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MADRAS RECORD OFFICE.

Government of Madras.

Public works **DEPARTMENT.**

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432 433

Dated 25-1-1871.

Not to be folded or roughly handled

Proceedings of the Madras Government, Public Works Department,
25th January 1871.

No. 432. Read the following Circular from the Government of India, Public Works Department, (Railway,) dated Fort William, 19th December 1870, No. 22-R. :—

G. I. P. Railway—Brake-power on Ghaut Inclines.

Read :—

Papers and the Orders of the Government of Bombay thereon, No. 658, dated 5th May 1870.

ORDER.—Ordered that copies of these papers be forwarded to the Local Governments and Administrations for information, and for communication to the several Railway Companies.

Madras.	Central Provinces.
Bengal.	British Burmah.
North-Western Provinces.	Mysore
Punjab.	Hyderabad.
Oudh.	Central India.
Rajpootana.	

(Signed) E. C. S. WILLIAMS, Major, R.E.,
Deputy Secretary.

To the Secretary to the Government of Madras, Public Works Department, (Railway.)

No. 433. ORDER THEREON, 25th January 1871, No. 213.

RAILWAY, No. 50.

COMMUNICATED to the Consulting Engineer for Railways for information, and for communication to the several Railway Companies.

(True Extract.)

Colonel, R.E.,
Secretary to Government.

To the Acting Consulting Engineer for Railways.

Exd. E. C. Shunker.

2

Enclosure to Circular No. 22 Railway.

No. 1499, dated 23rd April, 1870.

From—LIEUT.-COL. J. S. TREVOR, R. E., *Consg. Engr. for Railways, Bombay,*

To—Secretary to the Govt. of Bombay, in the P. W. Dept., Ry. Branch.

I have to submit, for orders, a report by Captain White on experiments conducted by him lately to ascertain the amount of brake-power required to ensure safety to descending trains on the Ghâts, a memorandum from Mr. Saunders on the best system of brakes, and a report from Mr. Berkley, suggesting the measures that, in his opinion, are required for the safe and economical working of the ghât.

2. Captain White's experiments have been conducted with great care, but, for want of instruments to determine accurately the actual velocity of trains and vehicles at different points, the figures he gives as the measure of the loss of momentum due to rolling friction, and of the resistance offered by braked wheels, cannot be accepted as strictly correct. But, although the results obtained are not close enough for the purposes of scientific enquiry, they are sufficiently accurate for the soution of the practical problem for which were made, and are, as far as my knowledge extends, the most valuable series of experiments yet made on the resistance required to arest the progress of trains descending a steep incline at speeds of 20 to 40 miles an hour.

3. The first, and most important, fact established by these experiments is, that the co-efficient of friction, derived from the bite of an engine for ascending trains, is no guide to the proportion of brake-power required to check a descending train. In ascending trains the co-efficient of friction is seldom found to be less than 1 in 9, and is sometimes as high as 1 in 4 and 1 in 5. In descending trains, with a perfectly dry rail, it varies from 1 in 8 to 1 in 15 With a damp rail, the co-efficient falls sometimes to 1 in 24, and, if the rail is oiled, it is as. low, on occasions, as 1 in 35. No expeiments were made by Captain White on what is termed on the Ghâts a dewy rail, that is, a ail covered with heavy dew ; but Captain White mentions some facts, and records the result of trials made by another Officer, which support his view that an oiled rail is not, on sone occasions, an exaggerated representation of the state of the rails when heavy dew is being leposited.

4. The second important feature manfested in these experiments is that, as far as can be judged, with identical conditions of rail and brake-power the results differ very widely. An explanation of these discrepancies must be looked for in the action of the brakes. These brakes are the principal elements of uncertanty. They are worked from the same centre for the four wheels of a vehicle, and it would require an accurate adjustment of parts to secure an even pressure on all points of contact; but this adjustment is not in practice possible. In the wagons used by Captain White, when probably special attention was paid to the condition of brakes, the conclusion he drew from experiments on the action of brakes skidding or allowing a slight revolution of the wheels was that, although on the latter method the resistance created by the brakes was from one-fourth to one-third greater than in the former, yet that, in ordinary practice, defects due to wear and tear of parts, and variations in the pressure required to skid the wheel occasioned by changes in the state of the rail, more than neutralized the gain in resistance derived from the application of brakes on the best principle. In the common run of vehicles, I think there can be no doubt that the greatest power will be developed, as a rule, by screwing the brakes hard down. But it must not be understood that the strange differences of result exhibited in these experiments can be explained entirely by want of uniformity in the resistance offered by the brakes. The experiments on the catch-siding show that identical results cannot always be relied on in identical conditions, even where no brakes are applied, when vehicles are allowed to attain high speed. Variations in result are caused in many ways. The mode in which wagons swing round a curve, the oscillation and deflection of vehicles from side to side, the loose or tight coupling of the train, and the varying force of the wind, all tend to affect the velocity acquired in falling, and to disturb, in more or less degree, the results of different experiments.

5. Besides these two great points, the experiments have demonstrated that the usual formula for calculating the resistances to trains at high velocities gives results less than practice ; second, that the friction on steel rails is less than on iron, but that the difference

is of no practical value; and third, that sanding from an engine, and brakes, although a most invaluable auxiliary method of adding to the resistance offered by the brakes of a train. cannot always be depended on to supplement deficient brake-power.

6. Regarding the future method of working the Ghât, Mr. Berkley makes several most valuable recommendations at the end of his report. These recommendations (noted hereafter in the margin) are 23 in number. I concur in the first two recommendations, and they have been carried out.

1.—Sand boxes to be attached to all Ghât engines.
2.—Sand to be clean, dry and sharp.

7. I do not think there is much use in adopting the 3rd recommendation, It will cost money, and will be of little practical service.

3.—A water jet to be applied for engine to clear rails of dew.

8. I concur in the 4th, as far as requiring the most effective description of brake to be used; but I am not prepared, without more information, to recommend the use of cast-iron blocks, though I have no objection to the use of Lindsley's.

4.—Brakes to be of most effective description, and cast-iron or Lindsley's brake blocks should be used.

9. In the 5th recommendation I concur. But, in my opinion, native firemen engaged for the Ghâts should be of a superior class to the ordinary firemen, and only men of whom it is possible hereafter to make drivers, that is, men of admitted nerve and knowledge, should be employed as firemen on the Ghâts.

5.—To give the Locomotive Superintendent power to engage either Native or European Firemen, at his discretion, on the Ghâts.

10. I agree with the 6th suggestion. It is one that ought to be adopted without delay.

6.—Practical mechanics to be engaged as carriage examiners on the Ghâts.

11. I concur in the 7th recommendation.

7.—Pulling and pushing engines to be employed with ascending goods train, and a brakesman to be put on at every 4th wagon for assisting in case of a fracture of a coupling.

12. I concur in this recommendation.

8.—Maximum weight of descending trains not to exceed the weight the engine can draw in ascending, and that engine or engines should be in front of the train.

13. I think that, on the Thull Ghât above the reversing station, and on the Bhore Ghât above the Wonee catch-siding, in the day time, between 8 A. M. and 6 P. M., one-fourth of the wagons should have their brakes weighted or held down by springs, and below these points one-sixth. I would not leave either the weight or pressure on the spring

9.—All wagons to have brakes acting on both pair of wheels. Three-fourths of these to have brakes weighted, or held down by springs before commencing the descent. The other fourth to be worked by brakesmen. This fourth to have brakes specially made for the purpose.

to be adjusted at the discretion of the Locomotive Superintendent, but would have a fixed weight sufficiently heavy to nearly skid the wheel in all weathers. Between 6 P. M. and 8 A. M. I would increase the proportion of fixed brakes to one-third the train above the two points indicated in the preceding para., and one-fourth below. On the remainder of the wagons I would have a brakesman for every two wagons. All but one of these brakesmen should be stationed at the head of the train; one man should be in charge of the last two wagons. Experience proves that, in case of the attainment of unusual speed, the tendency of native pointsmen is not to leave their brakes untouched, but to put them on hard. There is no danger of their neglecting this duty, and they can easily be made to act in concert by signal from the driver, or by communication with ropes from one to another.

14. I think all wagons should have brakes workable by hand, or by lever, and that these should be of the best known description.

10.—4,000 wagons to be fitted with powerful brakes.

15. I agree in this proposal, provided the goods vehicles used have screw instead of chain couplings. Unless this condition is insisted on, I do not consider that the train would be as safe as the public have a right to expect.

11.—Passenger trains to be worked up as at present, or with two engines, one being placed behind, the load being made up with goods vehicles.

16. I have no objection, as just observed, to the system in force up to the accident being continued as regards ascending trains, but I must protest most strongly against its continuance with descending passenger trains.

12.—The present system to continue in force till a continuous brake is devised.

Captain White's experiments prove beyond all doubt that, if the engine be not taken into

account, a train with less than 77 per cent. brake-power in vehicles is not safe, if by any oversight the train is permitted to attain speed; and that as much as 93 per cent. is required under certain possible conditions of rail. Every passenger carriage should, in my opinion, have a brake attached to it, and in descending, if the incline brakes are discontinued, a proportion of the vehicles equal in number to what has been recommended for goods trains, should have the brakes fastened down by weights or springs. For the remainder there should be a brakesman for every two carriages. These men should be able to communicate with one another by rope signal, or by walking from one carriage to the other along the foot-boards.

17. I think the weights proposed are reasonable. With a descending train, braked as I propose, it would not be necessary for purposes of safety to use two engines; but, as the ascending load must be limited, there is no objection to limit the descending load on the ground of its entailing needless expense. It is of course understood that the number of brakes to be used in rear of ascending trains will weigh not less than one-third the weight of the other vehicles, inclusive of engine.

13.—Maximum weight of ascending and descending passenger trains with single engine not to exceed 130 tons in ascending, and 150 tons in descending.

18. Captain White's experiments prove that the proportion of brake-power here recommended is not sufficient. My opinion on the amount of brake-power required is noted in para. 16 of this letter. The carriages braked down should be placed nearer the rear than the head of the train, and brakesmen should be employed on all the others, as before observed, in the ratio of one man for every two carriages.

14.—Brake-power with descending passenger trains not to be less than 50 per cent. of the weight of the the vehicles, exclusive of engine, and that the brake-vans in carriages should be placed in front of descending, and in rear of ascending trains.

19. If all vehicles are to have brakes attached, and a certain proportion are to be worked down with brakesmen, the same proportion may as well be worked up, as no expense is involved. I do not of course recommend that every wagon should be pulled up the incline with brakes fastened down.

15.—Proportion of vehicles to be available as brake-power in ascending trains.

20. I think above the reversing station, Thull Ghât, and Wonee catch-siding on the Bhore Ghât, the speed should be limited to 10 miles an hour. Below it might be fixed at 15 miles an hour. Above these points, both Ghâts are steeper than below, and it would be as well to maintain a difference in the rate of speed on the two sections.

16.—The velocity of descending trains to be limited to 12 miles an hour.

21. I am of opinion that this project should be abandoned. The expense will be enormous, and safety is insured by catch-sidings put in above the reversing stations.

17.—Diversions to do away with the reversing stations.

22. This has been carried out. There are catch-sidings of sufficient length and rise between the two reversing stations, to catch and stop a runaway train. On the Thull Ghât there are two other catch-sidings, and on the Bhore Ghât one other catch-siding between the top of the Ghât and the reversing station. On the Bhore Ghât there is one catch-siding between the reversing station and the foot of the incline. Another is proposed, but is not, in my opinion, wanted. It has been partly made, but its present length is so short that to allow a runaway train to enter it would ensure its destruction. The points have been taken out, and I would recommend that the rails be also removed.

18.—Catch-sidings at the reversing stations, and one catch-siding between the reversing station, Bhore Ghât, and the foot of the incline.

23. This suggestion has been carried out. The curves are as easy as it is possible to make them, and there are signals and Telegraph Offices close by. But, to permit of these sidings being used with safety, it is necessary that the character of the points should be improved. There are only ordinary points and crossings now at the catch-sidings. Instead of these, I think there ought to be points—used, I hear, sometimes on single lines at home—where the approach of a carriage within 20 or 30 yards of the points will jam them open, or shut, as may be desired by the pointsman, and will keep them so fixed till the train has cleared off with safety. The present points, unless locked, (and even then they are not free from danger), would probably not remain fixed if a train was rattling over them at 50 or 60 miles an hour, swaying, as these trains do, from side to side, and with the flanges of the wheels striking the rails at every oscillation in going round the sharp curves at which the points and crossings are set.

19.—That catch-sidings should be connected to descending line by easy curves, and that there should be telegraph stations and signals at the points.

24. This is the rule now. The only new feature in the recommendation is the suggestion that the incline brakesman should himself open or unlock the points. This suggestion has been frequently considered, but has not been hitherto carried out. It will be again discussed with the Company.

20.—Trains to stop at catch-siding points till the preceding train has been reported clear of the points of the next siding, or into the station.

25. I should like to see this done, but I am afraid it is not possible to make them, except so short as to cause the destruction of any wagon that slipped into them. The suggestion should, however, be carefully investigated; but there is an improvement that would cost but little, and would add to the safety of the line: I refer to putting in points on the cross over road on the ascending line of such pattern as to stand open to the ascending line when a train was on the descending line, within a certain distance of the crossing; while, at other times, they would stand open to pass a runaway wagon on to the catch-siding. I think points of this pattern would not be difficult to contrive, and they might prevent an accident.

21.—Catch-sidings in connection with the ascending line, which should not come into contact with the descending line.

26. I have already observed that I am afraid it is impossible to carry out this suggestion. It is obviously inadvisable to construct a catch-siding that must destroy everything running into it; but, on the other hand, it is difficult to find places where catch-sidings can be laid out of sufficient height and length to prevent this destruction.

22.—That catch-sidings for the ascending line should be long enough to destroy the momentum of any wagon that could run into it.

27. These signals were seen to before the line was opened.

23.—Signals at reversing station.

28. I have now, in conclusion, to recapitulate the conclusions I have arrived at from a study of the facts brought to notice by Captain White:—

1*st*.—All vehicles, passenger or goods, belonging to the Great Indian Peninsula Railway Company, ought to have an apparatus for braking every wheel, workable from both ends of the vehicle at pleasure, either by hand, weight, or spring.

2*nd*.—That all vehicles should have a projection at either end on which brakesmen can stand to work the brakes.

3*rd*.—That a certain fixed proportion of all vehicles in a descending train, regulated according to whether it is day or night, or by the section of the line, should have their brakes fastened down at the commencement of the descent.

4*th*.—That on every two other vehicles a brakesman should be stationed, who should have the control of the brakes of those vehicles.

Dated —February, 1870.

From—Captain J. H. White, R.E., *Depy. Consg. Engr. to the Govt. of Bombay, Ry. Dept.*,

To—*Consulting Engineer for Railways, Bombay.*

I have the honour to submit herewith the result of the experiments that I have carried out on the Bhore Ghât in accordance with Government Resolution No. 1886 of the 4th October 1869, in order to determine the co-efficient of friction of brake-power in the working of the incline.

2. The greater number of the experiments were made on the upper portion of the incline on the gradients of 1 in 40 and 1 in 50 between Lanowlee and Khandalla. As the distance between these two stations is only 2 miles, but a very short section of the line was blocked to traffic while the experiments were going on, and Lanowlee being the head-quarters of the Traffic and Locomotive Departments of the Ghât section, men and materials were always ready at hand, and we were thus enabled to avail ourselves to the full of the two or three hours' possession of the line accorded to us by the traffic in the early morning. The Assistant Locomotive Superintendent of Lanowlee, Mr. Bell, was present at nearly all the experiments, and my best thanks are due to him for the great assistance he has given me, and the ready manner in which he worked with me throughout.

3. A plan and section of the Ghât are annexed; it will be seen that the road at the head of the incline is straight for the first 814 yards; there is then 308 yards of curve of 80 chains radius, then 462 yards of straight, then 286 yards of a 40-chain curve, then 286 yards of straight, and after this an S curve of 40 and 30 chains radius, which reaches nearly to Khandalla Station; it will be allowed, I think, that for all practical purposes the line may be considered straight for the first 1,584 yards (or seven-eighths of a mile) at the head of the incline.

Plan of incline.

4. In the larger number of instances, the rolling friction has been determined from the experiments made on the straight line; it hardly appeared to me necessary to take into consideration the resistance of the curves, as I found in actual practice from a few experiments made on the curves of 40 and 30 chains radius, that the increase of friction was not appreciable; the difference of the co-efficient of friction on the same morning, running with the same vehicles, and over the same straight section of the line, was often greater than would be caused by any but a sharp curve. The influence of the curve was, in fact, only felt when the vehicle was running at very low velocity, that is, when it was at the point of stopping.

5. It is to be remarked also that the accuracy of the experiments was scarcely, if at all, affected by the varying force of the wind, for the upper portion of the incline is singularly free from those violent currents which are so prevalent at this time of the year at Khandalla and the reversing station. Whatever breeze there was, was in favour of the vehicle, increasing its velocity, and thus slightly diminishing the deduced friction.

Manner of carrying out experiments.

6. The experiments were carried out in the following manner:—

The vehicle or vehicles were allowed to descend the incline by gravity for a certain measured distance; at the end of this length fog-signals were placed at an interval of 66 and 44 yards (they were first placed at a distance of 66 yards, but as the increase of velocity was decidedly observable in running over this length, I reduced the interval to 44 yards); the velocity between the fog-signals, which was accurately registered by chronographs, was considered as the final velocity. On reaching the second fog-signal, the brakes were instantaneously applied, and the vehicle or vehicles were brought to a stand in a certain distance; this distance having been measured, the vehicles were hauled up the incline by an engine, and the experiment was then repeated at any required velocity.

7. As a rule, the experiments were carried out at what may be considered high velocities for the Ghâts, *i. e.*, at speeds varying from 15 to 40 miles an hour; there appeared to me no necessity for working either at low velocities or with heavy loads. In the former case, in an *ordinary* condition of the rail, if Ghât rules are adhered to, and there is a proper provision of dry sand, the incline may be considered safe; in the latter there would have been great delay in carrying out the experiments and with no corresponding results; the brake-power must be always proportionate to the load, and whatever proportion is found necessary for a train of 30 tons descending the incline, a corresponding proportion will always be required for a train of 200 tons, supposing both trains to descend the incline under similar circumstances.

8. The action of the brakes, both skidding and not skidding, was tested over a rail in every *possible* condition. Though I was most unfortunate in not being able to test the effects of a heavy dew, a considerable number of experiments were made in the early morning when there was a slight dampness on the rail, and the result of these has alone been quite sufficient to show what a dangerous element dew is in the working of early morning trains in the cold season of the year.

9. A very heavy dew may perhaps be represented by an oiled rail, though not to such an exaggerated extent as many would consider. I am, in fact, rather doubtful whether the effects of the former can be *much* exaggerated; one or two experiments will hereafter be alluded to regarding this point—at first cocoanut oil was employed for lubricating the rail, but as this congealed and was difficult to lay on, it was found better to use castor-oil, which has, I believe, higher lubricating powers. The rail was also treated with soap, but this dried up too soon, and then became sticky, so that the skidded wheel running over it gave but little, if any, difference of result from that of the dry rail.

10. The vehicles experimented on were generally Ghât brakes, open at both ends, opposing little resistance to the wind, and of an average weight of about 10 tons. Brake W, which was used oftener than the others, was provided, in addition to the ordinary brake-van, with a heavy lever, working on to 4 brake-blocks, which, when allowed to fall, skidded the wheels immediately, and thus secured a greater amount of accuracy in calculating the length run with skidded wheels, after passing the second fog-signal.

11. The manner in which the co-efficients of friction and adhesion of brakes have been worked out may be stated, though I have only followed ordinary mathematical principles.

Method of calculating friction.

If a body falls down an incline plane $A\,F\,B$, were there no friction, it would attain a velocity at a point F due to the height $A\,D = h$, but as motion is impeded by friction, it only attains a velocity due to a height which I will call h'; this loss in height, or the difference between h and h' divided by the length $A\,F = l$, gives the rolling friction, including the resistance of the air. Stated in other terms, if W be the weight and M the mass of the body, the work the body should accumulate at F without friction would be $W \times h$, but it only accumulates $W \times h'$. The work lost then is the work destroyed by friction *(F)*, or

$$Wh - Wh' = Mfl \text{ or } Mf = \frac{h-h'}{l} W.$$

where $h' = \frac{v^2}{2g}$, v being the velocity in feet per second shown by the fog-signals over the distance $F\,F'$ (44 yards).

When the vehicle runs skidded from F to B, where it is supposed to stop, motion is then entirely destroyed by friction (f'), which thus overcomes the work due to the height h' + that due to the additional height $D\,C = h''$ or $Wh' + Wh'' = M'\,f'\,l'$ where $F\,B = l'$

$$M\,f' = \frac{h'+h''}{l'} W = \left(\frac{v^2}{2gl'} + \frac{h''}{l'}\right) W = \left(\frac{v^2}{2gl'} + \frac{1}{40}\right) W.$$

supposing that the brake was running on an incline of 1 in 40.

12. All the problems have been solved by these equations, and the results tested by the experiments, which were afterwards carried out in the catch-siding. These will be compared hereafter.

Experiments with Ghât lorry. Skidding and not skidding.

13. As some alterations were being carried out on brake W, I commenced the experiments by trying the different effects of skidding and not skidding on a Ghât lorry. This lorry weighed altogether with its load 1,712 lbs., was in good running order, and was provided with 2 brakes, which allowed of the brake-power being applied to a nicety. The result was as follows:—

Running at a velocity of 26·4 miles per hour on the incline of 1 in 40 (experiments 1 to 12), the lorry was pulled up on a dry rail when the wheels were *skidded* in 87 yards, and the adhesion worked out $\frac{1}{8\cdot6}$; running at the slightly lower velocity of 25·6 miles per hour, it was pulled up *without skidding* the wheels in 56 yards, and the adhesion was as much as $\frac{1}{6\cdot4}$.

14. Experiments were afterwards made with an incline brake, which gave somewhat the same result. In an average of seven experiments, going at a velocity of 28·79 miles per hour, the vehicle was stopped with *skidded* wheels in 190 yards, and at a velocity of 34·4 miles in 241 yards; with the wheels *not skidded*, and going at a velocity of 28·12 miles, the vehicle was pulled up in 127 yards, and at a velocity of 33·75 miles in 179 yards. The adhesion obtained by not skidding the wheels was always greater than that by skidding. The results of these experiments will be clearly seen in the following Table:—

	No. of experiments.	Velocity in miles per hour.	Distance run after application of brake.	Adhesion.	
Lorry.			Yards.		
Wheels skidded ...	6	26·4	87	$\frac{1}{8\cdot6}$	Experiments 1 to 6.
„ not skidded ...	6	25·66	56	$\frac{1}{6\cdot4}$	„ 7 to 12.
Ghât Brake.					
Wheels skidded ...	7	28·79	190	$\frac{1}{13\cdot7}$	Experiments 39 to 45.
„ not skidded ...	4	28·12	127	$\frac{1}{10\cdot6}$	„ 50 to 53.
„ skidded ...	4	34·4	241	$\frac{1}{12\cdot5}$	„ 46 to 49.
„ not skidded ...	4	33·7	179	$\frac{1}{10\cdot5}$	„ 54 to 59.

15. The same experiments were also tried with two vehicles coupled together, one or both being braked, and with the lorry on an *oiled* rail, but not always with the same results.

	No. of experiments.	Velocity in miles per hour.	Distance run after application of brake.	Adhesion.	
Ghât and Main Line brakes, both vehicles being braked.			Yards.		
Wheels skidded ...	3	29·7	132	$\frac{1}{9\cdot7}$	Experiments 64 to 69.
„ not skidded ...	3	29·7	153	$\frac{1}{11\cdot2}$	
Only Ghât brake on.					
Wheels skidded ...	5	28·48	416	$\frac{1}{14\cdot7}$	Excluding first run. Experiments 166 to 170.
„ not skidded ...	6	29·	312	$\frac{1}{11\cdot5}$	„ 171 to 176.
Lorry on oiled rail.					
Wheels skidded ...	7	23·68	288	$\frac{1}{21\cdot4}$	Experiments 18 to 24.
„ „ ...	5	26·	344	$\frac{1}{21\cdot6}$	„ 13 to 17.
„ not skidded ...	10	24·66	372	$\frac{1}{23}$	„ 25 to 34.

When both vehicles were braked they ran *farther* when the wheels were not skidded, which may be accounted for by the difficulty in regulating the brake of the main line vehicle; when only one vehicle, the Ghât brake was braked, by not skidding, they were pulled up *in a shorter distance*; the velocity being nearly the same in all the experiments, the respective distances run by the vehicles after passing the signal, with wheels skidded and with the wheels just allowed to revolve, were 542, 479, 475, 257, 330, and 227, 310, 282, 308, 301, 442 yards; again the lorry was stopped sooner on an oiled rail by skidding.

16. In addition to these experiments I tried many others at different times, and came to the conclusion that the point was not of great practical importance. When the rail is greasy, and the brake-block is dry, there is not much choice in the matter, for the wheel skids at once when the brake is applied; when the rail is dry, the effect of applying the brake firmly is rapid in either case in checking the speed. Moreover, it is not always optional whether you shall skid the wheels or not, for, from a constant observation of the action of the brakes in working down the incline, I found it frequently the case, as might, in fact, have been expected, that the front wheel was revolving whilst the rear one was skidded, whilst in a few cases the wheels could not be got to skid at all; everything depends on the wear of the brake-blocks and the position of the vehicle; and, as the brakes are constantly applied to the vehicles working both up and down the Ghât and round sharp curves, it is difficult to obtain an equal pressure on the two pair of wheels at the same time.

17. It may be remarked, however, that in certain lines in France, where iron brake-blocks have been substituted for wooden ones, the wheels are allowed to turn slowly in descending the inclines; and it is stated that a "better retardation of the motion of the train is obtained if the blocks are not pressed upon the wheels during the whole time required for the stopping of a train, but are lifted up, and pressed upon again, at very short intervals." In the tabulated list of experiments at the end of this Report, where it is not stated to the contrary, the brakes are supposed to be skidded.

18. I will now refer to the different experiments on brake-power, taking first those on an ordinary dry rail, and secondly those on a damp and oiled rail.

Brake-power on a dry rail.

19. On an ordinary dry rail the co-efficient of friction varies from $\frac{1}{8}$th to $\frac{1}{15}$th of the weight, and an average of 102 experiments on the descending line makes it to be ·0918, or nearly $\frac{1}{10\cdot9}$; this co-efficient, worked out according to the method described in para. 11, is rather larger than that obtained by the experiments made on the contrary incline of the catch-siding (see experiments 216 to 222), where it varies from $\frac{1}{11\cdot2}$ to $\frac{1}{12\cdot4}$. In these latter experiments the vehicle descended the incline by gravity, and after passing through the points and crossing of the siding and reaching the point marked A on the section, the brake was

applied immediately it began to ascend the contrary incline; and the co-efficient of adhesion is worked out from the distance run on the ascending line, as in the previous experiments it is from the distance on the descending line.

20. There is no doubt that a coefficient of adhesion of $\frac{1}{10\cdot9}$ is much lower than what is generally allowed in calculating brake-power. The difference between the results of these experiments and the data given by Mr. Rankine and Mr. Fairbairn would be as follows, in the case of a train running on the level :—

Speed in miles	20	25	30	35	40
* Distance in feet required for stopping train on level with brakes on all the wheels according to Mr. Rankine's formula	96	150	216	291	384
* Ditto ditto according to Mr. Fairbairn's formula	105	171	242	325	420
Ditto ditto according to the Ghât experiments ...	142	231	327	439	568

21. For all practical purposes, however, in working the incline, it would be perfectly safe to reckon on a co-efficient of friction of $\frac{1}{7\cdot5}$ for all trains working over the Ghâts in the day time (from 8 A. M. to 6 P. M.) during all seasons but the monsoon; with this co-efficient, as will be hereafter shown in discussing the experiment on the damp and oiled rail 35 per cent. of brake-power would keep the train under perfect control on the steepest gradient of the Ghât inclines.

22. These results are derived from experiments with trains of from 10 to 64 tons weight; as it might have been considered that the experiments were incomplete without testing the efficiency of brake-power on heavy loads at high speed, a train of 200 tons, including the engine, was made up in the following manner; two covered cotton wagons and six low-sided wagons, each loaded up with fire-bars to 10 tons, and seven 10 ton Ghât brakes, which are open from end to end—weight of load 150 tons, of engine 49 tons; total load, say 200 tons. The train was what may be called a very compact one, and opposed little resistance to the wind; speed was got up at the head of the incline on the 1 in 40 grade (see experiments 195 to 200).

Experiments with heavy load on dry rail.

23. In the first experiment, after the train had passed over the fog-signals at about 22 miles an hour, the engine and one Ghât brake were braked (30 per cent. brake-power), and after running a short distance the speed was reduced to 16 or 17 miles an hour; the train kept up this rate steadily all along the incline of 1 in 50, though sand was used to the skidded wheels of the brake, and as I saw there was no prospect of stopping before reaching the 1 in 40 gradient (which had been sanded in case of accident) a second brake was applied (35 per cent. brake-power), and the train was finally pulled up after running a length of 1,540 yards; 30 per cent. brake-power was clearly not sufficient to give a perfect command over the train. In the second experiment, the engine passed the signals at 22½ miles per hour, and 35 per cent. brake-power was then applied, no sand being used; the train was pulled up in 594 yards, not having passed at all on to the 1 in 50 gradient. In the third experiment, the engine passed the signals at 25 miles an hour; 40 per cent. brake-power was put on (engine and three brakes), and the train stopped in 616 yards.

In the fourth experiment the engine passed the signals at 28½ miles per hour; 40 per cent. brake-power, as before, was put on with sand to the leading wheels of the engine, and the train was stopped in 528 yards.

In the fifth experiment the engine passed the signals at 24·6 miles per hour; with 50 per cent. brake-power (engine and five brakes), and sand to the leading wheels of the engine, the train was pulled up in 379 yards.

And in the sixth and last experiment, passing over the signals at 28⅓ miles per hour, putting on 50 per cent. brake-power, and using sand to leading wheels of engine and three wheels of three brakes, the train stopped in 355 yards.

According to Mr. Fairbairn's formula, in experiments 2 and 3 the train should have stopped in 162 and 178 yards, whereas in practice the distances were 594 and 616 yards: the discrepancy between theory and practice *on an incline* is very great in this case.

24. These experiments show, I think, that the trains are well under command in any *ordinary* condition of the rail with 35 per cent. brake-power, though allowed to attain speeds varying from 22 to 28 miles an hour on nearly the steepest portion of the incline, and confirm the theory laid down in para. 21, for the necessary amount of brake-power on a dry rail; secondly, that most efficient brake-power is afforded by the heavy class of tank-engine used on the incline; and thirdly, that even on a dry rail sand may sometimes be a valuable adjunct when sand-boxes and sand-pipes are in proper working order.

25. They also showed me how necessary it was that none but steady reliable men of previous railway experience should ever be appointed to such a responsible post as that of Ghât Guard; for days before we had been in the habit of experimenting on the 1 in 40 incline at speeds varying from 30 to 42 miles an hour with comparatively light loads, and were almost as much at ease as if we were working on the level; but when a *heavy* train once attains a high speed on a steep gradient, the impetus appears, as it were, irresistible; and then the noise, the grinding action of the brakes, and the rush down the incline, make up altogether a scene, amidst which it is not to be wondered at that a man of fairly good nerve should not always act with that calmness which the position demands of him. In the fourth experiment two Native brakesmen were so impressed with the idea that the train had got out of control, that, contrary to all orders, they rushed to put on their brakes, and were only just stopped in time by Mr. Pinnock, the Locomotive Foreman, who happened to observe them. If this effect be produced when a train is worked during the day-time, and under the most favourable circumstances, it may well be conceived what steadiness the case demands when train gets out of control in the dark, when the rails are greasy, and the brake-power apparently useless.

* See page 34 and remarks.

Note.—In these six experiments the engine, pushing behind, was only able in two instances to start the train on the 1 in 40; in the other four cases it was necessary to move down on to the 1 in 50 incline. Steam at 120°.

26. I will now refer to experiments that were made in the early morning, and on the oiled rail.

Experiments on damp and oiled rail.

The experiments show that the co-efficient of friction on a damp rail ranges from $\frac{1}{14}$ to $\frac{1}{23\cdot8}$, according to the varying condition of the rail, though I have every reason to believe that when the surface of the rail is covered with heavy dew, the co-efficient becomes as low as even $\frac{1}{30}$. It is most unfortunate that I am unable to prove this point from actual practice, for during the whole of the time the experiments were going on, there was no instance of a heavy dew; but I think I can show that there is every probability of there being the same variation in adhesion on the damp rail as on the oiled rail, and that if the co-efficient of friction on the latter, from some cause that it is extremely difficult to account for, becomes one morning as low as $\frac{1}{30}$ and $\frac{1}{33}$, there is no reason why the same thing should not occur on the damp or dewy rail, on which the co-efficient is generally as low as on the oiled rail.

27. In twenty-eight morning experiments, when the rail was not covered with dew, and the surface was only what may be called imperceptibly damp, the co-efficient of friction varied from $\frac{1}{14}$ to $\frac{1}{23\cdot8}$, and in fifty-three experiments on the oiled rail from $\frac{1}{18}$ to $\frac{1}{33}$, including the lorry experiments and those on the contrary incline of the catch-siding. The following table shows these results clearly :—

Rail in early morning.			Oiled rail.			Remarks.
Velocity before application of brake.	Distance run after application of brake.	Co-efficient of friction.	Velocity before application of brake.	Distance run after application of brake.	Co-efficient of friction.	
Miles.	Yards.		Miles.	Yards.		
25·7	396	$\frac{1}{22\cdot9}$	30·	1562	$\frac{1}{35}$	All the vehicles were braked.
31·03	264	$\frac{1}{15}$	30·4	299	$\frac{1}{17}$	
33·75	443	$\frac{1}{18\cdot7}$	32·1	1100	$\frac{1}{30}$	
34·	486	$\frac{1}{20}$	32·14	385	$\frac{1}{18}$	
40·9	908	$\frac{1}{28\cdot8}$	32·7	363	$\frac{1}{17}$	
19·15	More than 1980	Less than $\frac{1}{16\cdot9}$	40·9	521	$\frac{1}{17}$	
23·68		„ $\frac{1}{16}$	40·9	671	$\frac{1}{19}$	
27·7	1302	$\frac{1}{20\cdot6}$	42·8	627	$\frac{1}{17}$	
29·	970	$\frac{1}{18}$	22·5 Soaped.	More than 1980	Less than $\frac{1}{16}$	30 per cent. brake-power.
30·	1069	$\frac{1}{16\cdot5}$	25·71		„ $\frac{1}{15\cdot6}$	
32·14	1146	$\frac{1}{21\cdot7}$	33 33		„ $\frac{1}{14}$	
32·14	1729	$\frac{1}{20}$	25·71	434	$\frac{1}{14\cdot4}$	54½ per cent. brake-power. *Run on to sand; in damp rail experiments rail was not sanded.
32·14	2640	$\frac{1}{20\cdot9}$	26·47	1065	$\frac{1}{20\cdot7}$	
32·14	1650	$\frac{1}{19\cdot6}$	29·5	560	$\frac{1}{14\cdot4}$	
26·	778	$\frac{1}{19\cdot5}$	31·*	...	Less than $\frac{1}{17}$	
28·125	477·	$\frac{1}{17\cdot7}$	32·14	586	$\frac{1}{16}$	60 and 65 per cent. brake-power.
32·14	594	$\frac{1}{16}$	41·00	664	$\frac{1}{13}$	
33·33	940	$\frac{1}{19}$				

28. If, then, the adhesion is proved by a considerable number of experiments to be frequently greater on the oiled than on the damp rail; and experiment also shows that adhesion on the former becomes as low as $\frac{1}{30}$ and $\frac{1}{35}$: is it illogical to suppose that when the damp rail becomes a dewy rail, the co-efficient of friction on it may prove to be nearly as small as on the oiled rail?

29. I must say that when I first commenced the experiments on the oiled rail, I thought that the lubricating the rail freely with castor-oil was a great exaggeration of the effect that would be produced by dew; but with these experiments before me, I am strongly inclined to believe that it is no exaggeration at all.

30. In support of this I would first briefly notice two experiments (60, 61, 73, 74) that were carried out at the same time on the up and down lines, and the three cases of runaway trains that occurred on the Thull Ghât.

On the morning of the 5th January, the ascending or down line having been oiled, I took the opportunity of testing the running condition of two brakes with which several experiments had been carried out. The two brakes (60, 73 experiments) were started together from the head of the incline—the one on the up, the other on the down line; as the joints are slightly against the running on the ascending line, I thought that this might check to certain extent the velocity of the brake running on that line. The two vehicles, however, with some slight changes of position, passed over the fog-signals at nearly the same moment and at the same velocity, 32·7 miles per hour; the brakes were then immediately applied, and, as of course was anticipated, the vehicle on the dry rail was pulled up first, whilst that on the oiled rail ran 163 yards further.

31. The experiment was then repeated, and in order to try the extreme case of a vehicle attaining a high speed on what I consider to be as slippery a rail as could occur in practice, I changed the position of the fog-signals, and allowed both vehicles to run freely down the incline of 1 in 40 until they attained a velocity of 41 miles per hour, when both brakes were immediately applied as before, all wheels being skidded. The brake on the oiled rail at once shot ahead of that on the dry rail; but after running about 350 yards, much to our surprise, the brake on the dry rail passed us, and was not brought to a stand until it had run for 907 yards, whilst that on the oiled rail stopped in 521 yards (experiments 61, 74).

32. I will now refer to the three cases of runaway trains on the Thull Ghât, in which I think there is every reason to believe that the engine and brakes were worked with all care, but were nevertheless ineffectual in controlling the speed of the train.

* In the case of the 28th October 1868, the train consisted of—

6 wagons,
7 carriages,
1 Main line brake,
4 Ghât brakes,
1 engine with 6 wheels and bogee;

and the total weight was about 175 tons, of which 100 tons, including the engine, were brake-power. The evidence shows that this train, after running for a quarter of a mile on the 1 in 37, gradually *gained speed* until it had attained a velocity of 30 or 40 miles an hour; that this speed was reduced in passing through No. 4 Tunnel, and over the inclines of 1 in 60 and 1 in 73, and that the train finally ran into the catch-siding at from 6 to 10 miles an hour.

Now, if this train gained speed in the 1 in 37, the accelerating force must have been in excess of retarding force, or the force of gravity must have been greater than the retarding force of the brake-power and the rolling friction. The force of gravity amounted to 60·5 lbs. per ton, and if the rolling friction be put down at $\frac{1}{160}$, or 14 lbs. per ton, a co-efficient of adhesion of $\frac{1}{22}$ would have just kept the train in control, thus—

$\frac{2}{5}$ of weight of train braked, $\frac{3}{5}$ rolling free.

Accelerating force, = 60·5 lbs. per ton.

Retarding force = Brake-power + rolling friction = $\frac{2}{5} \cdot \frac{2240}{22} + \frac{3}{5} \cdot 14 = 66{\cdot}6$ lbs. per ton.

Excess of retarding over accelerating force—5·1 lbs. per ton; but as the train was not retarded, it is clear that the co-efficient of friction must have been much less than $\frac{1}{22}$.

33. Again, on the 27th December, the mail train consisting of—

10 carriages,
2 Road-vans,
2 Main line brakes,
5 Ghât brakes,
2 large Ghât engines,

got beyond control on the 1 in 37, but was most fortunately pulled up by the sanded rail above the Ehegaum Viaduct, which was then under repair. In this case the total weight of the train was about 242 tons, 170 tons of which was brake-power, including the engines.

* *See* Appendix to Bhore Ghât Commission Report. The cases are taken in the order reported.

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With 70 per cent. brake-power this train also gained speed on the same incline. If, therefore, the rolling friction be taken as before at $\frac{1}{160}$, the co-efficient of adhesion on that morning must have been less than $\frac{1}{28}$, thus—

Accelerating force of gravity = 60·5 lbs. per ton.

Retarding force of brakes and rolling friction = $\frac{70}{100} \cdot \frac{2240}{28} + \frac{30}{100} \cdot 14 = 60{\cdot}2$ lbs. per ton.

The Locomotive Superintendent remarks on this accident, that had the timely precaution of sanding the rail been taken, the train would never have exceeded the speed of 10 miles an hour. This may be true, but it is not easy always for men to anticipate what the state of the rails may be, which varies very much on different portions of the incline on the same morning, end the brake-power of the train was, moreover, on that occasion apparently ample. The fact, however, remains good, that according to the evidence, which was very trustworthy, the co-efficient for adhesion on that morning must have been less than $\frac{1}{28}$.

34. Thirdly, on the 2nd November 1868, a train consisting of—

19 loaded wagons,
7 carriages,
3 incline brakes,
2 large Ghât engines,

attained an excessive speed between Egutpoora and the Reversing Station, and was only pulled up by running a distance of 300 yards into the catch-siding. Then the total weight of the train with engines was about 282 tons, 70 per cent. of which was brake-power; and if this amount was insufficient to control the speed, the adhesion on the rails in certain portions of the incline must have been, as in the previous case, less than $\frac{1}{28}$. I say on *certain* portions, for the witnesses state that after running about ½ a mile beyond the head of the incline, the speed began to increase until it got up to 20 miles an hour, but that the train *then* maintained the same *uniform* velocity: the adhesion, therefore, on the lower portion of the incline must have been greater than on the upper, though not sufficient to check the speed of the train.

35. And, finally, with regard to the fatal Bhore Ghât accident, if a train with 60 per cent. brake-power gains speed on an incline of 1 in 37,—which that train did according to the evidence of the witnesses, though all available brake-power was applied,—it follows that the accelerating force must be in excess of the retarding force. The accelerating force was 60·5 lbs. per ton as before; the retarding force must have been less than this, and the co-efficient of friction therefore less than $\frac{1}{25}$.

In similar runaway cases that occur on the Mauritius incline, Mr. Mosse writes:—"In general it is found possible to check the statements (of those working the train), and, assuming them to be true, it would appear that when a train has attained an excessive speed on a slippery rail, all the brake-power which can be applied has but little practical effect."

36. To all this I know it will be replied, that if the co-efficient of adhesion be so low, how is it that the engines drag their heavy loads up the Ghâts, night and day, with so little difficulty? I can only say that there must be something very different in the adhesion of a skidded wheel going down the incline, and the grip of the wheel of the engine going up the incline; that there is a difference is manifest, for on no morning when the adhesion of the brakes was $\frac{1}{20}$ on the descending line, could the engine, according to theory, have dragged its load of 200 tons up on the ascending line; whereas it is well known that this duty is accomplished in all weathers, with but very few exceptions, and with no difficulty. I cannot yet see my way to a clear solution of this question.

37. It appears, therefore, that, for the safe working of the incline, it is necessary to take into consideration that the co-efficient of friction may often be as low as $\frac{1}{30}$, and that brake-power should be provided to meet this co-efficient in such proportion that the retarding forces of the train shall always be in excess of the accelerating force of gravity, apart from the application of sand. That sand is a most invaluable adjunct there can be no doubt, and, with the precautions that are now taken to secure its working efficiently, a train should always be kept under proper control; but times will arise when sand sand-boxes and sand-pipes may not be so well looked after, and it is imperative that the safety of passengers should not be dependent on such liabilities; the safe working of the traffic must also not depend only on trains not being allowed to attain a higher speed than 10 miles an hour, but should, if possible, be ensured, whatever contingency may arise.

Brake-power necessary in working incline.

38. In estimating also the brake-power of a train, it is very desirable that the brake-power of the locomotive should be left out of the question; the train should be able to hold itself, and the locomotive too on every gradient, and in every condition of the rail. Should anything unusual occur, you have then a valuable reserve of power in the locomotive; or should the brake-power of the latter become deranged, there will be sufficient retarding power in the train itself to prevent any acceleration of speed.

39. Irrespective, then, of the brake-power of the locomotive, if the rolling friction (see para. 42) of the carriages is taken at $\frac{1}{160}$ of their weight, every passenger train working on the Ghât should have 77 per cent. of its weight available for brake-power; with a co-efficient of friction of $\frac{1}{30}$, the retarding forces will then always be slightly in excess of the accelerating force; but if a co-efficient of $\frac{1}{35}$ be taken, 93 per cent. would be required, which practically amounts to breaking every carriage in the train.

Conclusion.

See page 164, Bhore Ghât Commission Report. Mr. Charlton's No. 14.

Let x = required brake-power, accelerating force on the 1 in 37 = 60·5 lbs per ton. Then if rolling friction $= \frac{1}{60}$, or 14 lbs. per ton, $\frac{x}{100} \cdot \frac{2240}{30} + \left(\frac{100-x}{100}\right) 14 = 60{\cdot}5 \therefore x = 77$.

40. In the goods trains it would be exceedingly difficult to secure this, and the available brake-power of the locomotive must therefore be relied on to a greater extent. Much, however, may be done to improve the efficiency of the present hand-lever brake, and the blocks should be made to act on both pairs of wheels.

41. The rolling friction, which includes the friction of the axle, of the wheel against the rail, and the resistance of the air, varies considerably in all the experiments. Neglecting experiments 50 to 59 and 161 to 172, when the velocity was calculated over too great a length between the fog-signals, the co-efficient of friction ranges between $\frac{1}{90}$ and $\frac{1}{274}$: this is no doubt a very considerable range; but it must be recollected, first, that the deductions are made from a vehicle allowed to fall absolutely from a state of rest, and that if the wheels and axle-boxes are not in good order, a considerable amount of velocity is lost in the slowness of the starting; secondly, that allowance must be made for errors occurring from time to time in registering the velocity with the chronographs. I had, unfortunately, no instruments capable of doing this with *perfect* accuracy; thirdly, the velocity which shown in all cases is slightly below the real final velocity, which would make the co-efficient of friction and adhesion slightly less than they have been worked out.

Rolling friction.

42. The average of the experiments on the descending line shows the average co-efficient throughout the whole length the vehicle ran to be $\frac{1}{125}$, or from 17 to 18 lbs. per ton, at velocities varying from 18 to 42 miles an hour; and the average of 18 experiments made in the catch-siding gives a co-efficient of $\frac{1}{145}$ or 15 lbs. per ton for velocities up to 47 miles an hour. The latter result I believe to be the more correct, as less element of error enters into the calculations. I endeavoured to find out the resistance due to passing through the points and crossings, but the instruments would not register this with sufficient accuracy. If, however, friction of 1 lb. per ton were allowed for this increased resistance, the co-efficient would then be $\frac{1}{160}$ of the weight, or 14 lbs. per ton, for vehicles working on the Ghât incline.

43. If these results be compared with Mr. Daniel Clark's formula $8 + \frac{v^2}{171}$, it will be found that in a considerable number of the experiments at the higher velocities of 30 to 40 miles an hour, there is not much difference in the results. It is in the lower velocities that difference occurs, the experiments giving a larger amount of friction than is generally allowed for. In fact, in comparing the different experiments, I find it quite impossible to work out the rolling friction according to the varying velocity, for the experiments at the lower speeds often give a larger amount of friction than those at the higher (up to 47 miles an hour). It is only when the vehicle is allowed to run a considerable distance, as in experiments 208 to 215, and to get up a very high velocity, that the great increase of friction with the velocity becomes quite apparent. At a velocity of 58·6 miles per hour, the resistances according to Mr. Clark's formula would be $8 + \frac{58{\cdot}6^2}{171} = 28$ lbs.; experiment 208 at this velocity shows that the *average* resistance throughout the whole run is 22 lbs. per ton. Again, in experiments 212, 213, 214, the formula would give a final resistance of 30, 30 and 28 lbs., but the experiments show that there is an *average* resistance throughout the whole run of 27, 29 and 30 lbs. per ton. This is a very considerable discrepancy, and can only be accounted for by the resistance increasing in a much greater ratio to the velocity than is given in the formula. To lay down a law for this would have required a very much larger number of experiments than have yet been carried out; but I think this much is probably true, that the resistances of trains at high velocities are considerably in excess of the amount that is usually estimated, which is derived too in most cases, from Mr. D. Clark's formula.

44. I think this will appear more clear if experiment 215 be examined. I will first state briefly how this was carried out.

Experiments in catch-siding.

Six low-sided wagons coupled together, each laden with earth up to 10 tons, were let loose from the head of the incline below the reversing station, and allowed to descend by gravity; the rails of the catch-siding, being old and rough, were oiled throughout the whole length of the siding, in order to represent a slippery condition of the rail; of course, it was

impracticable to do this on the main line—the points of the siding were spiked down, and the fog-signals placed at the foot of the descending gradient at an interval of 88 yards.

The distance of the head of the incline from the catch-siding is exactly 5 miles; the height fallen through is 621 feet; length of the catch-siding 1,276 yards, and height 159·6 feet.

The wagons were let loose at 7-50 (in the morning), and reached the points of the catch-siding at 7-55 exactly, having done the distance in five minutes, at an average velocity of 60 miles an hour; they passed the points of the siding at the rate of 75 miles an hour, going over the 88 yards between the signals in 2·4 seconds. Looking down on the wagons from a knoll above the entrance to the siding, they *appeared* to pass with ease through the points and the crossing, and I expected that, as in the previous experiments there was no increase of velocity, they would run only some few feet higher than in the previous experiments, and would then return down the incline of the siding. The end of the catch-siding was not visible from where we stood, but the rise of a cloud of dust soon told us that some accident had happened at the end of the siding. Mr. Pinnock, the Locomotive Foreman, who was stationed a few yards beyond where the wagons had generally run, informed me that they passed him with considerable speed, which they must have, for they struck the dead end of the siding with such force that the leading wagon was found a perfect wreck with its frame-work upside down in No. 2 wagon. No. 2 wagon was also nearly destroyed, and the others more or less damaged.

It will be noticed from the section of the siding that all this occurred on the gradient of 1 in 3; the only way of accounting for the vehicles running so much higher than in the previous experiments, when the *velocities are considered*, is, that they steadied each other in passing through the points and crossing, and the resistance of the air must have been less per vehicle.

45. Now, if the velocity attained in this experiment be examined, it will be found that there was an average friction throughout the whole run of 37 lbs. per ton; the formula would give a final resistance of 41 lbs. What, then, it is required to ascertain is the ratio between the total resistances and the velocity: experiments 205 to 215 will not determine this clearly, but if the velocity of a vehicle were taken at certain intervals of, say, ¼ of a mile, in the descent of the incline, it would then readily be seen when the maximum speed was attained and the force of gravity was counteracted by the resistances. I need hardly say that there would be considerable risk in taking these observations in the vehicle itself, and to have ascertained it in any other way required a larger number of instruments than were at my disposal. In the last experiment (264) I did endeavour to ascertain the velocity midway, but the person who had charge of the chronograph, being flurried by the sudden rush of the vehicles past him, failed to take an accurate observation.

$$W\left(h - \frac{v^2}{2g}\right) = lfM$$
$$\therefore Mf = \frac{\left(621 - \frac{110^2}{64{\cdot}3}\right) W}{26400}$$
$$= \frac{1}{60} W$$
or 37 lbs. per ton.

46. Regarding the catch-siding itself, it should be remarked that in all the experiments that were made the points were carefully spiked down; the vehicle entered the points without much oscillation, but always swayed *very badly* at the crossing. If a runaway train were to enter the siding at any speed with the brakes well on, as they would be, the elasticity of the springs would to a certain extent be diminished, and the vehicles would not take the crossing so easily. Moreover, if the points were not firmly held, the engine running at speed might, by a blow on the switch-rail, spring the points so as to throw the following vehicle off the line. I do not say that the entrance to the siding is unsafe, but these points have to be considered. I am not aware that anything can be done to remedy the crossing, but the very best description of facing point should be adopted for all catch-sidings on the incline. I believe there have been improvements lately in facing points on English Railways which would obviate the danger I allude to.

47. I saw no necessity for testing the height of the catch-siding with a runaway train; if vehicles running freely at 60 miles an hour only attained to a height of 59 feet out of the total height of 159 feet of the siding, no train running away with its brakes on, would reach anywhere near the end. Even when the catch-siding was oiled, it will be observed from experiments 223 to 230, that after the vehicle, going at a velocity of 32 miles an hour, was braked on the contrary incline, it only ran 343 yards (out of total length of 1,276 yards), and attained a height of only 4·3 feet.

48. As it appeared to me of some interest to ascertain what should be the fixed amount of brake-power in working down the Ghâts on an ordinary dry rail, supposing that self-acting brakes were used, and that the engine running free should drag the train down at the rate of 10 to 12 miles an hour, a light train was made up of 6 vehicles, 3 Ghât brakes, and the engine weighing altogether tons 112 cwt. 18.

Working incline with fixed amount of brake-power to passenger carriages.

In the first experiment 18 per cent. of the train was braked (the wheels of 4 wagons being spragged); the engine having put on steam on the 1 in 40, the train moved on at a low speed, and steam was then shut off; the train did not stop, but kept up the same steady rate.

An additional wagon was then braked in four wheels (giving 24 per cent. brake-power,) and the train started as before; after running a short distance it was brought to a stand; 21 per cent. brake-power was then tried, but this also proved too much, and the train was again stopped.

I concluded, therefore, to try the amount of fixed brake-power in the first experiment, *viz.*, 18 per cent. Having started the train and shut off steam, we proceeded at a steady rate of 10 to 12 miles an hour, but on reaching the 40 chain curve on the 1 in 50 incline, the speed became too low; steam was then put on for a few seconds, again shut off, and the train, going at a steady rate of 10 to 12 miles an hour, finally pulled up on the 1 in 330 at Khandala Station without applying any additional brake-power.

It is interesting to remark here, that practice corresponds with the results derived from experiment on a perfectly dry rail; for the train to maintain a uniform speed on an incline of 1 in 40, the accelerating forces must be slightly in excess of the retarding forces. They were so in the present instance, and reasoning from this fact, the co-efficient of friction works out between $\frac{1}{9}$ and $\frac{1}{10}$.

Working train with fixed brake-power over oiled rail.

49. On the 18th January I tried the same experiment on an *oiled rail*, the train being made up as follows:—

1 engine.
3 Ghât brakes.
4 low-sided wagons.
2 cotton wagons (with Mr. Bell's self-acting brake attached.) } Empty.

Weight of engine 49 tons, of train 64 tons; total 113 tons.

In order to be certain as to the state of the rail, I made two experiments, 77 and 78, which showed the coefficient of friction to be $\frac{1}{30}$ and $\frac{1}{35}$; the rail was therefore the most slippery that I had yet experienced. This being the case, and to guard against all chance of accident, all the vehicles of the train were braked (the wheels of the four low-sided wagons being spragged), and the engine allowed to run free (as a carriage) on to the oil; but when steam was shut off the train pulled up almost immediately, a certain portion of it not having worked on to the oiled rail.

The Ghât brakes were then taken off, and the train again started with about 30 per cent. brake-power, the engine running freely in front. A speed of 10 to 12 miles an hour was then kept up to the end of the incline of 1 in 40, and on to the 1 in 50; but after running some length on this gradient, as the speed began to increase, another brake was applied (33 per cent.), which brought down the speed too low, and was therefore again taken off. We, therefore, worked the train with the former 30 per cent. brake-power, which maintained it at a nearly uniform speed, until we were pulled up by running on to the sanded rail.

50. It would appear from this experiment that, with *great* care, the incline may be worked with safety under very trying circumstances, but that it is of the utmost importance that the slightest increase of speed should be at once checked; for this purpose there must be available brake-power, and it is this which strikes me as the weak point in the present working of the Ghât, that there is no brake-power to spare. As the carriages do not sustain themselves, all the work is thrown on to the incline brakes; if these and the engine prove insufficient, there is only the rear main line brake (which is not ordinarily used), and the use of sand to fall back upon; when every vehicle of the train is braked, and the arrangements for sanding are in good working order, all is done that can be done; and if the train runs away under these circumstances (supposing that there is no carelessness), the conclusion is, as remarked by Mr. Mosse, regarding the Mauritius incline, that the gradient is too steep. On the Indian inclines, however, we have not yet reached this point, for the available brake-power is not more than 60 to 70 per cent., and much can yet be done to secure greater safety.

51. I may mention that, after the train had been worked down over the oiled rail, as it was necessary to return to Lanowlee without delay, we tested the power of the engine in working it back over the same incline. Though the engine was working at first on sanded rail, the wheels had been so thoroughly oiled, she experienced great difficulty in starting: once started, however, she was able, with 120 lbs. pressure of steam, to push the load up at the rate of 2 miles an hour, at which rate the train was worked for some 5 or 600 yards on the 1 in 40, when to relieve the engine, the sand was brought into use; this acted like magic, and after a few revolutions the engine pushed the train at the rate of 20 miles an hour, up to the end of the oiled rail with perfect ease. When the rail is damp or oiled, the sand, of course, adheres to the rail more readily, and its efficiency is much increased.

Sand.

52. On the damp* rail the action of sand is very variable. I will now refer to the different experiments that were made upon the use of sand; but it should be remarked that it was difficult to obtain a *large* number of experiments, as, when the oiled rail was once sanded, the line was spoilt for further experiments that morning. In the following table the results are tabulated:—

No. of Experiment.	Description of Vehicle or Vehicles.	Brake-power per cent.	Before applying brake, miles per hour.	Distance run after applying brake, yards.	Co-efficient of Adhesion.
195	Train of 200 tons, including engine.	30 & 35	22·5	1,540	Less than ... ... $\frac{1}{14}$
198		40	28·125	528	Comparatively dry rail. $\frac{1}{10·5}$
199		50	24·6	380	$\frac{1}{12·7}$
200		50	28·125	352	$\frac{1}{10·7}$
105	3 Incline brakes.	35	31·03	1,370	Sand on soaped rail ... $\frac{1}{12}$
125		33	32·14	710	„ on oil ... $\frac{1}{9}$
100		35	33·33	692	„ on dry rail ... $\frac{1}{8·9}$
101		34	30·	718	„ „ „ ... $\frac{1}{10·4}$
102		34	36·	800	„ „ „ ... $\frac{1}{9·1}$
103		34	36·	960	„ „ „ ... $\frac{1}{10·1}$
104		34	36·	2,794	„ „ „ ... $\frac{1}{15}$
157	2 brakes.	50	36·7	387	„ „ „ ... $\frac{1}{9}$
226 to 229	3 brakes.	66	29 to 31	252	„ on steel rail ... $\frac{1}{10·7}$

It will thus be seen that there is not any advantage in some instances in using sand on the damp rail, and that in experiment 104 it was apparently of no use at all.

53. Experiments 101, 102, 103 and 104 were carried out consecutively on the same morning; the fog-signals were placed at the same point in each experiment; and as the vehicles, therefore, ran braked over the same section of the line in each instance, it was to have been expected that—the rail being roughened by the sand used—the vehicles would have been pulled up in a shorter length each time, and the co-efficient of adhesion have been larger. It was not so, however, the co-efficient was greatest in the second experiment; in the third experiment the co-efficient was less than in the second, and the vehicles ran

* Experiments were made in the early morning at 6 and 6-30 A. M., so that the rail was not actually dry.

160 yards further; and in the fourth the co-efficient was as low as $\frac{1}{15}$, and the brakes were not pulled up until they had run 2,794 yards. There was no doubt about the sand-boxes and pipes being in good order, for I stood on the foot-board of the brake, and watched the sand being steadily delivered on to the rail, close to the wheel: it seemed, however, to produce no effect. In the experiments also that were made with the heavy train the adhesion was not always increased by sand; experiments 196 and 197, where no sand was used, giving better results than some of the other experiments. On the oiled rail its effects are very apparent, for the co-efficient of adhesion was thereby at once reduced from $\frac{1}{15}$ to $\frac{1}{9}$; though it may be noted that, on the same morning, on which this experiment was tried,—the oiled rail having been freely sanded from the two sand-boxes of the leading brake,—when the engine of the mail train (ascending incline) arrived at this part of the line, it was quite unable to move its load, and it was found necessary to re-sand the rails from a sand-lorry, and send a second engine down from Lanowlee to assist. If on this latter occasion the use of sand on oil had developed an adhesion of $\frac{1}{9}$, the engine would have been able to move the train, for the resistances amounted to 11,750 lbs., and $\frac{1}{9}$th the weight of the engine to 12,444 lbs. (see para. 56 as to tractive power); but it is evident that, for the ascending train, the co-efficient was less than this.

		lbs.
Resistance of gravity	... 160·2240	
	40	8,960
Resistance of load	110 × 14 =	1,540
„ of engine	50 × 25 =	1,250
Total resistance	...	11,750

54. There can, I think, be no doubt as to the advantage to be derived from the use of sand on a damp rail: experience has demonstrated this all over the world: but it is of great importance that the sand-pipes should work as closely to the rail as possible, as in running round curves, owing to the swaying motion of the vehicle, the sand is often thrown clear of the rail, or very little is deposited. The sand-pipes used on the Ghât brakes undoubtedly deliver well on to the rail, but not having a flexible end, they are apt to be twisted by any imperfection in the permanent-way, and then, of course, become perfectly useless.

Steel-rails

55. As the co-efficient of adhesion is generally considered to be less on the steel-rail, I carried out experiments 231 to 240; from these it will be seen that the co-efficient varied from $\frac{1}{127}$ to $\frac{1}{70}$, which is a decidedly smaller co-efficient than on the ordinary rail. When sand was used, the co-efficient varied from $\frac{1}{9}$ to $\frac{1}{12}$, the average being $\frac{1}{107}$. The subject, however, is not of much importance, for whatever brake-power be eventually provided to meet an extremely slippery condition of the ordinary rail, will be sufficient to allow for the slight loss of adhesion that there is on the steel-rail.

Rolling friction of engine.

56. Regarding the rolling friction of the engine, the experiments, 241 to 264, show that this is greater than what is generally estimated. In 24 experiments (241 to 264) the friction varies from $\frac{1}{101\cdot8}$ to $\frac{1}{70}$ of the weight; 21 of these results are derived from experiments made on the descending line, the engine being allowed to run as a carriage, and the remaining three from experiments in the catch-siding. The former give an average resistance of 28·6 lbs. per ton, the latter of 23 lbs.: everything, of course, depends on the description of the engine and its condition. The engines experimented on were the 8-wheel coupled tank engines used on the Bhore Ghât—diameter of wheels 48 inches, of cylinder 18 inches, length of stroke 24 inches. As the friction appeared rather large, I endeavoured to test it approximately by the load of Ghât engines, that a Ghât engine would draw on the level. The pressure of steam was 120 lbs., and the weight of the engine 49 tons; its traction power would therefore be $\frac{18^2 \times 120 \times 24}{48} = 19{,}440$ lbs.

$$\text{then, load an engine will drag} = \frac{\text{Traction power}}{\text{Resistance in lbs. per ton.}} - \text{its own weight,}$$

$$\text{or resistance} = \frac{\text{Traction power}}{\text{Load + weight of engine.}}$$

It was found that the engine could drag 14 Ghât engines, weighing altogether 560 tons, at the rate of $\frac{1}{2}$ to $\frac{3}{4}$ of a mile an hour. I have no doubt the engine would have done more, but the strain on it was so great, from trying the experiments both on dry and on an oiled rail, that it was not considered advisable to continue the experiment. Allowing, however, that the load was 600 tons, the resistance of the engines dragged was $\frac{19440}{600+49}$, or about 30 lbs. per ton, and the adhesion $\frac{1}{5\cdot4}$. The oiling the rail made no difference, except that more time was taken to move the load; the wheels slipped, and burnt up the oil; the engine then moved forward slightly, stopped again, and so on, until the distance was accomplished.

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In reversing the engine and applying the brake, the friction obtained from an average of eleven experiments was $\frac{1}{10\cdot9}$, or ·0914 of the weight, and the three experiments made on the catch-siding show a co-efficient of $\frac{1}{11\cdot5}$; if para. 19 be referred to, it will be seen that there is very little difference in the result of the experiments on the brakes and on the engine. In both instances, the experiments on the contrary incline of the catch-siding show a less adhesion than those carried out on the descending line; and the bad effect of skidding the wheels is also very apparent (compare experiments 241 and 246 with other experiments).

Beyond these points, I do not consider that I am called to go into the further question of the proper system of working the Ghâts. Whatever system of brake-power be adopted, it is essential, as laid down by Mr. Hawkshaw regarding brake-power in general, that it shall be equally under the command of the engine-driver and guard: both should, if possible, have an independent command of the power by which a train may be stopped. If the suggestions made in Mr. Berkley's report of using Clark's new continuous brake be carried out, and prove successful, the whole difficulty is met; but if they are not successful, it is very probable that, by increasing the number of compound Ghât brake carriages, and attaching a self-acting brake to all but first class carriages, safety in the future working of the Ghât may always be relied on.

Experiments on Brake-power carried out on

Number of Experiments.	Description of Vehicle or Vehicles.	State of Rail.	Brake-power per cent.	Before Brakes were applied.		
				Distance run, yards.	Height fallen, feet.	Speed in mile per hour.
1 to 6 6	Lorry, weighing with load 1,712 lbs. diameter of wheels.	Dry ...	All ...	650	48·86	26·4
7 to 12 6	Ditto ...	Do. ...	Do. ...	650	48·86	25·66
13 to 17 5	Ditto ...	Greased with cocoanut oil.	Do. ...	650	48·86	26·
18 to 24 7	Ditto ...	Do. ...	Do. ...	528	39·6	23·68
25 to 34 10	Ditto ...	Do. ...	Do. ...	594	44·55	24·66
35 to 38 4	Ditto ...	Do. ...	Do. ...	594	44·55	24·66
39 1	Ghât Incline Brake weighing 10 tons 3 cwt. 1 qr.	Damp ...	Do. ...	660	49·5	25·7
39 to 45 7	Ditto ...	Dry ...	Do. ...	660	49·5	28·79
46 1	Ditto ...	Damp ...	Do. ...	Kicked over Incline.		33·75
46 to 49 4	Ditto ...	Dry ...	Do. ...			34·43
50 to 53 4	Ditto ...	Do. ...	Do. ...	660	49·5	28·12
54 to 59 6	Ditto ...	Do. ...	Do. ...	Kicked over Incline.		33·75
60 1	Ditto ...	Damp ...	Do. ...	660	49·5	32·7
61 1	Ditto ...	Do. ...	Do. ...	1,056	79·2	40·9
62 1	Ditto ...	Dry ...	Do. ...	616	46·2	32·1
63 1	Ditto ...	Do. ...	Do. ...	638	47·85	30·
64 to 66 3	Ghât and Main Line Brakes weighing T. C. Q. 10 2 2 and T. C. Q. 6 12 1.	Do. ...	Do. ...	660	49·5	29·7
67 to 69 3	Ditto ...	Do. ...	Do. ...	660	49·5	29·7
70 1	2 Incline Brakes ...	Do. ...	Do. ...	Kicked over Incline.		36·
71 1	Ditto ...	Damp ...	Do. ...	660	49·5	31·03
72 1	Ditto ...	Do. ...	Do. ...	990	74·25	34·
73 1	1 Incline Brake ...	Oiled rail ...	Do. ...	660	49·5	32·7
74 1	Ditto ...	Do. ...	Do. ...	1,056	79·2	40·9
75 1	Ditto ...	Do. ...	Do. ...	Kicked over Incline.		40·9
76 1	Ditto ...	Do. ...	Do. ...			42·8

Gradients of 1 in 40 and 1 in 50 on the Bhore Ghât.

After Brakes were applied.		Rolling friction, &c.	Friction of Brakes, &c.	Date of Experiment.	Remarks.
Distance run, yards.	Height fallen, feet.				
87	6·525	1/77·3	1/8·6	8th December	Wheels skidded.
56½	4·237	1/72·5	1/6·4	8th do.	Do. not skidded.
344	25·8	1/74	1/21·6	9th do.	Do. skidded on oiled rail.
288	21·6	1/76	1/21·4	10th do.	Do. do.
372	27·9	1/73·6	1/23	11th do.	Do. not skidded on oiled roil.
242	18·15	1/73·6	1/18	11th do.	Do. skidded on do.
396	29·7	...	1/22·9	13th do.	Do. do. early morning run
190	14·25	1/89	1/13·7	13th do.	Do. skidded.
443	33·25	...	1/18·7	13th do.	Do. do. early morning run.
241	18·075	...	2/25	13th do.	Do. do.
127	9·525	1/89	1/10·6	13th do.	Do. not skidded.
179	13·425	...	1/10·5	13th do.	Do. do.
200	15·	1/145	1/12	5th January.	Early morning run.
908	58·44	1/136	1/23·8	5th do.	Do. do.
171	12·8	1/157	1/10·8	18th do.	
168	12·6	1/108	1/11·8	18th do.	
153	11·47	1/99	1/10·6	14th December.	Not skidding.
132	9·9	1/99	1/10·6	14th do.	Skidding.
220	16·5	...	1/11	3rd January.	Do.
264	19·8	1/114·4	1/15	12th do.	Do. early morning run.
486	36·45	1/83·4	1/20	12th do.	Do. do. do.
363	27·225	1/145	1/17	5th do.	Rail oiled from point of application of brake.
521	39·075	1/136	1/17	5th do.	
671	50·16	...	1/19	5th do.	
627	47·00	...	1/17	5th do.	

Experiments on Brake-power carried out on

Number of Experiments.	Description of Vehicle or Vehicles.	State of Rail.	Brake-power per cent.	Before Brakes were applied.			After Brakes were applied.		Rolling friction, &c.	Friction of Brakes, &c.	Date of Experiment.	Remarks.
				Distance run, yards.	Height fallen, feet.	Speed in mile per hour.	Distance run, yards.	Height fallen, feet.				
77 1	1 Incline Brake ...	Oiled rail ...	All ...	616	46·2	32·1	1,100	75·9	$\frac{1}{157}$	$\frac{1}{30}$	18th January	Immediately after these experiments train with engine in front worked over incline to Khandalla. —See Report, para. 49.
78 1	Ditto ...	Do. ...	Do. ...	638	47·85	30·	1,562	103 95	$\frac{1}{108}$	$\frac{1}{35·7}$	18th do.	
79 and 80 2	3 Incline Brakes ...	Do. ...	Do. ...	638	47·85	30·	299	22·5	$\frac{1}{109}$	$\frac{1}{17}$	23rd December	
81 1	Ditto ...	Do. ...	Do. ...	660	49·5	32·14	385	28·875	$\frac{1}{132}$	$\frac{1}{18}$	23rd do.	
82 1	Ditto ...	Soaped ...	Do. ...	220	16·5	16 98	59	4·425	$\frac{1}{95}$	$\frac{2}{25}$	22nd do.	Rail re-soaped after each run.
83 1	Ditto ...	Do. ...	Do. ...	352	26·4	20·93	95	7·125	$\frac{1}{133·7}$	$\frac{1}{13}$	22nd do.	
84 1	Ditto ...	Do. ...	Do. ...	638	47·85	31·03	185	13·875	$\frac{1}{122}$	$\frac{1}{12}$	22nd do.	
85 1	Ditto ...	Rail damp...	33 & 66	660	49·5	32·17	1,848	...	$\frac{1}{132}$	Less than $\frac{1}{14}$	15th do.	Early morning run; velocity was diminished to a steady rate of about 22 miles an hour; as speed then showed no diminution, another brake was put on at 1,300 yards, and train pulled up in 548 yards.
86 and 87 2	Ditto ...	Do. ...	33 & 66	...	...	* 19·15 23·68	...	...	...	* Less than $\frac{1}{169}$ less than $\frac{11}{16}$	15th do.	* Speed was diminished in both cases to a very low speed of 4 to 5 miles an hour; train would not pull up in reasonable distance, so 2nd brake was applied.
88 1	Ditto ...	Dry ...	33	198	14·85	18·	228	17·1	$\frac{1}{148\frac{1}{2}}$	$\frac{1}{9·18}$	17th do.	
89 1	Ditto ...	Do. ...	33	220	16·5	18·75	259	19·5	$\frac{1}{138}$	$\frac{1}{9·47}$	17th do.	
90 1	Ditto ...	Do. ...	33	264	19·8	20·93	688	51·18	$\frac{1}{152}$	$\frac{1}{10·3}$	17th do.	
91 1	Ditto ...	Do. ...	33	440	33·	28·12	1,214	82·74	$\frac{1}{199}$	$\frac{1}{12·5}$	17th do.	
92 and 93 2	Ditto ...	Do. ...	33	440	33·	29·	690	51·3	$\frac{1}{274}$	$\frac{1}{9·2}$	17th do.	
94 1	Ditto ...	Rail slightly damp.	33	264	19·8	19·85	488	36·6	$\frac{1}{119}$	$\frac{1}{11·7}$	21st do.	
94 to 96 3	Ditto ...	Dry ...	33	264	19·8	19·8	333	24·975	$\frac{1}{118}$	$\frac{1}{10·2}$	21st do.	Rail cleaned by run 94.
97 to 99 3	Ditto ...	Do. ..	33	418	31·35	25·47	540	40·5	$\frac{1}{130}$	$\frac{1}{10·}$	21st do.	
100 1	Ditto ...	Dry rail sanded.	35	638	47·85	33·33	692	51·42	$\frac{1}{180}$	$\frac{1}{8·9}$	22nd do.	Sand used to 4 wheels of one brake.
101 1	Ditto ...	Do. ...	34	660	49·5	30·	718	52·98	$\frac{1}{102}$	$\frac{1}{0·4}$	20th January	
102 1	Ditto ...	Do. ...	34	Kicked over Incline.		36·	800	57·9	...	$\frac{1}{9·1}$	20th do.	
103 1	Ditto ...	Do. ...	34			36·	960	67·5	...	$\frac{1}{10·1}$	20th do.	
104 1	Ditto ...	Do. ...	34			36·	2,794	190·8	...	$\frac{1}{15}$	20th do.	
105 1	Ditto ...	Soaped rail sanded.	35	638	47·85	31·03	1,370	92·1	$\frac{1}{122}$	$\frac{1}{12}$	22nd December	

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Gradients of 1 *in* 40 *and* 1 *in* 50 *on the Bhore Ghât*—(continued).

Experiments on Brake-power carried out on

Number of Experiments.	Description of Vehicle or Vehicles.	State of Rail.	Brake-power per cent.	Before Brakes were applied.		
				Distance run, yards.	Height fallen, feet.	Speed in mile per hour.
106 1	3 Incline Brakes ...	Soaped ...	33	198	14·85	18·
107 to 109 3	Ditto ...	Do. ...	33	220	16·5	18·75
110 1	Ditto ...	Do. ...	33	264	19·8	20·93
111 1	Ditto ...	Do. ...	33	308	23 1	21·95
112 1	Ditto ...	Do. ...	33	352	26·4	22·50
113 1	Ditto ...	Do. ...	33	396	29·7	24·32
114 & 115 2	Ditto ...	Do. ...	33	440	33·	26·47
116 1	Ditto ...	Do. ...	33	484	36 3	28·12
117 1	Ditto ...	Do. ...	33	528	39·6	29·
118 1	Ditto ...	Do. ...	33	572	42·9	30·
119 1	Ditto ...	Do. ...	33	616	46·2	31·3
120 1	Ditto ...	Do. ...	33	660	49·5	31·3
121 1	Ditto ...	Do. ...	35	638	47·85	32·1
122 1	3 Incline Brakes T. C. Q. weight 30 8 0.	Do. ...	36	330	24·75	22·5
123 1	5 empty vehicles T. C. Q. weight 25 11 0 &	Do. ...	36	396	29·7	25·71
124 1	3 Incline Brakes.	Oiled ...	33	63	47·85	33·33
125 1	Ditto ...	Oiled & sand to leading brake.	33	638	47·85	32·14
126 & 127 2	T. C. Q. 5 Wagons 25 11 0 and 3 Brakes T. C. Q. 30 15 2.	Oiled ...	36	616	46·2	30·00
128 1	T. C. Q. 3 Brakes 30 5 0 and 6 Wagons T. C. Q. 33 13 0.	Damp, first run in morning *up line* damp.	48	616	46·2	27·7
129 1	Ditto ...	Do. ...	48	836	52·14	30·
130 1	Ditto ...	Rail now drier on *down* line.	48	616	46 2	29·
131 1	Ditto ...	Do. ...	48	1,012	75·9	39·13

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Gradients of 1 in 40 and 1 in 50 on the Bhore Ghât—(continued).

After Brakers were applied.		Rolling friction, &c.	Friction of Brakes, &c.	Date of Experiment.	Remarks.
Distance run, yards.	Height fallen, feet.				
490	36·75	$\frac{1}{148\frac{1}{2}}$	$\frac{1}{12}$	18th December	
253	18·975	$\frac{1}{139}$	$\frac{1}{9\,3}$	18th do.	
238	17·85	$\frac{1}{153·7}$	$\frac{1}{8}$	18th do.	
280	21·00	$\frac{1}{132}$	$\frac{1}{8\,5}$	18th do.	
347	26·025	$\frac{1}{111}$	$\frac{1}{9\,7}$	18th do.	
494	37·05	$\frac{1}{121}$	$\frac{1}{10\,1}$	18th do.	
533	39 975	$\frac{1}{137\,3}$	$\frac{1}{9\,7}$	18th do.	
557	41·775	$\frac{1}{146}$	$\frac{1}{9\,4}$	18th do.	
699	51·84	$\frac{1}{13}$	$\frac{1}{10}$	18th do.	
753	55·08	$\frac{1}{144\,4}$	$\frac{1}{10}$	18th do.	
934	65·94	$\frac{1}{132}$	$\frac{1}{11\,1}$	18th do.	
865	61·8	$\frac{1}{114\,4}$	$\frac{1}{10\,9}$	18th do.	
More than 1,900	...	$\frac{1}{144}$	Less than $\frac{1}{14}$	20th do.	Velocity of train was brought down to 4 to 6 miles an hour, but brake-power would not pull up the train, which would only have stopped on the 1 in 330 at Khandalla.
Do. 1,900	...	$\frac{1}{126}$	Do. $\frac{1}{16}$	22nd do.	Experiments tried on a different day to 121; result exactly the same, obliged to put on 3rd brake to avoid running on sand.
Do. 1,900	...	$\frac{1}{154}$	Do. $\frac{1}{15·6}$	22nd do.	
...	...	$\frac{1}{180}$	Do. $\frac{1}{14}$	23rd do.	Velocity of train brought down to 8 or 9 miles an hour; pulled up by 14 chains of sanded rail.
710	52·5	$\frac{1}{144}$	$\frac{1}{9}$ using sand on oil.	23rd do.	
Mean 832	59·83	$\frac{1}{115}$	$\frac{1}{12}$	3rd January	
1,302	88·04	$\frac{1}{90}$	$\frac{1}{20\,6}$	17th do.	First morning run; clean rail.
1,069	77·53	$\frac{1}{113·5}$	$\frac{1}{16·5}$	17th do.	Vechicles braked on a fresh length of rail.
337	25·275	$\frac{1}{103·6}$	$\frac{1}{10}$	17th do.	Down rail had been run over by goods train in early morning.
893	57·6	$\frac{1}{122·2}$	$\frac{1}{13·2}$	17th do.	

Experiments on Brake-power carried out on

Number of Experiments.	Description of Vehicle or Vehicles.	State of Rail.	Brake-power per cent.	Before Brakes were applied.		
				Distance run, yards.	Height fallen, feet.	Speed in mile per hour.
132 1	2 Incline Brakes ...	Damp; vehicles braked on a fresh length of rail each time.	49·75	660	49·5	30
133 1	Ditto ...	Do. ...	49·75	924	69·3	37·5
134 1	Ditto ...	Do. ...	49·75	990	65·01	32·14
135 1	Ditto ...	Do. ...	50	814	60·48	33·3
136 to 138 3	Ditto ...	Do. ...	50	814	60·48	34
139 1	Ditto ...	Do. ...	50	660	49·5	32·14
140 1	Ditto ...	Do. ...	50	660	49·5	32·14
141 1	Ditto ...	Do. ..	50	638	47·85	29
142 1	Ditto ...	Damp, 1st run	50	660	49·5	32·14
143 & 144 2	Ditto ...	Drier ...	50	242	18·15	18·37
145 to 147 3	Ditto ...	Dry ...	50	264	19·8	20·45
148 & 149 2	Ditto ...	Do. ...	50	286	21·45	21·68
150 1	Train consisting of 3 Incline Brakes and 5 wagons. T. C. Q. Brakes 30 8 0 Empty wagons T. C. Q. 25 11 0	Soaped ...	55	198	14·85	17·6
151 1		Do. ...	55	242	18·15	20
152 1		Do. ...	55	286	21·45	18
153 1		Do. ...	55	330	24·75	22·5
154 1		Do. ...	55	396	29·7	23·68
155 1		Do. ...	55	528	39·6	26·47
156 1		Do. ...	55	628	47·1	29
157 1	2 Brakes ...	Dry, with sand	50	Kicked over Incline.		36·7
158 1	2 Do. W. and X. weight 20 tons.	Oiled ...	50	616	46·2	31
159 1	Train consisting of T. C. Q. 3 Brakes 30 13 2 & T. C. Q. 5 Wagons 25 11 0	Do. ...	54½	462	34·65	26·47
160 & 161 2	Ditto ...	Do. ...	54½	462	34·65	25·71
162 1	Ditto ...	Do. ..	54½	616	46·2	29·5
163 1 164 1	2 Ghât Incline Brakes, weighing 10 tons each.	Dew on rail...	50	...	...	34·61

Gradients of 1 *in* 40 *and* 1 *in* 50 *on the Bhore Ghât*—(continued).

After Brakes were applied.		Rolling friction, &c.	Friction of Brakes, &c.	Date of Experiment.	Remarks.
Distance run, yards.	Height fallen, feet.				
1,694	113·85	1/102	1/21·4	11th January	
1,851	125·625	1/124·5	1/18·5	11th do.	
1,146	62·22	1/97·5	1/21·7	11th do.	
2,646	136·63	1/104·7	1/21·2	14th do.	Skidding.
Mean 877	53·89	1/112·7	1/16·2	14th do.	Not skidding, but rail cleaned by previous run.
2,640	184·8	1/132·5	1/20·9	3rd do.	
1,729	116·55	1/132·5	1/19·2	3rd do.	
970	68·1	1/97	1/14	23rd December	
1,650	110·55	1/132	1/19·6	17th do.	
205	15·375	1/100	1/11·8	17th do.	
148	11·325	1/141	1/9·3	17th do.	
330	24·75	1/160	1/13·2	17th do.	Tried not skidding, but brakes would not act.
143	10·725	1/136	1/12·2	20th do.	First run in morning.
130	10·2	1/150	1/9·9	20th do.	
159	11·925	1/80	1/13	20th do.	Velocity in this experiment rather doubtful.
154	11·55	1/126	1/9·8	20th do.	
176	13·2	1/108	1/9·8	20th do.	
223	16·725	1/97·3	1/12·1	20th do.	
297	22·275	1/99·6	1/10·5	20th do.	
387	29·025	...	1/9	3rd January	With sand rear brake skidded and sanded; front running feet.
...	...	1/132	Indeterminate, but much less than 1/17	23rd December	Rail was only oiled for 1,012 yards; ran this distance, and was then pulled up by 5 chains of sanded rail.
1,065	75·8	1/123	1/20·7	3rd January	
434	32·55	1/105	1/14·4	3rd do.	
560	42	1/109	1/14·4	3rd do.	
854	61·14	...	1/13·7	12th February	Experiments made by Mr. Bell in my absence.
1,174	76·5	...	1/16·8	12th do.	

15

Experiments on Brake-power carried out on Gradients of 1 *in* 40 1 *in* 50 *and on the Bhore Ghât*—(continued).

Number of Experiments.	Description of Vehicle or Vehicles.	State of Rail.	Brake-power per cent.	Before Brakes were applied.			After Brakes were applied.		Rolling friction, &c.	Friction of Brakes, &c.	Date of Experiment.	Remarks.
				Distance run, yards.	Height fallen, feet.	Speed in mile per hour.	Distance run, yards.	Height fallen, feet.				
165 1	Incline Brake weighing T. C. Q. 10 2 2 & Main Line Brake T. C. Q. 6 12 1	Damp, 1st run.	60	660	49·5	26·	778	56·58	...	$\frac{1}{19·5}$	11th December.	Brake skidded.
166 to 170 5	Ditto ...	Damp and dry.	60	660	49·5	28·125	477	35·8	...	$\frac{1}{17·7}$	11th do.	
171 to 176 6	Ditto ...	Dry ...	60	660	49·5	29·00	312	23·4	...	$\frac{1}{11·5}$	11th do.	Rail cleaned by previous experiments; wheels not skidded.
177 1	3 Incline Brakes *W, I, X—W & I* on total weight T. C. Q. 30 9 2	Damp ...	66	660	49·5	33·33	940	66 3	$\frac{1}{160}$	$\frac{1}{19}$	15th do.	Tried not skidding.
178 1	Ditto ...	Do. ...	66	660	49·5	32·14	594	44·55	$\frac{1}{130}$	$\frac{1}{16}$	15th do.	
179 1	Ditto ...	Dry ...	66	...	...	20·44	114	8·55	...	$\frac{1}{10}$	15th do.	Skidding; rail cleaned by experiments 177 and 178.
180 1	Ditto ...	Do. ...	66	198	14·85	17·64	106	7·95	$\frac{1}{133}$	$\frac{1}{12·3}$	15th do.	Do. do. do.
181 to 184 4	Ditto ...	Do. ...	66	220	16·5	18·37	168	12·6	$\frac{1}{127}$	$\frac{1}{14·9}$	15th do.	Wheels just revolving.
185 & 186 2	Ditto ...	Do. ...	66	264	19·8	20·45	128	9·6	$\frac{1}{135}$	$\frac{1}{11·4}$	15th do.	Skidded on and off.
187 & 188 2	Ditto ...	Do. ..	66	308	23·1	21·98	112	8·4	$\frac{1}{131}$	$\frac{1}{9·5}$	15th do.	Skidded.
189 & 190 2	Ditto ...	Do. ...	67	440	33·0	26·47	140	10·5	$\frac{1}{136·5}$	$\frac{1}{8·4}$	17th do.	Do.
191 1	Ditto ...	Do. ...	67	660	49·5	30·0	235	17·62	$\frac{1}{102}$	$\frac{1}{10·4}$	17th do.	Do.
192 1	Ditto ...	Soaped ...	66	638	47·85	32·14	286	21·45	$\frac{1}{144}$	$\frac{1}{11}$	22nd do.	Do.
193 1	Ditto ...	Oiled ...	65	638	47·85	32·14	586	43·95	$\frac{1}{144}$	$\frac{1}{16}$	23rd do.	Rail oiled from points of application of brake.
194 1	Ditto ...	Do. ...	65	Kicked over Incline...		41·00	664	49·8	...	$\frac{1}{13}$	23rd do.	Do. do. do.
195 1	Train of 200 tons, including weight of engine.	Dry ...	30 and 35	...	...	22·5	1,540	102·3	...	Less than $\frac{1}{14}$	4th February.	Engine and 1 brake braked; sand to brake.
196 1	Ditto ...	Do. ...	35	...	...	22·5	594	44·55	...	$\frac{1}{11·5}$	4th do.	Engine and 2 brakes braked; no sand.
197 1	Ditto ...	Do. ...	40	...	...	25·	616	46·2	...	$\frac{1}{12·4}$	4th do.	Engine and 3 brakes braked; no sand.
198 1	Ditto ...	Do. ..	40	...	...	28·125	528	39·6	...	$\frac{1}{10·5}$	4th do.	Engine and 3 brakes braked, sand to engine.
199 1	Ditto ...	Do. ...	50	...	...	24·6	380	28·5	...	$\frac{1}{12·7}$	4th do.	Engine and 5 brakes braked; sand to engine.
200 1	Ditto ...	Do. ...	50	...	...	28·125	352	26·4	...	$\frac{1}{10·7}$	4th do.	Engine and 5 brakes braked; sand to engine and 3 pairs of wheels.

Catch-

No. of Experiment.	Description of Vehicle or Vehicles.	State of Rail.	Brake-power per cent	On Main Line.		
				Distance run, yards.	Height fallen, feet.	Speed in mile per hour at foot of Main Line Incline.
201 1	2 Ghât Incline Brakes, weighing 20 ton.	Dry ...	None; vehicles allowed to run till they came to a stand.	528	34	25
202 1	Ditto ...	Do. ...	Do. ...	528		
203 1	Ditto ...	Do. ...	Do. ...	528		
204 1	Ditto ...	Do. ...	Do. ...	528		

No. of Experiment.	Description of Vehicle or Vehicles.	State of Rail.	Brake-power per cent.	Down Ghat Incline.		
				Distance run.	Height fallen, feet.	Speed in mile per hour at foot of Main Line Incline.
205 1	1 low-sided wagon filled with earth, weighing 10 tons.	Dry ..	Wagon allowed to run till it came to a state of rest on incline of catch-siding; then allowed to return up Main line.	½ mile	66	38·55
206 1	... ...	Do. ...		¾ do.	99	42·19
207 1	... ...	Do. ...		¾ do.	99	47·92
208 1	... ...	Do. ...		1 do.	132	58·6
209 1	... ...	.....		1¼ do.	165	58·6
210 1	... ...	.....		1½ do.	181	58·6
211 1	... ...	.....		1½ do.	181	58·6
212 1	... ...	.....		1¾ do.	212	61·36
213 1	... ...	.....		2 miles.	244	61·36
214 1	... ...	.....		5⅝ do.	300	58·6
215* 1	6 low-sided wagons filled with earth, each weighing 10 tons.	Catch-siding oiled.		5 do.	621	75·00

* *N. B.*—The line was blocked (except for experiment 215) between 2⅝ and 5 miles, owing to a tunnel being under repair.

16

siding.

On Contrary Incline of Catch-sidings.		Rolling friction, &c.	Friction of brakes, &c.	Date of Experiment.	Remarks.
Distance run, yards.	Height gained, feet.				
654 664 } 661 666 ...	17·76	1/219	.....	1st February.	Vehicles ran till they came to rest.

On Contrary Incline of Catch-siding.		Rolling friction, and resistance of air.	Distance up Main Line return from catch-siding, yards.	Height up Main Line, feet.	Rolling friction, and resistance of air.	Date of Experiment.	Remarks.
Distance run, yards.	Height gained, feet.						
1,012	30·12	1/158	180	13·5	1/815	Experiment on 5th January.	
1,068	40·88	1/143	264	19·8	1/169	Do.	
1,094	47·20	1/140	291	21·825	1/163	6th January.	
1,100	48·69	1/103	324	24·3	1/183	5th do.	
1,121	54·78	1/90	375	28·125	1/103	5th do.	
1,126	56·60	1/90	390	29·25	1/166	5th do.	Between the 1¼ mile and 1½ mile on the main line there is a length of level of 10 chains.
1,127	56·96	1/91	363	27·225	1/150	6th do.	
1,133	59·28	1/83	348	26·1	1/134	5th do.	
1,144	63·49	1/77	Experiment lost.	...	...	5th do.	
1,148	65·59	1/74	Ditto.	...	...	6th do.	
Whole length 1,276	More than 159·60	Indeterminate.	...	...	...	...	Ran to end of catch-siding into bank. The six wagons ran the five miles in five minutes; three wagons smashed; velocity was taken over a length of 88 yards.

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Catch-siding.

Number of Experiment.	Description of Vehicle or Vehicles.	State of Rail.	Brake-power per cent.	On Main Line. Distance run, yards.	On Main Line. Height fallen, feet	On Main Line. Speed in mile per hour at foot of Main Line Incline.	On Contrary Incline of Catch-sidings. Distance run, yards.	On Contrary Incline of Catch-sidings. Height gained, feet.	Rolling friction, &c.	Friction of Brakes, &c.	Date of Experiment.	Remarks.
216 1	2 Ghât Incline Brakes weighing 20 tons.	Dry ...	All on ...	528			79					
217 1	Ditto ...	Do. ...	Do. ...	528	34	25·71	84	80	1·45	$\frac{1}{132}$	$\frac{1}{12·4}$	
218 1	Ditto ...	Do. ...	Do. ...	528			77					
219 1	Ditto ...	Do. ...	Do. ...	704			101				1st February.	
220 1	Ditto ...	Do. ...	Do. ...	704	47·2	30·4	99	107	2·00	$\frac{1}{129}$	$\frac{1}{11·2}$	
221 1	Ditto ...	Do. ...	Do. ...	704			119					
222 1	Ditto ...	Do. ...	Do. ...	704			110					
223 1	2 Ghât Brakes W and H: tons. cwt. W ... 10 0 H ... 10 2	Oiled on contrary incline.	Brake put on to W 50 per cent.	528	34	26·47	181	182	3·3	$\frac{1}{149}$	$\frac{1}{27}$	Vehicle braked on contrary incline.
224 1	Ditto ...	Do. ...	Do. ..	528			180					
225 1	Ditto ...	Do. ...	Do. ...	528			186					
226 1	Ditto ...	Do. ...	Do. ...	704			278					
227 1	Ditto ..	Do. ...	Do. ...	704	47·2	30·	274	273	3·9	$\frac{1}{123}$	$\frac{1}{31}$	2nd February.
228 1	Ditto ...	Do. ...	Do. ...	704			238					
229 1	Ditto ...	Do. ...	Do. ...	836	57·1	32·14	334	343	4·3	$\frac{1}{110}$	$\frac{1}{34}$	
230 1	Ditto ...	Do. ...	Do. ...	836			352					

on 1 *in* 40.

Steel Rails

Number of Experiment.	Description of Vehicle or Vehicles.	State of Rail.	Brake-power per cent.	Before Brakes were applied. Distance run, yards.	Before Brakes were applied. Height fallen, feet.	Before Brakes were applied. Speed in mile per hour.	After Brakes were applied. Distance run, yards.	After Brakes were applied. Height fallen, feet.	Rolling friction.	Friction of Brakes.	Date of Experiment.	Remarks.
231 1	1 Incline Brake, W	Steel-rails, 1st morning run.	All ...	...	...	25·71	210	15·75	...	$\frac{1}{17}$	4th January	Skidding; ran over ordinary rail, and brakes put on on arriving at steel rails.
232 1	1 Ditto ...	Rail dry ...	Do. ...	...	...	30·	210	15·75	...	$\frac{1}{13·8}$	4th do.	Ditto
233 1	1 Ditto ..	Do. ...	Do. ...	...	...	34·7	251	18·825	...	$\frac{1}{13}$	4th do.	Ditto
234 1	1 Ditto ...	Do. ...	Do. ...	...	...	34·7	228	17·1	...	$\frac{1}{13·4}$	4th do.	Not skidding.
235 1	1 Ditto ...	Do. ...	Do. ...	...	...	32·14	220	16·5	...	$\frac{1}{12·7}$	4th do.	Ditto
236 1	1 Ditto ...	Do. ...	Do. ...	...	...	33·33	308	23·1	...	$\frac{1}{15·3}$	4th do.	Front wheel running free; rear skidding.
237 1	3 Incline Brakes, X, H, W. Sand used to 7 wheels.	Do.	With sand. 66	660	47·19	31·	336	252	18·9	$\frac{1}{132}$	$\frac{1}{10·7}$	20th do.	Skidding in all cases; vehicles ran free, entirely through curves of 40 and 30 chains' radius. Mean time of running 660 yards exactly the same as on straight.
238 1		Do.	66	660	47·19	29·	250			$\frac{1}{104}$			
239 1		Do.	66	660	47·19	31·	224			$\frac{1}{132}$			
240 1		Do.	66	660	47·19	30·	198			$\frac{1}{116}$			