3 ft. 3⅜ in.	3 ft. 7¼ in.
Boiler pressure	170 lbs.	170 lbs.
Heating surface............	155 sq. ft.	166½ sq. ft.
Grate area	3·8 ,,	3·25 ,,
Tank capacity	108 gallons	107 gallons
Bunker ,, ...	24¾ cub. ft.	18 cub. ft.
Weight in steam	6¾ tons	7½ tons
Adhesion (1/6)	2520 lbs.	2800 lbs.
Tractive force (at 65 °/o)..	2480 ,,	2780 ,,

A comparison of the work done by these engines respectively shows that, weight for weight, there is little to choose between them. Our engine will take a load of 18 tons of ore easily up the 1 in 25 grade, but cannot make steam fast enough to keep this up for a long distance; indeed, while steam holds, it can manage 19 tons gross load up a 1 in 25 grade. As a regular load it takes 15 tons easily up the six miles of gradient, and loses no pressure in the boiler.

At Mt. Lyell the Krauss engines take a gross load of 23 tons up one mile of 1 in 30 gradient, or 13¾ tons up half a mile of 1 in 16. The first performance is just about equivalent to our engine with 18 tons on a 1 in 25 grade, but the second, on the 1 in 16 gradient, is better than we can show; but our six-mile length of stiff gradients is quite on a different footing.

In calculating the adhesion and tractive force of locomotives, I find that taking the adhesion at one-sixth of the weight, and the tractive force at 65 per cent. of the boiler pressure, gives results that should be attained by an engine under good working conditions, and for runs of reasonable length. The load hauled up any given gradient may then be arrived at pretty closely, the weight of engine being included in the load so found. This will be found to apply closely in the case of the two smaller engines, and also in the case of the 20-ton engines on the North-East Dundas tram. Their weight available for adhesion is about 18 tons, giving the same adhesion as our No. 1 engine. The tractive force at 65 per cent. works out to about 7000 lbs., and the best work that I know they do under favourable circumstances is to haul a gross load of 60 tons, including their own weight, up a 1 in 30 grade with 1½-chain curves, equivalent to a resistance of 7500 lbs.

According to above method of calculation, I should expect these engines to pull a train-load of 36 tons without trouble up the grade mentioned, in good ordinary circumstances. They have ample cylinder-content, but hardly sufficient steaming power. I may note also that, as they burn coal exclusively, on a fire-grate larger than ours, that their fuel consumption must be considerably higher; this obviously follows from a consideration of the types of engines.

Going back to our compound engine, it may be noted that the tractive force at 65 per cent. is lower than the available adhesion; this points out the fact that the engine is under-cylindered, and experience on the road fully bears this out. An increase in the cylinder-diameters to 8½ and 12¾ inches respectively would bring this proportion about right, and the engine would certainly do better work. In ordering another engine, I should increase these diameters to 9 and 13½ inches; the engine would then have ample power for an emergency, a point in which it is deficient at present.

The last point to which I wish to draw attention is the best economic size of engines to use. At Mt. Lyell, after much experience of the Krauss engines, they have come to the conclusion that engines of about this weight (7½ tons) are the most economical that they can use, when running cost, repairs, &c., are included. I have not been working long enough here to pretend to estimate my repair-bill: but I do know this—that, under my conditions, the saving I effect by running the engine we have adopted will pay very heavy repair-bills indeed. My daily running costs, including interest, depreciation, &c., for one engine only on the road amounts to about £3 8*s*. 6*d*. per day.

To do the same work, two engines of 7½ tons would be required, which would cost me at the lowest £4 18*s*. per day. I believe that the cost at Mt. Lyell is considerably higher. This represents a difference of £1 9*s*. 6*d*. per day, or over £440 per year. I hardly think my repair-bill will amount to this, and the small engines will certainly not run without any.

One point in favour of lighter engines is that a lighter rail may be used; 7½-ton engines will run nicely on a 20-lb. rail, and this would diminish construction costs by, roughly, about £200 per mile.

The conclusion that I have come to, and which seems pretty obvious to me, is that, up to the limit that is fixed by another factor, it pays to use the heaviest engines that traffic on the line will keep fully at work.

The factor which, in my opinion, limits the economic size of engines on any road is the train length, taken in conjunction with the nature of curvature of the line. The effect of long trains is not usually felt on 3 feet 6 inches lines, though, even then, where curves are long and sharp, I have heard of several instances where a long light train offered a resistance apparently altogether disproportionate to its weight. The fact is that a considerable proportion of the curve resistance is strictly analogous to the frictional resistance of a flexible string wound round a post, and this may be proved to be proportional to the power of the number representing in circular measure the arc embraced—for example, assuming that this particular portion of the curve resistance amounts to 5 lbs. for a single truck, then for two trucks the resistance will be 5^2, or 25 lbs.; for three trucks, the resistance will be 5^3, or 125 lbs.; and for five trucks, it will be 5^5. or 3125 lbs.; and so on. Thus, if any material portion of train-resistance varies in this manner, as must evidently be the case, it is obviously most desirable to keep train lengths as short as possible, and most particularly so on lines of narrow gauge, almost the only excuse for whose existence is economy of construction due to the possibility of using sharp curves. The employment of trucks carrying as heavy loads as possible is evidently a move in the right direction.

From what I have seen, I am inclined to place the limit of economical train length at three 15-ton trucks, or a gross load of 54 tons; but it is quite possible that this might be increased to four trucks before the extra power required for haulage cut away the gain due to the employment of fewer train-hands, &c. I think, however, that I should not care to go higher than to three.

This train could be easily and economically hauled on a 1 in 25 grade by an engine of the Mallet type, and of about the following dimensions :—

Cylinders, 9 inches and 14 inches diameter, 14-inch stroke.
Wheels, 26 inches diameter.
Boiler pressure, 170 lbs.
Weight in steam, 22 tons.
Adhesion (one-sixth), 8213 lbs.
Tractive force (65 per cent.). 8420 lbs.
Work to haul load on 1 in 25 grade, 7940 lbs.

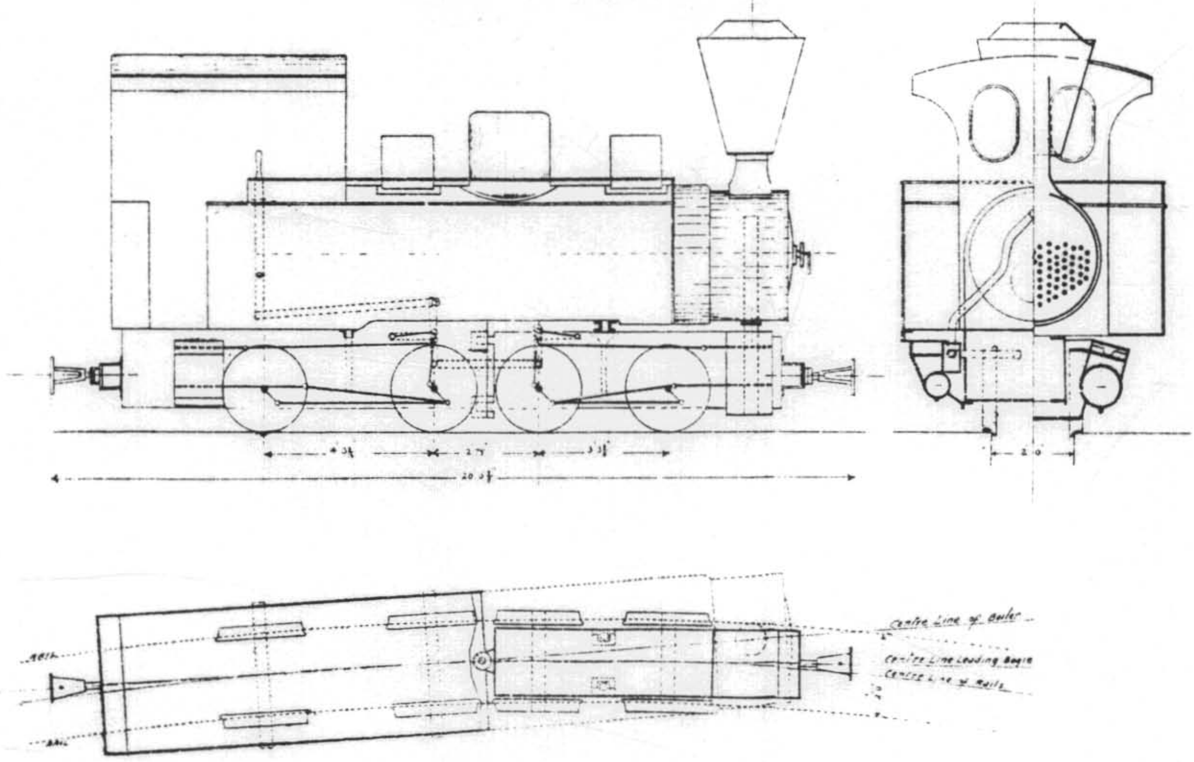
I may note here that one, sometimes heavy, item in repair-bills, the re-turning of tyres, is very materially reduced in engines with articulated frames. My tyres have run 5000 miles, and show no signs of wanting the lathe as yet.

The trucks used are the standard Government 15-ton, low-side, double-bogie waggons. These are excellent stock, tare only

MAGNET COMPANY'S LOCOMOTIVE.

MAGNET S.M.C^Y TRAMWAY

Compound Locomotive 2'0" Gauge Mallet System



Plan showing Carriage on 1¼ Chain Curve

5 cm

four tons, and will carry their nominal load. I have only hitherto loaded them, in regular work, to 13½ tons, but they will carry the full 15 tons without trouble. They have done all my ballasting, and have been in constant and heavy work for twelve months without any repairs whatever. These trucks are 24 feet long, and 6 feet 6 inches wide over all. While all the advantages are in favour of increasing the size of trucks for narrow-gauge lines, I do not think that these dimensions can be much exceeded in practice.

As prime cost was of maximum importance when the line was being constructed, stock was not fitted with vacuum brakes, though the saving in running cost is obvious; as on such work as ours a guard can be dispensed with, a saving of some £150 a year, or, in our case, of about 2*d*. per ton in freight cost.

On a line such as this, and indeed on all lines, the advantage of keeping the tare of trucks low is very marked. I have been strongly recommended (by the makers) to go in for a better class of steel framed and bodied truck, with a tare of five tons, or even heavier—with a guarantee that they would still be good trucks in ten years' time. I figure out the problem something like this. The present trucks cost me (from America) about £150 each. I can comfortably manage with them a train-load of 35 tons, of which 27 tons is ore, and 8 tons dead weight. The cost of carriage, taking into consideration wages, coal, and maintenance of road, amounts to about 2*s*. 6*d*. per ton of ore, but per ton of total load carried about 2*s*. If, therefore, I use five-ton trucks, I carry two tons dead-weight extra per train; that is, I must leave two tons of ore per train, or four tons, behind daily, which amounts to a loss of 4*s*. per truck per day, or £60 per year. So that, if I were given five-ton steel trucks for nothing, it would pay better to buy four-ton trucks, wear them out in three years, and then throw them away.

The guard's van was purchased with a view to accommodating general goods traffic; but I have hitherto always had full loading of ore for the trains, and we hardly use the van, as it does not pay to drag an extra two tons, in the shape of a van, for the reasons given above, for reducing the tare of trucks. We carry goods in the empty trucks on the back trip. We provide no passenger accommodation, except a seat on the ore-trucks.

The cost of construction and equipment ran out as follows:—

	£	*s*.	*d*.
Survey	1008	1	9
Clearing and grubbing...	682	17	3
Culverts and bridges	523	0	6
Earthworks	3876	3	6
Permanent way material	6171	1	4
Platelaying	519	14	2
Ballasting	1362	13	11
General equipment (buildings, &c.)	808	16	10
Supervision	1010	6	9
Rolling-stock	2961	7	8
Fuel	3	5	9
Stores	150	7	11
General expenses...	93	7	0
Interest and exchange	9	13	11
	£19,250	18	3

The details of this cost-sheet may be of interest.

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The line cost, equipped with rolling-stock, £1925 per mile; survey cost just over £100 per mile; clearing and grubbing, for a width of 20 feet from end to end of line, cost 16*s*. 6*d*. per chain; rails, sleepers, &c., cost £617 per mile, of which the sleepers (2200 per mile) cost 1*s*. each—cost per yard of road 7*s*. Platelaying, including curving rails, adzing and boring sleepers, charged with its share of locomotive, cost £52 per mile, or 7*d*. per yard. Ballasting cost £136 per mile, or about 3*s*. per cubic yard, laid and packed in the road. Finally, I may note that included in above costs is an amount of £2100 for duty, wharfage, and freight on the Emu Bay Railway from Burnie, which materially enhanced the cost of construction.

30th June, 1902.