

## MECHANICAL VEHICLES AND ROAD SURFACES.

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By BRIG.-GEN. THE RIGHT HON. LORD MONTAGU OF BEAULIEU,  
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The cost of transport affects the condition of every country, and the cost of almost every article produced and consumed in it. Bad roads add to the cost of transport, and are a burden on the owners of vehicles, though they do not always realize the difference in the cost of operation, maintenance and repair of their vehicles when used over good and bad roads respectively. The larger transportation companies are painfully aware of the facts, and comparative statistics show that often it would be desirable to abandon altogether certain routes where the roads cause abnormal wear. In other cases it would pay the owners of motor vehicles to combine to pay for temporary repairs, such as the filling up of deep pot-holes till the road as a whole can be repaired by the proper authority. The effects also of the surface over which vehicles pass are not confined to roads, and every locomotive engineer knows the difference which a good or bad road-bed and even or uneven permanent way makes in the cost of locomotive maintenance and repair. It is an interesting fact that it is only during recent years that the close inter-relation between the state of the permanent

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way and locomotive repair costs have been properly recognized on many of the great railway systems in Europe and America, and the expenditure on the improvement of permanent way definitely reflected in the diminution of engine failures and the locomotive repair bill. It is clear that if this is the case when smooth steel rails are employed as the surface for the steel wheel, the conditions of the road are much more important, when roads and road vehicles are considered.

There are four principal effects of bad roads as reflected in the wear and tear of motor vehicles. There is, first, the crystallization and fatigue produced in all metal structures by constant shocks and vibration as, for instance, by pot-holes, corrugations, uneven stone setts, and other irregular surfaces. There is a definite and ascertainable deterioration of the metallic structure in axles, axle-casings, frame, cardan shaft, steering gear, and other parts of the vehicle specially subject to this road vibration. Most of the shocks, although individually of very short duration as a rule, are at the same time of great intensity in some cases. For instance, an ordinary 3-ton motor lorry, weighing with its load about  $7\frac{1}{2}$  tons, at 15 miles an hour—a very ordinary speed—has often to run through pot-holes sometimes as much as 2 inches deep, or over corrugations whose wave lengths, if the expression may be used, from the highest and lowest points are generally 9 to 12 inches apart. On modern roads there is an almost unyielding surface on the far side of these obstructions or holes for the wheel to strike. The blow at the point of the impact is often, in force, as much as three times the weight of the vehicle, and in quite ordinary cases equal to one-and-a-half to twice its weight, or in the case of the 3-ton load vehicle mentioned an impact shock of 15 to 30 tons. This blow and shock has to be taken up first by the tyre, generally in the case of commercial vehicles made of solid rubber, which unfortunately, after a good deal of use, loses a large proportion of its natural resilience. After the tyre and wheel come the springs, comparatively stiff in character in the case of a commercial vehicle, which are compressed and relaxed quickly and constantly. Next in order to share in the shock comes the frame, and eventually the transmission-gear, the engine-bed and engine itself.

In the second place, there is the definite wearing of certain movable parts, which themselves have to move with shocks or vibrations, such as the leaves of the springs, the spring shackles and bolts, and wheel brake bands and brake connexions. Again, the various rods and the worm-gear connecting the front wheels with

the steering gear are in a state of constant movement. In the case of a heavily-laden vehicle, the spring shackles and bolts, unless they are carefully lubricated, show much wear in a short space of time, and when they become worn and loose in their fittings, not only is their wear accentuated, but a disagreeable chattering and noise is set up which, in fact, forms a great part of the noise nuisance which has lately become so serious in the case of heavy commercial vehicles. The body work is also strained and shaken over a bad road, and the fitting of doors, windows, and tail-boards affected.

In the third place, a considerable amount of extra power is necessary to propel a vehicle of equal weight and encountering wind resistance at the same speed over a bad road as compared with a good road. The extra power expended is due to the fact that the vehicle and its wheels have to be raised continually many inches or fractions of an inch after falling into every depression; in addition, side lurches produce unequal strains and wear the differential gears. Every form of vibration and uneven motion increases frictional resistance, which is again reflected in the consumption of motor spirit. From tests the Author made, in the engine and gears, some time ago, with a lorry carrying 3 tons, he is of opinion that under bad conditions, such as on an uneven and muddy road, the consumption of motor spirit is increased by at least 50 per cent compared with a good hard smooth road. On a road full of pot-holes and corrugations, but with a hard dry surface, the increase in consumption varies from 25 to 30 per cent. Besides the actual expenditure of energy involved by the continual raising of the vehicle, after its fall into pot-holes and hollows, the transmission of power from the engine to the road wheels is interfered with and proceeds in a jerky fashion, which is a contributory cause of diminished efficiency.

Fourthly, in the case of bad roads where the wheel is constantly interrupted in its actual contact with the road surface for fractions of a second owing to bumps and subsequent hollows, there is much extra wear and tear on tyres, on account of the tendency to sudden acceleration and deceleration in the rotation of the wheel, driven, as it is nowadays, by considerable engine power. This sequence takes place on every occasion when the wheel is not actually in close touch with the road surface. Again, the blow given to the tread and fabric of the tyres by uneven surfaces tend to make them wear out much more quickly, in the case of both solid and pneumatic tyres. In the case of solid rubber tyres the resilience of the rubber is gradually destroyed. Though pneumatic tyres undoubtedly damp down and neutralize small vibrations, and

minimize to some extent larger vibrations, a really bad road causes severe strains on the rims, walls, and general fabric of these, and on the air-valves and security bolts, especially if there is any attempt to run at high speeds. Every blow also increases momentarily the internal air-pressure, though the exact increases of pressure are difficult to ascertain or express mathematically. But the Author leaves it to the imagination as to what the strain on a pneumatic or solid tyre must be when a heavy vehicle, at considerable speed, encounters a succession of blows caused by obstacles, such as the far sides of pot-holes or corrugations in the road. The momentum of the vehicle, calculated in the usual way by multiplying the speed by the weight, is every time checked at the cost of shock and vibration. Probably the pressures in a pneumatic tyre rise for a second or fraction of a second to double or even treble their proper or usual amount, and it is conceivable that many of the bursts in the walls of fabric tyres and the loosening or bursting of cords in the case of cord tyres of the Michelin, Palmer, and other cord types occur when these blows are delivered. In the case of solid tyres the wheel of the vehicle strikes with a greater force than with a pneumatic tyre against any opposing surfaces, and the tyres in this case tend to split longitudinally or are sometimes partially wrenched from the rims.

In addition to these purely mechanical effects of bad roads, there is the considerable extra strain put upon the attention and endurance of drivers of vehicles, as there is a greater tendency to accidents observable in the direction of side-slips, skidding round corners, and failure of steering gear. The effect of vibration on the human frame has long ago been recognized by physiologists as a potent cause of fatigue in the case of the spine, brain, and heart, and the difference which drivers feel between a day's motoring over good and over bad roads—the mileage being approximately the same—is noticeable. In fact, the Author, speaking for himself, would rather drive his car, in the course of a day, 200 miles on good roads than 100 miles on bad roads.

From the foregoing instances of how depreciation is occasioned to vehicles by bad roads, it is clear that well-made and smooth roads are of great value to road-users. The direct interest, therefore, of the user of mechanical road transport in the construction and maintenance of good roads is very considerable, especially in a commercial sense. If in various countries the taxes for road improvement placed on motor vehicles were even heavier than they are to-day, the payers of those taxes would recoup themselves many times over in the consequent saving, were the roads they

use put into good condition, and vehicles enabled to run over comparatively smooth surfaces instead of over uneven and rough surfaces which are now only too common.

One therefore comes by natural sequence to the problem of how smooth and strong roads can be provided for the mechanical traffic of to-day and the future. In the case of the heaviest motor-lorries their hind axle-weight amounts sometimes to as much as 6 to 7 tons, while traction engines running at a slow speed are allowed 8 tons on a single axle, by the law as it stands to-day in Great Britain. A load of 3 to  $3\frac{1}{2}$  tons on each wheel is possible and by no means rare. Such a heavy load should be borne not only on strong wheels and broad rubber tyres, but the wheels should be of comparatively large diameter, say a minimum of 3 feet or 900 mm., heavily-laden wheels of small diameter being most destructive of road surfaces due to their small bearing surface on the road. But considering the universal tendency to-day to increase weights carried by each vehicle, the Author is inclined to think that the time has arrived when the weights of the heavier road motor vehicles should be borne on more than four wheels. Already certain systems use six wheels, with the power plant separate from the carrying vehicle, and the use of trailers is also becoming more common, which ensures that the weight on any individual wheel is kept within reasonable limits. A further increase in the weight of any vehicle must necessarily bring about the employment of more axles and wheels, as has been found necessary in railway rolling stock, where the average bogie passenger-carriage of to-day, weighing between 35 tons and 50 tons, with four wheels in each bogie, has its weight distributed over eight wheels. Consequently the old four and six-wheeled railway vehicles are disappearing, except in the case of small four-wheeled goods wagons carrying up to 12 tons only, which are run at slow speeds and for non-bulk traffic, and a few passenger coaches used on unimportant services. But it is an interesting fact in comparing road and railway vehicle practice, that as regards the latter to-day, the 40-ton bogie-carriage on eight wheels has, theoretically, a load of 5 tons on each wheel, whereas on some road vehicles not enjoying the advantages of a smooth, strong, steel rail, the weight is sometimes as high as 3 to 4 tons. Considering its form of construction and weaker resistance to shock, it is unwise to require a road to bear a far greater comparative strain than is borne by the steel rail. In saying this, the Author does not forget that, in the case of locomotives in Great Britain, the axle-load sometimes amounts to as much as 20 tons, or 10 tons a wheel in the recent and more powerful types

such as the new "Pacific" type on the Great Northern Railway, and 19 $\frac{1}{4}$  tons in the case of the latest L.N.W.R. locomotives. Weights up to 20 tons have been allowed since the 1908 curve, as it is called, was adopted by the Railway Engineers' Association. But locomotive engineers have been and are endeavouring to reduce weight per wheel in order to save expense in permanent way and get greater adhesion. They are therefore generally employing nowadays six instead of four driving wheels on the modern locomotive with a four-wheeled bogie under the fore part, and frequently an extra axle and two wheels under the fire-box, in order to distribute the huge weight, often over 100 tons, more evenly over the whole length of the engine frame and wheels. This is a tendency and example which the Author feels certain will be followed in the design and construction of motor vehicles in the near future.

In conclusion, it must be borne in mind that the problem of making roads strong enough to withstand the increasing strains, to which allusion has been made, is to-day one of finance, and only in a secondary degree one of engineering. Most competent modern road surveyors and engineers, if given sufficient money, can make a road strong enough to stand almost any strains and its use by vehicles at almost any speed. But to make such a road is very costly, and the expense increases rapidly if heavy weights at high speeds have to be provided for. Already roads specially surfaced cost as much as 15s. or even more per superficial yard in the case of main trunk roads through country districts, and as much as 30s. to 40s. per superficial yard in the case of much used streets in towns, which are paved with stone setts, wood blocks, or asphalt laid upon concrete foundations. It is clear that in over-taxed and over-rated Europe such a cost cannot continue to be provided, except in special cases where the heaviest and most constant traffic exists, and if only these expensive surfaces last for a really considerable period of years during which no repairs of any consequence are necessary. A cheaper form of road-making is therefore very desirable if we are to continue to improve our highways in strength and smoothness, and road traffic is to be worked economically. Any highway engineer or highway construction firm who can lay down a road in the neighbourhood of, say, 5s. per superficial yard for the ordinary main trunk road, will deserve the thanks of all motor-vehicle users, as well as of the suffering tax- and rate-payers. The Author is inclined to think that most of the present system of road-making by what is known as single or double carpet work on specially prepared foundations is too expensive for our present

impoverished state. Economy as well as efficiency will, it is hoped, be secured eventually by some other cheaper process.

Improvements in the methods of road-making and in the diminution of cost are of immense present and future interest to the users of mechanical vehicles, for Governments and Local Authorities are finding it increasingly difficult to obtain money to spend on road improvement and maintenance. It is, at the same time, incumbent on designers and makers of mechanical road vehicles to spread the weight of their vehicles over more wheels if possible, and to limit the total weight borne on each wheel to more reasonable amounts, say  $2\frac{1}{2}$  tons as a maximum.

The Author has shown the cost of bad roads to every owner and user of a road vehicle, and each nation as a whole has eventually to pay more for the extra cost of its transport under such conditions, which in turn increases the price of every kind of article to the manufacturer and consumer. To save this waste there must be more co-operation between road-makers, designers of road vehicles and road users, to promote economy in the upkeep and improvement of roads, which at once reflects itself in cheaper transport. Otherwise the road and the vehicle alike will suffer, and no prudent man can help seeing that there will be increasing difficulty in finding money in the next few years for road construction and repair. Bad and rough roads entail an extra burden on the community as a whole, for which every vehicle owner, road user, consumer, and manufacturer, has to pay. Every nation therefore is directly interested in keeping down the cost both of road making and the use of vehicles upon the road.

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The PRESIDENT said it was a source of much regret to him to have to announce that Lord Montagu was unable to present his Paper in person, but the Secretary of the Institution would do so on his behalf. As the Members were aware, the Author had a world-wide reputation on the subject with which the Paper dealt. The Institution was also very proud of him as one of its first Companions. At the time the alteration of the designation from "Associate" to "Companion" was made a certain amount of criticism was passed upon the suggestion, but he desired to inform the meeting that when Lord Montagu was made a Companion he sent a letter to the Institution thanking them for the great honour

that had been done to him. While the principal study of some peers of wealth was the horse, Lord Montagu had distinguished himself from the advent of the self-propelled motor by his study of the question of locomotion on roads.

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*Discussion.*

The PRESIDENT said he was sure the Members would agree that the Paper was a most valuable one. The Author, who thoroughly understood the subject, had brought out in a very clear manner that the cost of the mechanical vehicle did not fall merely on the owner of the vehicle but on the whole of the community, who were thus concerned with the depreciation that was brought about on the roads by badly designed vehicles and on the vehicles by bad roads. Those Members of the Institution who had been in the excursion by motor from Amiens, through the devastated regions, to Compiègne, had brought home to them in a very vivid manner that for every mile travelled by the motor on those bad roads meant a loss of money by way of depreciation to the vehicle. First, because it was impossible to travel fast and thereby valuable time was wasted ; and, secondly, because it was impossible to go even at the slow rate at which the cars travelled over the bad parts without depreciation to them. The subject dealt with in the Paper was, therefore, not only a question that concerned the owner of the motor vehicle, but every individual in the State.

Lieut.-Colonel T. M. HUTCHINSON said he thought the Members were greatly indebted to the Author for having brought to their notice the most important question of securing the co-operation of the engineer who designed the vehicle with the engineer who was responsible for making the roads. A great deal of development had taken place in the direction of the design of the automobile internally, in regard to its engine and gear-box, but he did not think sufficient attention had been paid to its suspension and its various reactions on the vehicle, and the damage it did to the road. It was well known that, if the road was bad, damage was caused to the vehicle. He was unfortunately aware of many instances in which extensive repairs had been caused by the fatigue of parts and the breakage of springs and frames which caused serious trouble, particularly during the War. It was also well known that a great deal of expense was involved in maintaining the roads, so that the two problems were closely related.

As a user of automobiles, he was convinced that a good deal could be done internally in the design of the vehicle. It was known from certain experiments already carried out, particularly in the United States,\* that very heavy hammer-blows were given to the road when a vehicle passed over any obstacle. That hammer-blow damaged the foundations and disintegrated the vehicle also. In the past he thought engineers had been working somewhat in water-tight compartments. The road-maker had tried to design a road surface to last as long as possible, and he was afraid that in many cases he had found that it was very expensive to do so. On the other hand, the automobile maker had tried to make his machine pass over bad roads with the maximum of comfort to the passenger. He thought it was necessary for the two branches of engineers concerned to come together. The most important outcome of the experiments made in the U.S.A. proved that the unsprung weight, that is, the axle-weight and the weight of the wheels, was a most important consideration. As a result of the Paper, he would like automobile designers to consider what could be done in the way of reducing unsprung weights. If more attention were given to that subject he was sure that much benefit would result. The Germans were experimenting extensively with aluminium road-wheels and had had a varying measure of success. Some experiments were also being conducted in England with aluminium road-wheels which weighed less than half the cast steel road-wheels. That was a very important item, because it meant that the weight of the hammer with which they were trying to break up the roads was nearly halved.

Another point was the encouraging of particular designs by means of legislation. It was well-known that a certain form of taxation would produce a certain class of engine; it tended to limit engine-power and produce high-speed engines. He was convinced that the most effective form of securing an improvement in the design of vehicles would be some form of legislation which put a premium upon or gave a rebate for light unsprung weight as compared with some of the old types.

With reference to the question of trailers hauled by tractors, there was a tendency at the present time to increase trailers behind tractors. It must be remembered that the damage was done to the road partly by the dead weight which was brought on the surface

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\* Report on "Impact Tests" carried out at Arlington, U.S.A., by E. B. Smith and J. T. Pauls, of the Bureau of Public Roads, Dept. of Agriculture. See *Scientific American*, Supplement 2292, 22 Dec. 1919.

of the road and partly by the tractive effort. In order to propel the whole train along the road a certain amount of horizontal force had to be applied, the effects of which could be seen particularly on gradients. The damage to the roads would not be entirely done away with by employing trailers, because the whole of the tractive effort was usually distributed in that case through one axle only, and he thought it might be necessary to develop the four-wheel drive for certain particular classes.

Mr. WILLIAM H. PATCHELL (Vice-President) thought the Paper had been read very opportunely in Paris. Most of the Members arrived in Paris only the previous evening, but personally, he arrived the day before, so that he had spent two nights in Paris. In view of the experience obtained in that time, he thought that the road-surfaces in Paris required serious consideration. The heavy unsprung weights and the bad roads were apparently having a detrimental effect on the buildings in Paris, and the subject, therefore, required attention.

The pioneering work which was being done in road-making in America was carried out with American enterprise. In the country districts the concrete roads were only wide enough for two motors to pass, and were about three inches thick, with the result that pieces of concrete got punched out of the table of the road. He inquired why the roads were not made better and thicker, and found out it was due to the old question of prohibitive expense. Following the opening up of the country districts by means of pioneer roads, the frontage values would increase, and the frontagers would then be in a position to subscribe for better and thicker roads to be made.

He did not understand the Author's figure (page 788) of 5s. per superficial yard for the ordinary main trunk road. Those Members who had seen anything of road-making, or road-breaking, knew that a road between 8 inches or 12 inches thick was required for heavy traffic, which meant three times 5s. or 15s. a yard, which would not pay for the material alone. He therefore did not know how the Author made his figures up.

The PRESIDENT said that Lord Montagu would reply to the discussion in writing. It afforded him very great pleasure to propose that a hearty vote of thanks be accorded to Lord Montagu for his excellent Paper.

The resolution of thanks was carried by acclamation.

*Reply by the Author.*

LORD MONTAGU OF BEAULIEU wrote that he had read with interest the discussion upon his Paper, and he was glad to know that the President and subsequent speakers agreed with him in his plea for more co-operation between the users and the makers of roads.

In regard to the remarks of Mr. Patchell, he was referring to the cost of surfacing, not to the making *de novo* of a road, when he quoted 5s. a superficial yard as the ideal to be aimed at for the cost of main roads. Recent "one coat" work had been carried out as low as 7s. 8d. a super yard, but as a rule 10s. to 12s. a yard were not uncommon figures, and "two coat" work like bitumen cost about 14s. a super yard.

The ratepayer was not going to continue to pay 50 per cent of the cost of the use of heavy Class 1 roads, and everywhere the same demand was made to reduce rates even if the result was seen in worse roads. Heavy traffic in Great Britain did 90 per cent of the damage to roads and only paid 10 per cent of the cost. Such an arrangement could not last much longer.

In conclusion, he would say that the road engineer—given enough money—could to-day make a road capable of bearing almost any legal traffic. But the financial problem—how to find the money—was as yet far from being solved, and it seemed that a larger payment for the use of the road by the users was inevitable.