

Report on Victorian Road Tests†

About four years ago the Victorian country roads board, recognising that strong and durable roads would be required, constructed an experimental length of road comprising several modern types of construction. A short length of the Prince's Highway at Oakleigh was chosen because it carried a considerable quantity of heavy horse-drawn steel-tyre traffic as well as a heavy motor traffic.

Construction

The road consists of five sections, each about 400 ft. long, and consisting of a main central pavement 18 ft. wide and two shoulders 3 ft. wide, giving a roadway 24 ft. wide.

Section A consists of an asphaltic concrete wearing surface 2 in. thick on a plain cement concrete base. The base is 4 in. thick at the sides and 6 in. at the centre, the bottom being flat and the top cambered.

The sub-grade was trimmed to grade, rolled, and immediately before the concrete was placed, watered. The concrete was composed of 1 part of cement to $6\frac{1}{2}$ parts of aggregate up to $2\frac{1}{2}$ in. in size, a minimum quantity of water being used. In all concrete sections particular care was taken to secure as dense a concrete as possible, and to that end sand, $\frac{1}{4}$ -in. toppings, $\frac{3}{4}$ -in. screenings, and $2\frac{1}{2}$ -in. metal (French coefficient of wear = 10) were mixed in the appropriate proportion. The concrete was mixed in a 4 c. ft. motor-driven mixer, and the complete gang consisted of one overseer, 11 men, and a boy.

The asphaltic concrete wearing surface was laid by the Sim Paving Co. Pty. Ltd., Melbourne, at a cost of 8/1 per sq. yd. It consists of a mixture of crushed stone up to $\frac{3}{4}$ -in. gauge, sand and stone dust passing a 200-mesh sieve, proportioned so as to have a maximum density, to which was added $12\frac{1}{2}$ per cent by weight asphaltum; 60-70 penetration. After consolidation the surface was given a second coat of hot asphaltum and, later, a coat of coarse sand. This section was opened to traffic in May, 1922.

Section B consists of a plain cement concrete pavement 18 ft. wide, 6 in. thick at the sides and 8 in. at the centre, the bottom being flat and the top cambered. It is composed of similar material to the base of section A, but the mix was 1 of cement to 5 of aggregate. After the concrete was deposited, it was well tamped, struck off with a heavy steel shod screed and, just before the initial set took place, the surplus water was squeezed out by rolling with a very light roller 6 ft. long, weighing about 10 lb. a linear ft. This left a glazed surface which was

removed by "belting" with a 12-in. belt stretched on a light timber frame. The concrete was thoroughly cured by covering with wet bags as soon as possible, and later by damp earth for 20 days. Traffic was allowed on after 30 days. Construction joints were placed at the ends of the morning's and afternoon's work. They were formed by placing a pre-moulded bituminous strip $\frac{1}{4}$ in. thick, with its upper edge $\frac{1}{4}$ in. below the surface.

Section C consists of a two-course reinforced concrete pavement 18 ft. wide. The bottom course is composed of 1 part of cement to $6\frac{1}{2}$ of aggregate up to $2\frac{1}{2}$ -in. gauge and is 4-in. thick at the sides and 6 in. at the centre. The top course is composed of 1 of cement to $4\frac{1}{2}$ of aggregate up to $\frac{3}{4}$ -in. gauge and is uniformly 2 in. thick. The reinforcement—No. 12 B.R.C.—manufactured by the Australian Reinforced Concrete and Engineering Co.—was placed between the two courses. Care was taken to place the top course before the bottom course had taken its initial set—usually within 30 minutes. The top course was finished off in the same way as section B.

Section D is similar to section C except that the bottom course is 1 in. thinner throughout, that is, the total thickness is 5 in. at the sides and 7 in. at the centre.

Section E consists of asphaltic macadam 18 ft. wide and 4 in. thick, laid in two courses on a base of Telford pitching 8 in. thick. The Telford pitching was constructed of "undressed dimensioned" spalls from Footscray, as the labor available was not skilful enough to lay a cheaper material. In spite of this, it was very difficult to get the spalls truly laid and well wedged up, and close supervision was required to prevent the men from laying the spalls with the broad edges up. The pitching was then rolled with a 15-ton steam roller, and finally $\frac{3}{4}$ -in. screenings were water-grouted in. Owing to delays in the earlier part of the work the winter was too far advanced to attempt to construct the asphaltic macadam wearing surface then, and, as the Telford pitching was true enough to carry traffic this work was postponed till November, 1922. The asphaltic macadam was constructed of 2-in. metal in two courses, each about 2 in. thick. The two courses were each rolled and penetrated by hand with asphaltum, heated to about 37 deg. F., then $\frac{3}{4}$ -in. screenings were spread evenly over the surface and rolled in. Including both coats, 1.85 gal. of 96 asphaltum a sq. yd. were used. After the road had been under traffic for about two weeks it was given a seal coat by a power sprayer—about $1\frac{1}{3}$ gal. a sq. yd.—and a coat of coarse sand.

†By A. E. Callaway, Chief Engineer, from the Annual Report of the Victorian Country Roads Board.

Shoulders 3 ft. wide were constructed of water-bound macadam 6-in. thick along all sections, but soon failed. They were reconditioned by lifting the metal, screening the dirt out and replacing, new metal being added where required. This metal was consolidated by a 15-ton roller and a coat of hot asphaltum applied by hand— $\frac{3}{4}$ gal. a sq. yd., coated with $\frac{3}{4}$ -in. screenings and rolled.

The total cost of the work was £6,448. Table 1 shows detailed costs of the different sections, which for convenience have been reduced to comparable units.

Table 1. Unit Costs

Cost of Roadway, Type A.

Pavement, 18 ft. wide of plain concrete base, 5 in. thick, with asphaltic concrete wearing surface 2 in. thick. Shoulders 3 ft. wide each side of asphaltic macadam 6 in. thick.

	Per lin. ft.
18-ft. concrete base at 15/0.13 a sq. yd.	£1 10 0.26
18-ft. asphaltic concrete surface at 8/1.04 a sq. yd.	0 16 2.09
6-ft. asphaltic macadam shoulders at 6/0.49 a sq. yd.	0 4 0.33
Earth work	0 0 2
Culverts	0 1 11.16
Guard fence	0 2 8.54
Miscellaneous	0 2 1.96
	£3 3 2.34

Or £16,680 a mile.

Cost of Roadway, Type B.

Pavement 18 ft. wide consisting of plain concrete 7 in. thick. Shoulders 3 ft. wide each side of asphaltic macadam 6 in. thick.

	Per lin. ft.
18-ft. concrete slab at 18/8.78 a sq. yd.	£1 19 7.56
6-ft. asphaltic macadam shoulders at 6/0.49 a sq. yd.	0 4 0.33
Earthwork	0 6 2
Culverts	0 1 11.16
Guard fence	0 2 8.54
Miscellaneous	0 2 1.96
	£2 16 7.55

Or £14,950 a mile.

Cost of Roadway, Type C.

Pavement 18 ft. wide consisting of reinforced concrete of average thickness of 7 in. Shoulders 3 ft. wide each side of asphaltic macadam 6 in. thick.

	Per lin. ft.
18-ft. reinforced concrete slab at 21/5.09 a sq. yd.	£2 2 10.18
6-ft. asphaltic macadam shoulders at 6/0.49 a sq. yd.	0 4 0.33
Earth work	0 6 2
Culverts	0 1 11.16
Guard fence	0 2 8.54
Miscellaneous	0 2 1.96
	£2 19 10.17

Or £15,800 a mile.

Cost of Roadway, Type D.

Pavement 18 ft. wide consisting of reinforced concrete of 6 in. average thickness. Shoulders 3 ft. wide each side of asphaltic macadam 6 in. thick.

	Per lin. ft.
18-ft. reinforced concrete slab at 20/2.38 a sq. yd.	£2 0 4.76
6-ft. asphaltic macadam shoulders at 6/0.49 a sq. yd.	0 4 0.33
Earthwork	0 6 2
Culverts	0 1 11.16
Guard fence	0 2 8.54
Miscellaneous	0 2 1.96
	£2 17 4.75

Or £15,150 a mile.

Cost of Roadway, Type E.

Pavement 18 ft. wide consisting of asphaltic macadam 4 in. thick on Telford pitched base 8 in. thick, the macadam being supported by pitchers.

Shoulders 3 ft. wide each side of asphaltic macadam 10 in. thick.

	Per lin. ft.
18-ft. asphaltic macadam at 9/9.68 a sq. yd.	£0 19 7.36
18-ft. Telford pitching at 15/0.62 a sq. yd.	1 10 1.25
6-ft. asphaltic macadam shoulders at 10/0.82 a sq. yd.	0 6 8.55
Earth work	0 6 2
Culverts	0 1 11.16
Guard fence	0 2 8.54
Miscellaneous	0 2 1.96
	£3 9 4.82

Or £18,320 a mile.

Note.—The above costs do not include any "overhead" charges.

Maintenance

During the four years that the road has been built, £430 has been expended on maintenance, and of this, £180 has been expended in repairing the shoulders and cleaning the table drains. This work is of the utmost importance, because, if the shoulders become waterlogged owing to defective drainage, the sub-grade under the concrete slab softens and its supporting power is weakened, thus tending to cause failure of the pavement.

In the asphaltic concrete section (A) 36 sq. yd. of the wearing surface have been relaid. The whole of this section has waved more or less, and in several places the material became so thin that it broke up and lifted off the concrete base. It is considered that this waving was due in part to a defective mixture, but mainly to the fact that the surface of the concrete had too smooth a finish to afford an effective bond with the asphalt. In sections B and C, the only maintenance required has been to the joints. They were formed by a strip of bituminous material placed with its upper edge $\frac{1}{4}$ in. below the surface—a method then in vogue in America, but since abandoned. These joints railed through the thin layer of concrete joining the two slabs cracking, and spalling off in small pieces. Repairs were made by cutting out the concrete to a depth of about 2 in. and the minimum width necessary to secure sharp vertical edges. This chase was then filled with toppings and sand mixed, while hot, with asphaltum. The mixture was made fairly soft and rammed with hot rammers and finished off flush with the concrete. Joints repaired in this way are still

in good order where the surface of the concrete is true across the joint and where the sub-grade has remained solid. Assuming joints are 50 ft. apart it would cost £150 a mile of 18-ft. road to make joints of this type.

Section D has required more maintenance than either section B or section C as it contains a number of short slabs and is 1 in. thinner, and only 5 in. thick at the edges where several corners have broken off. These were repaired with rapid-hardening aluminous cement. Concrete made with this cement attains a strength

wire stretched across the road. The height of the wire above the road surface is measured and compared with the height of the wire above two brass plugs which are grouted into the road with their tops about $\frac{1}{8}$ in. below the surface. The wire used is 0.022 in. in diameter and is supported by two steel anchors, which are fixed against the edges of the concrete slab and which are arranged so that a spring balance may be used to adjust the tension of the wire to 30 lb. With this tension the sag of the wire between its supports—18 ft. apart—is about 0.03 in., but

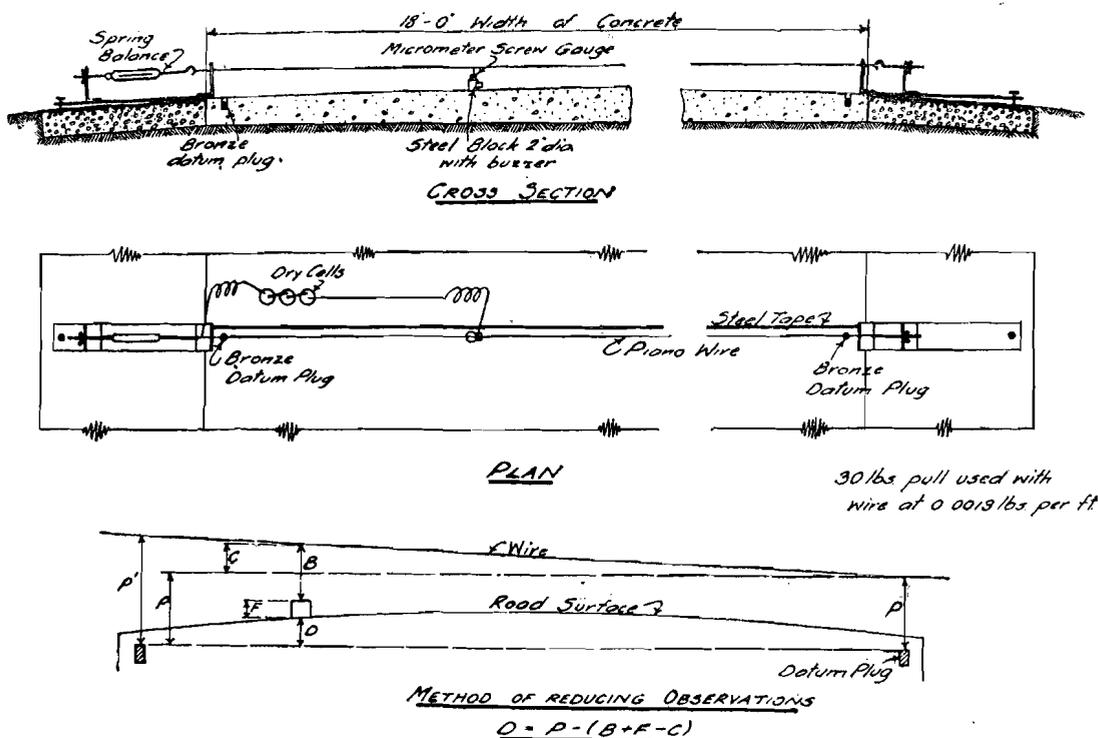


Fig. 1. Apparatus for Wear Measurement

in one or two days equal to that of Portland cement concrete in 28 days, so that it is not necessary to close the repair to traffic for more than 24 hours.

No repairs have been made to section E except near section D at the junction with the Ferntree Gully road. This piece carries heavy brick traffic and is in bad order, but the remainder of the section, which does not get much heavy traffic, is still in first-class condition.

Measurement of Wear

Before the road was opened, arrangements were made to measure the actual amount of wear which would be caused by traffic, so as to compare the relative merits of the different classes of concrete used.

The apparatus (Fig. 1) adopted from U.S.A. practice,¹ consists essentially of a steel piano

as it is always the same for the same sized wire with the same span and pull, this is neglected and the wire assumed to be straight.

The vertical height of the wire above the two brass datum plugs is read to 0.001 in. by means of an inside micrometer screw gauge, contact with the wire being determined electrically as it is impossible to "feel" the wire in the usual way.

In order to average out small irregularities in the road surface a steel block 2 in. in diameter placed on the surface is used to measure from. For convenience, an electric buzzer is mounted on its side and connected to a battery of three dry cells by a flexible wire. The other side of the battery is connected to the piano wire, and the buzzer sounds when the micrometer gauge resting on the top of the steel block touches the underside of the wire.

1. "U.S.A. Journal of Agricultural Research," Feb. 14, 1916.

Series of measurements have been made at intervals since July, 1922. The asphaltic concrete surface now appears to be wearing at the rate of about 0.025 in. a year, and the average wear over the section is about $\frac{1}{4}$ in.; portion of this is, however, due to consolidation of the material. Owing to the tendency of this class of material to wave, the measurements are somewhat irregular.

The measurements of the concrete sections are more consistent. Sections B and C are wearing at the rate of 0.07 in. a year, while section D is wearing at 0.10 in. a year. This difference may be accounted for by the fact that section D being 1 in. thinner is only about 86 per cent as rigid as the other two. Although section C is surfaced with a richer concrete than section B, it has worn slightly more than the latter. But larger metal ($2\frac{1}{2}$ in.) was used in section B than in section C ($\frac{3}{4}$ in.). The surfaces of all sections have worn quite evenly, the metal wearing at the same rate as the mortar. The wear for a period of 44 months is shown in Table 2.

Table 2

	Wear at edges	Wear at centre	Mean
Section A	0.19	0.21	0.20
Section B16	.27	.22
Section C21	.30	.26
Section D30	.51	.40

Traffic counts were made on two occasions, a summary of which is given in Table 3.

Table 3

	Dec. 19, 1922 6 a.m. to 10 p.m.			June 8, 1922 7 a.m. to 10 p.m.		
	No.	Avg. Speed	Avg. Wt. Tons	No.	Avg. Speed	Avg. Wt. Tons
Motors—						
Pneumatic tyres	199	20	1.2	256	20	1.1
Solid tyres	12	13	3.7	4	13	3.1
Horse-drawn	328		1.1	437		1.1
Others	18		1.1			
Total	557		640	697		760

Measurements of Pressure

During the construction of the road, pressure cells were built into it, so that the intensity of pressure on the underside of the slab could be measured. A pressure cell consists essentially of a flat circular box $5\frac{1}{2}$ in. in diameter and $1\frac{1}{4}$ in. thick, with one side flexible. This side is made of a sheet of brass 0.005 in. thick, stiffened over the greater part of its area by brass discs.

Normally, when external pressure tends to force this flexible side inwards, it rests against, and the pressure is taken by, a steel button fixed to, but insulated from, the body of the box. The cell is cast into the concrete slab with the

flexible side down and flush with the under surface, and is connected to the indicating apparatus by a brass tube $\frac{1}{8}$ in. diameter, through which passes an insulated wire soldered to the steel button. To use the cell an electric circuit is made up of a lamp and battery connected through the body of the cell, steel button, and the insulated wire. Compressed air is allowed to flow slowly into the cell, and when the pressure on the inside is just greater than that on the outside, i.e., the underside of the slab, the flexible side moves and breaks the circuit, causing the lamp to go out. Immediately this happens the supply of compressed air is shut off and the

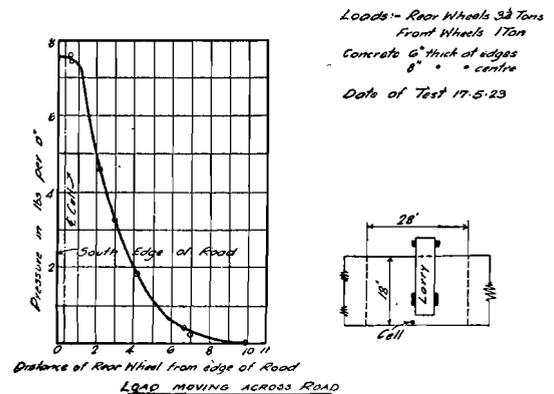
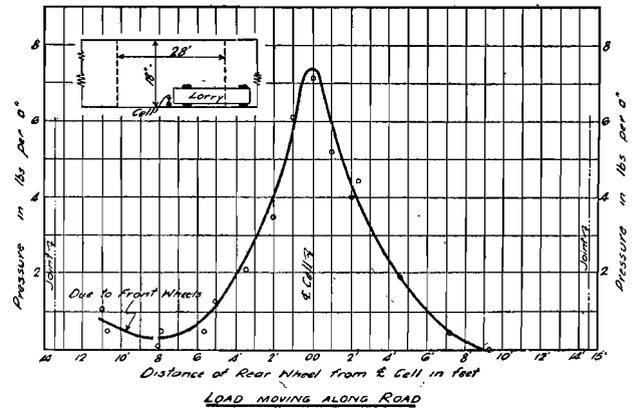


Fig. 2. Pressure Measurements

pressure in the cell is read on a sensitive pressure gauge. This is the intensity of pressure on the underside of the slab.

Typical curves showing the distribution of pressure under a loaded lorry wheel are given in Fig. 2. Unfortunately, some of the pressure cells failed to work, and a complete set of results could not be obtained. The maximum recorded pressure due to a load of $3\frac{1}{2}$ tons (rear wheel of heavy lorry) was $7\frac{1}{2}$ lb. a sq. in. (0.48 tons a sq. ft.) at the edge and 2 lb. a sq. in. (0.13 tons a sq. ft.) at the third point. It should be understood that these figures refer to static loads and that the pressures under moving loads would be at least twice their value. If the surface were rough, the pressures would be greater still.

Measurements of Stress

In October, 1923, a series of tests was made to determine the stress in a concrete road slab due to a static load. The method consisted in measuring the changes in slope of the slab due to bending caused by a static load, and thence calculate the corresponding moments and stresses. The following formulæ were used:—

$$M = E.I.di/dl.$$

$$M = f.I/y.$$

and $f = E.y.di/dl.$

Where M = bending moment (in.-lb.), E = Young's modulus (assumed 2,000,000 lb./sq. in.), I = moment of inertia of section (in. units), di/dl = rate of change of slope at point considered, f = extreme fibre stress (lb./sq. in.), y = distance from neutral axis to extreme fibre (in.).

The change of slope was measured with a very sensitive spirit level supported on an iron plate fitted with three levelling screws, which rest on the slab. One division of the scale (1/40 in.) corresponded very closely to two seconds of arc (about 1/8 in. per mile). As the levelling screws were 14.3 in. apart, a change in the position of the bubble of one division would be caused by an alteration in the relative height of the ends of the supporting screws of 0.00014 in.

The results obtained are shown in Tables 4 and 5.

Table 4. Stresses in vertical plane parallel to centre line of road, near wheel track, due to two rear wheels in centre of road, 3.3 tons each.

Distance of Loads from End of 22-ft. Slab 8 in. thick	Maximum Stress
6 in.	14 lb./sq. in. top in tension.
4 ft. 6 in.	18 lb./sq. in. top in compression.
9 ft. 6 in.	22 lb./sq. in. top in compression.
13 ft. 6 in.	14 lb./sq. in. top in compression.
21 ft. 6 in.	14 lb./sq. in. top in tension.

Table 5. Stresses in vertical plane parallel to centre line of road, near edge, due to two rear wheels near edge, 3.3 tons each.

Distance of Loads from End of 22-ft. Slab 6 in. thick	Maximum Stress
6 in.	47 lb./sq. in. top in tension.
4 ft. 6 in.	34 lb./sq. in. top in compression.
9 ft.	32 lb./sq. in. top in compression.
13 ft. 6 in.	46 lb./sq. in. top in compression.
18 ft.	38 lb./sq. in. top in compression.
21 ft. 6 in.	41 lb./sq. in. top in tension.

It should be noted that the above stresses were due to a static load, and that those produced by a moving load would probably be several times greater. Also the stresses occurring in a plane at right angles to the centre line of the road are probably greater than the ones measured (i.e., parallel to the centre line of the road).

Conclusions

After nearly four years of observation of experimental sections, there are still many questions that remain unanswered, but some conclusions appear quite definite. The first is that a properly constructed concrete surface is quite satisfactory to all classes of traffic, but that, under horse-driven steel-tired traffic it gradually wears down. (American records indicate that wear due to rubber tyres is negligible.) If the surface were properly constructed in the first place, this wear is quite uniform and the surface remains true.

The joints in a concrete pavement require constant watching so that any defects are remedied as soon as they appear and before they have time to grow. The method of repair adopted appears to be quite satisfactory. It is obvious that joints should be spaced as far apart as possible; the average spacing is about 25 ft. This could well be doubled.

It is evident from the behavior of section D that 5 in. at the edge is too thin to stand heavy traffic. Unfortunately the section adopted in all the concrete sections—with edges thinner than the centre—has been proved by research carried out in America to be uneconomical. Modern practice prescribes a pavement with thickened edges. Had the section been constructed with edges 7 in. and centre 5 in. thick, less concrete would have been required and, in all probability, it would have carried very heavy traffic quite satisfactorily.

The waving that has occurred in the asphaltic concrete section indicates that the mixture was not perfect, and that a smooth finish of the concrete base is not desirable. For the reasons given above the base should have thickened edges.

The asphaltic macadam section is quite satisfactory under motor traffic, but it does not appear to stand up to the heavier horse traffic. The Telford base is economical only for localities where suitable pitching stone is available and where skilled labor can be obtained.

Experience with the shoulders indicates that the road is too narrow for two lanes both of fast and slow moving traffic—too large a percentage of vehicles have to turn out on to the shoulders. This tends to cause rutting of the edge of the main pavement and in turn promotes drainage troubles by providing an entry to the shoulder for the water flowing off the pavement. If the sub-grade becomes water-logged the most scientifically constructed pavement will rapidly fail.

The Commonwealth high court by a majority decision has ruled that Garden Island, which was taken over from the New South Wales government at federation as a naval depot remains the property of the state.

New Publications

"Surveying," by W. Norman Thomas. Second Edition. Edward Arnold and Co., London. Price in Australia, 31/6; postage, 1/1.

"Coal and Ash Handling Plant," by John D. Troup, M.I.Mech.E. Chapman and Hall Ltd., London. Price in Australia, 17/6; postage, 6d.

"Mechanisms." A Text Book for the Use of Non-technical Students. By Ewart S. Andrews, B.Sc., A.M.Inst.C.E. Publisher, W. B. Clive, University Tutorial Press Ltd., London. Price in Australia, 5/-.

"Railroad Construction, Theory and Practice," by W. L. Webb, C.E. 8th edition revised. John Wiley and Sons, New York; Chapman and Hall Ltd., London. Price in Australia, 31/6; postage, 6d.

Railroad Construction. By Walter Loring Webb. Chapman and Hall Ltd., London. Pp. 849. Price in Australia, 31/6.

This is the eighth edition, revised, of the book which is designated as a text-book for the use of students in colleges and technical schools, and a hand-book for the use of engineers in field and office. Special attention has been given in this edition to the relations of locomotive power to grade and in chapter XXIII the author shows the real effect of undulatory grades on the power of a locomotive. The economic effects on the operations of trains, of the introduction of a sag or hump into an otherwise uniform grade is numerically illustrated. This sag or hump might save a great deal of capital cost, and the method given would demonstrate under what conditions it would be virtually harmless. The author says that these numerical solutions are based on the general methods outlined in the Manual of the American Railway Engineering Association, which is, in general, the ultimate authority for all the conditions and recommendations regarding practice which are found in the book.

Stainless Iron and Steel. By J. H. G. Monypenny, F.Inst.P. Chapman and Hall Ltd., London. Pp. IX + 304 + 22 plates. Price in Australia, 26/-.

In this meritorious work the author has produced a book giving a full and accurate account of the composition and properties of the stainless steels now on the market. The important factor in making a steel rustless is the presence of chromium to the amount of about 12 per cent.

Commencing with a short historical account of the development of the steels, the results of the influence of chromium on the structure and hardness of steel are given. The succeeding chap-

ters are devoted to notes on the handling of the steels in various manufacturing operations such as forging, welding, pickling; the effects of heat treatment on the mechanical and physical properties; and the resistance to corrosion as affected by composition and treatment. Then follows a chapter on special stainless steels and the last one on the applications of stainless steel. In this connection it is interesting to mention the use of stainless steel for valves of internal combustion engines, in which strength at high temperatures and resistance to erosion and oxidation are of prime importance. For this purpose a steel with a slightly higher carbon content than usual is used, and it is not necessary to use a very high content of chromium. The valves used in the first aeroplane to fly across the Atlantic were manufactured of a chromium-silicon steel, containing about one per cent of silicon, about six per cent of chromium and 0.5 per cent of carbon. Other practical notes and hints are given, all of which tend to make the book of considerable value to intending users. Mr. Monypenny is to be congratulated on the work he has put into the book which is well produced in legible type and with excellent illustrations of photographs and microphotographs.

Mechanisms. By Ewart S. Andrews, B.Sc., A.Inst.C.E. University Tutorial Press Ltd., London. Pp. 194. Price in Australia, 4/6.

Although classed as a text-book for non-technical students, this book contains many features that are interesting to technical men. It explains in ordinary language the principles involved in the leading types of mechanism and illustrates these principles by describing the machines which incorporate them. The author was at one time a lecturer in engineering at the university college, London, and found that many students failed to understand fully the principles of mechanics, owing to the practice of reducing things to mathematical formulæ. In this book he has attempted to make these complicated matters more lucid and understandable to the average student. This has been done by incorporating many diagrams in perspective.

The various chapters include: General principles, levers and pulleys, screw mechanisms, linkage mechanisms, various gearing, epicyclic gearing, governors, bearings, clutches and brakes, and types of heat engines. In the last chapter one notices with pleasure the diagrams explaining the four strokes (Otto cycle) of the internal combustion engine. This will be easily understood by the novice in motor engineering and is the first thing that should be grasped by those learning to drive a motor car. The book will be read by the non-technical and technical man and many points which have not been very clear in the past will be readily followed and understood.