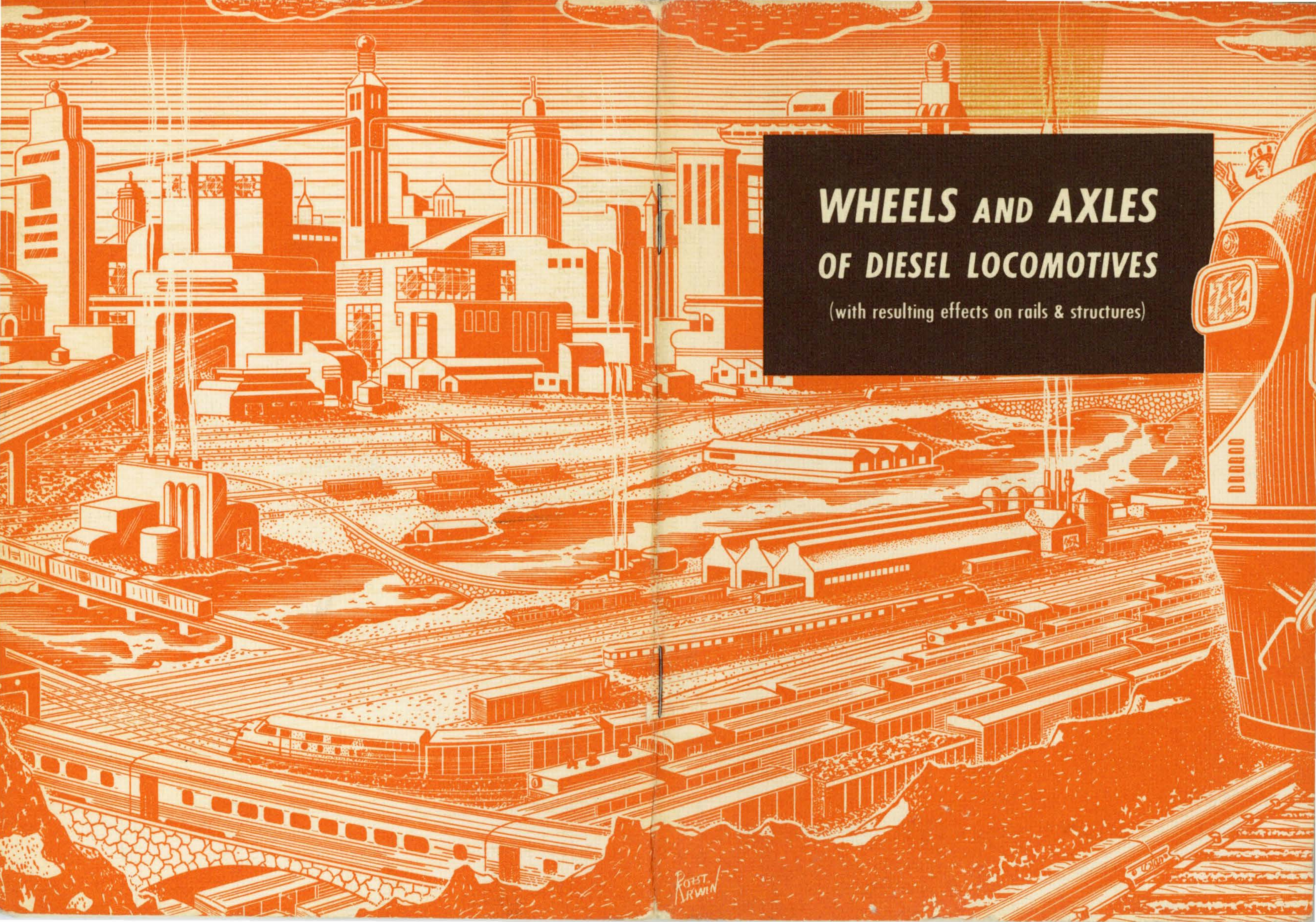
WHEELS AND AXLES OF DIESEL LOCOMOTIVES

(with resulting effects on rails & structures)



INTRODUCTION

The library of technical knowledge concerning wheels and axles as applied to railroad locomotives was assembled and recorded during the days of the steam locomotive. While much of the data is applicable to the Diesel-electric locomotive, other data which have been applied to it develop false conclusions. In addition, many areas exist where accurate factual information has been totally lacking. It is the purpose of this paper to relate the accepted data to the requirements of wheels and axles for Diesel-electric locomotive performance, to supply as much new data as is available, and to indicate the known effects of the stresses transmitted by such wheels and axles to rail and structure.

WHEELS

OUR greatest aids to transportation, the wheel and axle are known to have been used for the past 5,500 years. Archeologists have found a burial pit containing two four-wheeled wagons that are believed to be the oldest known vehicles. The wheels, of wood, are laminated of three pieces and have tires of leather, held to the tread by copper nails.

On one of the wagons the front wheels are approximately 24 inches in diameter and the rear wheels are about 31½ inches. The axle holes are about four inches in diameter. The four wheels of the second wagon are slightly under 40 inches in diameter and the axles are about 40 inches long.

The findings of these two wagons proves that the principle of the wheel and axle as used in transportation equipment

is as old as our oldest known civilization. Modern wheels and axles differ only in design, materials and accuracy of workmanship.

Down through the ages, the wheel and axle knowledge and usuage seems to have centered in the Near East. Egyptian chariots, war machines and wagons are referred to quite often circa 2000 B.C. Joseph's brothers brought wagons to fetch grain from Egypt at the time of the great famine.

The use of rails and track seems to have been unknown in ancient times. These belong to the "mechanical age", their first use being reported shortly after 1700 A.D.

Wheels, axles and rails became associated with modern transportation problems in the seventeen hundreds A.D. Early railroad wheels were made of wood with iron fittings and rims; axles in most cases were of iron. Rails started out as ordinary heavy wood planking with iron strips where the wheels contacted the rails. Progress was rapid and by the early eighteen hundreds, the pattern was pretty well fixed. Cast iron and wrought iron replaced the wood as loadings and speeds increased. Most of this development was in England. By 1820-30, railroad activity began in the United States.

In the following years the one-piece cast-iron wheel with chilled tread* became the standard in the U.S.A. Steel tires for cast iron wheels began to appear shortly after the Civil War. Advocates of the two types of wheels spent a great deal of time discussing the merits of each.

Experiments with one-piece wrought-steel wheels began in 1900 and continued for six years before they were

*1816.

used to any extent. Except for some forms of heat treatment, the 1906 wrought-steel wheel was practically the same as the multiple-wear wrought-steel wheel of today.

It is interesting to note that of the five thousand five hundred years history of the wheel, axle and wagon, the greatest application and refinement of development has taken place within the past one hundred and fifty years.

WHEELS IN RAILWAY SERVICE

Prior to the formation of the Master Car Builders Association in 1867, each railroad purchased whatever wheels were available or had wheels built to their own specifications. This was true of all railroad equipment. Standardization of wheels, axles, couplers, heights and widths of cars were among the items to be discussed by the new association. In the following year the American Railway Master Mechanics Association was organized for the purpose of improving locomotive design. These two associations became a part of the American Railway Association in 1919. The A.R.A. name was changed in 1934 to Association of American Railroads. The functions of the original associations are now incorporated in the Operations and Maintenance Department, Mechanical Division. Their publication, Wheel and Axle Manual, contains Standard and Recommended Practice that is generally followed by all railroads in the United States.

Recommended wheels may be divided into two general classifications, Cast Iron sometimes called Chilled Tread

DIESEL LOCOMOTIVE WHEELS

Six types are listed for use on Diesel locomotives. They are H-33, F-36, A-40, C-42, BX-38, AX-40*. Each of these wheel sizes is available in each of the above seven types of treatments, thus approximately forty-two different wheels are specified for Deisel use.

Two Tread and Flange contours are available for all multiple wear wrought steel wheels.

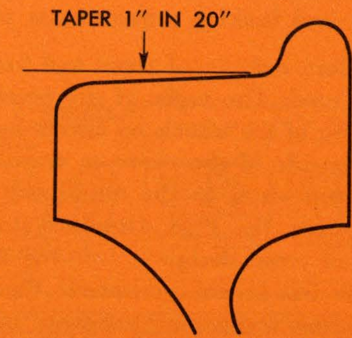
1 1942 Standard contour.

2 1948 Alternate standard cylindrical contour.

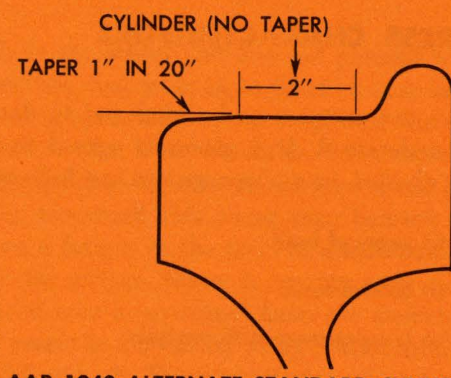
Most wheels are turned to the 1942 Standard Contour which includes a one in twenty tread taper, beginning at the flange slope.

The 1948 Alternate standard cylindrical tread contour calls for a cylindrical tread from the flange slope to within one and five-eighths of an inch of the front face of the rim. From there on to the front face of the rim, the slope is one in twenty. With this alternate tread contour, the choice of wheel types for Deisel locomotives is increased to approximately eighty-four.

Many of these types are seldom used. Class U, the untreated wheel, has been used on a few Deisel switchers, but it is considered too soft and wears very rapidly. Very few Class A wheels are used in Deisel service because they, too, are not suitable for the heavy wheel loading of most Diesel locomotives. The Class B, rim quenched wheel is



AAR 1942 STANDARD CONTOUR OF TREAD AND FLANGE



AAR 1948 ALTERNATE STANDARD CYLINDRICAL TREAD AND FLANGE CONTOUR

used more than all other types combined. The chemistry of the metal is such that the wheel is well suited for heavier wheel loading, high speed service and severe braking conditions. Class C wheels are intended for use where wheel loading is high and braking requirements are moderate.

The 1942 Standard contour of tread and flange design is most generally used. The taper of the tread is intended to reduce slipping of the wheels on curves by causing the wheel on the outside of the curve to travel on a larger diameter than the wheel on the inside rail. Where high speeds predominate, the 1948 Alternate standard cylindrical contour of tread design is believed by many designers to cause less lateral movement therefore wheels of this contour are standard equipment on some high speed Diesel passenger locomotives.

STRESS CHARACTERISTICS

Wheel stresses are complex and varied and to date not too well understood. It is generally agreed that they may be divided into three groups, as follows:

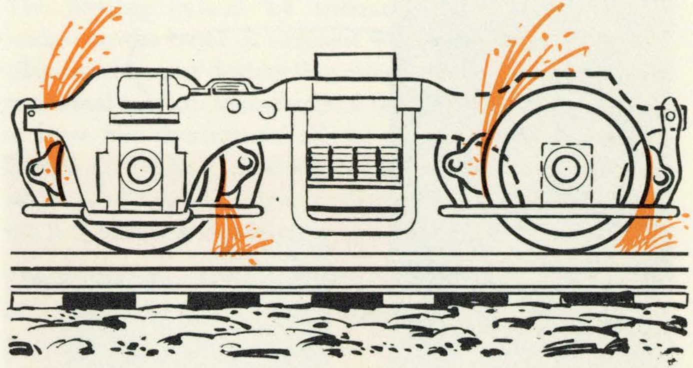
1 Stress due to vertical load.

2 Stress due to lateral load.

3 Stress due to temperature differentials.

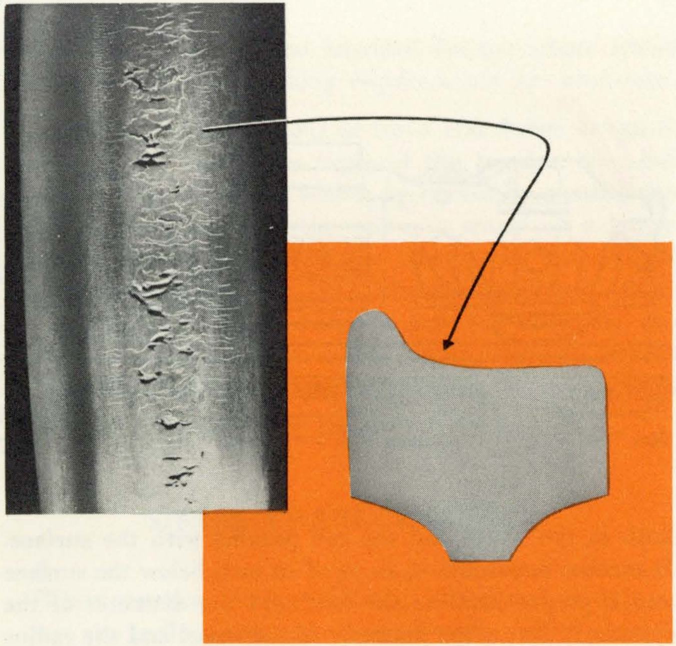
STRESS DUE TO VERTICAL LOAD

It was shown by H. Hertz in 1881 and expanded by Hoersh in 1930 that when a cylinder such as a wheel rests upon another cylinder such as a rail, the head of which may be considered as a cylinder, a shear stress is developed



both in the wheel and the rail parallel with the surface. It reaches maximum $\frac{1}{16}$ to $\frac{1}{8}$ of an inch below the surface and is proportional to the load and the diameter of the cylinders; that is the diameter of the wheel and the radius of the head of the rail. If the load is too high or the diameter too small this shear may become so high that it causes a fatigue in the form of a subsurface crack parallel with the surface. When it reaches such a size that a substantial area is separated from the underlying material it may result in a breaking away of the metal of the wheel or the rail or both. This condition is referred to as "shelling."

At the present time there is considerable discussion taking place as to how much of this type of failure is actually caused by excessive loading and how much is caused by wheel heating due to braking action on the wheel rim and to burned spots due to sliding of the wheel on the rail.



To date wheel loading limits have not been established for Diesel locomotive wheels. However most of the American railroads will permit axle loads equivalent to 750 to 800 pounds per inch of wheel diameter.

STRESS DUE TO LATERAL LOAD

Sidewise movement of car bodies and trucks due to curves and uneven track cause lateral loads that result in complex wheel stress patterns, flange wear and increased axle stresses. Attempts to measure these stresses in the wheel during operation have not been too successful due to their blending with the vertical load stresses.

STRESS DUE TO TEMPERATURE DIFFERENTIALS

The heating caused by common practice of applying brakes to the tread of railroad wheels is probably responsible for the most destructive stresses that are encountered in normal service. Metallurgical laboratory studies indicate at least two detrimental effects result from this practice. These are shallow thermal cracks on the tread and the reversal of the protective compressive stresses present in the rim of a new wheel.

These shallow thermal cracks on the tread of a wheel are caused by the violent dimensional changes accompanying the heating and subsequent transformation on cooling. Continued rolling of the wheel may cause the metal to flake out, creating a condition known as "spalling", which in many instances is incorrectly referred to as "shelling."

WHEEL SIZES

During the early development of the Diesel locomotive, wheel size was limited by the space available under the car body. The over-all height of the locomotive was, and still is, determined by existing railroad structures such as bridges and tunnels. The height of the carbody was dictated by available Diesel engines suitable for railroad use. This limited wheel size to a maximum diameter of approximately forty inches. The necessity of matching existing couplers also had its influence.

The first mainline locomotives were built for high speed, light weight passenger service, and safety was a prime factor. Smaller diameter wheels transmit less strain to axles and make possible a lower center of gravity for the locomotives.

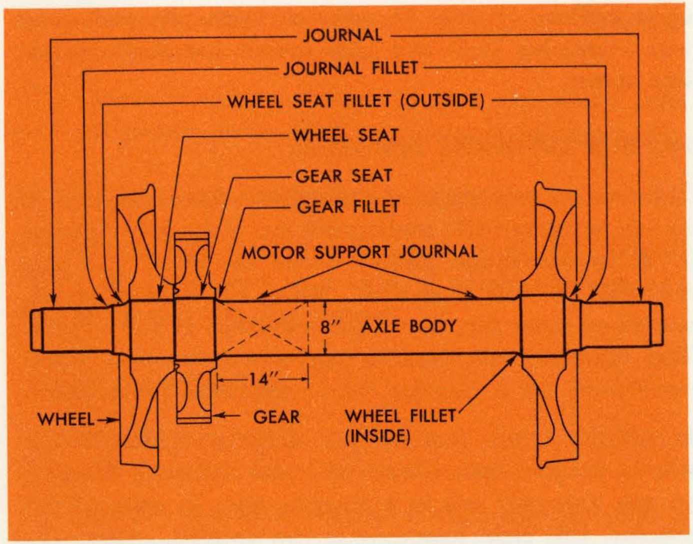
Switching locomotives did not require quite as much headroom in the carbody, due to the mounting of the radiators on the same plane as the engine and generator, thereby providing additional space for larger wheels. The forty-inch wheel has become the standard for switchers.

Freight locomotives are designed for lower speed and increased pulling ability. With increased weight to provide additional tractive effort and the desirability of having all weight on drivers, the four wheeled truck, with the additional weight carrying ability of forty-inch wheels, has become standard.

AXLES

The standardization of axles began with the theoretical formula developed under the Master Car Builders Association in 1896. That work, somewhat modified through the years, has resulted in the development of the highly efficient railway axles of today.

Throughout the ensuing years considerable improvement has been made in the manufacture of steel. Specifications are adhered to more closely and steels are more uniform. The sonic reflection and magnetic particle inspection tests have also helped to eliminate defects. The machining of axles for locomotives is very carefully done and improved finishing practices have produced surfaces free of scratches and tool marks from which cracks might start.



END AXLE PRACTICE

The original EMD switchers in 1936 made use of the AAR-E-12X, 6½″ x 12″ axle, modified, which had a 9¼″ wheel seat and an 8¼″ axle body. Except for slight dimensional changes, this same axle is used in present-day switchers.

In high-speed main line locomotives, the motor bearings resting on the axle required a softer lining and ¼″ was taken from the axle body and added to the motor bearing. In view of the somewhat lower axle loading and the existing standards, this was considered a legitimate design and was known as a 6½″ x 12″, E-12 modified axle with a special wheel and gear seat. Subsequent experience based upon millions of miles of operation with this axle, even with increasing loads and high speeds, has shown excellent results.

RELATION OF WHEELS AND AXLES

The railroad practice of mounting two wheels rigidly on an axle is theoretically undesirable and is the only instance in all transportation history where the wheel and axle are used in such a manner. When negotiating curves, one wheel must slip due to the difference in rail lengths. This difference amounts to approximately three wheel revolutions on a circular track one mile in diameter.

In addition, there is a sidewise slipping of some of the wheels because two wheels of equal diameter fixed to an axle can only roll in a straight line. In spite of the slipping, this rigid mounting is the simplest, safest, the least expensive, and the most practical method of wheel support that has been devised to date. Wheel spacing is maintained, braking is equalized and the transmission of power to the wheels is simplified.

LOCOMOTIVE WEIGHT LIMITATIONS

The demand for increased tractive effort has resulted in a gradual increase in Diesel locomotive weight. Early models were built with wheel loads of less than 700 pounds per inch of wheel diameter. Present day models approach 800 pounds per inch and in some cases exceed that value. Though there is no authoritative limit at the present time, design engineers are of the opinion that with presently available wheels, locomotive weights should not be increased except where the diameter or number of wheels per unit is increased.

The margin of safety in presently used wheels and axles does not permit increases in locomotive weights per axle.

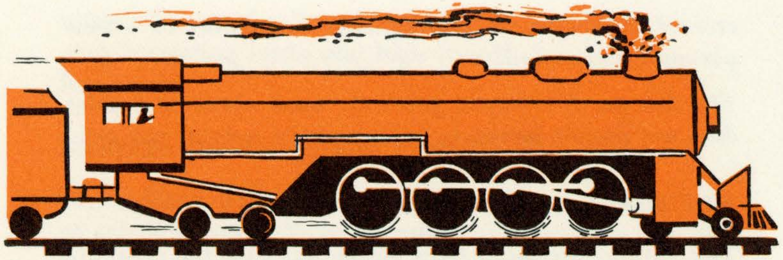
AXLE LOADS AND WHEEL ARRANGEMENTS

The stresses produced by a locomotive and the resulting effects are considered on a basis of weight per axle and may be divided into two groups:

1. The effect on rails.
2. The effect on bridges and viaducts.

The type of locomotive whether a steam locomotive or a diesel locomotive is a governing factor in determining permissible axle loads because of the difference in impact between the two types of motive power.

Whereas a diesel or electric locomotive does not transmit any appreciable vibration from its machinery to the axles and rails, the dynamic augment of a steam locomotive, due to its heavy reciprocating parts, operating at low frequency, adds both horizontal and vertical impact to its dead or static weight. The horizontal impact causes the locomotive to nose from side to side in a zig-zag manner. The vertical impact, aided by the locomotive springs and the spring action of a flexible track can cause the wheels to leave the rails vertically even when the dynamic augment is less than the static weight of the locomotive.



The dynamic augment and resulting hammer blow to the rails is proportional to the square of the speed and depends upon the manner in which the locomotive has been balanced. There may be a material difference between locomotives and it takes considerable study to determine the increase in rail stress due to the hammer blows of a specific locomotive. That it can be done with reasonable success has been demonstrated by A.A.R. and others who have calculated the dynamic augment and resulting hammer blows and measured the resulting rail stresses for a number of steam locomotives. A reasonable assumption is that the hammer blows increase the effective axle load under a steam locomotive by 100% at 100 MPH, 25% at 50 MPH and 6% at 24 MPH. The rail stresses will, of course, vary proportionally to the effective load.

The spacing of the wheels and the over-all dimensions of each rigid wheel base are important. Bridge stresses and rail stresses are affected by the wheel arrangement.

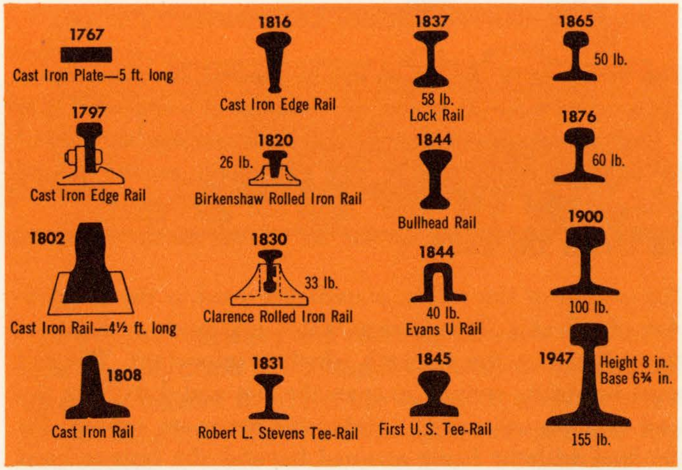
The flexibility between the wheel and the locomotive body has a marked effect upon the rail stress. The theory of "Isolation of Shocks" by elastic support is well known.

The diameter of the wheel has in general, no effect upon the bending moment in the rail, although it is conceded that it might have some influence upon the acceleration caused by small irregularities in the rails such as rail joints.

THE EFFECT ON RAILS

The weight of the rail in pounds per yard, is the designation of rail size. This is regrettable inasmuch as it is not the weight but the strength which is important. The rail must be strong enough to span the ties and distribute the load over enough ties to develop the necessary support for the load without being stressed beyond the fatigue limit for the load and the frequency of application.

Several investigators in the United States, Germany, Poland and Russia have studied the rail stresses and have come to the conclusion that the bending stresses and depressions of the rails can be estimated by treating the rail as a continuous beam over a flexible support. In the United States the theory was formulated and put into convenient form by Dr. Talbot and given in American Railway Engineers Association Proceedings, 1918. Many tests by American Railway Engineers Association and others have since substantiated Dr. Talbot's formula. According to Dr. Talbot the stress is dependent upon the load on the rail, the strength of the rail, the elasticity of the ballast and subsoil and the distance from the point of load to the point under consideration.



The more flexible the support, the higher the stress in the rail. Good ballast is important because it produces a firm and less flexible support for the ties, and thereby reduces the bending stress in the rails.

The maintenance of the track is all important to the rail stresses. Poor maintenance will invariably result in uneven rail support. As the ties decompose and the ballast becomes dislocated by the shaking of passing trains and by the roots of weeds and even of surrounding trees, the flexibility will increase considerably in spots and thereby cause local high bending stresses.

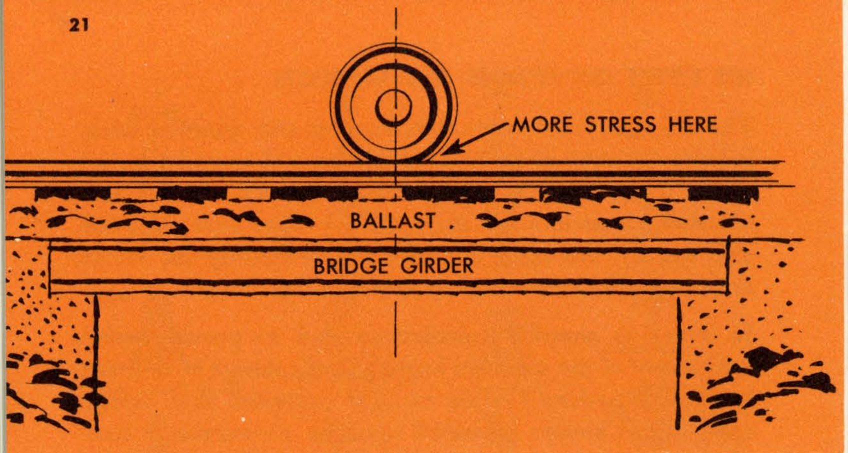
Talbot's formula shows that the bending moment in the rail under one wheel is reduced by another wheel nearby as long as it is more than two or three feet away, depending upon the elasticity of the ballast and subsoil.

THE EFFECT ON BRIDGES AND VIADUCTS

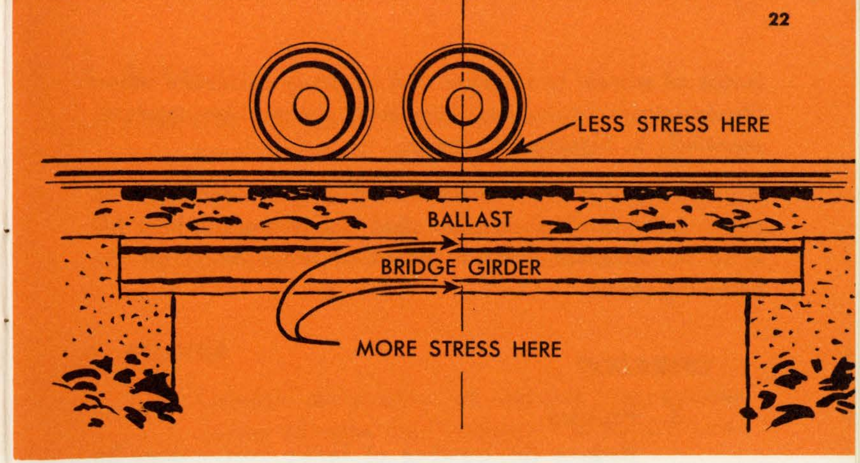
The effect of locomotive axle loading and wheel spacing is quite different on bridges and viaducts than on ballasted track. If an axle introduces a certain stress in the rail and a certain stress in a bridge, it will be found that a second axle nearby will have the effect of decreasing the stress in the rail but increasing the stress in the bridge.

In order to simplify calculations and to provide some uniformity of the assumed loading in the design of railroad bridges, Theodore Cooper in 1901 proposed that bridge calculations always be based upon an assumed live load of two consolidation type locomotives pulling a uniform load. He further proposed that the wheel spacing be fixed and that the weight on the rail per axle under the pony trucks, tenders and trailing cars always be assumed as a certain per cent of the weight on the rail of a driver axle. If the weight on the rail of a driving axle was 50,000 pounds he referred to the load as an E-50 load; if the weight per driving axle was 60,000 pounds the load would be designated as an E-60 load.

With this system it was possible to establish a standard measurement for the strength of all bridges. If the bridge was good for an E-72 Cooper load, then all concerned knew that the bridge would safely carry a standard Cooper load of which each driver axle weighed 72,000 pounds on the rail, and, of course, any other locomotive or trailing load which did not introduce larger moments and shear than the standard load. It was further possible to calculate for all locomotives irrespective of how they were constructed individually, the moment and shear they



would produce in a bridge span and compare it with the moment and shear which would be produced by a standard Cooper load. If it was found that a certain mallet-type locomotive, for example, would cause as high a moment as an E-70 Cooper standard load, even though the axle loading was less than 70,000 pounds, the mallet was given an E-70 Cooper rating. The two consolidation type locomotives provide the base line and are the only type of locomotives where the relation between the Cooper rating and the axle loading is direct. Diesel locomotives with fewer axles of say 50,000 pounds per axle will have a Cooper rating of less than E-50. When the Cooper rating for each locomotive is known and the strength of each bridge is expressed in Cooper load, it can immediately be determined which locomotive can safely pass over each bridge. In many instances it is necessary to impose severe speed limits on steam locomotives because of high dynamic augment.



Due to the continued increase of steam locomotive weight, the recommended loads for bridge design increased. In 1935 the American Railway Engineering Association recommended that railroad bridges be designed for an E-72 Cooper standard load. That was about the time the Diesel locomotive era began. Because of the high weight of steam locomotives it was found that the lighter Diesel locomotives could safely negotiate practically any railroad bridge in normal use. This will be readily understood when it is realized that practically all Diesel locomotives in use today are rated between Cooper E-30 and E-45 and cause very slight impact, most of which is from rail irregularities.

WHEEL WEAR AND MAINTENANCE

As Diesel locomotives have come into general use there has been a gradual increase in weight, horsepower and speed. These increases have naturally caused the load factor of wheels to increase and in many instances wheel life, in terms of miles, has decreased, as would be expected, especially in high speed service.

A careful study of wheel life under varying conditions on many railroads has revealed that if maximum wheel life is to be obtained, special attention must be given the following items:

1 *OPERATION*

A. Braking

Reduce the number of brake applications by making only one continuous application for each brake requirement.

B. Full utilization of dynamic brakes.

C. Although Diesel locomotives, because of their low center of gravity, are capable of greater speed on curves, excessive speed may increase flange wear.

D. The use of sand, a good cutting agent, should be held to a minimum.

E. The elimination of unnecessary slipping will materially increase the life of wheels.

2 *TRUCKS*

A. Maintain to specified standards.

B. Many railroads report that in high speed service, maximum wheel life is obtained by complete truck overhauling every two years.

3 *TRACK*

A. Bad rail joints, switch points and cross-overs are detrimental to good wheel life.

B. A well maintained road bed will materially reduce flange wear, especially in high speed service.

4 *WEATHER*

A. Careful observance of braking precautions during extreme cold weather will reduce temperature variations in wheels.

B. Excessive speed on rough track, when the road-bed is frozen solid, is an important contributor to excessive wheel wear.

C. When rails are wet or damp, operation should be handled with utmost care to prevent unnecessary slipping or sliding.

5 *CLASS OF WHEEL*

A. A careful analysis of the severity of braking will aid in determining the class of wheel to be used.

B. Although there is considerable variation of opinion, the use of standard tread in low to medium speed service and the use of cylindrical tread in high speed service warrants careful consideration.

6 GENERAL LOCOMOTIVE MAINTENANCE

A. Proper rate of brake shoe application to the wheel.

B. Accurate wheel slip relay adjustment.

C. Location of drains on locomotives and cars.

D. Type of brake shoes.

WHEEL MILEAGE

Railroads recognize that many wheel mileage records are not too reliable. However, a few railroads have sufficiently accurate records to give a fair idea of total mileage received from various classes of service. Most records do not specify the condemning limit which may vary from one inch to one and one-half inches of remaining tread. Some railroads have very accurate records of specific instances where trouble has been severe enough to warrant the extra time and effort necessary to produce such records.

In passenger service, thirty-six inch wheels in six wheel trucks have total mileage records varying from 30,000 to 300,000 miles. Many railroads consider 175,000 to 225,000 miles to be satisfactory. Forty inch wheels in four wheel trucks average about the same. The low mileage is undoubtedly due to malfunction of the trucks rather than differences of wheels.

Freight service with 40 inch wheels in four wheel trucks varies from 200,000 to 500,000 miles. In many cases, verbal reports of certain mileages could not be substantiated by facts from records, and in many other cases, the verbal reports turned out to be personal opinions.

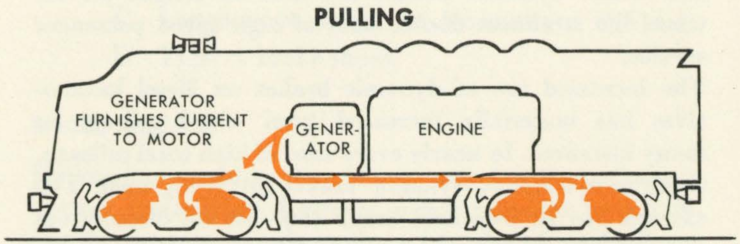
It has been observed that high speed and the attendant severe braking are among the main causes of short wheel life. High power pulling such as is common in heavy duty freight service seems to have little effect on wheel life and where dynamic brakes are used in freight service wheel life is almost double that of high speed passenger service.

The increased use of dynamic brakes on diesel locomotives has materially increased total wheel mileage in many instances. In nearly every case of high total mileage, those over 300,000, dynamic brakes are being used. The savings due to increased brake shoe life on locomotives and cars also becomes an important factor in maintenance costs when dynamic brakes are used.

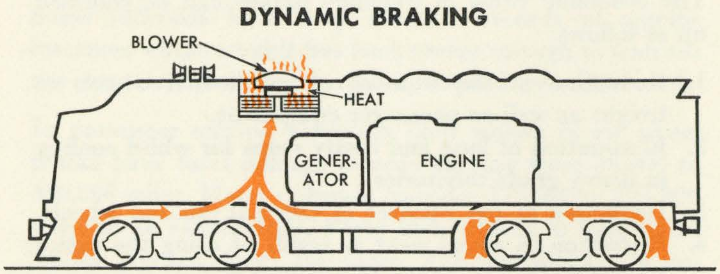
The economic value of dynamic brakes can be summed up as follows:

1. Reduction in the number of overheated wheels in freight as well as passenger equipment.
2. Elimination of long and costly stops for wheel cooling in heavy grade territories.
3. Reduction in the number of thermal cracked wheels.
4. Reduction in wheel wear as result of using the brake shoes against the wheels to a minimum.
5. Reduction of wear in brake rigging and attachments.
6. Reduction in the number of failures of brake beams and brake beam attachments.
7. Better train handling in regard to slack action where dynamic brake is properly used.
8. Time saved in transit, down severe grades, due to elimination of stops to adjust retaining valves.

9. Use of dynamic brakes for slow-downs due to block signals, etc. Their use, even on level terrain, saves fuel, wheels, time and the elimination of the possibility of air brakes not releasing.



Electrical connections are changed to cause the traction motors to act as generators. The several hundred horsepower required to turn each of them resists the motion or momentum of the train.



The current generated is dissipated as heat by grids (toasters) and fans in the roof.

Of these items, the thermal cracked wheel condition existing on the American railroads is one that has given all railroad officers a great deal of concern. The wheel manufacturers have not as yet developed a wheel that is entirely free from thermal cracking when it is subjected to the heat

imposed by the use of brake shoes applied to the wheels in some severe classes of service.

The dynamic brake offers positive relief from this condition and if used conscientiously by engine crews, it will reduce the number of thermal cracked wheels. In the past, these have proven very costly not only from the standpoint of labor involved in removing, turning and remounting of the wheels, but from the hazard involved due to wheel failures which often result in derailment and accidents.

SUMMARY

1 Two and four wheeled wagons were a part of our earliest known civilization.

2 Modern wheels and axles differ only in details of design, materials and accuracy of workmanship.

3 Rails, made of wood or iron, are a product of the "mechanical age".

4 One-piece wrought steel wheels are as modern as the automobile, their first use to any extent dates from about 1906.

5 Although approximately eighty-four types or variations of Diesel wheels are available, only a few, such as the rim-treated Class "B" or "C", are commonly used.

6 Wheel stresses are complex and varied and to date are not too well understood. It is generally agreed that they may be divided into three groups:

a. Stress due to vertical loads.

b. Stress due to lateral load.

c. Stress due to temperature differentials.

7 The resulting heating caused by the common practice of applying brakes to the tread of railroad wheels is probably responsible for the most destructive stresses that are encountered in normal service.

8 Thermal cracks on the tread of a wheel are usually caused by the violent dimensional changes accompanying the heating and cooling.

9 The three main items of importance in the life of railroad wheels are:

a. Operational procedures.
b. Condition and design of the trucks.
c. Material and heat treatment of the wheel.

10 The proper utilization of dynamic brakes will materially increase wheel life.

11 Improvements in the production of steel and forging procedures, testing and more careful machining and finishing have been combined to produce the excellent axles in use today. As a result of these improvements modern axles are safely carrying loads that would have been impossible a few years ago.

12 The margin of safety in presently used wheels and axles does not permit increases in locomotive weights per axle.

13 Hammer blows are non-existent in Diesel locomotives.

14 Good ballast is important because it produces a firm and less flexible support for ties and thereby reduces the bending stress in the rails.

15 Due to their low Cooper rating of from E-30 to E-45, Diesel locomotives can safely negotiate practically any railroad bridge in normal use.

In a young and growing industry there is often a lack of simplified, authentic literature pertaining to the use of the product. To a certain extent that has been true as far as Diesel locomotives are concerned. As a step in providing the kind of information that will be helpful to a broad group of users and operators, we at Electro-Motive have prepared this booklet. The subject matter is based on our experience in producing and observing the operation of more than twenty-five million Diesel horsepower on American railroads. Other booklets on problems incident to Diesel railroad operation will appear from time to time.

GENERAL MOTORS LOCOMOTIVES

ELECTRO-MOTIVE DIVISION
General Motors La Grange, Ill.