November 25, 1862.

JOHN ROBINSON M'CLEAN, Vice-President,
in the Chair.

No. 1,058.—“The Hownes Gill Viaduct, on the Stockton and Darlington Railway.” By WILLIAM CUDWORTH, M. Inst. C.E.

THE Stockton and Darlington Railway has been no exception to the system of gradual extension, which appears to be so commonly the policy, or the necessity of railway management. Its length, at the time of its opening in 1825, was 25 miles. It has now spread out, by numerous ramifications, to 183 miles. The branch upon which the Hownes Gill Viaduct has been erected was formerly the western part of the Stanhope and Tyne Railway. After the dissolution of that Company the part referred to came into the hands of the Stockton and Darlington Railway Company, in the year 1844. On account of the mountainous character of the country traversed by this branch, which has a summit level of about 1,450 feet above the sea, the adoption of steep gradients, worked by stationary engines and ropes, though diversified with occasional intermediate lengths comparatively level, was unavoidable; but it was carried to a greater extent than would be consonant with modern ideas. Thus, Hownes Gill, a dry ravine 800 feet wide and 160 feet in depth, situated near the Consett Ironworks of the Derwent Iron Company, in the north-western part of the county of Durham, was crossed by a descent and ascent corresponding with the contour of the Gill; the gradient on the west side being 1 in $2\frac{1}{2}$, and that on the east side 1 in 3. A small traffic, conveyed in chaldron waggons, was for some years taken over these gradients with little difficulty, although encumbered with what subsequently proved to be a needless contrivance, for preserving the waggons in a horizontal position. This consisted of cradles, or carriages, one for each incline, having front and hind wheels of unequal diameter, upon which the waggons travelled side foremost. Only one waggon could be passed across in each run, and delay and expense were incurred, by each having during its transit to be turned upon four turntables. It was, however, arranged that both inclines should be in operation at once, by which means the gravitation of the descending waggon aided the engine in drawing up the ascending one.

Soon after the connection of this branch with the Stockton and

Darlington Railway, the increased traffic was objectionably retarded at the Gill, and greater facility of transit became imperative. This was obtained by the simple removal of the cradles and turntables, and by allowing the waggons to travel upon their own wheels, when three could be linked together in a train, and passed across in less time than was previously occupied by one. This alteration was satisfactory, and the Gill was worked well for a time; but a large accession of traffic, consequent upon the discovery of the Cleveland ironstone, and its purchase by the Derwent Iron Company, at length demanded further accommodation. The trains were necessarily limited to three waggons, to avoid putting undue strain upon the couplings, and various methods of obviating this restriction were considered; but nothing less than the erection of a high level viaduct seemed to offer a satisfactory solution. The idea of a viaduct had been a favourite one with the Directors of the Stockton and Darlington Railway Company from the first; but for some years the traffic was insufficient to warrant the necessary outlay. As early as the year 1844, with the view of ascertaining the probable cost, the Directors issued advertisements offering premiums for the two best designs of viaducts, to be accompanied with estimates of cost. This met with a ready response, but the estimates attached to the premium drawings exceeded £17,000. When, in 1853, the subject became more pressing, the remembrance of the premium experiment was sufficiently encouraging to induce the Directors to repeat it. Upon this occasion their attention, and that of their engineer-in-chief, Mr. John Dixon (M. Inst. C.E.), was attracted by a design sent in by Mr. John Anderson, then of Edinburgh, now of Middlesbro'-on-Tees, contractor, and prepared by Mr. Thomas Bouch (M. Inst. C.E.), as it was accompanied by a tender to erect the viaduct, and to uphold it for twelve months after completion, for the sum of £11,697 if built of common brick, or of £13,237 if built of fire-brick. The design represented twelve arches each of 50 feet span. Although the ability of Mr. Anderson was well known to the Directors, and although they had also great confidence in Mr. Bouch, it was thought desirable to consult the late Mr. Robert Stephenson, M.P., as to the sufficiency of the design. In the interview which Mr. Dixon had with Mr. Stephenson, when Mr. G. P. Bidder (Past-President Inst. C.E.) was present and gave his advice, a general approval of the plan was expressed, with some limitations and recommendations, as the proportions of the viaduct were considered to be such as to leave no margin for inferior material, or workmanship.

Nearly three years elapsed before further action took place. At length, in 1856, Mr. Anderson's offer was accepted, to erect the viaduct in fire-brick, set in hydraulic mortar, the arches to be in

cement, for the sum of £14,100. As the premium drawing, with the modifications suggested by Mr. Stephenson and Mr. Bidder, was the basis of this contract, the sum required to be readjusted, when the circumstances of the foundation, site, &c., had been considered. In December, 1856, a revised contract was entered into, referring to a duly matured working drawing and specification. Mr. Anderson then undertook to erect the viaduct in eighteen months, and to uphold it for twelve months after completion, for the sum of £14,614. To avoid interfering with the traffic over the inclined planes, a deviation of the line was an obvious necessity. The piers in the slopes of the Gill found a firm foundation on the shales and stone of the coal measures. The only difficulty was the occurrence of abandoned iron-stone drifts, the entrances to which were concealed by a thick cover of débris. A careful probing of the doubtful foundations, with boring-rods, was therefore resorted to. Some of the drifts were entered and explored, and eventually both the abutments were sunk through the strata in which the mines occurred. In the bottom of the Gill there was a thick bed of heterogeneous material, consisting of the débris of the slopes, into which a bore-hole was put down for 30 feet, without indicating a change of stratum. Although this bed was by no means of a soft nature, it was not deemed firm enough to sustain the great weight of the structure with ordinary foundations. At the suggestion of Mr. Stephenson, the bases of the three central piers were extended, by the application of inverts, until the weight scarcely exceeded 1 ton per superficial foot. The choice of fire-brick, in preference to common brick, was made with the view of having the best material, the common bricks of the neighbourhood being inferior both in strength and regularity of shape. Large quantities of fire-bricks are made at the collieries in the district, for the linings of the coke ovens and of the iron furnaces of Cleveland.

The extreme length of the viaduct (Plate 1) is 730 feet, and its greatest height, from the bottom of the inverts to the level of the railway, is 162 feet, or from the surface of the ground about 150 feet. There are twelve semicircular brick arches, each 50 feet span, 14 feet in length, and 2 feet 6 inches in thickness, set in Portland cement. The inverted arches in the foundations, four in number, have a versed sine of about 14 feet, and are 38 feet in length, and 3 feet in thickness. The brickwork in these, as well as in the piers, and in the whole of the viaduct, with the exception of the arches, was set in hydraulic mortar. The height of the five loftiest piers, measured from the springing of the inverts to the springing of the arches, ranges from 114 feet to 110 feet; that of the six remaining piers diminishes rapidly towards each end. Their length is 14 feet at the top, and 38 feet at the bottom, in the case

of the high ones, the latter dimension corresponding with that of the inverts. The piers down to within about 15 feet of the inverts are stayed with buttresses, which are transverse to the line of the viaduct. At this point they are only 17 feet 6 inches in length, but below this level the buttresses merge into the piers, when they together present a rectangular horizontal section 38 feet in length. The buttresses are 3 feet thick at the top and 5 feet thick at the bottom; their projection from the piers being increased by offsets at intervals of about 35 feet. The piers, although light in their proportions, are reduced by recesses 7 feet 3 inches wide, and averaging 3 feet 9 inches deep, in each side, so that the horizontal section of the pier and buttresses is in the form of a double cross, the brickwork left in the middle being only 2 feet thick. These recesses are not continuous throughout the pier, but are divided into three compartments, the solid parts between affording facility for the introduction of two bond courses of stone, the continuation of which through the buttresses forms a finish and protection to the offsets. The amount of brickwork abstracted from one pier by the adoption of the recesses is 142 cubic yards, or about $14\frac{1}{2}$ per cent. of the contents of a solid pier without recesses.

Between the spandril walls, which are of brick 3 feet thick, two internal parallel walls of stone 2 feet thick were introduced, to sustain a platform of flagging 6 inches thick, upon which the 'way-beams' and ballast are carried. The arches between these walls are kept dry by a layer of puddled clay, which conveys the water to discharging-pipes over the piers in the usual manner. The way-beams are of Memel fir, 12 inches by 12 inches. They were at first fixed to the flagging with bolts secured to the internal walls; but it was soon found that there was an objectionable rigidity in the permanent way, indicated by the working of the ballast and the occasional fracture of a joint chair, and accompanied by an unpleasant amount of vibration. These evils were remedied by simply removing the nuts from the locking-down bolts, lifting the way-beams 6 inches, and interposing that thickness of the common coke ballast of the district, between the way-beams and the flagging. The external walls were covered with a simple projecting string course, 3 feet 6 inches by 1 foot 9 inches, and upon this was fixed a substantial cast-iron railing, forming the parapet. The choice of iron was more than a mere question of taste, it effected a considerable saving of brickwork; for if a brick or a stone parapet had been adopted, the upper part of the viaduct, including the arches, must have been about 16 feet wide, instead of 14 feet.

The fire-bricks, which were of excellent quality, were obtained chiefly from Pease's West Fire-brick Works, near Crook, about 14 miles from the viaduct, but having railway communication with

it. They were $9\frac{3}{4}$ inches by $4\frac{3}{4}$ inches by 3 inches in size, weighed 9 lbs. 11 oz. each, and cost the contractor 26s. 6d. per thousand at the works, which the railway dues increased to 31s. 2d. per thousand at the viaduct. The number used was 2,655,000. The greatest care was taken to insure the adhesion of the mortar and the solidity of the work, the bricks being freed from dust, well wetted, and set with a mallet. The internal work was as good and solid as the external portion; and in the arches, which were constructed in half-brick rings, whenever the coincidence of two courses admitted of it, radiating bond bricks, moulded for the purpose, were introduced. It is gratifying to be able to state, that not a single crack can be discovered in the whole of the structure.

The scaffolding used in the erection of the viaduct was of a very light character (Plate I.). It proved, however, to be sufficiently strong, and the work was completed without accident. The erection of the scaffolding was considerably facilitated by the hoisting tackle being made to traverse a stout wire rope stretched across the Gill, and firmly fixed at each side to the roots of trees. When the arches were about to be turned, the piers were stayed with two parallel wire ropes, $1\frac{1}{4}$ inch in diameter, stretched from end to end of the viaduct, and firmly fixed to the abutments and large springing stones of the arches. The first brick was laid on the 24th of February, 1857, and the first train passed over the viaduct on the 1st of July, 1858. The cost of the structure, which was increased by the additional depth of the foundations, a much heavier parapet than was originally specified, and other contingencies, amounted to £15,756. This may be analysed as follows, the prices affixed being those given in the contractor's schedule:—

			£.	s.	d.
Excavation	7,254 cubic yards, at	1s. 9d. .	634	14	6
Brickwork in inverts	999 "	20s. .	999	0	0
Brickwork in piers, spandrels, &c. .	6,796 "	19s. .	6,456	4	0
Brickwork in arches, set in cement.	1,371 "	22s. .	1,508	2	0
Ashlar masonry in foundations . .	4,558 cubic feet, at	1s. 6d. .	341	17	0
Ashlar masonry in piers	30,977 "	1s. 9d. .	2,710	9	9
Broken stone in foundation of west abutment	96 cubic yards, at	5s. .	24	0	0
Rubble masonry in backing of arches and internal longitudinal walls .	1,083 "	9s. 6d. .	514	8	6
Flagging, 6 inches thick	795 square yards, at	6s. .	238	10	0
Cast-iron parapet railing			688	10	9
Scaffolding, centres, and contractor's contingencies			1,581	0	4
Examining foundations, draining, etc			59	3	2
Total			£15,756	0	0

Regarding the viaduct as an unpierced solid, its contents would amount to 61,910 cubic yards, and its cost would be 5s. 1d. per cubic yard.

The question of the relative cost of brick and iron viaducts having engaged the attention of the Author, he will proceed to state the result of his inquiry. In his capacity of Engineer to the Stockton and Darlington Railway Company, he has under his care, besides the Hownes Gill brick structure, two iron viaducts, recently erected by Mr. Bouch, on the South Durham and Lancashire Union Railway.

These iron viaducts consist of three lines of trellis girders, resting upon skeleton piers, each of which consists of six cast-iron columns 12 inches in diameter, jointed at intervals of 15 feet, and braced together by horizontal cast-iron struts, and by vertical and horizontal diagonal tie-bars of wrought iron. The clear spans between the piers are in all cases 48 feet.¹

The Beelah viaduct is 1,000 feet in length and 197 feet in extreme height. The Deepdale viaduct is not so large, and more nearly resembles the Hownes Gill in its proportions, being 740 feet in length, and about 160 feet in extreme height. If applied to the Hownes Gill valley, it would only need the removal of one tier of columns in three of the piers to adapt it to that site. The cost of the Deepdale viaduct being £20,266, and that of the Hownes Gill viaduct £15,756, the first impression would be in favour of the brick structure. But further investigation would considerably modify this conclusion. The brick viaduct has only width for a single line of railway; the iron one was constructed to carry two lines. Considerable expense has been incurred upon the foundations of both structures, but in dissimilar ways; and it would be mere hasty assumption to treat the outlay upon one as a fair offset to that upon the other. It was thought that the best way of making a comparison would be by calculating, from the data already obtained, what would be the cost of the Hownes Gill viaduct if it were widened 11 feet, so as to carry a double line of railway, and then by computing what would be the cost of an iron structure, like the Deepdale, if erected across Hownes Gill, omitting the inverts in the former case, and adjusting the spread of the bases of both viaducts, so as to sustain a weight of $2\frac{1}{2}$ tons per superficial foot, including the greatest moving load. The prices of the brickwork and of the masonry in both erections were taken from Mr. Anderson's schedule; those of the timber and ironwork were the prices actually paid to Messrs. Gilkes, Wilson, and Co., of Middlesbro', the contractors for the South Durham and Lancashire viaducts, minus a deduction of 10s. per ton, the cost of cartage over country roads, which was not incurred upon the material for Hownes Gill. With this adjustment, the price of

¹ A description of these viaducts, with drawings, is published in Mr. Humber's work on "Iron Bridge Construction." 2 vols. 4to. London, 1861.
[1862-63. N.S.]

the cast-iron work was £9 2s. 6d. per ton, that of the wrought-iron work £22 7s. 6d. per ton, and that of the timber 2s. 0½d. per cubic foot, including erection and 32 miles of railway carriage. It was found that the cost of the viaducts calculated in this way, the details of which are given in the Appendix, would be £20,681 for the brick structure, and £16,249 for the iron one, giving a difference of £4,432 in favour of the latter. It is probable, however, that the interest on this sum, say £222 per annum, would be absorbed in the periodical examination and painting of the iron structure, and the depreciation of its perishable timber platform; and it may be assumed, that at the place referred to, a brick viaduct would be, ultimately at least, as cheap as an iron one. If the comparison were made between viaducts designed to carry a single line of railway, it is believed that the balance would be more evidently in favour of a brick one. Although the Author strongly prefers brick or stone, he by no means regards iron viaducts as ineligible under all circumstances. The Beelah and the Deepdale viaducts have stood remarkably well, no loosening of the bolts or cotters from vibration having been observed, while their steadiness during the passage of the trains is such as to inspire confidence. Much of this firmness is to be attributed to the excellent workmanship and the perfect fitting of the parts, for which great credit is due to the enterprising contractors.

The material to be used in the construction of any viaduct must depend upon local and other considerations, among which the absence of expensive carriage, and the facility afforded for expeditious erection, are not the least important. In situations which do not yield suitable building materials, and where there are no cheap means of conveyance, as by railway or by water, from a distance, the small relative mass of an iron viaduct would be a strong argument in its favour; for the whole weight of such a structure, including its foundations of masonry, would be less than one-fifth of that of a brick one. This might also lead to the selection of iron in cases of doubtful foundations. If, in the viaducts which have been compared, the material of every description had to be conveyed 20 miles at a cost of say 9d. per ton per mile, there would be an increase of cost of £17,719 or 85 per cent., entailed upon the brick structure, but of only £3,464, or 21 per cent., upon the iron one. The possible absence of scaffolding is also worth something, for the Deepdale and the Beelah viaducts were erected in a masterly way without its aid, and with such expedition in the case of the latter, that after the masonry foundations were laid, the fifteen iron piers with their girders were erected in less than five months. The South Durham and Lancashire Railway passes through a mountainous country, where stone is the only building material. Structures in masonry are

notoriously slow of execution, and there is no doubt, that if this kind of work had been adopted in the Deepdale and the Beelah viaducts, the completion of the line would have been retarded two or three years. It was important, too, that the Deepdale viaduct should be completed long before the opening of the line, as nearly 200,000 cubic yards of earth had to be removed from a cutting to form an embankment on the opposite side of the valley. Under these circumstances it is submitted that Mr. Bouch exercised sound judgment in selecting iron as the material for these viaducts.

The Paper is accompanied by two drawings from which Plate 1 has been compiled.

APPENDIX.

ESTIMATE of the COST of a BRICK VIADUCT, for TWO LINES of WAY over HOWNES GILL, without INVERTS.

		£	s.	d.	£	s.	d.
Excavation	10,068 cubic yards at	0	1	9	880	19	0
Brickwork in piers	9,730 „ „	0	19	0	9,243	10	0
Ditto in arches	2,388 „ „	1	2	0	2,626	16	0
Ashlar in footings	18,366 cubic feet „	0	1	6	1,375	4	0
Ditto in piers	36,052 „ „	0	1	9	3,154	11	0
Rubble in internal longitudinal walls, &c.	1,971 cubic yards „	0	9	6	936	4	6
Flagging to carry roadway .	1,615 square yards „	0	6	0	484	10	0
Iron railing	477½ yards „	1	8	10	688	17	11
Bolts	1,730 lbs. „	0	0	4½	32	8	9
Scaffolding	„ „	..	..	..	1,200	0	0
Draining foundations, &c. .	„ „	..	..	..	58	0	0
				<hr/>			
				£20,681 1 2			

ESTIMATE of the COST of an IRON VIADUCT over HOWNES GILL, similar in design to that at DEEPPDALE.

		£	s.	d.	£	s.	d.
Excavation	6,160 cubic yards at	0	1	9	539	0	0
Ashlar in footings	21,523 cubic feet „	0	1	6	1,614	4	6
Ditto in string course of abutments, &c.	1,186 „ „	0	1	9	103	15	6
Rubble in retaining walls to protect metal columns . .	199 cubic yards „	0	9	6	94	10	6
Brickwork in abutments . .	1,317 „ „	0	19	0	1,251	2	0
Cast iron	603·1 tons „	9	2	6	5,503	5	9
Wrought iron	275·75 „ „	22	7	6	6,169	18	1
Brass slides and moveable bearings	2cwt. 2qr. 12lbs. „	0	2	0	29	4	0
Wrought-iron stays, bolts and nuts for handrailing . .	„ „	..	..	..	17	9	1
Timber in transverse beams and planking	8,891 cubic feet „	0	2	1	926	2	11
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				£16,248 12 4			

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PLAN
Scale 36 Feet to an Inch

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CROSS SECTION OF
CENTRE PIER.

W. CUDWORTH H. DELT

KELL BROS LITHO CASTLE ST HOLBORN.