

THE USE OF THE DUDLEY "STREMMATOGRAPH"
IN DETERMINING STRESSES IN RAILS
UNDER MOVING TRAINS.

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[PLATES X-XIII.]

ON former occasions I have presented to the Academy diagrams of railway tracks showing the undulations of different weights of rails under moving loads as taken by my Dynagraph and Track Indicator car.

Attention was directed to the marked reduction in the undulations in the stiffer and heavier rails put into service in recent years as a result of the earlier investigations.

I also stated that with rails of a given stiffness, surfaced in the track to their highest condition, the trackmen can only reduce the undulations to definite minimum limits for the wheel loads; therefore, all undulations under the moving wheel loads of locomotives and cars with their increased dynamic effects due to speed can not be entirely reduced.

To carry the trains, the rails not only deflect under the wheel loads, but the ties, ballast and road-bed are compressed until the total resistance equals the load. Action and reaction must be equal and before the latter is obtained for heavy loads on light rails rapid destructive work is done upon the ties and ballast, requiring frequent surfacing to keep the track up to its proper standard. The destructive work on the ties and ballast under stiffer and heavier rails is reduced as well as the necessary labor to keep them in surface.

The weight of the locomotives and cars can only be transmitted to the road-bed through the wheel contacts on the rails, which produces a general deflection of the rails under the wheel

base of the locomotives and cars, the greatest deflection being directly under the wheels.

To carry and distribute the wheel loads to the ties, ballast and road-bed, the rail acts as a girder, the metal in the rails directly under the wheels above the neutral surface is in compression, while that below the neutral surface is in tension.

On and near the supporting ties, shearing stresses are set up extending through the web of the rails as the wheels pass over the rails.

The span of the deflection of the rails under the wheels is longer as a rule than the tie spacing, and in a short distance on either side of the wheels the nature of the stresses is reversed, the head of the rails being in tension and the base being in compression.

The picture on the screen is a representation of the wheel loads and base of a Boston and Albany 100-ton locomotive standing on 95-lb. rails, showing in figures the actual depression of the rails, ties and road-bed under the static loads. The rails under moving trains rise slightly in front of the pilot. [See Plate X., Fig. 2.]

The dotted line directly over the rail indicates its general depression under the wheel loads and base of the locomotive.

The vertical scale is enlarged to render the depressions more distinct; the greatest deflections in the rails and road-bed being directly under the wheel contacts.

The truck wheels carry 20,350 lbs. per pair; the drivers 37,500 lbs. per pair; the front tender wheels 18,500 lbs. per pair, and the rear ones 23,500 lbs. per pair. The depression and deflection shown for one rail is, therefore, for wheel loads only one-half of that per pair of wheels. Locomotives with much greater weights on the drivers are in general use.

The depression under the front truck wheel of the engine was 0.094 of an inch; between the wheels 0.086 of an inch, and under the rear truck wheel 0.100 of an inch.

In the wheel space between the engine truck and front drivers the depression was 0.088 of an inch; under the front driver 0.138 of an inch; in the wheel space between drivers 0.096 of

an inch, and under the rear drivers it was 0.140 of an inch. In the wheel space between rear driver and front wheel of the tender truck the depression was 0.086 of an inch; between front tender truck wheels 0.100 of an inch, showing abnormal conditions in the track, and under rear wheel of front tender truck 0.099.

In the wheel space between the two tender trucks 0.095 inches, and under front wheel of rear tender truck 0.113 of an inch and on the wheel space 0.106 inches and for the rear wheel 0.113 inches.¹

A measurement of a short gauged length, say 5 inches, of the base of the rail under the wheels showed extension, while between the wheels, compression. The measurements were not made in this manner, as it requires more time than can usually be obtained in the main line, but with a micrometer in one position on the rail each wheel and center of wheel space being stopped over the micrometer.

Apparent stresses per square inch of the metal for the extreme fibers of the base of the rail ran as follows in one position of the rail for the different wheels and centers of the spaces:

	Tension in pounds.	Compression in pounds.
Front engine truck wheel,.....	6780	
Center of wheel space,		1530
Rear engine truck wheel,	5340	
Center of space between rear engine truck wheel and driver,.....		3050
Front driver,.....	9160	
Center of space between drivers,.....		3050
Rear driver,	9920	
Center of space between driver and front tender wheels,		2290
Front truck front tender wheel,.....	3820	
Center of space between wheels,		760

¹ From Report for 1895, of Tests of Metals and other Materials for Industrial Purposes, made with the U. S. Testing Machine at Watertown Arsenal. Mr. James E. Howards, *Railroad Track Experiments*. By redriving the spikes in the ties, taking up all looseness between the rail and ties, the deflections and stresses were reduced over one-third in amount.

Front truck rear tender wheels,	3820	
Center of space between tender trucks,		1530
Front wheel rear tender truck,	6100	
Center of space between wheels,		0000
Rear wheel of rear tender truck,	6870	

The shaded ballast under the ties in Plate X., Fig. 2 is an ideal representation of the distribution of the pressure of the wheel loads through the rails, ties and ballast to the road-bed, the darker portions representing the most intense pressures. Under moving trains the wheel loads are transmitted as a series of waves of pressure to the ballast and road-bed.

A series of alternating stresses run through the rails in consonance with the speed of the trains, the waves of greatest intensity being between the ties. Some of the slides will show that the tremors and vibrations of the rails are very decided under the wheels passing in quick succession. The duration of the greatest intensity of the stress of the metal is very short per lineal inch, being only a fraction of a second for the high speed trains, less than $1/250$ of a second for a speed of 40 miles per hour; while the maximum stress increases with the speed, the duration of greatest intensity decreases.

A rail in the track, like any other girder, to carry its loads without taking a permanent set, must not have the metal stressed beyond its elastic limits and it should be much less for a proper factor of safety.

The diagrams of the earlier steel rails, which I have previously shown, indicate that nearly all the rails had taken more or less permanent set; therefore, the fiber stresses in the rails at times had exceeded the elastic limits.

This important fact must be borne in mind, for the stresses which occurred in the early steel rails, even for the lighter equipment, were greater than I shall report for the present 80-lb. rails. The stresses in rails may be much greater than would be permissible in bridge members, for in the latter they are of several seconds' duration and the material a much lower grade of steel. High stresses in rails are not of recent origin, but occurred a few times daily in the early rails. The rails

would stand some millions of repetitions of stress nearly up to the elastic limits before fracture would occur. If such stresses are of a half hour or longer intervals some recovery in the metal takes place; but when fracture does commence, it seems to start between individual adjacent mineral aggregates, rather than through them, becomes progressive, and in many cases the complete rupture of the section may take one or more years of further service.

The tests of many of the earlier steel rails show that the elastic limits only ranged from 35,000 to 48,000 lbs., the ultimate strength being about twice those amounts respectively.

In the testing machine it takes 30,000 pounds tension to elongate one square inch of steel per lineal inch $1/1000$ of an inch and the same force to compress it, which was nearly all the early steel rails permitted the extreme fibres in the base of the rail to be extended or compressed before set would occur. This margin was too small, and as the traffic increased it was impossible to maintain the tracks to a high standard even at a very large cost for labor. These facts lead me to urge the adoption of stiffer and heavier rails with higher elastic limits which would reduce the fibre stresses much below the elastic limits of the steel, increase the factors of safety and not require so much labor to maintain them to a high standard in the track.

When I look over the diagrams of the earlier steel rails, it is difficult to realize that it is only fifteen years since I designed the pioneer 5-inch 80-lb. steel rail for U. S., which was rolled for and put into service in 1884, by the N. Y. C. & H. R. R.R.

The Pennsylvania Railroad and others soon followed with 5-inch sections of 80 or 85 lb.; 80 lbs. becoming very general on Eastern Trunk Lines, forming a distinct epoch in the development of American Railways.

It takes many years to change the section of rails on a long main line, while the design of new equipment and construction is but a few months' work and easily keeps in advance of the permanent way improvements.

The slide on the screen is from a photograph of the "Empire

State Express" on the third day of its installation in November, 1891, taken near Syracuse when running at 60 miles per hour on 65-lb. rails before the entire main line had been relaid with 80-lb. The photograph, and another one of the same train, which will be shown, were taken by Mr. A. P. Yates, Official Photographer of the N. Y. C. & H. R. R. R. Co. [See Plate XII., Fig. 1.]

The installation of the "Empire State Express," the fastest long distance train ever attempted, aroused a great deal of discussion among railway men as to the possibility of maintaining it for any length of time. It was considered by many a doubtful experiment. But few people realized how high the standard of the track had been raised in the past few years and the decided advantages of the stiff 80-lb. rails in most of the track for such high speeds.

It is exceedingly interesting that one picture was obtained when running on 65-lb. rails as showing the depression of the rails under the engine, tender and front truck of the first coach. The picture will become historic. I have studied an enlargement of the picture nearly equal to that now on the screen and have traced the general depression of the rails and ties as stated. The wave of the rising rail preceding the pilot can also be seen.

A train at 60 miles per hour runs 88 feet per second, which is longer than the entire wheel base of the engine, tender and front truck of the first coach, making, in the case of the "Empire State Express," eleven wheels to run over a given point in the rail per second, each wheel causing and reversing stresses of several thousand pounds, violent tremors and vibrations being set up in the rails. The permanent set in the 65-lb. rails of the next track is very apparent. The 65-lb. rails were replaced by 80-lb. rails in 1892.

The majority of the earlier 60 to 65-lb. steel rails had all taken a set in the tracks, the ties were cut out from $\frac{1}{2}$ to $1\frac{1}{4}$ inches in depth under the rails, and the undulations per mile ranged from 8 to 12 feet. The slide on the screen is from a photograph taken of the "Empire State Express" at 60 miles per hour on 80-lb. rails. I have not been able to trace the depression of the

rails under the moving train ; nevertheless it occurred, but to much less extent than on the 65-lb. rails. [See Plate XII., Fig. 2.]

On the diagrams of the heavier rails of recent years, the undulations per mile on the 80-lb. rails have been reduced to less than three feet, and on the 100-lb. rails to less than two feet ; as measured by my car, the rails being in good surface ; the ties showing but little abrasion under the rails.

In 1883 it was considered by many that a 5-inch 80-lb. rail was stiffer and heavier than necessary, while others thought it would provide for the future development of the railways for all coming time.

The rails once in the track furnished a practical demonstration of the value of stiffness in rails and soon led to an increase of speed and heavier equipment, increasing the fibre stresses in the 80-lb. rails over that for which they were designed to sustain.

In March, 1892, my 6-inch 100-lb. rail section was rolled, the first to go into service in the United States, to again reduce the fibre stresses in the rails to meet requirements of increasing traffic. To date there are several thousand miles of 100-lb. rails in use in this country.

In the last decade all of the Eastern and many of the Western trunk lines have been laid with stiff rails for the purpose of keeping the fibre stresses in the rails down to safe and economic limits, though this feature of the matter has received but little discussion.

In 1888 in connection with Mr. James E. Howard, of the Watertown U. S. Arsenal, I had one of the Boston and Albany passenger locomotives weighed and ran it onto rails in the main track, the upper side of the base of the rail having been prepared with prick punch marks practically 5 inches apart, the space having been measured with a micrometer to $1/10,000$ of an inch. The measurements were repeated after the locomotive was on the rails to ascertain the compression of the base of the rail between the wheels and the elongation under the wheels.

From the results the apparent stresses in the rails were computed for the static loads which were probably too low as the

largest stress was only 13,500 lbs. on a $4\frac{1}{2}$ -inch rail for a load of 16,000 lbs. on drivers.

Mr. Howard in 1893, 4 and 5 repeated the tests on other railroad tracks and heavier rails and found apparently higher stresses. I repeated the experiments on rails in the tracks, and the results seeming low I had solid piers erected and with rails 30 feet long under known stresses I found my results were too low.

With micrometers designed for the work the results for static loads should be fairly accurate.

The determination of the stresses or rather the compression and elongation of the metal in the base of the rail under moving trains is a much more difficult problem, or rather a series of problems; than it is for static loads, and I am not aware that any one has attempted their solution before I attacked them the past year with my Stremmatograph and its accessories.

A mathematical expression for the stresses of rails under moving trains, its span for the ties and wheel spacing; the deflection and compression of the ties, ballast and road-bed, has not been fully determined, though many efforts to do so have been made.

Such a formula would also have to consider the many conditions of the path not only described by the centre of gravity of the locomotive, tender and each car of the train, but also those of the rotating wheels, their mass and speed, the smoothness of the rails and the more or less sudden application of the loads.

The principle of the Stremmatograph is to record on a moving metallic strip the molecular compression or elongation of the metal in a given length of the base of the rail, induced by the stresses, produced by each wheel of the moving trains under the many conditions of service.

These records can be measured by filar micrometers under a microscope and then from the modulus of elasticity of the steel compute the stresses which produce the given compression or elongation per square inch of the extreme fibres in the base of the rail. [See Plate X, Fig. 3.]

The object of the Stremmatograph is to convert rails of any section and weight, of any system of permanent way construc-

tion into testing machines in the track and show how much they are stressed due to the wheel loads and spacing of any type of locomotives and cars moving over the rails at the different speeds of service.

It is to replace what is now mere conjecture by reliable information that further progress may be made in the interest of greater safety and economy. [See Plate XI., Fig. 1.]

The picture on the screen shows the first form of the Stremmatograph attached to the base of the rail between the figures 2 and 3 on the scale bar, and under the front driver of the freight mogul engine, No. 596, of the New York Central & Hudson River Railroad. It is on the East-bound, or track No. 1; $5\frac{1}{8}$ -inch 80-lb. section; outside rail on a 3-degree curve and down grade of 10 feet per mile. The location is opposite the southeast corner of the West Albany Paint Shop. The ties are yellow pine 7 by 9 inches and 25-inch centres; gravel ballast; the tracks being in good condition. A number of tests of passenger trains were made under the same rail. The experiments made on track No. 2 were directly opposite, the rail being the inside one of the curve. The section was the 5-inch 80-lb. model of 1883; the rails were rolled in 1890 and all straightened on narrow supports in the mills; were heavily gaged and had a wavy surface.

The rails on track No. 1 are much smoother, the supports in the straightening presses having been made wider apart. On track No. 1 two experiments were made with locomotive No. 596, one at a speed of two miles per hour and one at ten miles per hour. The total weight of the locomotive was 96 tons; the engine 60 tons, with 15,500 lbs. on pony truck and 104,500 lbs. on three pairs of drivers. The tender weighed 72,000 lbs. or 9,000 lbs. per axle. This type of locomotive is the standard for freight service for the road.

It had been recently through the shops for general repairs, the tires of the drivers having been turned the same as when new.

The tender wheels were new cast-iron chilled wheels 33 inches in diameter and unground.

At a speed of two miles per hour the locomotive passed over

the rail to which the Stremmatograph was attached, the steam having been shut off a few feet before reaching the instrument.

The record of the molecular compression and elongation of the metal due to the stresses in the base of the rail was very smooth and distinctly delineated.

For the unground tender wheels slight tremors in the rail were distinctly indicated, a fact previously noticed under switching locomotives with the same class of tender wheels running over very light rails in the yard.

The apparent mean stresses for the extreme fibres of five inches in length of the base of the rail computed on a basis of 30,000,000 lbs. for the modulus of elasticity of the steel were as follows.

	For a speed of	
	Two miles per hour	Ten miles per hour
Compression in front of pony truck,.....	1417 lbs.	1653 lbs.
Tension under pony truck,.....	7086 "	7558 "
Compression between pony wheel and front driver,	2129 "	4724 "
Tension under front driver,	10629 "	9448 "
Compression between front and middle driver	5433 "	8031 "
Tension under middle driver,.....	5905 "	4960 "
Compression between middle and rear driver,	4015 "	5673 "
Tension under rear driver,.....	9376 "	9648 "
Compression between rear driver and first ten- der wheel,.....	4015 "	5473 "

For the speed of ten miles per hour the locomotive was working under steam and being accelerated as it passed over the instrument modified the wheel pressures to some extent.

The tremors from the tender wheels were very decided in this run and were felt for the entire length of the rails. The fibre stresses in tension are small for the loads upon the drivers even for an 80-lb. rail, while those in compression are higher than usual for the same weight of rail. The section is $5\frac{1}{4}$ inches high and the stiffest 80-lb. rail which has been rolled in this country.

There is also another reason for the nearly balanced stresses. The two ties between which the Stremmatograph was attached

to the rail were very firm in the ballast, and to the eye did not seem to depress as much as those on either side; therefore, the compression stresses should be higher than on ties all practically depressing alike in the ballast.

It will be exceedingly interesting and important to have the records of stresses under this type of locomotive when drawing one of the trains of fifty-five 60,000-lbs. capacity cars, each carrying 1,000 bushels of grain.

The picture on the screen shows two trains side by side of fifty cars each, the length of one train not quite reaching from New York to Chicago, but each is 2,000 feet long, and 2,640 such trains would fill one continuous track between the two cities. [See Plate XIII.]

In the trials of a number of switching locomotives in the yard, on tracks of not very uniform tie spacing, the locomotives having three pairs of coupled drivers, but without pony truck the front driver usually shows greatest tension on the 65-lb rails.

Under locomotive No. 1, at Grand Central Station, having 125,000 lbs. upon drivers, the instrument between ties of 30-inch centres, having tie plates, the apparent mean stresses were as follows; on 65- and 100-lb. rails respectively:

	65-lb. rail.	100-lb. rail.
Compression in front of driver,.....	3,071 lbs.	1,181 lbs.
Tension under front driver,	51,964 "	8,031 "
Compression between front and middle driver, 2,124 "		2,834 "
Tension under middle driver,	22,445 "	6,849 "
Compression between middle and rear driver, 2,362 "		2,834 "
Tension under rear driver,	23,856 "	6,142 "

The 65-lb. rails are of recent composition, the elastic limits of the steel being 60,000 lbs., while on the 100-lb. rails it is 65,000 lbs.

In the above table it is interesting to note the great reduction and more uniform fibre stresses in the 100-lb. rails as compared with those in the 65-lb. rails. The 65-lb. rails require from six to eight times as much labor to keep them in surface as the 100-lb. rails in the Grand Central Yard.

The record curves of the stresses of compression and tension of the metal in the rails between and under the wheels consist of a series of very much flattened upper branches for the compression between the wheels with very much sharper lower branches for the tension. [See Plate X., Fig. 1.] A similar record is obtained by having a particular portion of the rail stressed by a moving train as shown by the enlarged records of the Stremmatograph on the screen of two trains. [See Plate X, Fig. 2.]

After the Stremmatograph is attached to the rail a reference line is ruled on the metallic strip and then the scriber point is moved a few thousands of an inch, the instrument started and a line about $\frac{1}{4}$ of an inch long ruled, which in reality becomes the measure for a median line, and the distance to the reference line measured by the micrometer. When the train is within a rail length of the instrument it is again started; the metallic strip moving at right angles to the rail; the scriber point recording the mean molecular compression and extension of the base of the rail usually for five inches in length.

The upper lines are the records for the 5-inch 80-lb. rail on inside of curve as already described in track No. 2. The rail has a very wavy surface, the stresses being very largely augmented owing to that feature. The locomotive was No, 888, Class I, of the N. Y. C. & H. R. R. R., drawing five Wagner Palace Cars,; speed 40 miles per hour and being rapidly accelerated. The extension of the metal in the base of the rail due to the the several wheel loads of the locomotive and car can be traced, those of the locomotive being very distinct, while the compression of the metal between the wheels can also be seen.

The rail was the inside one of the curve, track No. 2, in location already described. The rising of the rail in front of the pilot is plainly seen, the stresses of:

Compression being.....	1,417 lbs.
Tension under front truck wheel.....	13,070 "
Compression between front and rear truck wheel.....	3,069 "
Tension under rear truck wheel.....	12,579 "
Compression between rear truck wheel and front driver. 5,433 "	
Tension under front driver.....	31,415 "

Compression between front and rear driver,	2,126 lbs.
Tension under rear driver,	26,454 "
Compression between rear driver and front tender,	2,362 "
Tension under front tender wheels,	12,755 "
Compression between front truck wheels,	1,181 "
Tension under rear front tender wheels,	13,463 "
Compression between front and rear truck,	2,362 "
Tension under rear front truck wheel,	12,991 "
Compression between front and rear wheels,	1,889 "
Tension under rear tender wheels,	12,755 "
Compression between rear tender wheel and car truck,	709 "
Tension under front car wheel	14,408 "
Compression between 1st and middle wheel,	1,181 "
Tension under middle car wheel,	14,172 "
Compression between middle and rear wheel,	3,443 "
Tension under rear truck wheel,	13,224 "
Compression in center of space between trucks,	00 "

The other wheels of the several trucks of the cars indicate nearly the same stresses.

The record of the other train on the slide is quite similar to the one just described. The tremors and vibrations which are set up by the rapid reversal of the stresses, the slight irregularities in the surface of the wheels are very decided, as the records show.

On the wavy surface of the rail on which these records were taken, the combined static and dynamic effects in producing stresses are about double at 40 miles per hour of the static effects from the same wheel loads. This rate is much higher than has been found upon smooth rails.

The importance of having the rails well finished, as we have compelled the mills to do for some years, is very fully confirmed. The necessity of having smooth wheels, perfectly round is very important, particularly for fast trains.

In a number of records on the same rail, the engines when using steam to accelerate the train, the front driver has shown greater stress than the rear driver except in one instance.

The position of the counter-balance in all of these experiments has been noted by the eye, and up to 35 miles per hour it has

not made any noticeable difference in the stresses whether it was up or down on the N. Y. C. & H. R. R. R. locomotives designed for the high-speed trains. This statement must only be taken as applying to the conditions under which these experiments have been made.

For the fast trains the locomotives will be photographed as they pass over the Stremmatograph in the track, and as this must be done nearly on the side it is much more difficult than taking the locomotive on an angle head on, as in the case of those shown of the "Empire State Express."

Stresses in track No. 1, $5\frac{1}{8}$ -inch 80-pound rail, engine No. 901, with train; speed 20 miles per hour:

Compression in front of pilot,.....	2,362 lbs.
Tension under front truck wheel,	11,574 "
Compression between truck wheels,.....	4,724 "
Tension under rear truck wheel,.....	6,849 "
Compression between truck and front driver,.....	5,905 "
Tension under front driver,.....	12,046 "
Compression between front and rear driver,.....	9,448 "
Tension under rear driver,.....	14,172 "
Compression between driver and tender wheel,.....	3,779 "

The rail in this case is the outside one on the curve and in a number of records the stress under the front truck wheel of passenger locomotives have been much higher than in the rear wheel of the same truck, especially on outside rail on a curve.

In static tests the front truck wheel almost invariably shows larger proportional stress than the drivers.

Stresses in 100-pound rail under the "Empire State Express," engine No. 870 and four cars, leaving Grand Central Yard, speed 10 miles per hour.

Compression in front of pilot,	1,322 lbs.
Tension under front truck wheel,.....	5,947 "
Compression between truck wheels,.....	1,652 "
Tension under rear truck wheel,	3,304 "
Compression between truck and front driver,.....	3,139 "
Tension front driver,.....	8,425 "
Compression between drivers,	2,478 "

Tension rear driver,	6,443 lbs.
Compression between driver and tender truck,.....	3,965 "
Tension front tender wheel,.....	4,460 "
Compression between truck wheels,.....	1,487 "
Tension rear tender wheel front truck.....	4,460 "
Compression between trucks.....	2,979 "
Tension front wheel rear truck.....	4,130 "
Compression between wheels,	1,156 "
Tension rear wheel rear truck,.....	3,469 "

The rail was the outside one on a 3-degree curve; stone ballast; oak ties with tie plates—24-inch centres.

The marked reduction in the stresses on the 100-lb. rails is very plainly seen.

Testing the Stremmatograph February 14th, 1898; Grand Central Yard at 48th Street, on 100-lb. rail, special brick piers capped with chilled iron supports 30 feet apart. Temperature 44 degrees Fahr. Fairbanks U. S. Standard weights.

The modulus of elasticity taken at 30,000,000 lbs. which for the temperature a number of tests have shown for the same rail to be practically correct.

The Stremmatograph was applied to the base of the rail, and the deflection measured by a micrometer, securely attached to a heavy bridge abutment by which the brick piers were purposely located, and from the centre of the rail 500 lbs. of standard U. S. weights were suspended and the deflection again measured. From the observed deflection the moment of inertia of the rail was recalculated. The section for the test was originally slightly over-weight. The rail has undergone considerable oxidation in two years, reducing the moment of inertia as originally rolled.

For the 500-lb. load the stress in base of the rail computed, 2,747 lbs.

On the Stremmatograph slide, the scribe point was set and a short line ruled, the scribe point was not moved and a second line ruled, but merely displaced by the elongation of the metal, and then the slide slightly moved forward. The slide was then measured under the filar micrometer with the utmost precision and the observed stress computed 2,745 lbs.

Results within a few pounds should be expected between the computed and observed stresses on the brick piers. Close results must be obtained to test the mechanical perfection attained in the construction of the instruments.

The tests mentioned in the paper and many others have all been made upon locomotives and trains in regular service.

TABLE NO 1.

GIVING THE GENERAL DIMENSIONS OF THE DIFFERENT RAIL SECTIONS MENTIONED IN THE TESTS OF THE PAPER.

Weight of Section per Yard.	Height of Section in Inches.	Width in Inches of		Thickness of Web. Inches.	Moment of Inertia. Inches. ⁴	Neutral Axis Above Base. Inches.	Moment of Resistance. Inches. ³	Moment of Inertia Vertical Axis. Inches. ⁴
		Head.	Base.					
65-lb. Old Model.	4½	2½	4½	½	16.60	2.20	7.546	
80-lb. Dudley, 1883.	5	2½½	4½½	½	26.00	2.47½	10.526	
80-lb. Dudley, 1890.	5½	2½½	5	½½	28.50	2.50	11.400	4.90
100-lb. Dudley, 1890.	6	3.00	5½	½½	48.50	2.93	16.553	9.60

NOTE.—In answer to a number of inquiries since reading my paper, regarding the stresses in rails under static loads, I have added as an appendix, a portion of Mr. James E. Howard's description and three tables from his experiments for "Static loads," set forth *in extenso* in the United States Government Report on Tests of Metals and Other Materials for 1895.

This will be a convenience to many who have not access to the above valuable paper.

APPENDIX.

RAILROAD TRACK EXPERIMENTS BY MR. JAMES E. HOWARD.

From Report of the Tests of Metals and other Materials for Industrial Purposes, Made with the U. S. Testing Machine at Watertown Arsenal, Massachusetts. For 1895.

THESE experiments comprise observations on the fibre stresses developed in rails in the track, the depression of the rails, and the slope or inclination of the rails caused by the weight of the different wheels of the locomotive.

The results show some of the phenomena displayed by rails in service under static conditions of loading or when a locomotive passes slowly over the track.

The tests will in a measure supplement laboratory experiments in this class of material, in addition to the aid which they may afford to practical questions pertaining to maintenance of way.

The series were made chiefly on the track of the Pennsylvania Railroad, where exceptional opportunities existed for examining road-bed, embracing a wide variety of conditions of weight of rails and different kinds of ballast, and its behavior under heavy types of freight and passenger locomotives.

The tests were made during the early part of the month of November, 1894, on track in the condition it was found in service.

The experiments on the Boston & Albany Railroad were made, with track on frozen gravel ballast, in the month of February, 1895.

Describing the methods of making the experiments, the fibre stress tests were made by means of a micrometer mounted on the upper side of the outer flange of the base of the rail, at a place midway adjacent ties. The instrument covered a gauged length of 5 inches.

The micrometer was adjusted in position, and then the several wheels of the locomotive were successively brought over the gauged length, or until the same was midway adjacent wheels.

The instrument was read when the locomotive was at each of these positions. It was found practicable to make the micrometre observations without arresting the locomotives in all cases, taking the readings as the locomotives passed slowly over the rail.

In this manner the strains developed were measured, and elongation of the metal showing tensile stress, and a contraction in the gauged length showing compressive stress.

The measured strains were reduced to stresses per square inch, assuming the modulus of elasticity of the steel to be 30,000,000 lbs. per square inch, and correcting the observed strain

in order to obtain the maximum fibre stresses, on the further assumption that the strains were proportional to their distances from the neutral axis of the rail.

TABLE NO. 1.
RAILROAD TRACK EXPERIMENTS—GENERAL DIMENSIONS OF RAILS.

Weight per Yard.	Height.	Width of Base.	Width of Head.	Thickness of Web.	Moment of Inertia <i>I</i> .	Moment of resistance. $R = \frac{I}{s}$.	Distance Neutral Axis to Outside Fibre.	
							Head <i>s</i>	Base <i>s'</i>
Pounds.	Inches.	Inches.	Inches.	Inch.			Inches.	Inches.
60	4 $\frac{1}{2}$	4 $\frac{1}{2}$	2 $\frac{1}{2}$	$\frac{1}{2}$	14.222	6.693	2.125	2.125
70	4 $\frac{1}{2}$	4 $\frac{1}{2}$	2 $\frac{7}{8}$	$\frac{1}{2}$	18.055	8.282	2.32	2.18
85	5	5	2 $\frac{7}{8}$	$\frac{3}{4}$	26.374	10.853	2.57	2.43
100	5 $\frac{1}{2}$	5 $\frac{1}{2}$	2 $\frac{1}{2}$	$\frac{1}{2}$	38.957	14.812	2.87	2.63
95	5 $\frac{1}{2}$	5 $\frac{1}{2}$	3	$\frac{1}{2}$	32.280	13.563	2.65	2.38

TABLE NO. 2.
WEIGHT OF LOCOMOTIVES.

Locomotive.	Total, Pounds.	Engine.		Tender, Pounds.	Weight per wheel.		
		Pilot, Pounds.	Drivers, Pounds.		Wheel.	Pounds.	Tons.
Passenger No. 809, Class Pk.	197.050	39.750	87.300	70.000	Pilot.	9.937	4.968
					Driver, first.	21.750	10.875
					Driver, second.	21.900	10.950
					Tender.	8.750	4.375
Passenger No. 1515, Class T.	222.500	50.300	95.200	77.000	Pilot.	12.575	6.287
					Driver, first.	24.250	12.125
					Driver, second.	23.350	11.675
					Tender.	12.833	6.416
Freight No. 557, Class R.	188.600	11.000	113.800	63.800	Pilot.	5.500	2.750
					Driver, first.	13.250	6.625
					Driver, second.	13.750	6.875
					Driver, third.	15.650	7.825
					Driver, fourth.	14.250	7.125
Passenger No. 209, B. & A. R. R.	199.700	40.700	75.000	84.000	Tender.	7.975	3.987
					Pilot.	10.175	5.087
					Driver, first.	18.750	9.375
					Driver, second.	18.750	9.375
					Tender.		
					First truck.	9.250	4.625
					Second truck.	11.750	5.875



FIG. 1

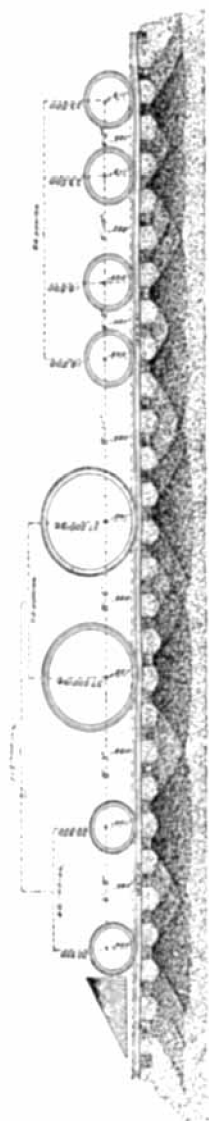


FIG. 2.



FIG. 3

TABLE NO. 3.
MAXIMUM FIBRE STRESSES IN BASE OF RAIL.

Rail Weight per Yard.	Ballast.	Locomotive.	Tensile Fibre Stress per Square Inch.			Compressive fibre stress per square inch.
			Pilot.	Drivers.	Tender.	
Pounds.			Pounds.	Pounds.	Pounds.	Pounds.
60	Gravel.	Pass., No. 809, Class Pk.	6.180	11.670	2.750	1.370
60	"	Frgt., " 557, " R.	3.430	7.550	3.430	.690
60	Stone.	Pass., " 809, " Pk.	11.860	19.540	9.770	3.490
60	"	Frgt., " 557, " R.	11.160	16.050	9.770	1.400
70	Cinder.	Pass., " 809, " Pk.	10.730	17.170	10.020	4.290
70	Gravel.	" " " " "	8.970	18.620	8.280	5.520
70	"	Frgt., " 557, " R.	7.590	13.790	6.210	4.830
70	Stone.	Pass., " 809, " Pk.	10.070	14.390	7.910	6.470
70	"	Frgt., " 557, " R.	6.470	11.510	6.470	2.880
70	Bridge.	Pass., " 809, " Pk.	9.450	18.180	10.910	2.180
70	Splice bar.	" " " " "	13.840	22.140	9.230	8.300
85	Cinder.	Pass., " 809, " Pk.	7.160	10.030	5.020	3.580
85	"	" " 1515, " T.	5.730	12.180	7.880	4.300
85	"	Frgt., " 557, " R.	3.580	10.030	5.020	4.300
85	Gravel.	Pass., " 809, " Pk.	10.750	12.180	6.450	4.300
85	"	" " 1515, " T.	9.310	17.120	9.310	5.020
85	"	Frgt., " 557, " R.	7.160	10.030	2.870	7.880
85	Stone.	Pass., " 809, " Pk.	7.160	10.750	4.300	4.300
85	"	Frgt., " 557, " R.	4.300	10.030	5.020	3.580
100	Stone.	Pass., " 809, " Pk.	6.320	9.840	5.620	4.220
100	Stone—tie removed.	" " " " "	10.540	18.970	8.430	2.110
100	Stone.	Frgt., " 557, " R.	3.510	8.430	4.220	2.810
95	Frozen grav. rail No. 1.	Pass., " 209, Bra. R. R.	6.870	9.920	6.870	3.050
95	Frozen grav. rail No. 2.	" " " " "	7.630	11.450	6.870	2.7630

"a" Taken at different point on the rail.

PLATE X.

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EXPLANATIONS OF PLATE X.

FIG. 1.—Representation of the continuous curve showing how the metal of the rail is stressed under the wheel loads of a train.

FIG. 2.—Wheel loads and wheel base of Boston and Albany Passenger Locomotive, No. 209, on 95-lb. rails ; showing deflection of rail and depression of the ties, ballast and road-bed under the wheel loads.

FIG. 3.—Stremmatograph records, enlarged $2\frac{1}{2}$ times. The first made under fast trains, the tremors and vibrations in the rails being very decided. The records on the bronze plates are more distinct than in the reproduction. The upper record was from locomotive No. 888 and 5 Wagner Palace cars ; the lower record was from locomotive No. 889 and 7 cars.

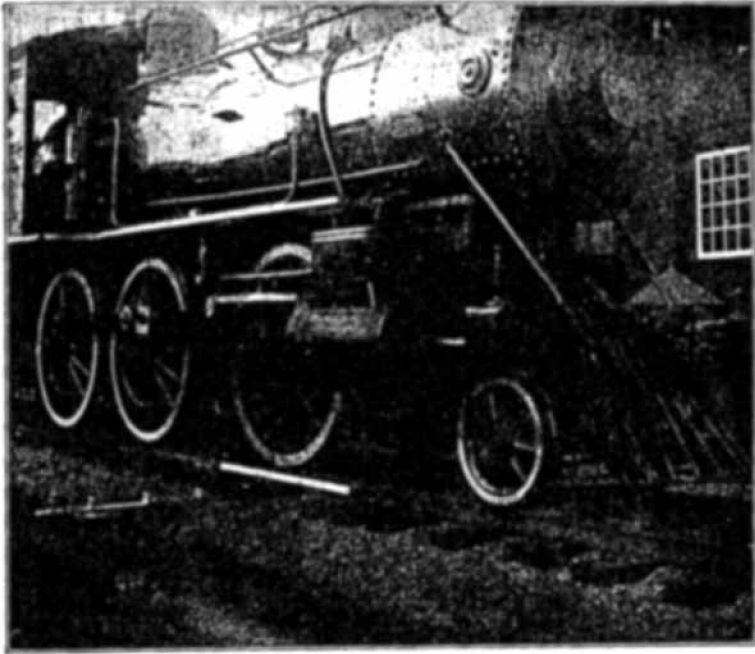


FIG. 1.

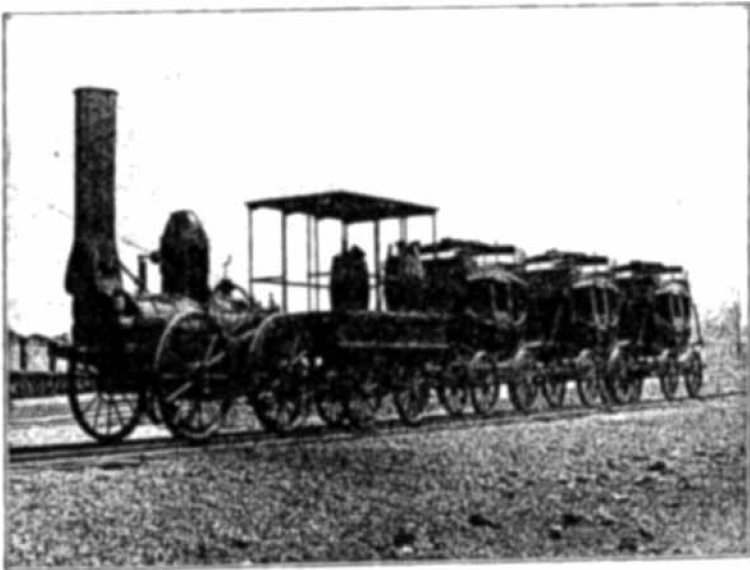


FIG. 2.

PLATE XI.

(111)

PLATE XI.

FIG. 1.—Stremmatograph attached to base of rail to obtain record of the stresses of locomotive No. 596 on Track No. 1, $5\frac{1}{8}$ -inch 80-lb. rails.

FIG. 2.—Locomotive "DeWitt Clinton" and train of the Mohawk and Hudson R. R. Co., 1831. The first American constructed locomotive and train. The inception of the New York Central and Hudson River Railroad. The progress of 60 years was demonstrated by the installation of the "Empire State Express" in 1891, the "fastest long distance train in the World."



FIG. 1.



FIG. 2.

PLATE XII.

(113)

PLATE XII.

Fig. 1.—“Empire State Express” running 60 miles per hour on 65-lb. rails. Locomotive No. 862, Nov., 1891.

Fig. 2.—“Empire State Express” running 60 miles per hour on 80-lb. rails. Locomotive No. 903.

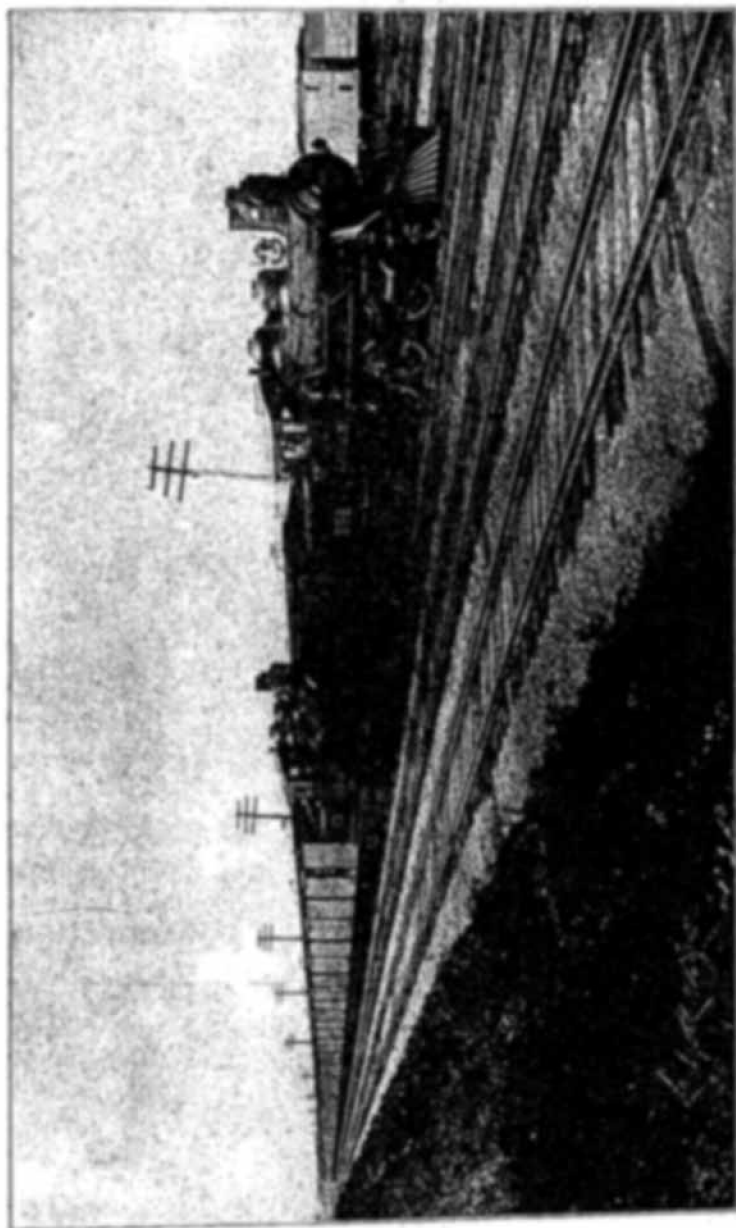


PLATE XIII.

(115)

PLATE XIII.

N. Y. C. and H. R. R. R. freight trains, fifty cars each. Karmer,
N. Y. 1893.

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