

Paper No. 5126.

“Some Experiments on Locomotive Springs, with Reference to Bridge Impact-Allowances.” †

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Mr. C. W. Clarke, of Bombay, observed that the impact upon the rail from the driving wheel of a steam locomotive at any instant might be expressed by the general equation

$$Z=(R+W)+N+H+ky-W\ddot{x}/g$$

where R denoted the static loading on the bearing spring, W the weight of the wheel plus half the axle, N the thrust due to the slidebar-effect, H the dynamic augment due to counterbalancing, k the rigidity of the bearing spring, y the deflexion of the bearing spring from the mean position, and x the amplitude of oscillation of the wheel-centre, the values of x and y being taken algebraically. It would appear that the investigations had been conducted in order to determine the values of ky in the general equation.

In a locomotive, unless $H > (R+W)$, as a first approximation, the wheel could not lift, in which case the values of y were unaffected by H .

In the case of the I.R.S. “pacific” type locomotives, for $H > (R+W)$ the frequency of the coupled wheels had to exceed 10·7 revolutions per second, which was equivalent to a track-speed of over 140 miles per hour. It had been shown that, whilst the sinking of a rail started some six or seven sleepers ahead of the wheel, the trajectory of the centre of the wheel between rail-joints was practically a straight line. When the wheel struck a rail-joint, even at medium speeds, the values of \ddot{x} in the general equation were certainly very much higher than those given by frequencies of rotation of up to 5 revolutions per second, as conducted by the Author.

The experiments conducted on the forced oscillations produced by rotating weights had no direct practical application in determining either the values of ky or the values of \ddot{x} in the general equation.

The impact due to the effect of rail-joints would lead to the occurrence of “sub-impacts” as demonstrated by Mr. R. N. Arnold *, and it would be necessary to calculate the “statical equivalence.”

† Journal Inst. C.E., vol. 8 (1937–38), p. 295 (March 1938).

* “Impact Stresses in a Freely Supported Beam.” Proc. Inst.Mech.E., vol. 137 (1938), p. 217.

The frequency of rolling of a locomotive appeared to be independent of speed, and was fairly constant for any given design; it was about 1.1 second for a complete oscillation in the case of the I.R.S. class XB locomotives. It would seem, therefore, that if, in the experiments conducted to determine the free oscillations produced by the cradle and kentledge, the cradle and kentledge had been so designed and pivoted as to have a period of oscillation about the fulcrum of about 1.1 second, and with the static load on the specimen corresponding to the static load on the locomotive bearing-spring, actual conditions could have been reproduced enabling the values of ky in the general equation to be determined.

The arrangement shown in Figs. 1, Plate 1 (facing p. 304 §) for conducting pulsating-load tests, corresponded more to the conditions of lateral spring-control in a bogie. The static-load-deflexion tests showed that the frictional effect for used springs varied on an average from 19 per cent. to 61 per cent., so that any experiment using a coil spring having the same calculated stiffness might produce errors many times greater than the errors of observation.

In the pulsating-load tests, if instead of the coil spring a second laminated bearing spring placed in an inverted position under the bearing H (Figs. 1, Plate 1 (facing p. 304 §)) had been used, the effect of a laminated-control-spring bogie would have been reproduced. The length of the shaft S and the balance-weights would have to be calculated to produce a dynamic augment equivalent to the couple causing nosing, with the frequency of the dynamic augment corresponding to that of nosing. The frequency of nosing varied with the speed, but frequencies of from 0.5 per second at slow speeds to 1.3 per second at high speeds would cover the range for I.R.S. "pacific" type locomotives.

Another modification of Figs. 1, Plate 1 (facing p. 304 §) was suggested. If instead of the coil spring between the housing H and main frame G, a strut were substituted to bear against the underside of the housing H, and then to pass clear of the main frame G and to rest on a rail mounted on sleepers (the rail-track being clear of the main frame G), the damping effect due to the resilience of the track on the blow produced by the dynamic augment could be determined. That could be done either by using Fereday-Palmer optical strain-recorders to determine the deflexion of the underside of the rail, or by fitting a suitable extensometer to the calibrated strut between the housing H and the rail.

It would be a simple mechanical construction to combine the arrangements shown in Figs. 1 and 2, Plate 1 (facing p. 304 §), so that the effect of rolling on the bearing springs could be reproduced by the oscillating cradle and kentledge acting on top of the bearing spring, and with the

§ Page numbers so marked refer to the Paper. (Footnote (†), p. 501.)—SEC. INST. C.E.

pulsating load produced by the rotating weights (representing the dynamic augment) acting on the housing H at the same time.

An extensometer fitted to the strut between the housing and the rail would show the combined effects of functions ky and H on the rail.

The Author, in reply, would emphasize that the object of his investigation was to enable a bridge-designer to calculate impact-allowances in medium-span railway-bridges with more certainty than had been possible heretofore. In such bridges, the fundamental natural frequency could synchronize with locomotive hammer-blow pulsations at the highest train-speeds, and considerable oscillation could occur with the structure and the unsprung mass oscillating in unison and out of phase with the sprung mass. Steam locomotives were still being constructed which caused considerable hammer-blow, and the extent to which such oscillations were possible largely depended upon spring and other damping forces.

The Bridge Stress Committee in their report of October 1928, took the spring-friction force to be constant in magnitude and alternating in sign, with a periodicity equal to that of the hammer-blow. Only the primary harmonic component of that alternating force was found to be of practical importance, and its phase-relationship was chosen so that the force was zero at instants of zero velocity of spring-movement. The spring-friction force in fact led the spring displacement by a quarter period.

The present investigation showed that the friction-force and its phase-relationship with spring-movement both depended upon the amplitude of the oscillation. That called for a little more work in calculating the bridge-oscillation, as a "trial and error" process had to be followed.

The Author had shown that spring-friction was negligible for small oscillations up to about ± 0.04 inch, and those limits were somewhat greater when the spring was assembled in the locomotive, on account of the flexibility of hangers, etc. The extra deflexion at properly maintained rail-joints came within the limit of negligible spring-friction, and therefore the absence of any factor for spring-friction in the formula given by Mr. Clarke for rail-impact from a driving wheel called for no comment, at least where permanent-way maintenance was good.

After examining a large number of rail-joint deflexion- and stress-records, the Author was able to state that the phenomenon of sub-impacts did not occur under any ordinary rail-joint conditions, which were essentially different from those in a beam subjected to a falling-weight test.

Many experiments had been carried out in the testing machine which had not been described, because they had no bearing upon the question of railway-bridge impact. Those experiments included fatigue-tests upon various standard and special types of laminated springs. Such springs were, in fact, tested in pairs as had been suggested by Mr. Clarke, but in that case the friction was so great that the limit of power of the

machine was reached before sufficient amplitude of oscillation had been attained.

The Author did not agree that Mr. Clarke's proposal would reproduce the conditions of a laminated-control-spring bogie. In such a bogie, the effective stiffness was usually half that for one of the springs, whereas in all arrangements used in the Author's machine for pulsating-load tests the sum of the stiffnesses of the springs had to be taken to give the effective stiffness.

