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Friday 22 June

Dear Jim,

As promised I enclose a copy of a paper given in Perth in 1867 by Joseph Mitchell. Unfortunately there does not appear to be any reference to Dornoch but Struan may be interested!

I also spent some time this morning at the Reference Library when I went through the Ross-shire County Council minutes 1898–1901 1912–1914, 1915, and 1916. I could find no reference to any crossing of the Dornoch Firth. Time prevented me covering the period 1901–1912. but from the style of the minutes I would not be too optimistic that the matter was discussed at Council level – I could be wrong!

Coincidentally this week's 'New Civil Engineer' magazine arrived yesterday and lo and behold there is a feature on the new Dornoch Bridge crossing. I enclose a copy for your information and again I suspect Struan will be interested!

This is a very rushed note so excuse

the worse than usual scrawl!

I forgot to ask last night if Jessie had fully recovered but having heard her voice in the background I assume she's back to normal!

We are off to Oldshoremore on Sunday for our annual slog of the hill lochs!

We must try and get up to Dornoch to see your exhibition in July!

Regards to all.

Yours sincerely.

Ted

On the Construction and Works of the Highland Railway. By JOSEPH MITCHELL, *F.R.S.E., F.G.S., C.E., and Member of the Institution of Civil Engineers.*

THIS title represents the union of several Companies in the north of Scotland, amalgamated three years ago under the name of the Highland Railway Company. The works consist of a main line from a point near Perth, extending northward 117 miles to the town of Forres, and a base-line running nearly at right angles to the other, extending westwards from the town of Keith by Elgin and Forres along the shores of the Moray Firth to Inverness, and thence along the Beauly, Dingwall, and Dornoch Firths, northwards to Bonar Bridge, measuring from Keith to Inverness 55 miles, and from Inverness to Bonar Bridge 58 miles, and making together a base-line of 113 miles. These railways traverse the northern part of Perthshire, and are the main lines of communication through part of Banffshire and the counties of Inverness, Nairn, Moray, and Ross, the whole including three branches—two to the ports of Burghead and Findhorn in Morayshire, and the other to the village of Aberfeldy in Perthshire—and extending to 246 miles length.

The country is fertile and comparatively flat for a distance of about 40 miles north of Perth, and also along the shores of the Moray, Dingwall, and Dornoch Firths; but between Perthshire and Morayshire the line crosses two ranges of the Grampian Mountains, the one separating the valley of the Tay from that of the Spey, and the northern range separating the Spey from the valley of the Findhorn.

The large rivers which drain these mountain-regions debouch into the Tay, the Moray, the Dingwall, and the Dornoch Firths, and as the railway in most cases crosses these rivers near the sea, bridges of considerable magnitude were required. Besides the crossing of these rivers, other difficulties of a formidable character arose in crossing the mountains at so great an elevation, and in passing the rocky and precipitous defiles through which portions of the line had to run.

The northern counties traversed by these railways, except along the shores of the Firths, are chiefly pastoral, exporting large numbers of sheep and cattle.

The fisheries also are on an extensive scale; besides the salmon fisheries in the rivers, the annual take of white fish in the Moray Firth amounts to about 60,000 tons.

The object of the promoters, therefore, was to sweep the fertile shores of the Moray Firth, and to send the produce of the country by the most direct route to Perth, across the mountains, thus saving a detour by Aberdeen of nearly 60 miles. In laying out the main line and crossing the Grampians between Perth and Forres, long and steep inclines could not be avoided, but there is no steeper gradient than 1 in 70 throughout. The line to Blair, 36 miles from Perth, rises only 443 feet above the level of the sea, but from Blair to the summit of the southern range of the Grampians, a distance of 17 miles, the line rises 1045 feet, making the extreme summit 1488 feet above the sea. In this distance there are gradients for 10 continuous miles of 1 in 72 and 1 in 70, and in the remaining 7 miles the inclines vary from 1 in 78 to 1 in 110. After passing this summit the line descends into the valley of the Spey, falling 747 feet in 18 miles, the steepest gradient being 1 in 80. On crossing the Spey, the line is comparatively level for a distance of 24 miles, when it again ascends by gradients of 1 in 84, 80, and 100, in order to pass the northern ridge which separates the valley of the Spey from that of the

Findhorn. This summit is 1046 feet above the sea-level. It afterwards descends to Forres (the point of junction with the base-line) by gradients, the steepest of which are 1 in 70 for 8 miles, and 1 in 76 for 4 miles.

In this length of the main direct line of 104 miles, there are two small tunnels, one of 350 yards near Dunkeld, and the other in the Pass of Killiecrankie of 110 yards in length, both constructed very much with the view of avoiding injury to the adjoining scenery.

The principal difficulties that arose in laying out the line were in passing through the narrow defile at Dunkeld, the beautiful demesne of the Duke of Athole, and again in penetrating through the picturesque Pass of Killiecrankie, where the mountains, as it were, close in upon each other for a great height; likewise in passing along the narrow, precipitous, and rocky valley of the Garry, close to a large and rapid mountain-stream; also the Park at Castle Grant, and the defile at Huntley's Cave near Grantown. These points in particular required much study, with repeated trial and contour levels, so as to obtain a knowledge of the precise formation of the ground, and to choose the best direction at the lowest possible cost. At the Pass of Killiecrankie the banks were so precipitous and steep that the line had to be supported by breast or retaining walls to the extent of 690 lineal yards, and to the average height of 26 feet, the extreme height of one being 55 feet; and in order to carry the railway at the narrowest point in the Pass where the precipices close in, as it were, on either side, and afford scarcely any additional space beyond that occupied by the channel of the river, instead of supporting the line by breastwalls, it was deemed prudent to construct a viaduct of 10 arches, 60 feet above the river, which with a tunnel at the north end carries it successively through the Pass. At two other points on the line, in running up the sides of the Garry, breastwalls had to be formed, respectively 94 and 35 yards in length, and 15 feet in average height. All these breastwalls, extending to 1650 lineal yards, are built with lime, and set on a solid foundation of dry gravel or rock, at right angles to the face of the wall, which batters at the rate of $1\frac{1}{2}$ inch to the foot.

The spaces behind the walls are filled with rubble stones, set by hand for 10 feet wide, and further back with dry gravel, it being important that all earth or clayey substances should be excluded. The writer prefers the curved to the straight batter, as it gives more effectual resistance if well built; but breastwalls are to be avoided wherever earth embankments can be substituted, as, in his experience, there are subtle influences in the Scottish climate of alternate frost and wet in winter, which operate imperceptibly to their destruction, and they require careful and constant inspection. Except where those breastwalls became necessary, the whole of the lines were formed in cuttings and embankments, and for considerable distances along the slopes of valleys. Where the ground was precipitous or irregular in the cross section, level benchings were formed, 10 feet in width, immediately underneath the permanent way, in order that the sleepers should have an equal and solid bearing throughout.

In running through so large an extent of mountainous country, the line, as might be expected, had to pass over some lengths of soft ground and morass. The principal of these were for two miles near the town of Nairn, also for about two miles near Keith, one mile on Dava Moor, and about a mile in crossing through a hollow at Drumochter on the summit of the Grampians. In all places where the ground was particularly soft, a uniform mode of treatment was adopted. Two parallel drains were first cut outside the fences, about 50 feet apart, from 4 to 6 feet deep, and with slopes of 1

to 1. This drained off the surface-water; and, after making up the holes and other irregularities of the surface with turf, the space for the railway to a breadth of about 15 feet was covered with two or three layers of swarded or heather turf, having the sward side of the lower layer undermost, and that of the top layer up, the joints breaking band. In this way a good sustaining surface has uniformly been obtained*. On this bed of turf the ballast was laid for 2 or 3 feet in depth. This was quite sufficient to support the traffic, but as in some cases the bed of moss was from 20 to 30 feet in depth, the railway merely floated on the surface, and was in the first instance undulating, and yielded in some parts from 3 to 4 inches under the weight of the engines passing over. To obviate this undulation longitudinal beams of timber were tried at one place, 30 to 40 feet long, below the sleepers, but this was found objectionable, as rendering it more difficult to raise or repair the surface of the road; and an additional sleeper (making the sleepers 2 feet 6 inches from centre to centre, instead of 3 feet) was found preferable. There was nothing for it, at the worst, but to lift the road every other week as it sunk, until it had acquired a solid bearing. In many places we had to lay on 4, 5, or 6 feet in depth of additional gravel, and in one place no less than 27 feet, before the road became solid. In the course of two or three years, however, with due attention, the rails being fished, the lines through these mosses were all that could be desired for solidity and permanence.

As the writer has said, in crossing so many mountain-rivers, bridges of magnitude had to be constructed, involving considerable varieties of execution. The principal of these bridges may now be described, and any peculiarity will be noticed which may have arisen during the progress of the works. It will be observed that the beds of the rivers in the north of Scotland differ in many respects from what is common in England, consisting frequently of depths of 10 or 12 feet of gravel and boulders, the solid and compacted débris of successive floods, below which, if the country is of rocky formation, there is usually hard clay, and then rock, or, as in one case at the mouth of the River Ness, after penetrating 12 feet of shingle and boulders, a sort of admixture of whitish clay and sand was obtained. In some cases we had to deal with soft clay and mud of great depth, but these were exceptions. Nor was it possible in general to ascertain, by boring, the precise nature of the foundations, because many of the boulders in the gravel were of large size, and were often mistaken for rock. The only way in which an approximate knowledge of the foundations could be obtained was by driving iron rods at various places, and, when the bed of the river admitted of it, wooden piles. Still we worked very much in the dark; but the writer's long experience of these rivers, and of the nature of their floods, was of great advantage in enabling him to fix the depth of the foundations and the precise description of works, to secure the necessary stability of construction. In only two or three cases was there any fear of sinking. What had chiefly to be guarded against was sudden and impetuous floods, sometimes accompanied with floating ice and trees, undermining the foundations and damaging the piers; it was therefore important to provide ample waterway. The construction of these bridges ranged over twelve years, and during that time there has been considerable changes in bridge building, by the adoption of iron cylinders for piers, and lattice girders in spanning the waterways, so that, as the works progressed, these improvements were adopted where found suitable.

* Had this plan, which the writer has found to answer so well both for roads and railways, been adopted in the clayey ground at Balaklava in the Crimea, a good road might have been formed.

In planning these works, the writer, while having every regard to economy, felt the importance of their being of the most substantial character, seeing that they were exposed in these districts to every vicissitude of climate and flood; but indeed he feels that all permanent public works involving the safety of the lives of the community should be of undoubted stability. On the whole system there are only three timber bridges, which he was forced to adopt, chiefly with a view to save time, but these are very substantial of their kind. All the other bridges are constructed of stone, and where iron is adopted the piers are in general constructed of masonry.

The iron work of the bridges on all these lines were constructed by Messrs. Fairbairn and Sons of Manchester, for about £20 per ton on the average, and are admirable specimens of workmanship in this department.

Accompanying this paper, the writer furnished the working drawings of fourteen of these bridges, with the sections and dimensions in detail. They exhibit a variety of forms suited to the localities in which they are built.

No. 1 is an *iron-girder bridge across the Tay*, 6 miles north of Dunkeld, with stone abutments and pier, constructed on platforms and piles in the usual way. The banks are low, and the river is spanned by two openings, one of 210 feet, and the other of 141 feet. The cost of this work was £20,395. Extreme length 515 feet; height above the bed of the river 67 feet; cost per lineal foot £39 12*s*.

Nos. 2 and 3 are the most recent bridges erected by the writer; and here he has taken advantage of the modern plan of using cylinder piers to carry the girders. Both bridges are constructed in the same manner, and on the same principle. The cylinders form the piers in the centre and abutments. Each cylinder is 8 feet in diameter, and has been sunk into the bed of the river 27½ feet in their extreme depth, by means of divers. When these cylinders were adjusted and brought to the full depth, about 3 feet of cement concrete was lowered into the bottom. On the concrete setting, the water was pumped out, and the interior filled in with rubble masonry, laid with Portland cement. To provide for extreme floods, two side openings were made, 41¼ and 35 feet span, of plate girders, one end resting on the masonry in the cast-iron cylinders, and the other on a stone abutment landward, secured on a platform and piles. These bridges answer their purpose very satisfactorily. The cost of No. 2 bridge, which consists of two openings of 122 feet, and two side openings of 35 feet span, was £11,156. Total length of No. 2 350 feet; cost per lineal foot £31 17*s*. 6*d*.; height above the bed of the river 36 feet.

The cost of No. 3 bridge, consisting of two openings of 137 feet span, and two side openings of 41¼ feet span, the cylinders being sunk into the bed of the river 25 feet, amounted to £13,772. Length of No. 3, 419¼ feet; cost £32 16*s*. 7*d*. per lineal foot; height above the bed of the river 49 feet.

No. 4 is the *viaduct in the Pass of Killiecrankie* already alluded to. It consists of 10 arches of 35 feet span, with an extreme height from the foundations to the top of the parapet of 54 feet, and is built with a curve of 20 chains radius. The Pass of Killiecrankie is a well-known object of picturesque beauty, and it is generally admitted that the railway, now that the slopes have attained their proper verdure, has in no way diminished its attractions. Indeed this viaduct is thought to give it additional interest. The cost was £5720. It is adapted to the single line, and is 17 feet in width over parapets. Length 508 feet; cost per lineal foot £11 5*s*.

No. 5 is a viaduct across the *River Tilt, near Blair Athole*, spanning the river by one wrought-iron girder of 150 feet. The abutments are of stone, laid three feet below the bed of the river on a platform of timber 6 inches

HIGHLAND RAILWAY.—Abstract note of the chief Viaducts on the Highland Railway.

Nos. on plans.	Situation.			Extreme length.	Height above the bed of the river.	Cost.	Cost per lineal foot.	Remarks.
				feet.	feet.	£	£ s. d.	
1	Viaduct over the River Tay at Dalguise.	Abutments and pier of stone.	2 spans of wrought iron 210 feet and 141 feet.	515	67	20,395	39 12 0	Built for a single line.
2	Viaduct over the River Tummel at Ballinling.	Piers of cast-iron cylinders.	2 spans of 122 feet each, and 2 of 35 feet.	350	36	11,156	31 17 6	„ „
3	Viaduct over the River Tay at Logierait.	Piers of cast-iron cylinders.	2 spans of 137 feet each, and 2 of 41¼ feet.	419¼	49	13,772	32 16 7	„ „
4	Killiecrankie Viaduct. ...	Stone and lime. ...	10 arches of 35 feet span ...	508	54	5,720	11 5 0	„ „
5	Viaduct over the River Tilt at Blair Athole.	Abutments of stone.	1 span of wrought iron 150 feet.	256	40	6,500	25 7 9	„ „
6	Viaduct over the River Garry at Calvine.	All stone and lime.	1 arch 80 feet span, 2 arches 40 feet span.	274	55	5,100	18 12 3	„ „
7	Viaduct over the River Dulnain.	Stone abutments ...	1 wrought iron span of 80 feet.	148	27	3,298	22 5 6	„ „
8	Viaduct over the River Divie.	All stone and lime.	7 arches of 45 feet span ...	477	106	10,231	21 0 0	„ „
9	Viaduct over the River Spey near Keith.	....	1 span of 230 feet of wrought iron, and 6 side arches of stone and brick, each 30 feet span.	660	74	34,482	52 5 0	Double line.
10	Viaduct over the River Findhorn near Forres.	Stone abutments and piers.	3 spans of 150 feet each of wrought iron.	608½	40½	21,430	35 4 4	Single line.
11	Viaduct over the River Nairn at Nairn.	All stone	4 arches of 55 feet span......	371	56	8,620	23 4 8	Double line.
12	Viaduct over the River Ness at Inverness.	All stone	5 arches of 73 feet, and 4 side arches of 20 feet span.	669	40	13,410	20 0 0	Single line.
13	Swing bridge over the Caledonian Canal.	Stone piers	2 wrought iron girders each 126 feet long, set on a turntable.	......	......	4,718	......	„ „
14	Viaduct over the River Conon in Ross-shire.	All stone and at a skew of 45°	5 arches of 73 feet span built in square ribs.	540	45	11,391	21 2 0	„ „

thick secured to piles. As it is situated close to Blair Castle, it has been made somewhat more ornate than was otherwise necessary. The cost of this bridge is £6500, being for a single line. Length 256 feet; cost £25 7s. 9d. per lineal foot; height above the bed of the river 40 feet.

No. 6 is a *bridge across the River Garry* at Calvine of 3 spans, one of 80 and two of 40 feet, and is 55 feet from the bed of the river to the top of the parapet. There was considerable difficulty in fixing the crossing of the river at this place. The Garry is here a large and rapid mountain-stream, on a rocky bed, with several falls immediately adjoining, running through an ornamental plantation, and as this was a spot of interest in the grounds of Blair Castle, we were precluded from crossing the river at any other point within the demesne. It occurred to the writer, however, as the road-bridge passed over about the narrowest part of the river, the object aimed at could be effected both economically and unobjectionably by spanning both road and river, thus forming an object of additional interest in this peculiar locality. The cost of this bridge was £5100. Length 274 feet; cost per lineal foot £18 12s. 3d.

No. 7 is a bridge of no particular interest, 80 feet span, crossing the *River Dulnain*, a mountain-stream near Grantown, but is given as a specimen of a substantial bridge of this size. The cost was:—Masonry £2238; iron work £1060. Total £3298. Length 148 feet; height 27 feet; cost per lineal foot £22 5s. 6d.

No. 8 is a viaduct crossing a picturesque ravine and stream called the *Divie*, 10 miles south of Forres. Its length is 477 feet, constructed for a single line, and the cost amounted to £10,231. It is 106 feet in height from the river-bed to the top of the parapet, and 16 feet in width; all the piers within the limits of the stream are founded on rock. It consists of seven arches of 45 feet span each. Cost per lineal foot £21 9s.

These viaducts constitute the principal works on the through line between Perth and Forres. The writer will now proceed to allude briefly to the principal works on the coast-line between Keith and Bonar Bridge.

The portion from Keith to Inverness being one-half the distance of the railway from Aberdeen to Inverness, the capital of the Highlands, extends to 55 miles in length. It may be stated that this portion from Inverness to Keith originally formed part of the Great North of Scotland Railway, the act for which was obtained in 1846, but pecuniary difficulties prevented the promoters from constructing this part of their scheme, involving, as it was then supposed, the construction of very heavy work in the neighbourhood of the River Spey, and it was eventually left to the Highland Companies to carry it out. There is a deep and precipitous ravine on the south side of the Spey, with flat meadows on the north side, and the original plan of the Great North of Scotland Company was to cross the river at a gradient of 1 in 90 with a high viaduct, with expensive works in the ravine, at a cost of about £100,000, the bridge being estimated at £60,000. After much careful survey and consideration, and consultation with Messrs. Locke and Errington regarding this work, it was fixed to pass through the ravine by a gradient of 1 in 60 for $2\frac{1}{2}$ miles, which is the steepest gradient on the Highland system, and span the river by a box girder of 230 feet, with six side arches of masonry, each of 30 feet span, to meet the contingency of flood waters, which are on this river very sudden and very rapid, and the work has been carried out successfully. It may be mentioned that this was about the greatest single span of an open girder at the time built (1856). The propriety of a stone bridge at this place, with a gradient of 1 in 70, was considered by the Directors, but it was found to be too expensive. The present line, however, answers quite sufficiently for the traffic of the country,

which is now chiefly local since the opening of the Highland line. The cost of the bridge, which is 660 feet long and 74 feet high from the foundations to the top of the towers, constructed for a double line, was £34,480; cost per lineal foot £52 5s. The east abutment of this bridge is founded on rock, and it was provided that the west abutment should be sunk and founded on piles and a platform, the first imperfect trials having led to the conclusion that there was nothing beyond indurated shingle at this place. On sinking 14 feet from the surface, however, through a conglomerate of boulders 2 to 3 feet in diameter, hard mountain clay appeared, and on penetrating this for about 3 feet, rock was found, thus securing for this structure a rock foundation on either side. Immediately at the east end of this viaduct, the line, as already said, runs through a narrow and precipitous ravine, the stream of which had to be diverted for the railway, by a new channel cut out of the solid gravel 30 feet wide, sloping longitudinally 1 in 40, and pitched with stones from 12 to 18 inches deep. This pitching, which consists of squared stones, had to a small extent broken up several times since the line was opened ten years ago, from the floods bringing down stones and trees, and we found that the most effectual way of securing it was by inserting walings of timber 40 feet apart, 12 inches by 4 inches, across the channel, secured at every 3 feet by iron piles, and grouting the joints of the pitching in dry weather with lime-grout so as to prevent the lodgment of air and water, which under the pressure of floods has a tendency to dislocate the stone work.

No. 10 is a *viaduct crossing the Findhorn*, a dangerous and rapid river. It sometimes comes down in great flood, almost in a body of 2 or 3 feet of perpendicular height at a time, notwithstanding that in summer it is a very moderate-sized stream. This bridge consists of three spans of 150 feet each, with stone abutments and piers of solid ashlar, and is constructed for a single line. There was no appearance of rock in the immediate neighbourhood of the site, although rock appeared on one side of the river about half a mile above; and the channel, as far as could be ascertained, consisted of shingle and gravel. It was provided, therefore, that the foundation should be sunk 6 feet below the deepest part of the bed of the river on a platform and piles. The east abutment was so sunk, and the piles were driven through the gravel to a depth of 10 feet, making 16 feet below the bed of the river. It was observed that at that depth the piles uniformly would drive no further, and this suggested the possibility of rock. Rock was accordingly searched for, and it was found that about 18 feet under the bed of and across the river, rock existed. Cofferdams were therefore formed, and rock foundations were secured for the remaining piers and abutment. The cost of the bridge, including a pitched embankment on the east side, the bottom of which was secured by piles and a waling of timber, amounted—masonry to £11,170; ironwork £10,260, making a total of £21,430. Extreme length $608\frac{1}{2}$ feet; height above foundations $46\frac{1}{2}$ feet; cost per lineal foot £35 4s. 4d.

No. 11 *is a bridge across the River Nairn*, consisting of four arches of 55 feet span, and is an admirable piece of masonry. An incident connected with the foundations of this bridge deserves to be mentioned. The contractor, when instructed to ascertain the nature of the foundations, insisted that it was unnecessary to take any trouble about them, as rock cropped out on either bank; the turnpike-road bridge across the river a quarter of a mile below was founded on rock, and he said there could be no doubt that rock would be got in the centre 3 or 4 feet below the bed of the river. Rock, however, was not reached until we sunk from 13 to 14 feet, showing that experienced persons may be misled even under the most convincing circumstances. The structure, however, is founded on the solid rock throughout, and the cost for a double line was £8620. Length 371 feet; height 56 feet; cost per lineal foot £23 4s. 8d.

No. 12 *is a viaduct across the Ness*, consisting of five arches of 73 feet span over the river, 4 land arches of 20 feet span, and 2 cast-iron openings of 27 and 35 feet span over roads. The foundations of this bridge, as in many others, consisted of shingle for 20 feet down, but at the north abutment and pier the iron rods driven in appeared to penetrate considerably easier than at other points of the channel, and it was deemed prudent to construct this abutment and pier upon bearing piles and a platform, and they were accordingly so done, as exhibited in the drawings. The total length of this bridge, including the side arches, is 669 feet, and the total height from the bed of the river to the top of the parapet is 40 feet. It is constructed for a single line, and cost £13,410. Cost per lineal foot £20.

No. 13 is a good example of a *swing bridge* built across the *Caledonian Canal*, which the line spans on a skew of 65 degrees. It consists of 2 girders of 126 feet in length, 78 feet of which, from the centre of the turn-table, spans the canal, and the remaining 48 feet forms the balance weight. Advantage was taken of the canal being emptied for repairs to lay the foundations of the masonry, which are on a platform and piles in the solid gravel, 9 feet below the surface of the water. The depth of the canal is 18 feet, and the width of the locks 40 feet, the canal banks being 120 feet apart. Some difficulty occurred at first during hot weather from the expansion of the iron affecting the adjustment and closing of the bridge, which was remedied by means of a powerful screw, and the bridge has been worked with satisfaction and safety for the last five years. This bridge, with its machinery, timber, wharves for protection from vessels, distant and station signals, &c., complete, cost £4718.

No. 14 *spans the River Conon in Ross-shire*. From peculiar circumstances it was necessary that this bridge should cross the river on a skew of 45 degrees to the stream, and as there were rock foundations, there was no difficulty to contend with beyond that of 4 or 5 feet of water in the channel of the river to reach the rock, which was successfully accomplished. The peculiarity of the skew with the river at this place would have been more easily provided for by the adoption of iron girders from pier to pier, but as the writer found at that time that iron girders would be fully as expensive, and not so permanent as a stone bridge, and as there were admirable quarries in the neighbourhood, he resolved to construct this bridge, as already said, on a skew of 45 degrees with the river, by a series of right-angled ribs or arches spanning from pier to pier. This is no new arrangement; but the writer is not aware of the plan being adopted for a series of arches of so large a span in any previous instance. The bridge consists of 5 arches of 73 feet span each, the arches being constructed of four ribs, each 3 feet 9 inches wide; the arch-stones are 4 feet deep at the springing, and 3 feet deep at the crown. The keystones of the centre part of each arch were made to connect with each other, as were the stones in the haunchings of the arches, and some cramps of iron were inserted at the joints to connect the ribs. The work was successfully accomplished, and constitutes a very perfect piece of bridge masonry. The total length of the bridge is 540 feet, and the height 45 feet from the bed of the river. The north abutment is founded 304 feet lower down the river than the south, and the whole structure, when the centres were removed, was found so accurately built that no joint in it showed any indication of setting. The cost of this bridge for a single line was £11,391. Cost per lineal foot £21 2s.

There are many other bridges, as may be supposed, over so great an extent

of country, and a country so much exposed to floods, but those above described are the principal; the entire waterway spanned over the entire system being 9828 feet.

On the Central Railway from Dunkeld to Forres, 104 miles, being a single line, there are 8 viaducts, 126 bridges over streams, 119 public and accommodation road-bridges, and 8100 yards of covered drains, varying in size from 18 to 36 inches square. There are 1650 lineal yards of breastwalls, 304,700 cubic yards of rock cutting, and 3,416,000 cubic yards of earthwork, being, including rock and earth, at the rate of 35,776 cubic yards to the mile. The largest embankment was at Rafford near Forres, which contained 308,000 cubic yards.

The permanent way consists of larch and natural-grown Scotch fir sleepers of the usual size, 3 feet apart; the chairs are 22 lbs. in weight; the rails weigh 75 lbs. to the lineal yard, are in lengths of 24 feet, and are fished at the joints.

The total cost of the works, including all extra and accommodation works, amounted for the 104 miles, to £798,311; the land, including severance, to £70,000; and the preliminary, parliamentary, engineering, and law expenses to £50,893, making the cost of this portion of the Company's lines £919,204, or £8860 per mile*.

The contracts were entered into immediately after the passing of the Bill in July 1861; the first turf of the railway was cut on the 17th of October of the same year, and the whole line was passed by the Government Inspector, and opened for public traffic on the 9th of September 1863, being one year and ten months, an unprecedentedly short time for works of such magnitude. The works between Forres and Dunkeld were divided into nine contracts let by public competition, and were undertaken £15,705 below the Engineer's estimate, and were completed at 12 per cent. over the Engineer's estimate, including 4 per cent. for accommodation works ordered by land valuators.

The traffic has been worked successfully and without accident for four years. The mail trains perform the journey between Inverness and Perth (144 miles) in 5½ hours. It was proposed to the Post Office, but not agreed to, on account of the expense, to run them in four hours.

An ordinary goods train of 20 waggons, or 200 tons gross load, is drawn up the steepest inclines by one engine, having 17-inch cylinders and 24-inch stroke.

The traffic is rapidly increasing. The sheep and cattle, which used to reach the southern markets by a toilsome journey of a month or six weeks, are now conveniently transported in a day at less cost, the Company having carried in one week upwards of 21,000 sheep.

In passing over the mountain-ridges already described, it was feared that serious interruptions would arise from snow during the winter, but as the writer had a knowledge of the whole country for many years, he did not anticipate any difficulty on this head which might not be overcome. The summit is about 500 feet higher than that of the Caledonian line, or some 1500 feet in all above sea-level, and is no doubt more exposed. The first winter, viz. 1863-64, it was wholly open and the traffic uninterrupted; in February of the second winter, viz. 1865, a very heavy snow-storm occurred all over the north of Scotland, impeding the traffic of almost all the northern railways, and stopping the traffic on the Highland line for four or five days, which was only restored with great difficulty by the labour of large bodies of

* The extra work claimed by one Contractor is still unsettled, but is valued and paid at the rate at which the extra works on 169 miles of this system of railways have been amicably settled.

men. It was evident, therefore, that some decided steps must be adopted to overcome the snow difficulty, and in the beginning of 1866 the road was kept pretty well open by the application of snow-ploughs; and the experience of that winter made it quite clear that this difficulty might, with proper appliances, be effectually overcome, and means were accordingly adopted for that purpose.

In these elevated regions, when a snow-storm occurs, it is accompanied with high wind, and the snow is consequently drifted with great rapidity into the hollows and cuttings. With the view of obviating this, screen fences of light timber, or of decayed sleepers, on earthen mounds were erected a few yards from each side of the cuttings where the line was exposed. These were found very effective for intercepting the drifts. There was then provided snow ploughs of three descriptions, viz:—One, a light plough fixed to all the engines running on the line, and capable of clearing 12 to 24 inches of new snow. The second was a more formidable snow plough, which was fixed to a pilot engine, and was found capable of clearing 2 to 5 feet of snow. This pilot engine was attached to goods or passenger trains. The third, and largest class of plough was found to clear snow 10 or 11 feet deep, with the aid of four or five goods engines. These appliances, notwithstanding the very serious snow-storms which were encountered on the line in January last, were capable of keeping the line almost wholly clear.

This I consider a great triumph, inasmuch as the Highland line, over such high elevations, was kept clear, while, by the same storm, the lines throughout Scotland, England, and France were more or less blocked up; the lines in the north of Scotland being stopped entirely five or six days—the mails for Aberdeen being delayed three days from London, and two from Edinburgh. The Norfolk line was blocked up for some days; the Holyhead mail detained from 12 to 16 hours; the London, Chatham, and Dover blocked up for two days, as well as the trains in France to Marseilles.

Much credit is due to the activity and attention of the Highland Company's officers—Mr. Stroudley, the Locomotive Superintendent, and Mr. Buttle, Superintendent of Permanent Way—Mr. Stroudley having planned and constructed the snow-ploughs.

As a specimen of a cheaply constructed line of railway, the writer annexes a note of the details of the northern portion of the Highland Railway, from Invergordon to Bonar Bridge, 26½ miles in length. The country through which this section of the line passes is comparatively level, and several parts skirt and run through the sea, where the works had to be protected at considerable cost. The cuttings amounted to 549,000 cubic yards, of which about 20,000 were rock. There are 27 bridges over streams, 4 of them 40 to 50 feet span, 26 public and accommodation road-bridges, and 2942 lineal yards of drains, varying from 18 to 36 inches square. The rails are double-headed and weigh 70 lbs. to the yard, and are fished at the joints; ⅔ of the chairs are 20½ lbs., and ⅓ 28 lbs. in weight. There are ten stations, with permanent dwelling-houses for the agents and porters.

The total cost of this portion of the line, the works being of the very best quality, and the masonry all of stone, amounted to £5018 per mile, or including parliamentary and law expenses and land, £5888 per mile.

Commercially, these lines, extending over 246 miles, have not as yet been quite successful, from the fact of too great an extent of line having been undertaken at once, it requiring in an agricultural country considerable time to develope the traffic.

Under the whole circumstances, however, the traffic is satisfactory.

The works are of the most substantial character. The capital account,

which is under £2,800,000, is about closed as far as new works are concerned, while the revenue is rapidly increasing. For the half-year just ended, the Company will be able to pay its preference and debenture stocks, 5 per cent. on its floating liabilities, and about 2 per cent. on its ordinary stock of £740,000.

It will thus be seen that if the revenue increases in the same ratio that it has hitherto done, viz. from £15,000 to £20,000 per annum, the Company will be able to pay in two or three years a satisfactory dividend of 5 per cent. When that event occurs, the Directors may with propriety give some moderate aid to the further extension of the main lines of communication to Caithness and Skye, both of which must prove valuable feeders to the Highland system.

These lines were promoted chiefly by the great landed proprietors in the country, among the most prominent of which were the Earl of Seafield, Lord Fyfe, Mr. Matheson of Ardross, M.P., Mr. Merry of Belladrum, M.P., Mr. M'Intosh of Raigmore, Col. Fraser Tytler, the Duke of Sutherland, &c.

Experimental Researches on the Mechanical Properties of Steel. *By* W. FAIRBAIRN, *LL.D., F.R.S., &c.*

THERE is probably no description of material that has undergone greater changes in its manufacture than iron; and, judging from the attempts that are now making, and have been made, to improve its quality and to enlarge its sphere of application, we may reasonably conclude that it is destined to attain still greater advances in its chemical and mechanical properties. The earliest improvements in the process of the manufacture of iron may be attributed to Cort, who introduced the process of boiling and puddling in the reverberatory furnace, and those of more recent date to Bessemer, who first used a separate vessel for the reduction of the metals, and thus effected more important changes in the manufacture of iron and steel than had been introduced at any former period in metallurgic history. To the latter system we owe most of the improvements that have taken place; for by the comparatively new and interesting process of burning out the carbon in a separate vessel almost every description of steel and refined iron may be produced. The same results may be obtained by the puddling furnace,—but not to the same extent, since the artificial blast of the Bessemer principle acts with much greater force in depriving the metal of its carbon, and in reducing it to the state of refined iron. By this new process increased facilities are afforded for attaining new combinations by the introduction of measured quantities of carbon into the converting vessel, and this may be so regulated as to form steel or iron of the homogeneous state, of any known quality.

By the boiling and puddling processes, steel of similar combinations may be produced, but with less certainty as regards quality, as everything depends on the skill of the operator in closing the furnace at the precise moment of time. This precaution is necessary in order to retain the exact quantity of carbon in the mass so as to produce by combination the requisite quality of steel. It will be observed that in the Bessemer process this uncertainty does not exist, as the whole of the carbon is volatilized or burnt out in the first instance; and by pouring into the vessel a certain quantity of crude metal containing carbon, any percentage of that element may be obtained in combination with the iron, possessing qualities best adapted to the varied forms of construction to which the metal may be applied. Thus the Bessemer system is not only more perfect in itself, but admits of a greater degree of certainty in the results than could possibly be attained from the