the mine to the canal in its way to Par Harbor, is 1127 feet long, and 80 feet in perpendicular height. We must needs defer until our next, further observations on this mine and the district.

Ibid.

Remarks on the Theory of Arches, made before the Institution of Civil Engineers, London. By GEORGE RENNIE, Esq.

Mr. Rennie concurred in the accuracy of the description of the Wellington Bridge; it presented an excellent example of theory and practice, not only on account of its strict conformity with the principles of equilibrium, but from the correctness with which the works had been executed, as was evinced by the small subsidence of the arch after the centres were struck. Respecting the theory of the arch, writers were nearly agreed upon the principle established by De la Hire, upon the equilibrium of a loaded chain, or of a series of voussoirs, or wedges, with polished touching surfaces, as shown in his "*Traité de Mécanique*," in 1695.* The subject had been variously demonstrated by writers, but with little effect; architects were forced to select examples at random, for which no precise rules existed; but any persons on examining the actual state of an equilibrated arch of solid materials, or of a substantial chain suspended at its extremities by points, would immediately perceive the difference in the curves, or loads, on the extrados, arising from the want of sensibility in the arch, or, in other words, from friction and adhesion. Hitherto theory had been unable to comprehend these retarding forces, which had actually been so serviceable to the architect. Perronnet was, perhaps, the first to throw any real light upon the subject; the experiments that he undertook, on the absolute strength of materials, in the year 1758, previously to the commencement of the celebrated bridge of Neuilly,† and, subsequently, those by Gauthey, on the failure of the piers of the church of St. Geneviève,‡ at Paris, were very instrumental in the advancement of the art. It was, however, chiefly owing to the good quality of the material, that Perronnet was enabled to surmount the difficulties which arose from the unusual subsidence of the arches in the bridge of Neuilly. The splaying of the arches, by which a double curvature was given to them, and which had been injudiciously copied in this country, was neither justified by science nor practice. The results of the French experiments were much too slow in reaching this country, and the strength of building materials was but little attended to, until within a recent period.

In the year 1824, the late Dr. Thomas Young, having engaged to contribute the article "Bridge," to the Supplement of the sixth edition of the "*Encyclopædia Britannica*," applied to Mr. Rennie, to furnish the particulars of the Waterloo and Southwark bridges, then just completed; when, finding the data insufficient, Mr. Rennie undertook

* "*Traité de Mécanique*." De la Hire. 12mo.: Paris, 1696.

† "*Description des projets et de la construction des Pons de Neuilly, de Nantes, d'Orléans &c.*" Perronnet. 4to.: Paris, 1778.

‡ "*Construction des Pons*." Gauthey. 4to: Paris, 1809.

a series of experiments on the absolute and relative strength of materials, part of which he communicated to Dr. Young, and he, subsequently, published the whole in the Philosophical Transactions for 1818.* The results were then applied to the calculations, on the lateral thrust of the arches of those bridges, perhaps for the first time in this country, and which were more amply applied afterwards to bridges in general, by Mr. Ware, and his tables of the relative boldness of brick, stone, and iron bridges, were valuable accessions to our knowledge on this subject.† As regarded the friction of arches, Mr. Rennie found that the arch stones of Waterloo and New London bridges commenced gliding, or pressing, upon the centres, at angles of from 33° to 34° ; he believed that soon after the adhesion of the mortar commenced, the centres would have very little pressure on them, even from stones at an angle of 45° . As to the gliding of the arch stones at the haunches, from the pressure of the upper voussoirs, he had never seen an instance of it; but he had seen the haunches so much eased from the centres, by the lateral action exerted in driving the stones into the vertex of the arch, as to allow the lagging, or cross bearers above the ribs, to be taken out. This proved the correctness of the rotative system of voussoirs, as shown by experiment. With respect to adhesion, Mr. Rennie had seen its effect on broken arches of considerable magnitude, among the buildings of Rome, and also in the bridge of Alcantara, over the Tagus, where the centre arch, of nearly 100 feet span, had been blown up by the French, leaving the adjoining arches and piers, which were upwards of 90 feet in height, standing perfectly undisturbed. With respect to the magnitude of arches, M. Perronnet expressed himself confident that arches of 500 feet span could be safely executed. The bridge which he proposed to construct, over a branch of the Seine, at Melun, consisted of a segment of a circle of 400 feet. The experience he had derived from the length of the primitive radii of the arches of the bridge of Neuilly, and his experiments on the strength of materials, would appear to justify so bold an experiment.

Mr. Rennie was of opinion, that with our strong magnesian limestones and hard granites, arches of larger span than any hitherto built, might be safely constructed. There were numerous examples, both in ancient and modern times, of very large arches. The bridge of Narni, in Italy, of Vielle Brioude, in France,‡ and of Alcantara, in

* Vide "Philosophical Transactions," 1818, p. 118.

† Vine "A treatise on Arches, and their abutment piers," by Samuel Ware. 8vo: London, 1809.

‡ The following dimensions of the Pont de Brioude, are given in a letter from M. Seguin to Mr. Rennie, dated Feb. 27, 1827:—"The ancient bridge was constructed by the Romans, for the use of foot passengers, pack mules, and small carts drawn by oxen.

	Metres.		English feet.
Length of the arch,	56	=	183.730
Breadth "	5	=	16.005
Height "	18 to 19	=	59.058 to 61.339

"The arch was a segment of a circle, formed of volcanic stone, of little consistence. The bridge gave way in the course of time, but was upheld for fifteen years, by means of buttress walls, 6 metres (= 21.68 English feet,) in thickness, and 10 metres, (= 32.8 English feet,) in height; and also by bars of iron, fixed in the wing wall, and through several courses of the

Spain, by the ancients; and those of Gignac, and of Castel Vecchio, by the middle ages; but the most remarkable example of cylindrical vaulting, (the remains of which still existed) was the bridge of Trezzo, over the Adda, in the Milanese.* The span was 251 feet over the chord, and 266 feet over the semi-circle. The stone beams in the church of the Jesuits, at Nismes, and those between the towers of Lincoln Cathedral, the former equal to the segment of an arch of 565 feet span, and the latter to one of 262 feet span, proved how much could be done with materials of small dimensions.† In modern times there were examples of bold vaulting in France, in the bridges of Neuilly, Mantes, St. Maixence, and Jena; in Italy, in the Ponte Sta. Trinita, Turin; in England and Wales, in the bridges of Llanrwst, of Pont-y-tu-Prydd, of Gloucester, of Chester, and those of London and Waterloo, over the Thames; independently of numerous arches and viaducts, more recently erected for the use of railways. The radii of curvature of the centre arch of New London bridge, taken near the vertex, would equal, in boldness, an arch of 333 feet; and the length of the key-stone, at 4 feet 9 inches, would make the depth only $\frac{1}{70}$ th of the whole span.

The origin of the arch had occasioned much controversy. The subject had been learnedly investigated by Duteus, Le Roy, King, and others, but, apparently, to little purpose, as the invention of the arch would now appear to be, with more justice, attributed to the Egyptians, as they seemed to have used it many centuries before the Christian era. The researches of modern travelers, particularly those of Sir Gardiner Wilkinson,‡ proved that the brick arch was known in Egypt in the reign of Amenoiph I, 1540 years B.C., and the stone arch in the time of Psamaticus II, 600 years B.C. "The most remarkable," says Sir Gardiner Wilkinson, "are the door-ways surrounding the tanks of Assassief, which are composed of two, or more, concentric semi-circles of brick, as well constructed as at the present day, and all the bricks radiate to a common centre." Mr. Hoskins was of opinion, that arches were constructed long anterior to the time of the Ptolemies; for in the pyramids of Ghebel Birkel and Dunkalie, which were of more ancient date, both round and pointed stone arches were discovered. Mr. Perring stated that he found at Thebes, some remarkably well formed arches of 12 to 14 feet span, built in concentric half brick rings, the bricks of which were marked with the name of Sesostris; consequently they were upwards of 3180 years old.¶ A

arch-stones. The structure finally fell, and a new stone bridge has been erected upon the same site, of which the following are the dimensions:—

	English feet.
Opening of the arch, which is a semi-circle,	150.9
Breadth of " "	24.7
Height from the stream to the pavement,	83.7

* A section of this arch is shown in Part I, of the "Theory, practice, and architecture of Bridges." Hann and Hosking. 8vo: Weale. London, 1839.

† Robinson, in his "Travels in Palestine," mentions the remains of an arch over the valley of Kedron, at Jerusalem, supposed to have been 350 feet span.

‡ "Manners and Customs of the Ancient Egyptians." Wilkinson. 3 vols., 8vo: London, 1837.

¶ Vide Minutes of Proceedings, Inst. C. E., for 1843, p. 170.

representation of the tomb of Saqqura, and its arched vault of stone, was given in the vignette of the tenth chapter of the third volume of Sir Gardiner Wilkinson's "Manners and Customs of the Ancient Egyptians." The arch seemed to have been known to the Etruscans; and from the representations of their palaces, and their sea-ports, the arch appeared generally to have been employed for moles and jetties. With reference to the knowledge of the arch among the Greeks, opinions were very contradictory. The researches of modern travelers had brought to light many curious remains of Cyclopean, or Pelasgic, architecture; but in confirming the descriptions of the ancient cities of Mycenæ and Orchomenos, they had left us still in ignorance as to their actual knowledge of the arch.

Mr. Rennie exhibited a series of lithographic prints, from drawings made by the late Mr. Dodwell, during his travels in Greece. They displayed the various door-ways of Pelasgic fortifications, from the lintel of single stones resting on upright jambs, to the overlapping of the stones until they reached each other, in the form of a triangle, as in the gate of the lions, the entrance into the treasury of Atræus, &c. But the most remarkable monument was the subterranean chamber, of which Mr. Dodwell's lithographic plate gave an imperfect idea; complete plans and sections of that extraordinary building were given by Mr. Donaldson, in the supplement to the "Antiquities of Athens,"* from which it appeared to have been constructed in the form of a parabolic cone of 48 feet in diameter at the base, and 44 feet 6 inches in height, by means of rings of regular masonry, overlapping each other until they reached the apex, where the aperture was closed by a flat stone. From this, and other buildings of a similar kind, there was reason to infer that the ancient Greeks had very imperfect notions of the arch. Mr. Kinnaird, in his "Description of the Antiquities of Delos,"† gave a representation of a portal, or gateway, on the ascent of Mount Cynthus, formed to support the wall of the ancient fortifications. The entrance was constructed with ten large stones inclined to each other, like those at the aperture into the great Egyptian pyramid. It was, perhaps, the earliest specimen of Pelasgic architecture in Greece, displaying the first step towards the principle of the arch. That it was known by the Etruscans, seemed evident, from the remains of arches and bridges, now existing in the country of the Volsci in Italy; and the researches of travelers in that country, within the last few years, had brought to light many curious examples, anterior to the period of the Cloacæ of Rome, and the tunnel of Albano, by Ancus Martius. Mr. Rennie was of opinion, from his examination of the subject, that there existed no sufficient evidence to establish the knowledge, or use, of the arch among the Greeks.

Mr. Page presented two sketches made by him of two arches at Cape Crio, (Cnidus, Rhodes.) These arches were semi-circular, built of large stones regularly radiating from a centre, without any mortar in the joints, and stood among Cyclopæan remains, of which they apparently formed a part. He was of opinion, that the Greeks were

* "Antiquities of Athens," &c. Stewart and Revett. Supplement. Folio. London, 1830.

† "Antiquities of Athens," &c. Stewart and Revett. Supplement. Folio. London, 1830.

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aware of the properties of the arch. They evidently appreciated its form, for it must have been noticed by all travelers, how frequently the flat lintels were cut out on the under side; several specimens of this existed in the sepulchral remains now in the British Museum. At Athens, he had noticed a very considerable excavation of a regular arch form through solid marble.

Mr. Rennie observed, that as more useful lessons were given by failures in construction, than by records of successful undertakings, he had caused a large drawing to be made of the bridge of Boverie, at Liège, showing its state at the time of the report upon it, by the commissioners appointed by the Belgian government, when it was condemned, and was ordered to be reconstructed, at the cost of the contractor, which, however, had not yet been done. The bridge, which was built of hard, compact, magnesian limestone, consisted of five arches of 78 feet span each, with a versed sine of 8 feet, which was between $\frac{1}{9}$ th and $\frac{1}{10}$ th of the span. The form of the arch was that of a segment of a circle of 100 feet radius, the angle of the springing was, therefore, $46^{\circ} 45'$. The abutments at either extremity were of rubble masonry, and were very deficient in weight and dimensions. The obvious consequence of this want of due proportion was, that the abutments gave way, all the arches sunk at their centres, many of the stones nearly falling out, several of them were fractured in both directions, serious dislocations occurred in each pier above the springings of the arches, and also down upon the cutwaters, and, in spite of all attempts to remedy the defects, the bridge was condemned, and was taken down, although it had cost upwards of £25,000. It was evident that these flat arches were not well proportioned, and that the abutments were insufficient to support their thrust. It appeared also, from the report of the commission, (of which he presented an abstract, No. 672,) that sufficient attention had not been paid to the quality of the workmanship, or in the selection of the materials employed.

Civ. Eng. and Ar. Journ.

On the Reduction of Inclined to Horizontal Angles. By Lieut. A. G. EDYE, R.N.

The accompanying simple diagram having suggested itself to me, for the speedy reduction of the inclined angle between the sun and an object, to the horizontal angle, I take the liberty of forwarding it to you, with an example of its application to practice, for insertion in your useful Magazine.

The principles of this diagram are lines of cosines, drawn on a semi-circle, and which I call cosines of distance. To the centre of this semi-circle is attached a movable radius, which is also divided into cosines, called cosines of altitude. The following example will show its use: Suppose the true angular distance between the sun's centre, and the object, to be $45^{\circ} 0'$, and the sun's corrected altitude $20^{\circ} 0'$.

To the *cosine of distance* 45° on the semi-circle, bring the *cosine of*

altitude 20° on the movable radius, and you will find that the extremity of the movable radius on the arc will be found at $41^\circ 12'$, within a few minutes, for the reduced angle; if the lines of cosines on the semi-circle and radius are correctly drawn, and their scale sufficiently large, the reading off will be the same as if the operation were performed by logarithms.

The diagram I send you is of small radius, for convenience of insertion, and only divided at every 5° , but for practical use the larger the scale on which it is constructed, the greater will be the accuracy of reading off; every degree and quarter degree, at least, should be drawn in lines of cosines.

A diagram carefully drawn on card board of eighteen inches radius would be found to approach pretty near the truth; but, of course, greater accuracy would be obtained if it were made on a metal plate.

The usual method of reducing Sun's Hor. $\angle$ is as follows:—

Take, for example, Cor. Dist. Sun, and object 45° , Alt. Sun. 20° .

Dist. $45^\circ 0'$	 Cosine	9.849485
Alt. $20^\circ 0'$	 Secant	0.027014

Red. Hor. $\angle \odot 41^\circ 12'$	9.876499 cosine.
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The principle on which the diagram is constructed, being lines of Cosines,

Dist. $45^\circ 0'$	 Cosine	9.849485 + 10 to index.
Alt. $20^\circ 0'$	 Cosine	9.272986

Red. Hor. $\angle \odot 41^\circ 12'$	9.876499 cosine.
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In the application of this angle to the sun's true bearing, (supposed to be already found) + or—according as the object is to the right, or left, of the sun's centre, it would, in strictness, require a further reduction for the convergency of meridian, but, in practice, under ordinary circumstances, this might be dispensed with, the quantity of correction being but small.—[We commend the foregoing to the attention of nautical surveyors.]

Naut. Magazine.