REPORT

RELATIVE TO A

DESIGN FOR A CHAIN BRIDGE,

PROPOSED TO BE THROWN OVER THE

Frith of Forth at Queensferry,

IN ORDER TO

CONNECT THE COUNTIES SITUATE ON THE FORTH,

AND TO

FACILITATE THE COMMUNICATION BETWEEN THE SOUTHERN AND NORTHERN DIVISIONS OF SCOTLAND.

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REPORT of James Anderson, Civil Engineer and Land Surveyor, Edinburgh, relative to a Design for a Bridge of Chains proposed to be thrown over the Frith of Forth at Queensferry, in order to connect the Counties situate on the Forth, and to facilitate the communication between the Southern and Northern Divisions of Scotland.

The importance and value of a country are generally estimated according to the state of its internal improvements. The progress of the arts and sciences in this country, and the degrees by which they have attained to their present comparative state of perfection, is a subject which justly attracts the inquiries of the learned and ingenious, and which has strong claims on public attention.

Where learning and genius abound, improvement in the arts generally follows. But this does not invariably take place: In some countries, particularly China, where learning is considered to be in a very low state,—a country not to be compared with Britain, either in point of civilization, or scientific attainments,—works of art have been executed, of a magnitude which astonishes the inhabitants of more civilized nations. We have credible accounts from various travellers, of Bridges of

Stone thrown over large Rivers and arms of the Sea, several thousand Feet in extent; and particularly one in the province of Xenzie, called Cientao, or the Road of Pillars, composed of stone and wood, of the enormous length of upwards of three Miles. It unites the summits of several mountains, was erected to avoid the numerous windings to the capital, is partly supported by Beams, but in most places, from the great depth of the vallies, rests on stone Pillars of tremendous height. Another Bridge, constructed of Chains, in the neighbourhood of King-tung, is described by Duhaldé, as connecting the tops of two mountains, and thrown over a frightful valley of 750 Feet in height, through which the River Laffreny has its course.

It is a well known fact, that Chain Bridges have long before now been erected, and with considerable success, over very large spaces. There is one mentioned by Major Rennell, in Hindostan, 600 Feet in length, over the Sampoo River. And in a late American publication, where several are described, there is one about 250 Feet in length, over the River Merimack, along which carriages of all descriptions pass readily, without any perceptible motion in the Roadway.

In our own country, which possesses every requisite for such undertakings, much yet remains to be done; and this is the more remarkable, as, whether we consider Bridges with regard to their numerous advantages and public utility, or their magnificence and expence, there are no operations of art in which the generality of its inhabitants are more deeply interested.

The Reporter has lately heard of a Design for a Bridge of Chains, by suspension, intended for the River Mersey, at Runcorn, near Warrington, by that eminent Engineer, Mr. Telford, and which is understood to be 1200 Feet span. From the known character and abilities of that gentleman, we may rest assured that he would never offer to the Public a Projection, which he did not consider in all its parts as insuring complete practicability, and this can alone be founded on the Experiments he has made.

But it is needless for the Reporter to specify the many instances and Designs of extensive Bridges that are in existence, or notice the construction of them; neither is it necessary to state the numerous advantages derived from them: as there are few individuals in this country, and none who will peruse his work, who do not know something of their general formation and usefulness. He will proceed, therefore, without farther comment, to enter on the merits of the subject of his present Report.

In taking a general view of the Frith of Forth, the attention is arrested by the striking appearance which it assumes at Queensferry. There the River is contracted, by the projecting promontory on the north shore, to the breadth of 5830 Feet, or 550 Feet more than a Mile, at high water, the breadth both above and below the strait being from three to five Miles. The singularity of this strait is greatly heightened by the situation of the Island of Garvie, which lies nearly one third of the breadth of the River from the north shore. The appearance and situation are altogether so favourable, and so inviting for some work of art, that it has often occurred to the Reporter, when he considered them attentively, that a Bridge of some description ought to be attempted. The idea seems also to have struck others: and indeed some years ago a Tunnel was proposed; but the porosity of the strata, and the great depth of the River, in a certain degree preclude the possibility of this latter scheme. About the same time, some hints were thrown out that a Bridge might be projected over the Frith at this point; but these hints were vague and unscientific. The Reporter had some conversation with the person who suggested them, but found, upon minute investigation, that the data of his scheme were far from being correct, and would by no means admit of practicability.

The Reporter now lays before the Public his own proposal upon this subject, which he has had in contemplation for a considerable time, and

which has been formed, not upon slight or unsubstantial grounds, but after the most mature consideration of every point in which the matter can be viewed. He determined to submit a Plan of a Bridge of Chains over the Forth, at this place, in the beginning of the year 1817, and accordingly proceeded with the necessary Survey, Levels, Soundings, &c. in order to ascertain the respective situations and heights of both shores, and the stations of the proposed Abutments, and Piers or Pillars; and likewise to make Experiments on Iron and other materials. It is upon the satisfactory results of these operations, that he thus ventures to announce the practicability of an undertaking, yet unequalled in the annals of mechanical enterprise.

The different points of which the Reporter, as an Engineer, may be expected to treat, are the following, viz. the proposed Site; the Height, as it affects the Navigation; the Length, Openings, and Breadth of the Bridge; the general description of the Designs, and some notice of the particular parts; the detail of the Experiments necessary to justify the Reporter in forming such a Design, and the mode of executing it; Sketches of the advantages, and Prospectus of the Revenue that will arise from such an undertaking; and the probable Expense and time employed in the Execution.

The Description of the Ground and Situation.

The proposed Site, or nature of the ground in general, is in many respects favourable for such a Projection. There is, on the Edinburgh side, or south shore, a steep bank running down nearly to the water's edge, which has the appearance of a loose soil; but where the foundation of the proposed Abutment is intended, there exists a compact sand-stone rock. The station of the proposed Pier or Pillar to be founded under water, is a stratum of clay, about the depth of four feet on rock, the most favourable for founding under such circumstances. Garvie Island, elevated a considerable height above high water, is a hard durable rock, well adapted for the erection of a Pier or Pillar. The Fife Side, or North Shore, is very bold and steep, being entirely composed of Rock;

a good foundation either for a Pillar or for the establishment of an Abutment.

Proposed Line, or Direction of the Bridge.

The southern Abutment, or beginning of the Line of the Bridge, is proposed to be stationed about 260 Yards to the North of the Edinburgh road, immediately at high water mark, and about 400 Yards to the East of Newhalls Inn, which point on the road is 120 Feet above spring tides: continuing the direction from this abutment over the most desirable part of the Island of Garvie, the Line would terminate on the Battery Rock on the north shore;—this being the shortest space, and most suitable for the openings of the Bridge, and for the erection of the Abutments and Pillars.

Height of the Bridge, with regard to the Navigation of the Forth.

The Reporter proposes two different heights for the Bridge, viz. 110 and 90 Feet above stream tides. These heights are fixed upon as the best calculated to preserve the Navigation of the Forth free and uninterrupted;—the greater height being sufficient to allow a vessel of 400 Tons burthen to pass through with her top gallant masts up. The Reporter measured the height of a Vessel of this description at Leith, and found her extreme height, with all on end, to be 108 Feet above water; consequently the greater elevation would leave the Navigation as free as at present.

The other proposed height of 90 Feet above stream tides, will allow a vessel, such as already described, to pass through with her top mast up, which rises 78 Feet above water. This height is perfectly sufficient for the greater proportion of vessels that navigate the Frith passing through with all on end. The difference of Estimate of the two heights, which is very considerable, will be treated of in its proper place.

Description of the Breadth of the River, and Length of the Bridge.

The Breadth of the Forth at Queensferry, where the Station of the proposed Bridge is intended, is already stated to be, at high water mark, about 5830 Feet. But, if the Bridge be carried 110 Feet high, there will be about 1500 Feet more added to the length of it, that being the distance from the Battery Rock to the highest rock to the north. This additional length is necessary for the greater height, in order to

pass the Valley betwixt the Pillar formed on the Battery Rock, and the Abutment at the highest Rock to the North.

Spaces or Openings of the Bridge for 110 Feet high.

The distances or spaces and stations of the Piers, if the Bridge be carried to the height of 110 Feet, will be as follows:

From the Front of the Southern Abutment, immediately at high water mark.

	Feet.		Yards.
First space,	1770	or	590
Pillar founded under water,	30	or	10
Second space,	2000	or	$666\frac{2}{3}$
Pillar on Garvie Island,	30	or	10
Third space,	2000	or	$666\frac{2}{3}$
Pillar on Battery Rock,	30	or	10
Fourth space over land, and to the front of northern Abutment,	1500	or	500
Total distance or length of the Bridge,	7360	or	$2453\frac{1}{3}$

Being 1 Mile, 3 Furlongs, and $33\frac{1}{3}$ Yards.

For 90 Feet high.

The distances or spaces, and stations of the Piers, if the Bridge be carried 90 Feet high, will be as follows:

From the Front of the Southern Abutment immediately at high water mark.

	Feet.		Yards.
First space,	1770	or	590
Pillar founded under water,	30	or	10
Second space,	2000	or	$666\frac{2}{3}$
Pillar on Garvie Island,	30	or	10
Third space, and to front of northern Abutment,	2000	or	$666\frac{2}{3}$
Total distance or length of the Bridge,	5830	or	$1943\frac{1}{3}$

Being 1 Mile and $183\frac{1}{3}$ Yards.

It must be understood that the Spaces or Spans of the Bridge on each side of the Island of Garvie will not admit of being shortened, owing to the great depth of the River, and the boldness and immediate depression of the shores. The Pillar founded under the water is nearly on the brink of the Bank, and is from eight to ten feet under low water. The Space next the south shore may be shortened, and an intermediate Pillar built; but this the Reporter does not think necessary. If a Span of 2000 Feet is practicable, there is no doubt of executing one of 1770 Feet; but this will be better understood by looking at the longitudinal Sections in the Engraving, Figs. 1. and 3.

The Reporter, at present, will treat only in the first instance, of a Bridge of the height of 90 Feet. There are two Designs of that height represented in the Engraving, the Spaces or Openings of each being the same as have already been given in the description of the breadth of the River and length of the Bridge. It will be necessary, before entering on the general description and merits of the two Designs, to state the proposed breadth of the Bridge, and give some account of the proposed points of Suspension.

Breadth of the Bridge.

The breadth of the Bridge to be 34 Feet in the extreme, or 33 Feet from outside Railing to Railing, allowing Four Feet on each side for Foot paths, and 25 Feet for Carriage way.

Points of Suspension.

In the one Design, marked Fig. 1. in the Engraving, it is proposed that the points of Suspension shall be at the extremity of the Breadth of the Bridge. In the other Design, marked Fig. 3., it is proposed to have four points of Suspension, one over each extremity of the Breadth, the other two over the points between the Foot paths and Carriage way. The Reporter would prefer, in this Design, the two inner points of suspension being nearer the centre of the Bridge: the division in this case would be, two Carriage-ways each 13½ Feet broad, with a Foot-path of six Feet in the middle. But his objection to this arrangement is, that carriages on the same road-way, and going in the same direction, might, in passing each other,

endanger the sides of the structure, owing to the narrowness of the passage : a heavily loaded waggon, for example, coming forcibly against them, may injure them more than fifty times its weight resting on the same point of the Bridge. Besides, it would be otherwise inconvenient, if the regulations were that carriages should follow one another ; for instance, a heavy loaded waggon may take, in crossing, about 25 minutes, whilst a gentleman's carriage may cross it with ease in eight or ten minutes.

General Description of the Design, Fig. 1. in the Engraving.

The first Design to be described is Fig. 1. in the Engraving. The building of the Abutments and Piers to be 90 Feet above high water, with Cast-Iron Frames on the tops, and Cast-Iron Columns raised 100 Feet above the Roadway of the Bridge, inserted into, and carried up with the Building. It is proposed to support the Roadway at every 100 Feet by Rods suspended in equilibrio from the top of the Cast-Iron columns, which is forty Rods from each Pillar of Columns or Pier, or twenty to each side. These suspending Rods, acting at the same time as mooring Chains, are represented in Fig. 2. the ground Plan of the Bridge, and in Figs. 13. and 14. the Transverse Elevation and Ground Plan of one of the Piers of the other Design. This is in order to counteract the effects of the wind, and any undulating or vibratory motion that may arise from a great weight being on one part of the Bridge at the same time, which, from the position of the suspending Rods, combined with the general construction of the Bridge, will never take place. Figs. 8, 9, 10, 11. in the Engraving, are representations of a Side view of an Abutment, and a ground Plan and Views of one of the Pillars, shewing the distribution of the suspending Rods, were it not necessary to have them acting as mooring Chains ; or, if it were necessary, to have ten more suspending Rods, that is, to support the Bridge every 50 Feet instead of 100.

The suspending Rods must not be considered either as constituting the real strength of the Bridge, which is actually the case in all Chain Bridges hitherto designed on the same principle, whether by professional men or projectors; or as affording the principal strength, and sustaining

the weight of the Bridge. If one or two of the suspending Rods were to give way in these Bridges, (the Roadway of which is sometimes formed of heavy pieces of Cast-Iron,) and more especially at the centre of the Span, where the greatest strain takes place, there is no doubt that the whole fabric would be precipitated into the gulph below. But the suspending Rods are to be held in a secondary point of view, as supporting the Basis Rods at every 100 or every 50 Feet towards the centre of the Span, where the suspending Rods meet from the opposite Pillar. The Basis Chains having a certain tension, would, in a great measure support themselves, and are the principal strength of the Bridge. It is known by experiments made, that a certain description of Chain, 300 Feet in length, composed of Rods, may be stretched nearly straight, without being strained, or suffering any derangement of its particles. Hence there is no difficulty in stretching the Basis Chains from point to point, being every 100 Feet throughout the whole length of the Bridge from Abutment to Abutment.

It may be then questioned, What force or weight will be required, and how secured at the Abutments, to preserve the tension of the Basis Rods, and also be a counterpoise to the strain of the suspending Rods proceeding from the Pillars? This is easily answered. The mass of rock, and building at the Abutments, the mean length and breadth of which being 155 Feet long, 40 Feet broad, and 100 Feet high, allowing one Ton to a cubical yard, will amount to nearly 23,000 Tons; a weight, which, when combined with the construction of the Fixture and formation of the Building, the application of no supposable mechanical force could remove.

The Reporter considers the points of Suspension at every 100 Feet as sufficient; but, if afterwards considered necessary, they may, with an additional expense, be at every 50 Feet; and having in view, in the construction of this Design, that the different parts of the Bridge may be taken out and renewed, without materially affecting the strength of the Structure, it may, by these means, be kept for any length of time in a perfectly secure state.

The Basis Rods which form the Roadway, are proposed to be 40 Longitudinal Rods in number, reaching throughout the whole length of the Bridge from Abutment to Abutment. Fig. 16. in the Engraving is a representation of the 40 Rods, with one of the Cast Iron Bearers in the centre of the Span. The reason why the Reporter prefers the Basis Rods, which support the Roadway extending from Abutment to Abutment, in preference to any other construction, is obvious, viz. that when a great weight is on one part of the Bridge, say 50 Tons, it may not affect that part materially, but in a certain degree distribute itself throughout the whole; whereas a Bridge by Suspension, composed of detached heavy parts, and these only connected by Slender Rods, is liable to this objection, that, when a weight equal to what has been already mentioned comes upon one part of it, that part of the Bridge will descend, while another part will rise, and hence the Slender Rods will be apt to break, and through length of time, the whole Structure will be deranged. But, even supposing these parts to be strongly secured, and that the only parts affected are the Suspending Rods, which, in some Designs, are lying loose on the Pillars, five Tons will cause a Friction, which, if often repeated, there cannot be a doubt, would ultimately destroy them.

General Description of the Design, Fig. 3. in the Engraving.

The Design, Fig. 3. in the Engraving: The building of the Fronts of the Abutments, and building of the Pillars to be 160 Feet above high water, with Cast Iron Frames on the Tops; the Roadway of the Bridge 90 Feet above high water, passing through the Pillars by means of Arches; see Fig. 18. in the Engraving. The construction of this Design differs from the former, in this respect, that, instead of Suspending Rods which support the Bridge, there are strong Iron Rods or Cables, twelve in number, reaching throughout the whole length, three over every point of Suspension, (which is described in treating of the breadth of the Bridge,) these Rods forming an Inverted or Catenarian Arch, whose Curvature or Versed Sine is 66 Feet 4 Inches, being one-thirtieth part of the Chord Line, with Perpendicular Suspenders, Cross-Ties, and Diagonals. There must also be Mooring Chains to this Design, to counter-

act the effects of the wind and undulating motion, and these will also act as suspending Rods co-operating with the strong Rods or Cables in supporting the Bridge. The Basis Rods, which form the Roadway, are proposed to be 20 in number, extending the whole length from Abutment to Abutment, receiving, as in the other Design, a certain degree of Tension; so that the weight may distribute itself in a certain measure throughout the whole. The construction of the other parts of this Design, is in every other respect, the same as the other.

If it shall afterwards be found necessary, in these two Designs, to have the Pillars more Elevated, in order to give the Suspending Rods more power, or the strong Cables a greater degree of Curvature, it can be done at an additional Expense. In the meantime, the Reporter considers the proposed heights of the Pillars sufficient for the purpose required.

Road to the South End of the Bridge.

The formation of the Road, from where it leaves the Edinburgh Road, to the Southern Abutment, might be easily accomplished. It will have a regular descent of 30 Feet to the Abutment, being about one in 26; the principal Expense will be in Erecting Fences on both sides, and Metalling the Roadway.

Road from the north end of the Bridge.

The Road to the north of the Northern Abutment, would have a regular Declivity of one Foot in 50, and in the same direction with the Bridge, until it meet the High Ground to the north of North Queensferry. The Formation of this part of the Road would be rather expensive. It will consist of Longitudinal Retaining Walls and Transverse Ruble Walls, the Gully east of North Queensferry being to be passed by Four Ruble arches of 40 Feet Span—the Road to be filled or made up with the cutting in the Formation of the Road to the North, which might easily be made along the Sloping East Side of the High Ground, and have an easy Descent to within a short distance of the Town of Inverkeithing.

The following descriptions of some particular parts, are common to both Designs.

Construction of the Building.

The Materials of the Abutments are proposed to be large Stones, well squared, and strongly connected with Iron-Ties and Duals: The joints to be grated hard up with Channel, Pebbles, and Decayed Whinstone, so as to resemble in a certain degree the Formation of a Rock. The Piers or Pillars to be hollow, with Cross Walls—the Building to be of large Square Stones, strongly connected by Iron-work, &c. the same as the Abutments.

Wood-Work.

It is proposed that the Wood-work be all of Oak, which, though more expensive than Fir, will be cheaper in the end, as being more Durable, besides affording greater Security. The Wood-work in both Designs, to cover or rest on the whole upper Surface of the Basis Rods, which, in a great measure, will add to their Strength and Security; for it is a well known fact, that one body may be placed along the surface of another so as to prevent it being injured by a weight, which would be sufficient to break it, were it exposed without such addition. The Formation of the Wood-work to be as follows: Upon the Surface of the Basis Rods, Planks of Oak three Inches thick are to be laid in a transverse direction, and upon these planks are to be laid 20 Longitudinal Beams, that is, two of nine Inches by one Foot on the ends of the planks or the extremities of the Breadth; two of nine Inches Square laid along the Inner Sides of the Foot-paths, and two of nine Inches by six Inches in the intermediate Spaces; these six to form the Foot-paths, which are to be covered over with one Inch planking, and raised above the Carriage-way three Inches. The other 14 Beams, four Inches thick, and nine Inches broad, to be laid, at equal distances throughout the Carriage-way. Across these Longitudinal Beams, and in a transverse direction, is to be laid two-Inch Oaken planking. Above these, and in the same direction, are to be laid two-Inch planks, in such a manner that the Middle or Centre of them may cover the joints of the under planks. The upper ones may be removed when worn, and others put in their place without removing the other part of the Wood-work, and at a small expense. The whole to be properly secured to the Beams by Screw Bolts passing through the Foot-paths and Carriage-way; and all the Wood-work to be so construct-

ed as to be taken out and replaced at pleasure. The Angles betwixt the Carriage-way and Foot-paths to be covered or laid over with Plate-iron one Foot broad, six lbs. to the Square Foot. This is to preserve the ends of the Planks of the Carriage-way, and prevent the Sides of the Foot-paths from being injured by the wheels of the Carriages. The Construction of the Wood-work will be better understood from Fig. 7. in the Engraving, which represents the Transverse Section of the Bridge.

For the longer wear of the Upper Surface, it may have Iron Studs put into it, or be covered with two or three Inches of a Composition of Tar and Pitch, Clay, Chalk, Gravel, and Sand, which is very Durable, and in a certain degree Elastic.

Fixture of the Abutments.

The Fixture or Internal part of the Abutment, (see Fig. 11. in the Engraving,) to be 150 Feet from the Front, and the Cast Iron Block 100 Feet below the level of the Roadway. The Internal sides of the Abutment for the Fixture, to be six Feet apart. The proposed Block for the Fixture of the Chains, to be of Cast-Iron, composed of detached pieces of convenient weight, the ends of which to be formed in the manner of Sockets; the whole to form a Block or Beam 34 Feet long, and two Feet square, with Wrought-Iron Bolts, twenty in number, three Inches diameter, and three Feet long, cast into it, to receive the Chains which form the Basis of the Bridge, and the Suspending Rods or Cables. The Cast Iron Block to be secured as follows: One side of the Abutment to be built one Foot upon it; on the opposite Angle of the Block to be inserted the ends of 20 Cast-Iron Beams or spurs, nine Inches by six Inches, and nine Feet long; the other ends of these Bearers to be built into the opposite side of the Abutment, which will be better understood by looking at the perspective view of the Internal part of the Abutment, Fig. 4. in the Engraving. Figures 5. and 6. are representations of the Internal Elevation, and Ground Plan of the Abutment.

Figs. 17, 18.

There is another kind of Fixture represented in Figs. 17. and 18. which give a Side View and Ground Plan of an Abutment, and is also

of Cast-Iron; the sides of the Building five Feet separate. It is formed of short Beams of Cast Iron, 20 in number, laid in a longitudinal direction at the foundation of the Building, the Internal Sides of the Abutment being built on the ends of the Beams, with Bearers or Spurs inserted into them, immediately at the Fixture of the Chains, from the opposite side of the Building.

Either of these Fixtures, if properly executed, is more than sufficient for the Retention, and such as no mechanical power applied could remove.

There are many other sorts of Abutments which the Reporter has thought of, and which perhaps might merit equal attention; but he considers those already described sufficient to shew that there can exist no doubt of their being formed to withstand the application of any force or weight.

Description of Bolts for Fixtures.

The strong Iron Bolts for the Fixture of the Chains or Rods, one of which is represented in the Engraving, Fig. 15. to be of Wrought Iron, three Inches diameter and three Feet long; to be cast into the Iron Block four Inches below; to be secured by a proportionate Nut and Screw eight inches above, with a shoulder and swell at the top, and a hole to receive a ring $2\frac{1}{2}$ Inches diameter; 20 of these Bolts to each Abutment. It is proposed to have Chains composed of links, one Foot each in length, immediately at the Fixture, with a detached Bridle, (see Fig. 20.) for the conveniency of lengthening or shortening and adjusting the Chains to their proper tension and bearing.

Figs. 13, 14.

Figures 13. and 14. are representations of a Ground Plan and Elevation of one of the Pillars for Design Fig. 3. with Cast Iron Columns connected together, five on each side of the Pillar, projecting 100 Feet from the sides of the Bridge, raised perpendicularly, inserted into, and brought up with the Building to the height of high water; afterwards carried 160 Feet high, and braced by Stays, Struts, Cross Ties, &c. At the top of these Columns are attached the Suspenders, and

Acting Mooring Chains which support the Bridge. The Cast Iron Pillars are seemingly of a light and superficial appearance, but their strength is more than sufficient for the purpose required.

Parapet and Railing.

Parapet, or Cast-Iron Railing, to be formed of Cast-Iron Balusters, six Feet in height, each one Inch square, weight 18 lbs.; five Balusters to the Yard, being a little more than seven Inches from Centre to centre; a Main Baluster every ten Feet, weight 30 lbs. General weight of the balusters 77 lbs. per lineal Yard. Top Rail to be Wrought Iron, 10 lbs. per Yard. The inside of the Railing to be faced up with Sheet Iron, five Feet in height, two lbs. per Square Foot of 30 lbs. per lineal Yard, to prevent the effects of the wind on passengers.

The Railing between the Foot-paths and Carriage-way to be Cast-Iron Balusters, one every three feet, one Inch square, and four Feet in height; weight 12 lb. each Baluster; top-rail 8 lbs. per Yard. Intermediate space to be 12 strong wires one-fourth Inch diameter; weight eight lbs. per lineal Yard.

In the Design, Fig. 3. it will not be necessary to have Cast-Iron Railing, either on the outside, or between the Foot-paths and Carriage-way, these being the Points of Suspension; the Sheet Iron and Wire can be fixed on the perpendicular suspending Cross-ties and Diagonals.

Wrought Iron work.

The Reporter prefers the general feature of the Iron Work being in Straight Lines; that is, the Chains to be of Straight Rods, and as few joinings as possible, instead of Links: and he has two reasons; first, because he has found, that by experience, the less Iron is twisted or bent, the stronger it is; and, secondly, because a Chain composed of Straight Bars instead of Links, can be made, of equal strength, with one-half the weight of material and of expense.

The proposed Chains, Rods, and Cables, to be made of the best Wrought or Malleable Iron; their forms are represented in the Engraving, Figures 19, 20, 21, 22. Figures 21. and 22. are Sections of the proposed Cables, composed of nine square Bars, of three-fourths Inch Iron, each Bar first jointed, then welded together, and so disposed

that two joinings may not be opposite one another; making a Square Bar of 2¼ Inches, covered on each side with an Iron Segment, forming altogether a Round Cable of three Inches diameter, which will be covered with a composition to defend them from the effects of the weather and atmosphere.

The Reporter may here state, that previous to using any of the Malleable Iron, he proposes giving it a preparation, in order to add to its durability, which is, to dip or saturate it, when of a sufficient temperature, in Linseed Oil, or other adhesive substance, so that its pores may be completely filled.

Fig. 19. Fig. 19. represents the general form of the Basis Rods, Suspending Rods, and Perpendicular Suspenders. These, however, differ with regard to quantity of material, but shall be each treated of severally. The description and dimensions of the Basis Rods, to be as follows:

Basis Rods. Basis Rods to be made of 1½ Inch Iron in depth, one Inch in thickness; say each Bar 10 Feet long, weight, including Joints, five lbs. per Foot. The one end to be single, with a swell proportioned to the general strength, which will be one inch by 2½ in depth, in order to admit of a hole made through the side three-fourths of an Inch diameter, and two Inches from the end to receive a Steel Pin of the same diameter. The other end to be double, and as far separate as just to receive the single end. The double pieces or sides of the Joint, to be three-fourths of an Inch thick, and 2½ Inches in depth, with a hole through the sides, of three-fourth Inch diameter, for the insertion of the Steel Pin. There will be two catches in the Joint formed on both sides of the single end, and in the insides of the double pieces, resembling a dove-tail; the dimensions of the Joint will be 2½ Inches square and five Inches long, which will be covered over with a Shield or thin Box of Iron.

Suspending Rods. The Suspending Rods for Design, Fig. 1. will vary in their dimensions or diameters, in proportion to the distance they act from the Abutments or Piers; the greater the distance, the greater is the strain, consequently the greater will be the diameter required. The Reporter

has calculated the degrees of Strain at the different points of Suspension, and the diameters of the Rods required, but from their variety he does not think it necessary to describe them in this place. The Joints of the Suspending Rods to be executed in the same manner as in the Basis Rods already described.

Perpendicular Suspenders for Design, Fig. 3.

The diameter of the Perpendicular Suspenders for Design Fig. 3. will be according to their number, or the number of Points of Suspension, and the weight to be suspended; the Joints of course the same as the other rods. Fig. 20. is a portion of Chain intended for the Fixtures of the Abutments: the dimensions of it are, each Link one Foot in length, 1¼ inch diameter in the sides, 1¼ inch diameter at the ends and turnings, width two Inches, with a Cast Iron Stay, three-fourths Inch diameter, weight eight lbs. per foot.

Fig. 20.

The Cables and Suspending Rods to be stronger at the extremities.

The Reporter thinks it necessary that the strong Rods or Cables, and the Suspending Rods, should be stronger at the Extremities; that is, at the resting places of the Abutments and Pillars. His reason for this is, that, from the Experiments he has made, he finds the Strain to be considerably greater at the Extremities of the resting places than at the Centre, or at the lower ends of the Suspending Rods. The degree of strength ought to be in proportion to the length of the Chain.

Stretching Machine, Fig. 12.

Fig. 12. is a Machine for the purpose of stretching and giving tension to the Chains, &c. It is of simple construction but very powerful. Its strength or force is derived from the multiplying power of Wheels, actuated by means of the Winch or Handle, turning round a small Pinion, acting upon a Wheel, on the Axle or Cylinder of which is an endless Screw, turning round the large Wheel of the Barrel. The power of this Machine is above 1500 times the weight applied, or laid on the Winch, when in a horizontal direction; one eighth part to be deducted for friction. So that 100 weight on the Handle, will over-

come a weight or resistance of 65 Tons, that being the net strain of the weight so applied.

Detail of, and Inferences from Experiments.

The Chains being the principal and most important part of the Structure, in order to insure practicability, (which can alone be founded on the result of the Experiments,) it was found necessary to make the proper trials. With this view the Reporter proceeded in trying the strength of various descriptions of Chains, in order to obtain a knowledge of their safe strength, and the best Forms and Joints. The conclusion from his own Experiments, which is confirmed by those of others, was, that a Rod of good British Malleable Iron, one Inch square, will suspend, before it breaks, about 30 Tons, and the best Swedish Iron, from 30 to 40 Tons; and that it would bear, without causing any derangement of its particles, half the weight that would tear it asunder.

Figures 19, 20, 21, 22, on the Engraving, are representations of Chains, which the Reporter considers to be the most suitable for the Projection.

Having obtained a general knowledge of the strength of Iron, the next consideration was, how it ought to be applied, with regard to its strength and economy? The first idea that presented itself to the Reporter was, how near a Chain could be raised to a straight line, over a space of 2000 feet, without being strained, supposing 20 Feet of curvature. For this purpose the Reporter caused to be made a Chain of a particular description, of the best Swedish Iron, weight 7½ lbs. per Foot, and proved its strength to bear 120 tons before it broke. Its safe strength might be considered at 65 Tons. After having ascertained the strength and weight of this Chain, it was then necessary to know what force was required to raise it to the proposed curvature of 20 Feet from the Chord Line, over a space of 2000 Feet, and what additional Strain would be upon it, after receiving its proportional weight of Wood and other materials. Suppose that 60 of these Chains were to form the breadth of the Bridge, the weight of a Chain 2000 Feet in length, 7½ lbs. per foot, is 6 Tons, 13 Cwt. 104 lbs. A Cubical Foot of American Oak,

after being properly dried, weighed 45 lbs. The whole weight of Wood, Cast-Iron Railing, Sheet Iron for Railing and Carriage-Way, Bolts, &c. for the said space, is 1018 Tons, 15 Cwt. or 16 Tons, 19 Cwt. and 65¼ lbs. on one Chain.

The Reporter considered the best body for trying the Experiment, as having an even surface, was a strong well-made Hempen Rope. He procured one, and proved it several times to suspend, before it broke, about three Tons. The proportion of strength which the Rope bears to the Chain is as 1 to 40,—the latter, as already mentioned, bearing 120 Tons. The space chosen was 50 Feet, the 40th part of 2000 Feet. The one end of the Rope being fixed, and resting on the top of an upright, the other end was stretched, and laid over the top of a Pulley 50 Feet distant, and on a level with it. There were then laid regularly along the surface of the Rope 375 lbs. including its own weight, this being the weight of the Chain for that space; next, on the end over the Pulley, were suspended Weights, until the Centre rose to the proposed Curvature of six Inches from the Chord Line, or below the level of the two ends, that being the 40th part of the Curvature of 20 Feet. The Weight on the end of the Rope to produce this effect was 42½ Cwt. 40 times 42½ cwt. make 85 Tons, the force required to give tension to the proposed Chain 2000 Feet in length, with the Curvature of 20 Feet in the middle.

The Rope being properly secured in that position, there were then laid regularly along it thin pieces of Wood, on which were laid 950 lbs. the 40th part of 16 Tons, 19 Cwt. and 65¼ lbs. being the weight of Wood, Iron Railing, Sheet Iron, &c. on one Chain, for 2000 Feet. This Weight did not injure the Rope in the smallest degree; so far from it, that there was laid on it besides, upwards of 2½ Tons, so that the strain and weight on the Rope amounted to 3 Tons, 4½ Cwt. being almost twice the amount that it suspended vertically; and had not one of the Uprights given way, there is not a doubt that it would have sustained a considerable deal more. It was intended to put Weights upon it until it actually broke down.

Any one who is acquainted with the general rules of Proportion, will readily comprehend the principle on which the Experiment is founded. It also proves, that Wood, if laid regularly along the surface of Chains, would add to their strength; or, as the Reporter has already noticed, that one body laid along the surface of another will prevent it being injured by a Weight which would otherwise break it, were it exposed alone to the strain.

However, the foregoing Experiment completely put the Reporter's first idea quite out of the question; the force required for the tension of the Chain, for 20 Feet of Curvature, being 20 Tons greater than the safe strength of it.

The other ideas which afterwards occurred, were to raise the Abutments and Pillars a considerable height above the Road-way of the Bridge, and from the top of them, either to have Suspending Rods supporting the Chains at regular distances, or to have Chains with a greater curvature from the Chord Line, and support the Basis Rods by perpendicular Suspenders; and accordingly from these ideas the two Designs in the Engraving, Figs. 1. and 3. are formed, and the preceding description of them given in this Report.

With regard to the preference of the Designs.

The Reporter, for the present, defers giving his decided opinion with regard to the preference of the Designs, until the result of the Experiments on a large scale be known. But were he at present to determine, he would feel inclined to recommend Design Fig. 1. and that for two reasons, namely, as being much less expensive, and less difficult and complicated in the execution. With regard to the comparative strength of the two Designs, he does not think it necessary now to speak with any degree of nicety. It may be sufficient to state, that, from the calculations and Experiments he has already made, the part of the Bridge over one of the greatest Spans, 2000 feet in length, of either of the Designs, provided the other Spaces were equally loaded, would sustain a weight of 3200 Tons, without causing any derangement in the Structure; and the probability is, that the 30th part of this weight would never be on the said Space at one time.

With regard to the mode of Execution.

It is not at all necessary to enter into the particulars of the Execution. Something may be said as to the method of putting the Basis Rods, Suspending Rods, and Strong Cables into their proper places. What the Reporter conceives at present as most advisable, is, first, to erect the Abutments and Pillars, with the Cast Iron Frames and Columns; then, over the top of these, to stretch Iron-Work of small dimensions, which would be a Catenarian Arch for forming a Foot-path, raised a little higher than the Road-way of the Bridge; along which to be conducted the Suspending Rods of both sides of the Bridge that meet in the middle of the Span; then let the Middle Bearer, with two of the Basis Rods, one fixed on each end, be ready lying on Boats immediately below the Middle of the Opening, let the Bearer be hoisted up, and the Suspending Rods fixed to each end; then let them gently descend, and they will fall into or near their proper place, having a counterpoise on the other sides of the Pillars equal to their weight, after which the remaining Suspending Rods, with the Bearers, may be easily fixed, and the Basis Rods fitted in at pleasure.

The strong Rods or Cables may likewise be conducted along the Foot-path, and fixed in their proper places and in the middle of the Span; a few of the perpendicular Suspenders to be fixed on the Cables: then the Basis Rods and Bearers may be let down from above, or hoisted up in the same manner as is already described, and so on, until the whole of the Iron Work be completed and adjusted.

Sketch of the Advantages that will arise from such an Undertaking.

The erection of a Bridge across the Forth, at Queensferry, is a projection that every one who is acquainted with the Situation, must consider as a work of the greatest utility, indeed of the first National and Commercial advantage that this part of the Kingdom will admit of. This must be universally acknowledged by those who know its relative Situation as to High Roads, and that it is the principal Opening or Great Road to the North of Scotland; likewise, that it would be the only communication by means of a Bridge over the Forth between its mouth (which may be said to commence at Dunbar) and Stirling, a distance of about 60 Miles. On looking at the Map of Scotland, and tracing out the High Roads, and their destinations, the great importance of such an undertaking will readily appear to every one.

The present Road will be much improved.

The present Road will be much benefited and improved on both sides of the Forth, by the proposed Bridge. It will avoid the Great Fall on the South Shore down to Newhalls Inn, and shorten the Road about 250 Yards. It will also do away the Pull on the North Shore, and cut off about three quarters of a Mile from the length of the Road. These are by no means slight considerations.

The Mails would never be stopped or interrupted.

This Bridge would also secure the Mails from ever being interrupted, which, notwithstanding the great improvements of the Passage, happens occasionally for many hours, during stormy weather; besides obviating

the danger to the lives of the Passengers, and lessening the difficulties of conveyance.

Considered in a Military point of view, and in cases of necessity, when Troops might be speedily required in the North, this proposed Bridge would be of the greatest advantage. The communication between Edinburgh and Perth, by the Bridge of Stirling, will bear no comparison, when the time occupied in that circuitous route is taken into view; and as the Passage of the Ferry, (besides the accidental delay that may take place during a storm,) even at the best, is very inconvenient, from the great trouble and danger attending the Embarkation of Cavalry and Artillery Horses, the proposed Bridge would obviously be of the greatest use and benefit in cases of emergency.

Advantage of it in a Military point of view.

It cannot admit of a doubt, that, in every country, Inland Communication is, in the greatest degree, facilitated by means of Bridges; and in this case, the Populous, and Manufacturing Districts in the Shires of Fife and Kinross, particularly Dunfermline, Inverkeithing, &c. and the Proprietors and Tenants of Land in these Counties, will reap advantages by having a ready access to the Market of Edinburgh for their commodities, which will place them in a far superior situation in every respect to that in which they stand at present: But, as the Reporter has already noticed, every person who is acquainted with the nature of the subject must at once be satisfied of the great and manifold advantages which would be derived to the Country in general, if the Plan were carried into effect. He considers it quite unnecessary, at present, to enlarge farther on the subject.

Advantage in a Local point of view

Prospectus of Revenue.

If a sum were obtained sufficient for the execution of this Plan, it is highly probable, from the benefit which will be derived from it by the whole of Scotland North of the Frith of Forth, and several Districts of the South, by the extended Communication, and great Thoroughfare, that the Revenue of Tolls or Pontage Duties would be very considerable, and the concern prove highly beneficial to Subscribers. There are good grounds for entertaining this opinion. The Queensferry Passage is at present let for a Rent exceeding L.2000 *per annum.* When, in addition to this Sum, are considered the expence of maintaining a number of large Boats, Yawls, and Pinnaces, besides a number of Seamen, defrayed by the Tenants, and the Profits which they must necessarily derive from their risk and trouble, the amount of Fares actually received, may be estimated, upon a low computation, at L.5000 *per annum.* But the Navigation being often very dangerous, and at times even impracticable; and the conveyance of Carriages and Cattle by water, being attended with considerable inconvenience, the accommodation of a land conveyance would naturally give rise to a much more extensive and direct intercourse betwixt the North and South Districts than is at present carried on. It must also be considered that the numerous Stage Coaches and Post Chaises which daily convey travellers who cross at Queensferry, proceed no further than the South Side. Carriages, of course, are employed on the North Shore to carry the travellers forward. It is well known that many travellers prefer the Circuitous Route by the Bridge of Stirling to the dangerous and uncertain Passage of the Ferry; and almost all the Carts and Waggons from those Districts on the Forth which are situate above Queensferry proceed by the Bridge of Stirling, although their Destinations be immediately North and South of Queensferry. By the proposed Commmunication, the present obstacles to the Passage would be effectually removed, and an immense increase both of Passengers and Conveyance might reasonably be expected.

These circumstances afford just data for calculating the Revenue that might be expected from the accomplishment of this Plan, and from a very moderate calculation the return to Subscribers would not be less than ten *per cent.* But it is highly probable, that after the full benefit of a free communication began to be felt, the intercourse betwixt the North and South Shores of the Forth would increase to a much greater extent than has hitherto occurred; and, consequently, give rise to a great increase of Revenue. It is expected also, as the proposed Bridge may be considered as a National Improvement, that a considerable Sum might be granted by Government towards defraying the expence of it, provided a proper application were made for that purpose.

There is every reason to believe that this Undertaking will receive the support of the Trustees of the Queensferry Passage, and also of the General Post-Office; and it may be expected, that considerable Subscriptions may be obtained from the Trustees on the different Lines of Turnpike Roads, leading to and from the proposed Bridge, as the Revenue of these Roads will be greatly increased by the communication which would take place.

The Reporter will now proceed with the last Article enumerated, viz. the probable expense and time required for the Bridge. He will only give an Abstract Estimate, although in his Private Papers he has calculated the expense of each particular. It is necessary to observe, that the advantages of the Situation compared to others are great, in regard to the easy access and conveyance of the necessary Materials, as these may all be shipped to the place, and a great Saving consequently take place in the expense of Carriages.

There is an excellent and durable Free-Stone on the North Shore. The Stones may be taken from the Well Dean Quarry, about one Mile West of North Queensferry. The Lime, which is of excellent Quality, could be brought from the Elgin Lime-Works on the North Shore, a

few miles farther west. The Iron direct from the place where it is Manufactured; and the Oak-Timber directly from America. The whole Shipped and laid down immediately on the spot.

Abstract Estimate for Design.

FIG. 1.

Excavation, Rock-Cutting, preparatory for Foundations, &c. Cofferdam or Cassions,	£3,210	10	0		
Building Abutments and Pillars; Masonry *per* Cubic Yard, -	17,595	7	0		
Retaining Walls, Cross-Walls, Lodges, Arches, &c. - - -	3,211	13	0		
Iron-Ties and Duals for Abutments and Pillars, - - -	750	0	0		
				£24,767	10 0
Wrought-Iron for Basis Rods,	£20,680	0	0		
Ditto ditto for Suspending Rods,	12,200	0	0		
Allow for Fixing, Stretching, and Adjusting them, - -	5,000	0	0		
				37,880	0 0
Cast-Iron for Fixtures of Abutments,	£750	0	0		
Forty Strong Wrought-Iron Bolts, with large Rings, - -	80	0	0		
Cast-iron Frames for Tops of Abutments and Pillars, - -	1,250	0	0		
				2,080	0 0
Carry forward,				£64,727	10 0

Brought forward,		£ 64,727	10 0
Cubical Feet of Oak-Timber,	£ 29,520 0 0		
Sawing, Dressing, and Laying, -	2,460 0 0		
Iron-Bolts for Fixtures, -	512 10 0		
		32,492	10 0
Cast-Iron Bearers for Basis Rods,	£ 450 0 0		
Cast-Iron Pillars or Columns, -	17,600 0 0		
		18,050	0 0
Cast-Iron Railings, - -	£ 2,470 10 0		
Top Railings, Wrought-Iron, and Wires,	1,332 10 0		
Sheet-Iron for Railings, - -	1,537 10 0		
Plate-Iron for Angles of Foot-paths and Carriage-way - -	922 10 0		
For putting up Railings, Fixing Plate and Sheet-Iron, &c. -	1,025 0 0		
		7,288	0 0
Oil for preparing Iron, Painting, &c. - -		5,000	0 0
Erecting Temporary Foot-path over Abutments and Pillars for Conducting and Adjusting Chains, with Expence of Stretching Machine, -		3,000	0 0
		£*,* 130,558	0 0
Allow for Contingencies, - - -		13,442	0 0
Total Estimate, - -		£ 144,000	0 0

, If this Design be carried 110 Feet high, the Estimate will be £ 170,000.

Abstract Estimate for Design.

FIG. 3.

Excavation, Rock-Cutting, preparatory for Foundations, &c. Cofferdam or Cassions,	£	3,510	10	0	
Building Abutments and Pillars; Masonry *per* Cubic Yard, -		22,361	7	0	
Retaining Walls, Cross-Walls, Arches, Lodges, &c. - -		3,211	13	0	
Iron-Ties and Duals for Abutments and Pillars, - -		1,000	0	0	
					30,083 10 0
Wrought-Iron in strong Rods or Cables, - -	£	28,220	0	0	
Ditto for Basis Rods, -		11,340	0	0	
Ditto for Suspending Rods, -		10,200	0	0	
Perpendicular Suspenders, Cross-Ties, and Diagonals, -		9,970	0	0	
Allow for Stretching, Fixing, and Adjusting them, - -		6,000	0	0	
					65,730 0 0
Cast-Iron for Fixtures and Abutments, - - -	£	750	0	0	
Forty strong Wrought-Iron Bolts with Rings - - -		80	0	0	
					830 0 0
Cast-Iron Frames for the Tops of Abutments and Pillars, -		1,250	0	0	
Cast-Iron Bearers for Basis Rods,		450	0	0	
Cast-Iron Pillars or Columns, -		15,680	0	0	
					17,380 0 0
Carry forward,					£ 114,023 10 0

		Brought forward,			£114,023	10 0
Cubical Feet of Oak Timber,	£29,520	0	0			
Sawing, Dressing, and Laying,	2,460	0	0			
Iron-bolts for Fixing Wood, -	512	10	0			
					32,492	10 0
Sheet-Iron for Outside Railing,	£1,537	10	0			
Plate-Iron for Angles of Foot-path and Carriage-way, -	922	10	0			
Wire-Work for Inside Railing, Foot-paths, - -	540	0	0			
For fixing on Plate and Sheet-Iron Wire, &c. - -	500	0	0			
					3,500	0 0
Oil for preparing Iron, Composition, Painting, &c.					6,000	0 0
Erecting temporary Foot-paths over Abutments and Pillars, for Conducting and Adjusting Chains, Machine, &c. - - - -					3,000	0 0
				£	159,016	0 0
Allow for Contingencies, - -					15,984	0 0
Total Estimate, - -				£	175,000	0 0

*** If this Design be carried 110 Feet high, the Estimate will be £205,000.

With regard to the *time* employed in the Execution of the Bridge, the Reporter is of opinion that it may be completed in four Years from its Commencement.

The Reporter has thus generally, and in some of the points minutely, detailed his views and ideas on this subject. He thinks it necessary to add, that, before the design were put in execution, it would perhaps be necessary to investigate the matter still farther; more especially by Experiments on the Strength of Materials, particularly Iron; this, however, would be attended with too much expense for an individual, unless indemnified for his outlay and trouble. It has cost him already a considerable sum in making the necessary Survey, taking Levels and Soundings, also in Experiments and Investigations. One of the principal Experiments he would recommend is, to make a Chain equal to one of the greatest Openings 2000 Feet in length, to try it at different degrees of Curvature, and the weight it may safely suspend at the different positions.

He may here observe, that he cannot expect Subscribers to embark their Money in this Undertaking, until they are fully satisfied in every point with regard to its Practicability. It is for this purpose he publishes this Report, and the accompanying Engraving, in hopes of thereby calling the attention of philosophical and practical men to a subject of such importance. If Government were to grant a small sum for making Experiments, the Money expended would not be lost, though the proposed undertaking were abandoned; as, it may be presumed, it would be of great advantage to the Country in general, in determining the strength and tenacity of Iron, so as to form a precedent for all similar Designs and Plans wherein the application of it on a large Scale was necessary.

He may likewise state, that in more minute investigations, and in making Experiments on a more Enlarged Scale, in all probability there might arise New Ideas and Improvements upon different parts of the Construction, which might be substituted in place of others already proposed. But these, he reserves, if it shall be found necessary, to be treated of at a future period.

It may suffice for the present to shew that there can be no doubt of the practicability of the Projection.

The Estimate he considers a full and competent allowance both for materials and workmanship; and although it may appear small for an

undertaking of such magnitude, yet he may state, that in his private papers and calculations of the expense of each particular of the Work, he has given an ample allowance, besides a considerable sum for Contingencies.

Edinburgh, January, 1818.

*** Since putting the plan into the hands of the Engraver, and consigning this Report to the Printer, a Professional Gentleman has been so good as send me the Report, with an Engraving annexed, of the proposed Chain Bridge over the Mersey, by Mr. Telford; the Spaces or Openings of this Design are one of 1000 Feet, and two of 500 Feet each—and not, as I have stated in this Report, of one Span of 1200. In looking it over, I find that my Ideas in the Design Fig. 3. in general coincide with his. The most material difference is, that he allows a greater degree of Curvature from the Chord Line, in proportion to the length, and his Basis Rods and Wood-work are somewhat different.

But, I may here observe, that had I received this Report and Design sooner, I would not have altered any particular of my Designs; for, as I have already noticed, in making experiments on a larger Scale, new Ideas and Improvements may arise that could be substituted in place of others; and still farther, these alterations may take place even in the execution of the Work itself.

As somewhat confirming the expectation alluded to in page 25 of this Report, I may here mention that Government has recently granted £10,000 in aid of a Bridge of Chains, of very considerable extent, to be erected over the Menai in Wales.

JAMES ANDERSON.

Edinburgh, August, 1818.

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