1m. 10. When the thermometer varied from -4° C. down to -6° C., the weight had only to be raised, in an average of twelve experiments, to a height of 5 feet 6 inches, in order to break the rail; but when the thermometer rose from $+3^{\circ}$ to $+8^{\circ}$ C., then the weight had to be lifted for a fall of 7 feet 9 inches. Similar experiments conducted in 1860, showed that a difference of temperature from -4° to $+5^{\circ}$ Centigrade, was sufficient to greatly influence the height of fall necessary to break the rail. It is not unnatural to suppose that the particles of iron, after being worked at a heat and allowed to cool and set at a medium temperature, should, when that temperature is lowered, get into a state of mutual strain; or that any initial mutual strain should be thus intensified. The toys made of suddenly cooled glass, known as Prince Rupert's drops, are exaggerated instances of a similar action. The outside portions of a bar, of whatever size, would evidently cool, and consequently contract, first of all. The inside portions would also at last cool; but, having kept the outside portions distended, when the inside does cool, it then becomes a question to be determined by various circumstances, whether it would pull the outside shell into a state of compression, or whether the outside shell will draw the inside into fissures by tension. A somewhat similar explanation is given by Mr. Mallet of the rents caused in the interior of very massive forgings; and this state is probably always induced by the conditions of cooling in a small bar, but with, of course, a smaller range both as to size and temperature. In any case, it is apparent that a ductile, elastic material ought to be less affected by these doubtlessly complicated conditions of tensile and compressive strains. It is, therefore, probable that a hard, harsh, iron would be more affected by frost, than a soft ductile iron; and also, that the breaking strength of both qualities would be less affected by cold than their extensibility.

On Elastic Railway Wheels. By VAUGHAN PENDRED, Esq. C.E.

From the *Lond. Mechanics' Magazine*, May, 1864.

[Read before the Society of Engineers, May 2, 1864.]

The author commenced by stating that the subject of the paper he was about to read, "Elastic Railway Wheels," or, more strictly, certain expedients for imparting elasticity to these important members of the railway system, was one possessing much interest; indeed, he thought he was justified in saying that the adoption of certain mechanical expedients for seating tyres elastically on the wheels to which they belonged, afforded fair promise of enabling important changes to be introduced into the present system of constructing permanent way; while experience had shown already that by their aid, the duration of engine tyres might be nearly, if not quite doubled, especially on lines of rapid curvature, and that slipping or want of adhesion might be reduced to a minimum.

The paramount object had in view in the formation of a railway, was the reduction to a minimum of those forces which retard the motion of wheel carriages. Setting aside for the moment every other con-

sideration, he might, therefore, define a perfect railway as consisting of two unyielding bars—parallel—absolutely hard on their upper surface at least, and so secured to the sub-structure on which they were ultimately supported, as to be incapable of moving or deflecting under the action of any practical load which they might be called on to sustain. Such a railway, the author stated, would not only reduce the amount of tractive force required for the propulsion of trains or carriages to the lowest limit, but would also possess elements of permanence, which are wanting in any track constructed with timber sleepers, cast iron chairs, &c., under existing arrangements; while, on the other hand, it would be open to certain objections, which have hitherto precluded its adoption.

After describing a theoretical railway track formed of girders laid down on stone blocks, the author went on to say that, were it but possible to introduce the use of stone sleepers, and to permit the ballast to settle its own differences with the sleepers after its own fashion, the expense of maintenance would be greatly reduced. Good ballast always had a tendency to consolidate and become hard, but, under existing circumstances, this quality which ought to be of all things the most desirable, is, on the contrary regarded as a great evil, and no sooner does the ballast become hard, and the timber manifest a tendency really to sleep, than the navvy stirs them both up with his pick. This we are told, is done to secure elasticity; but the ballast was not properly treated if compelled to become the elastic member of the system—to take a part for which it had no vocation, and could not properly assume. If it were not necessary that elasticity should be provided somewhere, a very excellent track indeed, might be made with stone blocks and rails bolted down directly to them, without chairs, and such a track would be infinitely more durable than any other involving the necessity for the use of wood in its construction, always provided that it were exempt from these destructive influences, to obviate the effects of which the elastic element is introduced; in other words, the author believed that the elastic element in our permanent way, as it is called, is the principal cause of its want of permanence, because wood rots and wears out, because nothing has been found as yet which is better than wood, under the given conditions, and because the mechanical arrangements are all so imperfect, and the bearing surfaces so small, that if that motion takes place among the parts which constitute an ordinary railway track which the element of elasticity is presupposed to permit, they quickly become loose, and the true rigidity on which the integrity of the entire structure depended, can only be approximately maintained by an excessive outlay of money and labor.

The author then explained at some length the nature of the action which a rapidly revolving wheel exerted on the rail beneath it, showing that elasticity prevented percussive action, and that the elastic element may be applied with more mechanical propriety beneath the tyre, than beneath the rail, and with equally good effects; and went on to say, that the percussive action of railway wheels traveling at

speed is due directly to their revolution, and is almost independent of any true jumping whatever, and that elasticity operates more as a *preventive* of percussion than as a cure. In other words, the suddenness of strain characteristic of percussion was prevented, as he had just endeavored to show, instead of being absorbed or taken up, as might be the case, if the wheels were supposed to be lifted off the rail for a space and suffered to drop.

No means had yet been discovered for preventing the effects of percussion taking place between revolving wheels and the rail which supported them, but the introduction of elasticity, somewhere, into the system; and experience showed that this elasticity could be introduced with the utmost advantage into the wheel, or beneath the tyre, instead of, or in addition to, elasticity beneath the rail or the sleeper, and if no better expedients for securing this necessary element in track could be devised than those already in use, which depended for success on soft ballast, or costly destructible timber, then he believed it might yet be found advantageous to seat rails as rigidly as possible on heavy stone sleepers, and to adopt some expedient beneath the tyres of not the engine alone, but every wheel of the train, which should supply that elasticity which would, in such a case, be absent from the permanent way. This was, however, a point open to discussion, and he would therefore proceed to the consideration of the various expedients which had been proposed from time to time for seating tyres elastically, or in some one way imparting resilience in no ordinary degree to the wheels of vehicles. The idea of an elastic wheel was by no means new. Patent Office records showed that, with the first notion of propelling carriages by the adhesion of the wheels on which they rested, men sought to increase that adhesion by enlarging the surface in contact with the ground, either by using a very broad wheel, or by adopting certain expedients which would permit the wheel to depart slightly from a true circular shape, and become more or less oval.

The author then gave a short history of the elastic wheel theory, showing that Mr. T. Neville, the inventor of the multitubular boiler, had been one of the first to propose to use elastic tyres to obtain increased adhesion, as early as 1825. After describing many inventions, the author went on to say that all those expedients were indirect, and more or less unlike the arrangements adopted in modern railway practice; but he found that, in 1837, Sir George Cayley took out a patent which included nearly all that had been done since, in the idea at least, if not in the actual mode of application. Not only this, but he found that, in 1831, he had suggested, in the pages of the *Mechanics' Magazine*, an improvement in railway wheels, designed to reduce their wear, which possessed many points in common with the Griggs' wheel. Sir George writes, "If the wear and tear of railway conveyance be found too expensive, owing to the friction caused by such high pressure and great velocity, and that the use of springs to these carriages are not sufficient to remedy the evil, I think it probable that a dovetailed groove, filled with hard oak, driven in small pieces endways within the rim of the wheels, and then turned off in the lathe, might be serviceable and

could be cheaply renewed ; these pieces might be secured by a fox-wedge as commonly practised in similar cases." In Sir George Cayley's patent he describes a wheel "made with a deep flange, and to the opposite side of the tyre is secured a ring or annular plate of less depth than this flange ; the space between the flange and the ring is to be occupied by a filling up of hoof or horn, or tough woods, or of other partially elastic substances, suitable for giving a slight degree of elasticity to the periphery, for diminishing the effects of percussion.

In 1839 Mr. W. Bridges Adams brought out a very ingenious elastic wheel, with spokes composed of steel rings, while the tyres were seated on wood blocks or felloes. Mr. Adams' wheels were tried under his own supervision, and at one time he had several sets running. The results obtained were not quite so satisfactory as he desired, principally because of certain practical difficulties met with in the construction of the wheel.

Setting aside one or two isolated instances of the use of elastic wheels, he found that Mr. George S. Griggs, locomotive superintendent of the Boston and Providence Railway, United States, was the first to seat the tyres of his driving wheels elastically on a practical scale. The means he employed to effect this purpose are very simple. American locomotives almost invariably have cast iron driving wheels, fitted with wrought iron or steel tyres. The Griggs' wheel was made with a number of transverse dovetailed grooves, cast in the periphery ; into these grooves blocks of thoroughly dried, hard wood, such as fine-grained old oak or hickory, were driven, so that the grain of the timber ran parallel with the axle, and across the periphery of the wheel. When these blocks had been driven into their places, the wheel was put into the lathe, and so much turned off them that they only stood up above the surface, an eighth of an inch or so. The tyre, previously turned up true inside and out, was then heated and placed on the wheel, care being taken not to scorch the blocks on which it then bears, no metallic connexion of any kind existing between the wheel and its tyre.

The Griggs' wheel was brought out in 1857, and has been, and is extensively used in America, with the best results.

The "Canton," an engine on the Boston railway—as an example from many cited by the author—had run 133,373 miles ; the tyres were now reduced to $1\frac{1}{4}$ inch in thickness. The four coupled drivers are 5 feet in diameter, and loaded with nearly 14 tons.

The thinness to which tyres seated elastically on Mr. Griggs' plan had been worn was very remarkable, and such as we dare not attempt on a rigid seating. Yet the fracture of an engine tyre on the Boston and Providence road is all but unknown.

Mr. Bridges Adams had lately introduced a very elegant arrangement. The rim of the wheel is turned slightly convex ; the tyre is rolled with a groove on the inside. Into this groove two hoop springs, made in segments, and each about one-third of an inch, thick are placed, so as to break joint. These hoops are made of steel of the best quality. They bear only at their ends on the sides of the groove in the tyre,

and the convex wheel rim, resting only on the centre of their breadth, is supported elastically. The tyre is secured in its place by a ring of iron sprung in at the back of the wheel. In a more recent modification the rim of the wheel is turned perfectly flat, and only a single spring hoop is used, thickened in the centre of its cross-section. This hoop is made in one piece, with the ends abutting, and forced on the wheel after being placed in the tyre by water pressure. The tyre of the first Adams' wheel, when unloaded, can be rotated on the wheel by hand, and a slight rocking motion of the wheel within the tyre is permitted, which enables the tyre always so adapt itself to the rail in the best possible manner. Wheels so fitted seldom or never slip. The area of surface between the spring and the tyre, and the spring and the wheel rim, is so great in consequence of the circular shape of the parts, that the wheel cannot turn with ease within the tyre when loaded; and this last, being elastically supported, yields slightly, becoming a little oblate, instead of remaining truly circular, and thereby acquires a better hold of the rail, consequent on an increase of bearing surface. Tyres usually break from tension; but the tyres in this case, being elastically supported, can scarcely be said to be in tension at all, and it was, therefore, very improbable that they should break even in intense frost. Indeed, two of these tyres had been cut across for the purpose of experiment, and in that state actually did three days work drawing coal trains.

The first trial of Mr. Adams' spring wheel were made on the North London Railway, in 1858 or 1859. The spring tyres were applied to a set of disk wheels. The tyres were of Staffordshire iron, and ran a distance of 104,000 miles with very little wear. Low Moor tyres, rigidly seated on the same class of wheel, were completely worn out in running the same distance.

The next trial was on the Eastern Counties line, in the early part of 1859, when Staffordshire tyres were fitted, on the Adams' system, to the four coupled wheels, 5 ft. 6 ins. diameter, of a goods engine. The tyres were of the worst possible quality, and the springs very little better. These last broke and set so that they had to be removed, and thus far the experiment was a failure. In September 1859 however, a pair of Cooper & Co.'s tyres, elastically seated on the same principle, were applied to the leading wheels of a tank engine, working the Woolwich branch of the same line. This branch abounds in sharp curves, one of them being but $5\frac{1}{2}$ chains radius, and another but $4\frac{1}{4}$ at the sharpest part. The engine had a 12 foot wheel base, and the load on the spring wheel was $7\frac{1}{2}$ tons.

The engine began working on September 21st, 1859, and the wheels ran up to July 26th, in the following year, a distance of 25,240 miles before being turned up. The wheels were put under again in September, 1860, and ran up to January, 1861, a further distance of 8776 miles. At this time the tyres got quite loose from the breakage of one or two of the springs, and the engine requiring repairs generally, was taken out of work for a time, and the spring tyres were not replaced. The same class of tyres put on in the ordinary way require re-turning

when they have run but 8000 to 10,000 miles, when the flanges are found much worn; afterwards they must be turned up every 4000 or 5000 miles until they are worn out.

Mr. Adams' tyres were largely used on the St. Helen's Railway, with great advantage. The author detailed at length the results obtained in the daily working of these tyres, showing that when Staffordshire iron was elastically seated, it actually gave a 3-5ths greater mileage than Krupps' steel rigidly seated.

The last form of elastic seating to which he would call attention had been recently patented by Mr. Mansell. The wheel rim is first turned up, and then the inside of the tyre is bored out, so that when put in place a space of about one inch intervenes between the two surfaces all round. This space is filled with a ring of wood—teak being used by preference—on to which the tyre is forced, and secured in its place by six segments of iron on each side of the wheel. A groove is turned in each edge of the tyre, and a similar groove in each edge of the wheel rim, into which raised ribs on these segments enter, while pins pass through the wood and secure the whole in place. These wheels have been so short a time in use, that many data do not exist about their performances yet. A good many of them were running on the South Eastern Railway. On the Great Eastern Railway one engine had the leading wheels fitted on this plan; they had been running some months, and showed little signs of wear.

An interesting discussion followed, in which Messrs. W. B. Adams, Z. Colburn, Ordish, Musey, and several other gentlemen took part. The paper was fully illustrated by diagrams.

On the Bursting of the Bradfield Reservoir. By HEWITT DAVIS.

From the London Builder, No. 1108.

I have read with much attention the evidence that has been given as to the cause of this sad accident, and must confess that I think as yet very little light has been thrown on it.

I have for many years been engaged as a draining engineer and government inspector in the drainage of clay land, and have had to observe the wonderful contractile power that clay exhibits in drying. I may instance the cracking of clay land in autumn, and our ability to make the strongest soil porous by inserting 4-foot drains every 27 feet. This experience leads me to think that this accident may have been caused by the drying and cracking of the clay puddle in the embankment, consequent upon the sinking of the water in the reservoir during this singularly dry winter, and its exposure while in this state to the sudden rise in the reservoir after the heavy rains at the time of the accident.

The reservoir was formed by an embankment carried across the valley, 90 feet high, for the purpose of collecting the water that came down in the wet seasons; and the embankment has been made watertight by having a puddle of clay carried up along its centre. This