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ASSOCIATION OF AMERICAN RAILROADS

RESEARCH DEPARTMENT

REPORT NO. MR-448

STUDY OF FRICTIONAL CHARACTERISTICS OF COMPOSITION COMPARED TO CAST IRON BRAKE SHOES

APRIL 1968

Office of Research Director
AAR RESEARCH CENTER
Chicago, Illinois 60616

Railroad at Waycross, Georgia, beginning on April 15, 1968 and ending April 19, 1968. The field work was supplemented with laboratory work conducted at the AAR Research Department on the brake shoe dynamometer machine which has the capability of measuring stopping distances under various brake shoe pressures. The frictional effect for breakaway resistance of wheels was also studied by the use of this machine.

The braking force generated by any brake system is dependent upon two primary factors. The first of these factors is the coefficient of friction between the brake shoe and the wheel tread and the second is the amount of pressure applied to the shoe. Friction between two given bodies is directly proportional to the pressure. The coefficient of friction is constant for all pressures. However, when the tread surface of the wheel reaches a high temperature, there are some variations in the coefficient of friction compared with the coefficient of friction that would be experienced at the lower temperatures. In the case of a locomotive in the type service comparable to that investigated in the test reported herein, high temperature-high speed characteristics would not be encountered. Consequently, the variations in coefficient of friction are due almost entirely to the type of material in contact with the wheel tread.

It is a fundamental axiom that the frictional resistance is proportional to the load applied and that it is independent of the area of the sliding surfaces. Consequently, as will be discussed in the data of this report, the contact area of the brake shoes on the wheel tread does not relate to the braking force generated so that it is not a function of whether or not clasp or single shoe brakes are used, but the pressure applied to the shoe under a given coefficient of friction that establishes the braking or stopping force.

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Mr. J. W. Hawthorne, Assistant Vice President, Seaboard Coast Line Railroad, made available equipment and personnel for this study. Mr. W. B. Kirk, Director of Railroad Engineering, Westinghouse Air Brake Co., furnished instruments and personnel. Mr. J. G. Britton, Mechanical Engineer, AAR Research Center, coordinated the test data and supervised its preparation for this report. Mr. O. W. Knoblock, Engineer of Tests, AAR Research Center, supervised the laboratory work.

PROCEDURES AND INSTRUMENTATION

A meeting was held at Jacksonville, Florida on April 5, 1968 to arrange a field test program for making an investigation of the braking ability of composition brake shoes and cast iron brake shoes on switching type and road-switcher type locomotives. This meeting was attended by representatives of the Seaboard Coast Line, AAR Research Department and Westinghouse Air Brake Company. A tentative procedure for making this investigation was developed which is shown as Figure 1. It was agreed at this meeting that each of the manufacturers of composition brake shoes would be requested to supply composition brake shoes of the type used on switching and road-switcher locomotives to the AAR Research Department for study of the frictional characteristics of these shoes using the brake shoe dynamometer.

The Westinghouse Air Brake Company agreed to supply all instrumentation and manpower to run the instrumentation for the field investigation as this company has special devices which can be used in such tests to quickly develop stopping distances, brake cylinder pressures, speeds, braking ratios, and drawbar pull. It was decided that this instrumentation would be placed in a cabin car to be used as an instrument car during the field studies.

The brake cylinder pressure was measured by a Fred Flader Co. transducer which had been calibrated by Westinghouse Air Brake Company on a dead weight tester from 0 to 100 psi. Figures 2 and 3 are views of this transducer. The output of this transducer was recorded on an Electro Instruments, Inc.'s XYY' Recorder Model No. 580. Figure 4 shows a view of this recorder and stopping distance counter.

The speed in miles per hour was determined by using a rubber-tired aluminum wheel, 12 inches in circumference, which was driven by a wheel on the cabin car. Figures 5 and 6 are views of this device. This small wheel drives a Servo-Tek Products Co.'s DC generator. This device also measured stopping distance which was converted into feet and read on an electronic counter mounted in the cabin car. The speed in miles per hour from this device was recorded on the XYY' Recorder.

The horizontal distance on the recorder charts is time; and the amount of time from initiation of brake application to a complete stop can be read on the XYY' charts. Figure A in the Appendix illustrates an XYY' recorder chart for runs 169 through 177 which are included to illustrate the method used. The ordinate on this chart shows the brake cylinder pressure in psi and the train speed in mph. The initiation of brake application starts the recorder by a switch mounted on the independent brake valve. Figure 7 shows a view of this switch in place on the brake valve. However, to insure accuracy, two observers using stop watches also measured the time from brake application to the point at which motion had ceased. Another speedometer was placed in the cab of the locomotive (see Figure 8) and the speed for this instrument was determined by another aluminum rubber-tired wheel, 24 inches in circumference, which drove another Servo-Tek generator. Figure 9 is a view of this wheel. The power for the instrumentation was obtained from a Briggs and Stratton gasoline engine driving a Master Mechanics Manufacturing Co.'s 115 volt, 60 cycle alternator. This power was fed to a Harrison 6284A DC power supply for instrument operation. Figure 10 is a view of the instrument set-up in the cabin car.

The static drawbar tests were conducted by installing a Baldwin-Lima-Hamilton 50,000 lb. Type U-1 load cell between the locomotives. This load cell had been previously calibrated on an Olson Universal testing machine at Westinghouse Air Brake Company. Figures 11 and 12 are views of this load cell between two locomotives. Figure B in the Appendix shows the traces developed for five trials in Run No. 281R. This series of runs was made to establish the breakaway resistance of the locomotive brakes. The ordinate on this chart is drawbar force and the abscissa is the elapsed time in building up the drawbar force.

Data for determining braking ratio of the locomotives was obtained by using a dynamometer brake shoe and installing it in each brakehead for the GP-7 type of locomotive. The shoe forces at various brake cylinder pressures were measured on a Budd SR-4 static strain indicator. Figure 13 is a view of the dynamometer shoe in place and Figures 14 and 15 are views of the test operation. This dynamometer brake shoe was calibrated on a Baldwin Universal Testing Machine in the test laboratory of the Seaboard Coast Line Railroad at Waycross, Georgia.

The composition brake shoes used on the switchers and road-switching type locomotives of the Seaboard Coast Line are of the high friction type. This type of brake shoe is covered by AAR Specification M-926-65. The specification requires that the brake shoes meet conditions related to the stopping distance from various initial speeds using a light braking load of 2,000 lb. brake shoe force and a heavy braking load of 6,000 lb. brake shoe force. The specification also includes a simulated grade test in which a wheel on the brake shoe dynamometer is rotated continuously against the brake shoe to determine the braking force under these conditions.

The brake shoe dynamometer at the AAR Research Department is equipped to make stop tests under the heavy braking type conditions and tests of breakaway friction can also be made using the dynamometers attached to this machine. A series of tests was made with composition brake shoes which were of the same design and type as those used in the field tests at Waycross, Georgia. The procedure for determining the stop distance under the heavy braking series described in AAR Specification M-926-65 was used to measure the stopping distance with the various types of brake shoes. The static coefficient of friction was determined by observing the deflection of the dynamometer pen when the wheel was rotated against a brake shoe with a force applied ranging from 2,587 to 6,000 lb. The brake force value obtained from the dynamometer is directly convertible to static coefficient of friction.

RESULTS

The field tests were conducted on the Waycross Freight Lead on the Jacksonville main line of the Seaboard Coast Line Railroad starting on April 15, 1968. Stopping tests were begun the following day and continued through April 19, 1968. A list of those in attendance is shown in Table 1 and shows the days during which they were present for the field investigations. Table 2 shows a schedule of the tests as they were conducted on the different types of locomotives, brake shoe arrangements, and brake shoes. Figure 16 is a copy of a data sheet prepared for recording the stop test information. A similar form of data sheet was used for recording information in the locomotive static drawbar tests.

STOP DISTANCE TESTS

Stop distance tests were conducted with locomotives used in switching service at speeds up to 14.5 mph. The test train in each case consisted of the locomotive, instrument car (SCL 0844) and a trailing load of 1,083 tons made up of

15 gondola cars loaded with scrap metal. The gondola cars were equipped with plain bearings. Figure 17 shows the gondola cars used for the stop distance tests. The trainline was connected throughout the train and charged with air. However, for the stop tests only, the independent brake was used to stop the train and to actuate instrumentation measuring stopping time, distance and brake cylinder pressure build-up.

SW Type Locomotives with Clasp Brake Arrangement

Two locomotives of the SW-9 type (1,200 HP) were selected to make stop distance tests and to compare the stopping capabilities of composition shoes with cast iron flanged shoes. Locomotive No. 155 which was equipped with the cast iron flanged shoes, had a rail weight of 247,100 lb., 34 psi brake cylinder pressure and a theoretical braking ratio of 56.8 percent. Locomotive No. 147 was used for tests with composition shoes and weighed 246,600 lb. Brake cylinder pressures used on Locomotive No. 147 were 27 psi giving 45.0 percent braking ratio and 33 psi resulting in 55.2 percent braking ratio. The data from these stop distance tests are plotted in Figure 18. This plot shows that at speeds below 4 mph, the stopping distance was independent of the type of shoe used at the brake pressures investigated. Stopping the test train from 4 mph required 60 ft. to 90 ft. stopping distance.

At speeds exceeding 4 mph, the composition brake shoes show a definite trend toward shortened stopping distances and this trend becomes more pronounced as the initial speed increases. For example, stopping from a speed of 10 mph using composition shoes and 27 psi brake cylinder pressure required 510 ft. compared to 775 ft. required for the locomotive equipped with cast iron shoes with a higher braking ratio and 34 psi brake cylinder pressure. In the case of the composition shoe arrangement with 33 psi brake cylinder pressure, locomotive wheel sliding occurred (see Figure 18) when making a stop from 5.8 mph, indicating a braking ratio for the conditions under which this locomotive was used to stop the train that cannot be exceeded without risk of sliding wheels.

GP-7 Locomotives (1,500 HP) with Clasp Brake Arrangement

Locomotives No. 773 and No. 805 of this same type and having clasp brake arrangements were used in the stopping distance tests. Locomotive No. 773 was equipped with cast iron brake shoes and had a brake cylinder pressure of 45 psi which provides 52.3 percent braking ratio based on a rail weight of 247,900 lb. Locomotive No. 805 weighed 244,900 lb. and was equipped with composition brake shoes. The brake cylinder pressures on Locomotive No. 805 were varied from 27 psi producing 31.6 percent braking ratio to 45 psi giving 52.9 percent braking ratio. Data from five series of stop tests on the GP-7 locomotives with clasp brake arrangement are shown in graphical form in Figure 19.

The data shown in Figure 19 indicate that the stop distance from 4 mph for the cast iron shoe and for the three highest brake cylinder pressures in the composition shoe arrangement were between 80 to 100 ft. With a brake cylinder pressure of 27 psi for the composition shoe, the stop distance increased to 142 ft. As the initial speed increased, the composition shoes showed a more favorable trend toward shorter stopping distance when compared with cast iron shoes. Above 5.2 mph, the stopping distances obtained with composition shoes (except for the arrangement with 27 psi brake cylinder pressure) were considerably better than the cast iron shoe brake. At 10 mph, the cast iron shoe was equivalent to the composition shoe with 27 psi brake cylinder pressure and at speeds above 10 mph, all of the composition shoe arrangements provided a better stopping distance condition than the cast iron shoes. At an initial speed of 10 mph, for example, the stopping distance was 490 ft. for composition shoes with 45 psi brake cylinder pressure. The cast iron shoe under the same conditions of brake cylinder pressure but with slightly lower braking ratio, had a stop distance of 725 ft.

GP-7 Locomotives with Single Shoe Brake Arrangement

A GP-7 locomotive with a single shoe brake arrangement and with composition shoes was compared with Locomotive No. 773 which had a clasp brake arrangement and cast iron shoes. As previously described, Locomotive No. 773 weighed 247,900 lb. and had a 45 psi brake cylinder pressure resulting in a braking ratio of 52.3 percent. The single shoe arrangement with a composition shoe in place is shown in Figure 20 and was applied to GP-7 Locomotive No. 796. This locomotive weighed 248,200 lb. and brake cylinder pressures of 45 psi to 74.5 psi were investigated in this study. These brake cylinder pressures resulted, respectively, in a braking ratio range of 26.1 percent to 43.6 percent.

The comparison between the stopping distances with cast iron shoes and composition shoes is shown graphically in Figure 21. The stop distance curves on this graph for Locomotive No. 796 is similar to the curves developed by the locomotive having the clasp composition shoe brake arrangement. At brake cylinder pressures above 58.5 psi, the composition shoe locomotives have substantially the same stopping capabilities from 4 mph as the cast iron shoe equipped locomotive. This stopping distance ranges from 85 to 108 ft. from an initial speed of 4 mph. Above 10 mph, all of the tests with the composition shoes throughout the entire range of brake cylinder pressures provided better stopping distances than cast iron shoes although Locomotive No. 796 was equipped with a single shoe brake arrangement in comparison with the clasp arrangement on Locomotive No. 773. At 8 mph, except for the composition shoe locomotive with 45 psi brake cylinder pressure, the stopping distances for the composition shoes was equivalent to or better than the cast iron shoe performance. For example, at an initial speed of 8 mph, the stopping distance for the composition shoe with 74.5 psi brake cylinder pressure was 322 ft. compared to the 422 ft. stopping distance from the same initial speed for the cast iron shoe.

Comparison of Composition Shoe Types on the SW-9 Locomotive

The stopping distance data shown in Figure 18 was obtained with a Cobra Brake Shoe, Type V-149 marketed by Westinghouse Air Brake Co. A brake shoe design for the ~~sample~~ application is sold by Griffin Wheel Co. and is called the Anchor Shoe, Type H-71-6. These shoes were compared under the same conditions on Locomotive No. 147, an SW-9 type switcher. The shoes were compared using 27 psi brake cylinder pressure resulting in a 45.0 percent braking ratio. The speed and stop distance information is shown in Figure 22 which shows that these two brands of composition brake shoes produced the same stop distance curve indicating no difference in stopping characteristics between the shoes tested.

Comparison of Brake Shoe Types on the GP-7 Type Locomotive with Single Shoe Braking Arrangement

The information presented in Figure 21 for the composition shoes on Locomotive No. 796 was based on the Cobra Brake Shoe, Type V-103, marketed by Westinghouse Air Brake Co. Two other composition brake shoes were used for comparison with the Cobra type shoe using a single shoe arrangement on Locomotive No. 796. These shoes were the Anchor Type H-25-2 shoe sold by Griffin Wheel Co. and the Comet Type C-158 shoe produced by Abex Corp. All of these shoes were studied using a brake cylinder pressure of 67.5 psi resulting in a braking ratio of 39.2 percent. The data developed in this series of tests are presented in Figure 23. The curves for stopping distances resulting from the use of all three brake shoe types follow a similar pattern and within the limits of reproducibility, it appears that the three brake shoe types can be considered equivalent for this type of application.

STATIC DRAWBAR TESTS

Static drawbar tests were conducted on each type of locomotive by varying the brake cylinder pressure and noting the drawbar pull load developed on the dynamometer coupler when the wheels on which the brake was applied on the test locomotive first began to rotate. Since the dynamometer coupler limit was 50,000 lb., which was below the forces that would develop with the brake on all wheels, the brakes were applied to only one truck of the test locomotive. The brake application was made to the lead truck in one series of tests and to the trailing truck in a second series. The tests were begun at 0 brake cylinder pressure to determine the train resistance of the locomotive at starting. Figure 24 shows the arrangement used on the static drawbar pull tests in which Locomotive No. 155, an SW-9 type, is being tested for breakaway resistance. Locomotive No. 773, a GP-7 type, was used to provide the drawbar pull and breakaway force to Locomotive No. 155. Figure 25 shows a similar arrangement where Locomotive No. 796 with a single shoe brake rigging arrangement is being pulled by Locomotive No. 805 through the dynamometer drawbar arrangement.

Figure 26 is a plot of the data obtained in static drawbar tests. The scatter of points shows the wide range of values determined at each brake cylinder pressure setting. The total resistance to breakaway force represented by the drawbar pull is shown in Figure 26 and includes brake shoe resistance and locomotive train resistance. Figure 27 shows static drawbar curves developed by subtracting the locomotive train resistance with no brake applied from the values obtained with the brake applied under various brake cylinder pressures. Table 3 shows the average values for starting resistance for the five locomotives used in the test when no brake was applied. These values range from 625 lb. for Locomotive No. 796 to 6,250 lb. for Locomotive No. 773. The locomotives on which the cast iron shoes had been applied and worn-in prior to making the tests had a somewhat higher static resistance than the locomotives on which composition shoes had been applied and worn-in prior to test. This variation in the locomotive train resistance is an effect that appears to develop because the composition shoe does not create a build-up of brake shoe metal on the wheel tread and continuously keeps the wheel tread in a relatively smooth condition. With cast iron shoes, the brake shoe metal develops a roughened tread condition because of the localized heating and abrasion which occurs during brake applications. This difference in tread condition may explain in part the variation in starting resistance found between the locomotives equipped with the two types of shoes.

Referring to Figure 27, it is evident that the brake cylinder pressure for a locomotive equipped with composition shoes which is required to develop the same breakaway resistance as a locomotive equipped with cast iron shoes, is somewhat greater. This effect develops from the fact that the coefficient of friction of cast iron on steel at extremely low speeds approaching zero is high, whereas the coefficient of friction of composition shoes on steel wheels is more uniform over a wide speed range and does not increase at very low speeds approaching zero. Locomotives No. 147 and 805 which were, respectively, an SW-9 and GP-7 type both having clasp brakes, showed essentially the same breakaway resistance. Both of these locomotives were equipped with composition brake shoes. Locomotive No. 796, a GP-7 type road switcher equipped with a composition single shoe brake arrangement, showed a markedly lower value of breakaway resistance for all brake cylinder pressures. The same comparison did not apply in the case of locomotives equipped with cast iron clasp shoe brake arrangement as is evident from the plotted data. Locomotive No. 155, an SW-9 type switcher, showed a much higher static resistance throughout the range of brake cylinder pressures tested than did GP-7 Locomotive No. 773 which was also equipped with a clasp brake arrangement having cast iron shoes.

DETERMINATION OF BRAKE FORCES

A dynamometer brake shoe was used to study the braking pressures on the locomotives used in the field test work. The theoretical braking pressure was computed and the curve for this braking force is shown on Figure 28 for GP-7 locomotives used in the tests. This study was not made for the SW-9 locomotives because the dynamometer brake shoe was damaged and required extensive repair. This work is scheduled to be conducted at a later time. Figure 28 also shows the variation of shoe force with brake cylinder pressure as determined by the dynamometer brake shoe.

The ranges of shoe force for each brake cylinder pressure used are quite large. This can be explained by a difference in the brake rigging efficiency during any particular test. With the vibration of locomotive movement, it is expected that the braking force would have a more narrow range than is shown in Figure 28. This figure also shows that the shoe force ranges for Locomotive No. 773, with the cast iron shoe clasp brake, is similar to the shoe force range for each of the GP-7 locomotives equipped with composition shoes.

There is not sufficient difference in the information developed in this study of braking forces to indicate that one type of brake shoe arrangement or shoe type has an advantage over the other types tested.

LABORATORY TESTS

The five types of high friction composition brake shoes studied in the field investigations were also studied on the brake shoe dynamometer machine at the AAR Research Laboratory. This work was divided into stop distance tests and static coefficient of friction tests. The brake shoe pressure was 6,000 lb. per shoe and single shoe tests were used for the stopping distance data. The wheel load on rail was equivalent to 20,[illegible] lb.

Stop Distance Tests

The stop distance tests were conducted in accordance with the schedule for heavy braking tests described in AAR Specification M-926-65. A 33-in. diameter wrought steel wheel was used in these tests requiring that the brake shoes be machined to the approximate wheel radius since the shoes used in these studies were designed for locomotives having a larger wheel diameter than 33 in. The wheel tread was highly polished with a special brake shoe and each brake shoe was worn-in on the wheel to obtain a good bearing condition. Prior to each stop-distance run, the wheel tread was cooled to a temperature not exceeding a maximum of 125° F.

Data for each brake shoe type from the stop-distance tests were averaged for each initial speed and this information is presented in Table 4. At initial speeds of 10 and 30 mph, all of the brake shoes were within the range of stop-distance values given in the Specification. At these speeds there was little difference noted in the stop-distance performance among the brake shoes studied. At 50 mph initial speed, the brake shoes generally were within the proper range of values taking into account slight normal deviations from experimental error. Shoe H-26-4 was an exception at this speed with the average stopping distance being 1,692 ft. However, all stops made at 10 and 30 mph were surprisingly consistent. The major exception in the 50 and 70 mph stop test was the Griffin H-26-4 shoe. Other than this variable, all results were consistent.

Static Coefficient of Friction Tests

The measurement of static and kinetic friction at low speeds is difficult and is likely to show wide variations, particularly when using a simulated wheel and brake shoe assembly. No laws on friction are absolute in practice and each one is modified for certain circumstances. The coefficient of friction, as was stated earlier, is independent of the speed of movement between the two contact surfaces. Some experiments have shown that the time of contact of the surfaces affects the coefficient of friction. The coefficient of friction is slightly greater for small pressures on large areas than for high pressures on small areas. With all of these variables in combination with the variable resulting from friction in the brake rigging, there has been a reasonable degree of consistency in the readings obtained during the laboratory tests.

Table 5 shows the static coefficient of friction for various composition shoes and one cast iron brake shoe. It will be noted that the V-103 composition

CONCLUSIONS

1. Braking force developed by the brake system is dependent upon the fundamentals of coefficient of friction of the brake shoe on the wheel and pressure applied on the shoe.

2. The stopping distances measured in the test covered by the foregoing data are independent of the type brake shoe or whether single or clasp brakes are used, provided that proper coefficient of friction of brake shoes and brake shoe pressure are used in the design.

3. Brake shoe pressures that develop restraining forces greater than can be withstood by the wheel-rail contact will result in the tendency to reduce braking effort and cause slid flat wheels.

4. Brake systems should be designed and maintained for the type of brake shoe it is desired to use.

5. Wide variations in the coefficient of friction of composition brake shoes of the manufacturers' shoes that were tested were not shown to exist in this investigation.

6. The coefficient of friction values for the cast iron shoe compared with the composition shoes are sufficiently similar to permit use of either type of shoe provided proper brake cylinder pressure is maintained and suitable lever ratios are used in the design.

* * * * *

Research Director

Approved, Assistant Vice President

Approved for Release, Vice President