Mr. R. Stephenson, M.P.,—President,—said, this Paper touched upon an important point, which had deeply engaged the attention of engineers—the comparison of suspension bridges with those of the girder construction, for use on railways. The Authors had evidently given considerable attention to the subject, and he hoped the Paper would lead to an interesting discussion.

Mr. Lukin said, in the Figures given in the Paper, the stay chains were omitted, but they must be supposed to exist as in ordinary structures of the same kind. In referring to the bridge with convergent rods, Fig. 4, he mentioned the fact of there being one on a similar principle at Harper's Ferry, in America, in which, however, the use of stay chains was obviated, by the employment of a tube between the towers, somewhat like that in the Chepstow Bridge, designed by Mr. Brunel. The Harper's Ferry Bridge was an instance of the disadvantage of employing rods, without chains; for whereas the longest rod was 114 feet, in the arrangement advocated, in which chains were used, the longest rod for the same span (150 feet) would scarcely exceed one-fourth of that length. There would also be much less "sagging" of the rods, when main chains were used, than when the direct rods alone were employed. He thought one great object of the chain was to tighten the suspension rods, which had a tendency, by "sagging" down, to draw up the platform. Indeed, in those suspension bridges, having a girder platform, it might be a question, whether the girder should not be chiefly considered as resisting the upward strain, caused by the tension of the chains and rods, and therefore causing stability by that means. It had been endeavoured, as far as possible, to remove the undulations affecting the platform and chains of a common suspension bridge, and by the proposed arrangement to keep the bridge in its normal position. A girder platform, rigid enough to restrain the disturbances of the main chains, must be strong enough to carry the weight which caused that disturbance. He thought the best mode of obtaining stability was by suspension, rather than by trusting to any rigidity of the platform. In fact, he considered the duty of the platform to be, simply to carry and distribute the weight, and that all tension should, as much as possible, be thrown on the chains and rods. The platform of railway bridges might consist merely of cross sleepers, suspended from the rods, with longitudinal timbers to carry the rails, forming a skeleton platform not likely to be acted on by the wind. If a girder was used, it should be sufficiently stiff to distribute the weight, or pressure, over at least one-third of the span, so as to throw less weight upon any particular rod. The Niagara Falls Suspension Bridge had two platforms, one over the other, braced together so as to form a deep truss. He did not know how far such a girder would support the load, independently of the chains, or what sustaining power it had; but besides the chains, and the vertical rods, there were direct rods, from the top of the tower to one-third of the span, and also stay rods underneath. One-third of the platform, at each end, was thus supported, independently of the chains, an arrangement which no doubt had the effect of preventing a great deal of undulation. As had been mentioned, rods forming acute angles with the platform threw the strains very much towards the tower, without exercising any great amount of vertical strain. In Fig. 3 a portion of a main chain was shown in two positions, so as to prove that when the chain rose, or fell, the point of the platform to which the rod was attached rose, or fell, about half the distance. This was one of the advantages of the inclined rods. When he made experiments upon a model, it was evident, that it was altogether so much stiffer, in proportion, than would be the case with a real bridge, that he had merely noticed general results; but if the load caused a considerable deflection at any one point, without causing a corresponding elevation at another point, so far it might be argued, that there would be no material undulation. The model was for a span of 240 feet, at a scale of a quarter of an inch to a foot. When a truck loaded with 7 lbs. or 8 lbs. was sent across the loaded bridge, at various speeds, he found that a deflection at one point did not produce an elevation at any other point; there was, in short, no undulation. The platform sank gradually from the tower: and the whole length was deflected into one gradual equable curve. But as he had before said, he did not desire to draw any positive conclusions from such experiments.

Mr. Conder remarked, that the Tables 1 and 2 (Appendix pp. 470, 471) might be found useful, as showing the economy, comparatively speaking, of different forms of suspension bridges. But though the actual weights of girder bridges might be from 40 tons to 400 tons, for similar breaking weights, yet that was not a fair criterion, in point of economy, because from 50 to 75 per cent. must be added to the weight of the suspension bridge, for the stay chains. The weights of girder bridges were put down, merely to afford some data for comparison. Mr. Lukin and himself were anxious that it should not be understood, that they did away with the stiffness of the platform. The vertical stiffness of the platform was important, as distributing the load over the whole, or the greater portion, of the chains, as well as for resisting the effects of gales. The way in which the chains tore up the roadway, in violent storms, was well known, from the instances of the bridge over the Menai Straits, and the Wheeling Bridge in America. On comparing the superficies which the platform exposed to the action of the wind, with that which was exposed by the chains, it became evident, that the disturbance naturally began in the platform, as undergoing the most pressure. Although the platform might disturb the chains, the chains could not steady the platform. Therefore, it was important, that the platform should be sufficiently stiff to withstand the pressure of the heaviest gales. There was, however, another danger to be guarded against, resulting from the mobility of the chains, which precluded the stiffness of the platform being increased beyond certain limits; since it seemed very undesirable to connect a perfectly rigid structure with a mobile chain. In the case of the Britannia Bridge, it was decided not to do so; but when there were two platforms, as in the Niagara Bridge, the intervening depth not only admitted of a deep trussing, but also afforded room for many dead points, to which to fix the chain, so that it ceased to be a mobile structure. It became more like an arch, with the spandrils reversed. The investigation had simply been into the best mode of rendering the chains steady in themselves, and as little liable to undulations as possible. If there was danger from too stiff a platform, this danger was lessened, in proportion as the chains were steady. At the same time, the steadier the chains were rendered, the less stiffness was required in the platform. Thus, the first point to settle related to the chains: having decided this, it could afterwards be considered what to do with the platform. In speaking of multiple spans, he might mention the case of the tube, as applied in the bridges at Chepstow, at Saltash, and some other places. By the use of the tube, both the continuous chain and the stay chain were dispensed with. The question might arise, how far it was economical to use stay chains, notwithstanding the acknowledged safety of the tube. The plan of using inverted chains below the platform, to prevent its being pulled up by unequal loading, in multiple spans, was adopted in the suspension bridges, designed by the late Sir Isambard Brunel, in the Isle of Bourbon. The convergent arrangement did away with the horizontal strains, which the action of a single set of slanting rods threw on the platform. These strains resembled those in a girder, in which the depth was the same as the rise of the chains. In support of this, he might adduce the remarks made by Mr. Dredge, in his pamphlet[1] containing the calculations of a bridge of 500 feet span, with a load of 625 tons. The rise of the chains was 41 feet 10 inches,—about one-twelfth of the clear span. With a load of 625 tons upon the platform, Mr. Dredge considered there was a horizontal strain upon the platform of 954 tons, or 50 per cent. more than the load. This was within a few tons of the strain that the same load would occasion, in the top

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[1] *Vide* "Description of Suspension Bridges on Dredge's Patent Taper Principle," pp. 10, 20. Edinburgh. Printed by W. Burness, 1851.

or bottom flange of a lattice girder of 500 feet span, and 41 feet 10 inches rise. This horizontal strain rendered it necessary to give a large sectional area to the platform. Thus, in the case adduced, the platform (if of iron) ought to have 190 inches sectional area, and would thus weigh more than 140 tons. The convergent rods removed this necessity for a heavy platform; and any vertical stiffness, that would be required, might be secured in a light platform, by giving a sufficient depth of truss.

It might be objected to long slanting suspension rods, that they were apt to "sag." A "sagging" bar, however, had nothing in common with a catenary, except the fact of its not being straight. It was quite clear, that the facility of acquiring and transmitting undulatory motion, which was the main cause of the unsteadiness of suspension bridges, did not exist in a rod, in the same sense that it did in a chain.

Mr. P. W. Barlow said, that as engineer of the Londonderry and Enniskillen and Londonderry and Coleraine Railways, he had recently received instructions to design a bridge for crossing the river Foyle, at Londonderry. It was proposed, that the bridge should have two platforms, the upper one to carry the ordinary road traffic, and the lower one to support the railway carriages drawn by horses, the connection with the two lines being by means of turn-tables. That object, he believed, could be best effected by a suspension girder bridge. The chief point to be aimed at, was to prevent the horizontal and vertical oscillation, common to ordinary suspension bridges. This he had endeavoured to accomplish in the proposed structure. The upper platform was formed of wrought-iron plates, laid horizontally, and connected with the lower platform by lattice work. The chains were carried down to the lower platform, and were united to the girder throughout, so that in one-half of the bridge, in the centre, the chains performed the double duty of supporting the bridge and contributing to its stiffness. A cast-iron tower, 100 feet in height, and having an opening 36 feet in width, afforded a passage for ships, which was required by the Admiralty authorities. This plan had been approved by Sir William Cubitt, M. Inst. C. E., consulting engineer to the Bridge Commissioners, and he had considered that it was the best way of meeting the case.

It appeared to Mr. Barlow, that the modification, alluded to in the Paper, of having two chains on each side of the roadway, rising from the platform level, at one tower, to the summit of the other tower, and crossing each other in the centre of the span, only attained stiffness by doubling the quantity of iron used, but he doubted whether it would preserve rigidity under vertical pressure. Mr. Barlow disagreed with the assertion, which was unsupported by a single fact, that a girder could not be applied to a flexible chain. There was no more difficulty in rendering a flexible chain rigid than an arch, which, being usually constructed with solid spandrils, was supposed to be, in principle, more rigid; whilst chain bridges were usually made with light platforms, with no attempt at rigidity. The only case, he remembered, of a rigid iron platform for a suspension bridge, was that at Inverness, where the parapet was made of wrought iron plates 3 feet 6 inches in depth. This bridge had been tested by a locomotive being drawn across, by fourteen horses, at a trot. Relative to that test, the following report by the late Mr. Rendel, M. Inst. C. E., dated 11th September, 1855, had been made:—

"When the locomotive passed over, I placed Coates (the foreman) at the end of the longitudinal girders, where he noticed a slight bend, not $\frac{1}{4}$ of an inch, opposite the engine. I stood on the centre of the bridge and narrowly watched the handrail, as the locomotive passed; the deflection appeared to me less than Coates observed. The shake, or vibration, although the bridge was half full of people, rushing by as the horses trotted over, was less than is perceptible when a single carriage goes over."

Mr. Edwin Clark remarked, that the proposed modification in the arrangement of the chains, did not affect the general principle of construction, nor was the comparison with the chains in an arch an admissible argument. On the one hand, the arch was, it was true, a series of links in stable equilibrium, but without any motion whatever. In the other case, the suspension bridge was a series of links connected by pins, in such a manner that the whole strength of the structure depended upon its instability. No such system could resemble an ordinary arch. The oscillation arose from the play of the chains at the joints of the links, and so long as the chains were of considerable length, however they might cross each other, or in whatever direction they might be placed, this oscillation would exist. A rigid suspension chain must consist of two links alone. The pin that joined them would then be a fixed point, and if such a structure could be made, they would have a perfectly rigid bridge. Unfortunately, the links themselves, when of any great length, became suspension bridges; their length made them catenaries, and if they were connected at the points where they crossed each other, a bad trellis girder merely would be formed, in which each bar was curved, and in a state of unstable equilibrium. The real difficulty had not been touched upon. It had been attempted to give rigidity to suspension bridges, by making the roadway rigid; but the simultaneous expansion of the chain and of the girder, was incompatible with the preservation of a horizontal platform. In the Britannia Tubular Bridge, with a span of 460 feet, under the ordinary temperature of this climate, the vertical rise and fall of a chain at the centre would be through a space of 6 or 7 inches, whilst the horizontal motion of the roadway itself would be only through a space of 2 or 3 inches. Yet the roadway must necessarily be capable of rising and falling with the chain, through the space of 6 or 7 inches. If the roadway was so rigid that it did not follow this motion of the chain, it would evidently, at times, be doing all the work, and at other times nothing at all; whilst any partially flexible roadway, sufficiently rigid for railway traffic, must necessarily be of such great independent strength, that the addition of the material in the chain would be employed to greater advantage in converting it into a simple rigid girder. Two such incompatible systems could not be combined, either with economy, or advantage, nor could they be made, practically, to act in unison. In the example given of a locomotive being taken over such a bridge at a trot, he did not think it was a case in point; and it was to be remarked, that the person who took an account of the deflection was upon the bridge, not the most favourable point for making such observations. With regard to the Niagara Bridge, he had reasons for believing, that it was not efficient for the purposes for which it was intended. The deflection was so great, that the trains passed over at a very slow pace, and the passengers frequently alighted at one end and walked to the other, where they again entered the train. The effect of the slow speed, which was rendered indispensable by the deflection of the bridge, had been greatly to impede the traffic. He understood, that it was in contemplation to erect some other bridge at that place.

Mr. BARLOW remarked, that in a communication he had received from Mr. Brackstone Baker, the Secretary to the Great Western Railway Company of Canada, he stated, "I never heard, before you mentioned it, that it was our intention, or anybody's intention, to build another suspension bridge; but its great success may perhaps induce railway men to build similar bridges elsewhere. Mr. Hodges, an engineer of the Grand Trunk Line, did, indeed, once make a model of a tubular bridge, to replace our suspension bridge, when it gives way."

Mr. R. STEPHENSON, M.P., President, remarked, that the discussion went to show, that difference of opinion existed on this subject, and he hoped it would not be allowed to rest where it was. A further communication upon it had been promised, and he trusted, by the end of the next session, they would be able to reconcile these differences, and to reduce the question to a simple form.

May 26, 1857.

The Session was concluded by a CONVERSAZIONE, at which the President received the Members of the Institution, and a numerous circle of distinguished visitors. The rooms were decorated with many choice works of art, and there was also exhibited a large and interesting collection of mechanical models.