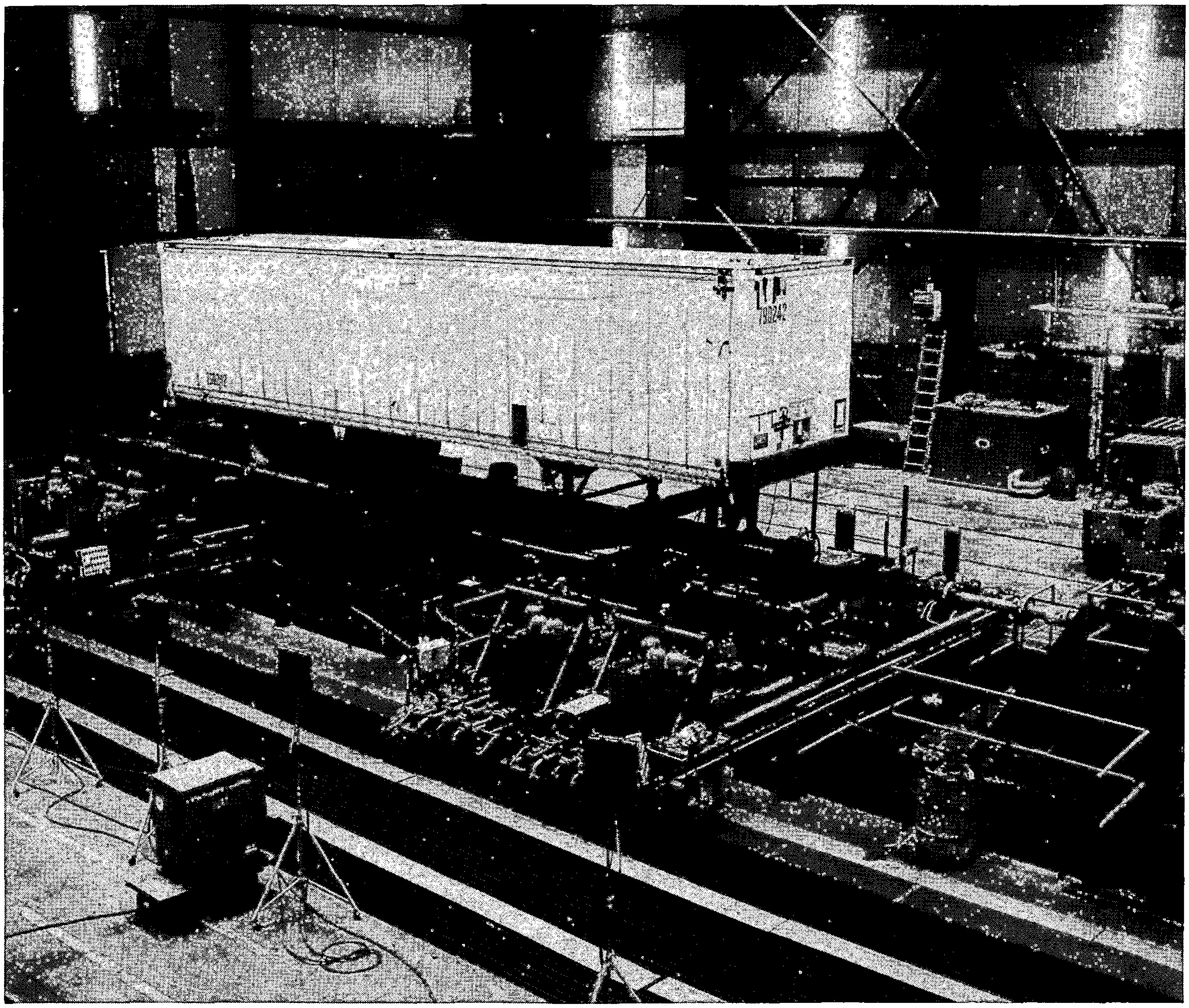
ORTH

U.S. Department of Transportation

Federal Railroad Administration

Recent Developments in Railroad Safety Research

Office of Research and Development
Washington, D.C. 20590



DOT/FRA/ORD-88/03

January 1988

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Preface

The Federal Government's present involvement in railroad research and development (R&D) began as a result of the High Speed Ground Transportation Act of 1966 in an office by that name established at the Department of Commerce. Shortly thereafter, in 1967, the Office of High Speed Ground Transportation was reassigned to the then-new Department of Transportation and the Federal Railroad Administration (FRA). The first ten years saw emphasis placed on the development of such advanced high speed passenger systems as the Tracked Air Cushion Research Vehicle (TACRV) and the Linear Induction Motor Research Vehicle (LIMRV), as well as the establishment of what is now known as the Transportation Test Center near Pueblo, Colorado. In 1975, as the technical feasibility of the high speed ground systems was being demonstrated, Congressional and Executive direction shifted the research emphasis to support of the then-troubled conventional railroad system. The research thrust was directed to stimulation of the economic recovery of the Nation's railroads through the application of advanced technologies to improve productivity while, at the same time, providing for protection of the public's safety. Early in 1981, in another policy shift, the resources of the FRA R&D program began to be applied solely to railroad safety research leaving economic-oriented research to private sector initiatives. In furtherance of this, the Office of Research and Development was placed under the executive direction of the FRA Office of Safety in the fall of 1985.

This report is a summary of the railroad safety research conducted over the seven-year period from 1981 through 1987. It does not include all of the research and development activities undertaken but rather is considered representative of the work done. Many projects were undertaken in conjunction with the railroad industry. In those cases where the Federal Railroad Administration's public safety responsibility required, the work was done independently. Organizations participating in cooperative research included: the Association of American Railroads, the Railway Progress Institute, the American Railway Engineering Association, the Brotherhood of Locomotive Engineers, the United Transportation Union, individual railroads and their suppliers, and the Canadian Government and railroads. The FRA Office of Research and Development is grateful to these organizations for the support they have provided over the years to the research achievements described in this report.

Robert L. Krick
Director, Research and Development
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RECENT DEVELOPMENTS IN RAILROAD SAFETY RESEARCH

An effective safety research program is essential to the Federal Railroad Administration's safety assurance and regulatory responsibilities for railroad transportation. To this end, the FRA Office of Research and Development conducts safety research, development, test, and evaluation projects to be responsible to the public trust and to furnish direct support in the development or revision of safety standards, for regulatory action, or for voluntary industry implementation and use. Every attempt is made in research and development (R&D) planning to anticipate and prevent the development of potential safety threats. Inevitably, however, there are spontaneous or reactive research requirements that develop in direct response to a major accident investigation or as a result of observation reports from FRA's Office of Safety Enforcement field safety inspectors indicating unusual, unexplained, or potentially unsafe conditions developing for which a technical explanation may be necessary or desirable. In either case, anticipatory or reactive research, the emphasis is on producing technically and economically sound countermeasures to ensure the continuing and enhanced safety and efficiency of railroad transportation.

Beginning early in 1981, in recognition of the recent deregulation of railroads and an improved rail carrier ability to deal with the predominantly economic-oriented issues, FRA's R&D program became focused exclusively on safety-related problems. Consistent with this shift from a much broader earlier mission of helping to stimulate the industry's revitalization, the Department's Transportation Test Center (TTC) near Pueblo, Colorado, developed and built by FRA with major support from UMTA in the transit test area, was transferred from Government control to private sector control in 1982. It was believed that under more direct railroad community control, TTC would attract clients otherwise reluctant to conduct proprietary research and testing in the Government's presence. It was also thought that the railroads, among themselves, would be more likely to enter into joint ventures in a more familiar surrounding. Thus, in recognition of its inherent understanding of railroad problems and unique industry role, a sole source contract was awarded to the Association of American Railroads (AAR) for the care, custody, and control of the Test Center. The FRA retains ownership of the facility and one employee is located at TTC to provide resident engineering management and liaison for the FRA property interests and the research and testing conducted there on behalf of FRA.

Throughout the years, while achieving FRA research goals, the Office of Research and Development has relied upon cooperative and coordinated programs with other research organizations, other Government agencies, industry associations, individual railroads, and railroad suppliers. Key examples of Government-industry cooperation exist in the Vehicle Track Systems Program, formerly the Track Train Dynamics Program, and in the operation of the Facility for Accelerated Service Testing (FAST) at the Transportation Test Center. In both programs, all parties in the railroad community are involved. The FRA interest in these programs stems from its preference to fulfill the overall safety mission in a way which establishes cooperative interaction early in the industry's design process. There are obvious benefits to the industry, the public, and the FRA in attaining a status wherein the new concepts being introduced are consistently both cost-effective and safe in actual service. One of the best ways to accomplish this is to imbed safety assurance in the routine analytical and testing phases of development. Safety research sponsored by FRA looks toward the kind of up-front cooperative ventures which will maximize the likelihood that new railroad products and procedures will not inadvertently introduce unacceptable safety hazards.

Within accepted criteria for Federal involvement, FRA research seeks to eliminate the introduction of systems with basic incompatibilities between track, vehicles, and operators and to prevent sudden track, equipment, or human failures which may cause major derailments or collisions. It is important that changes of the magnitude now underway in the railroad industry be thoroughly analyzed and that any potential safety implications be explored prior to widespread implementation. Recognizing that complete elimination of derailments is unrealistic, FRA research further attempts to ensure that employees, passengers, and the segment of the public in close proximity to hazardous materials carried in trains are protected—even in the event of an accident.

Essential testing and simulations are carried out at three major facilities. Two built by FRA are currently operated by the private sector. Notably, most testing of track structures and rail vehicles is accomplished at the Transportation Test Center. A significant portion of train handling evaluations, locomotive cab environment assessments, and engineer training and performance experiments are performed in the Research and Locomotive Evaluator/Simulator (RALES) facility at the Illinois Institute of Technology Research Institute, Chicago, Illinois. In addition, a special purpose dynamometer apparatus, owned by the Association of American Railroads and located at its Technical Center in Chicago, has been a key element in research sponsored by FRA in an attempt to arrest the rate of wheel failures in service.

The FRA research is organized into two functional areas, equipment and track. In the first, research is conducted under the Equipment, Operations, and Hazardous Materials Safety Program. Its program elements and associated research objectives in support of the FRA safety rulemaking process, enforcement activities, and enhanced voluntary safety practices are as follows:

Equipment and Components--Provides sound technical information, analytical procedures, and applied methods and techniques necessary for the test and evaluation of railroad equipment and components in the determination of the cause and effect of accidents, and in the development of preventive measures and improved inspection methods and procedures for application to existing or new equipment.

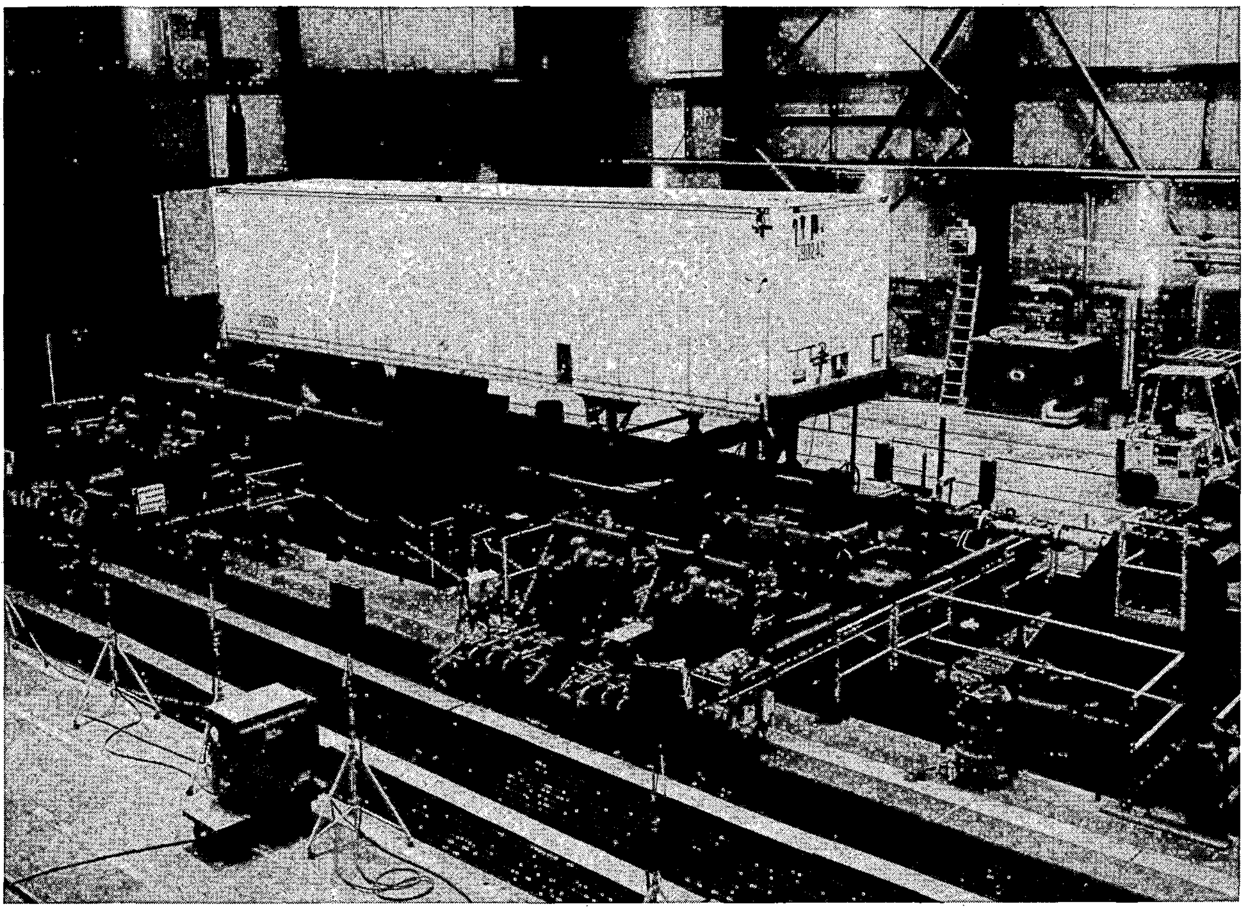
Operating Practices--Provides the information, methodologies, and/or aids necessary to enhance the safety of railroad operating practices with special emphasis on human factors. Provides guidelines and tools to improve the ability of railroad management and employees to safely and efficiently complete maintenance and train handling tasks in the railroad environment.

Hazardous Materials--Provides factual data concerning tank car failures and accidents involving hazardous materials, including determination of cause, the development of measures to prevent failure, and protective countermeasures to minimize potentially catastrophic results that may occur in a railroad accident.

Examples of accomplishments in the Equipment, Operations, and Hazardous Materials Program over the 1981-1987 time frame include the following.

Safety Assurance for New and Untried Freight Cars--In recent years, there has been an influx of new and untried freight cars placed into railroad service to meet the competitive demand. This situation has served to exacerbate problems with the existing industry standard for the acceptance of new and untried cars which is too time consuming and costly. To correct this, a joint FRA and industry research project was organized to develop improved methodologies and techniques for evaluating new and untried cars for safety performance. The project focus has been to develop and validate the appropriate analytical simulation models and test scenarios that will more efficiently and effectively evaluate new car or truck (suspension) systems and provide safety assurances prior to their entry into widespread revenue service.

The initial rail car subjected to the newly developed and proposed acceptance process was a single-axle (per end of car), skeleton, platform, trailer-on-flatcar (TOFC) car called "The Front Runner." It has recently completed its trial of the new acceptance process at the Transportation Test Center. In an elaborate series of dynamic characterization tests on the Test Center's Vibration Test Unit (VTU), in the Rail Dynamics Laboratory (see photo) and other test fixtures, the physical constants and variables to be used in the New and Untried Cars Analytical Simulation (NUCARS) model were obtained.



Front Runner on Test Center's Vibration Test Unit in the
Rail Dynamics Laboratory

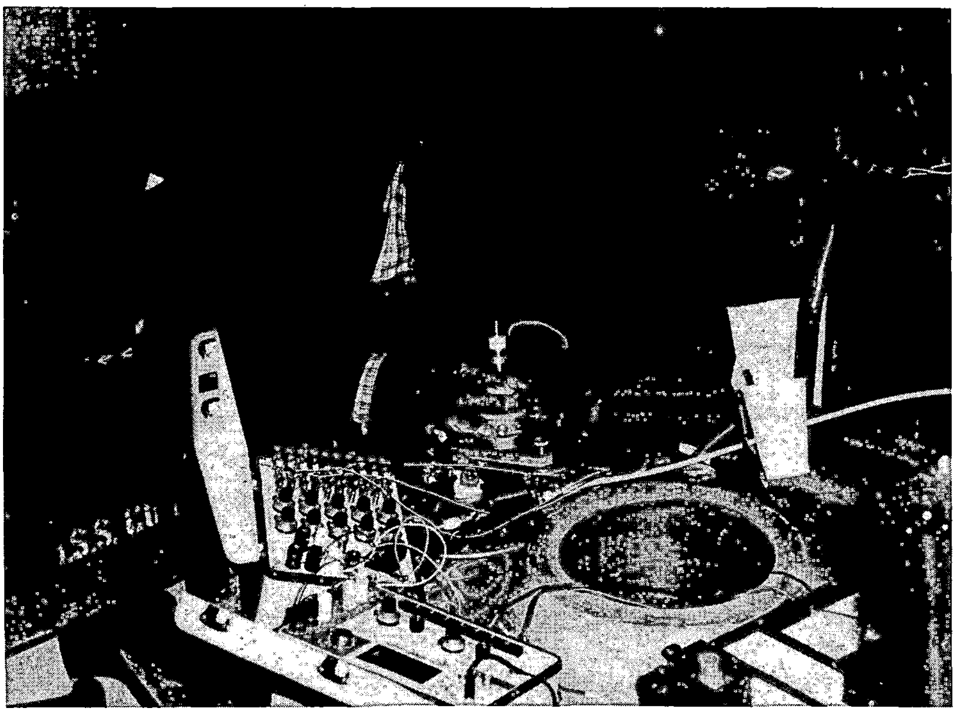
The joint membership project committee established test conditions and acceptance procedures to be used in the trial process. The test conditions were to replicate the difficult track conditions and resulting vehicle movements believed to be representative of the real-world behavior a new and untried car will experience in regular service. A peer critique of the test conditions used and the test results will provide suggestions for further simulation model enhancement. The NUCARS model, at this time, is considered partially validated based on the initial car tests. Further validation awaits additional car tests.

The second car selected for a trial run of the process using the NUCARS model and prescribed VTU and track testing is an aluminum coal gondola car with steel underframe and conventional three-piece, two-axle trucks under each end. This selection is intended to illustrate whether truck suspension performance under the extremes of loaded to empty weight ratios (typical of aluminum cars) can result in unstable riding conditions, particularly while in the empty state. The goal is to develop and build a "vehicle characterization laboratory" that will ultimately drive down the cost, complexity, and time required to assure safe car performance. Additional model refinements and validation of the combined use of model and test measurements should result in a more cost-effective and reliable measure of the actual safety peformance of new and untried car and suspension systems when placed in revenue service.

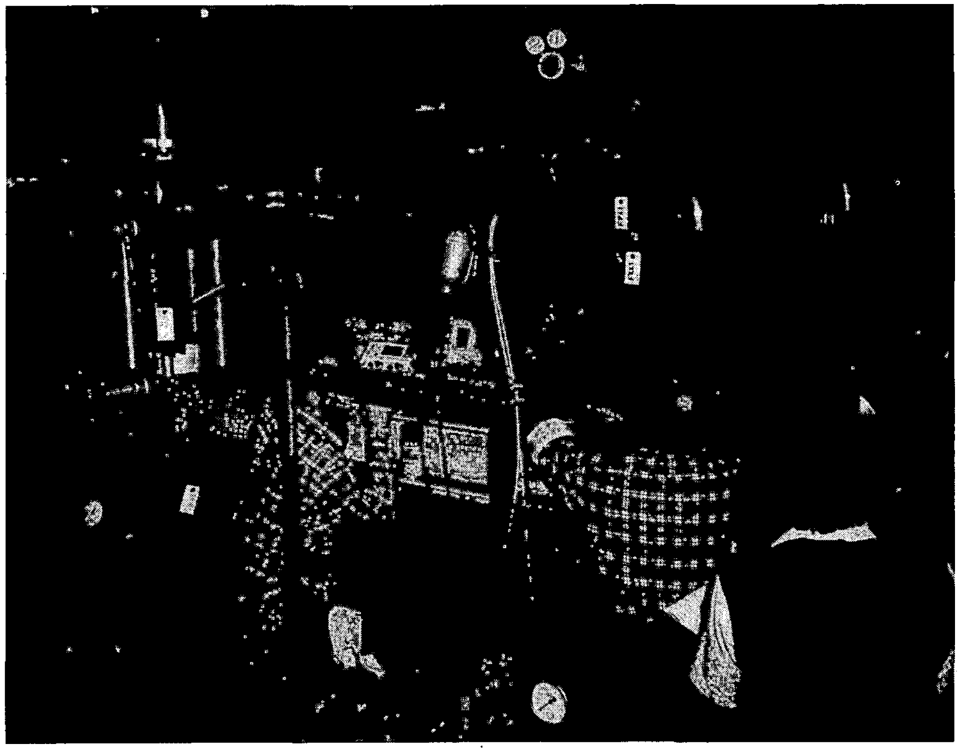
Understanding Wheel Failure Mechanisms--The steel wheel on the steel rail is at the very heart of what gives railroads the highest potential for productivity and fuel efficient transportation. Yet, each of these vital components, the wheel and the track, is in and of itself, cause for considerable concern over its continued overall soundness in today's demanding operations. The in-service failure of either a wheel or the track is usually a costly proposition and in the worst of cases can produce catastrophic consequences.

To improve the safety performance of railcar wheels (track is discussed elsewhere), the FRA with the AAR conducted an extensive investigation to better understand important wheel failure mechanisms. The objective was to develop technically sound wheel removal/replacement criteria and establish guidelines for safe operation and improved inspection practices.

Major issues explored included the effects of wheel plate design (curved vs. straight), heat treatment (treated vs. untreated), ability to resist thermal damage (exposure to severe and prolonged braking action), the relationship between wheel discoloration and residual stress reversal, and the amount of brake energy required to cause changes in the residual stress in a wheel. Sophisticated strain-gaged hole drilling, saw cutting, and finite element analysis techniques were used to measure residual stress. Experiments were conducted on the Chicago dynamometer and the Roll Dynamics Unit (see photo) and test tracks at the Transportation Test Center.



Strain Gauged Hole Drilling to Determine Wheel's Internal Residual Stress



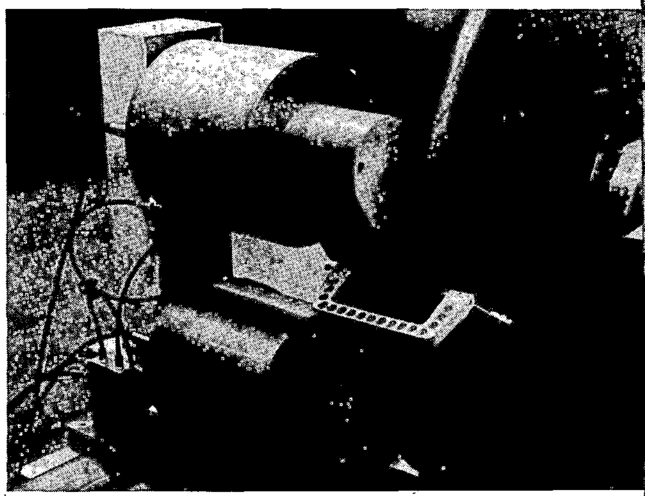
Wheel testing on the Roll Dynamics Unit, Transportation Test Center

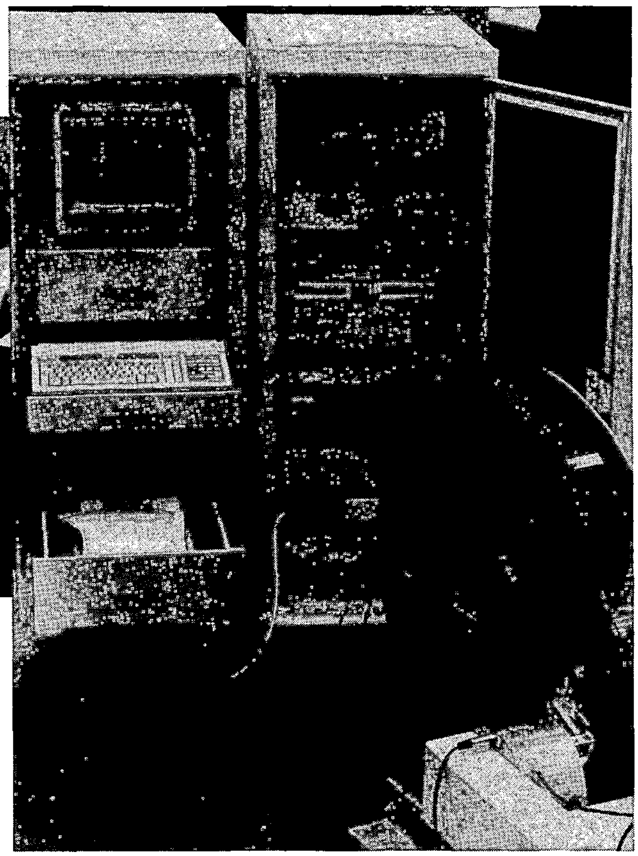
The investigation also included a field survey of wheel performance using data based on industrywide wheel removals and derailments. Overall findings were: that derailments due to thermally induced wheel failure are highly seasonal with the majority of failures occurring during winter months; the number of derailments caused by thermally induced wheel failure has declined over recent years as have all derailment causes; and mechanical damage, i.e., tread metal flow, excessive wear, metallurgical transformation, is necessary for initiation of thermal cracks and thus failure. Curved plate designs are several times less likely to fail than wheels of straight plate design; and heat-treated curved plate wheels are more resistant to both stress reversal and mechanical damage and, therefore, to thermally induced failure. Overhanging brake shoes and nonuniform tread heating were found to be conditions contributing to undesired stress levels. Specific combinations of speed, time, and brake shoe force are required to produce thermal damage in the rim for each wheel design and heat treatment. The thermal damage data derived from this research can be used to promote brake system performance specifications. Discoloration, although it indicates thermal input, is not necessarily evidence of destructive thermal damage but does indicate a greater probability of an adverse change in residual stress. The study results clearly show that heat-treated, curved plate (low stress) wheels, the direction in which the industry is headed, are the most resistant to thermal damage and failure.

Development of Wheel Inspection System--The railroads and the Federal Railroad Administration are faced with a dilemma in determining the safe life of an abused wheel--the failure to remove a questionable looking wheel before it fails in service versus the uneconomical premature removal of an otherwise safe and useful wheel. The previous work describing the study of Wheel Failure Mechanisms was one effort at ameliorating the problem through increased knowledge and understanding.

In an example of interagency and Government-industry (NASA/FRA/AAR) cooperative research, magnetic ultrasonic acoustic technology developed by the NASA Langley Research Center has been exploited by applying the technology to the nondestructive evaluation of residual stress in railroad wheels. Following successful laboratory testing at NASA, the "proof of concept" equipment has demonstrated its effectiveness as a Wheel Inspection System (see photos). Additional demonstration and evaluation is underway in a more practical railroad setting at the Transportation Test Center where the system will be used to evaluate known thermally abused wheel samples.

During the field evaluation stage, drawing from the magnetoacoustic interactions of the Wheel Inspection System, a nondestructive characterization of residual stresses, tensile or compressive, will be made of each sample wheel. The wheel examined will then be "hole-drilled" and "saw cut" followed by a subsequent finite element analysis as in the Wheel Failure Mechanisms Study. The results of the nondestructive and destructive evaluations will then be compared in an effort to establish a confidence level for use of the Wheel Inspection System.





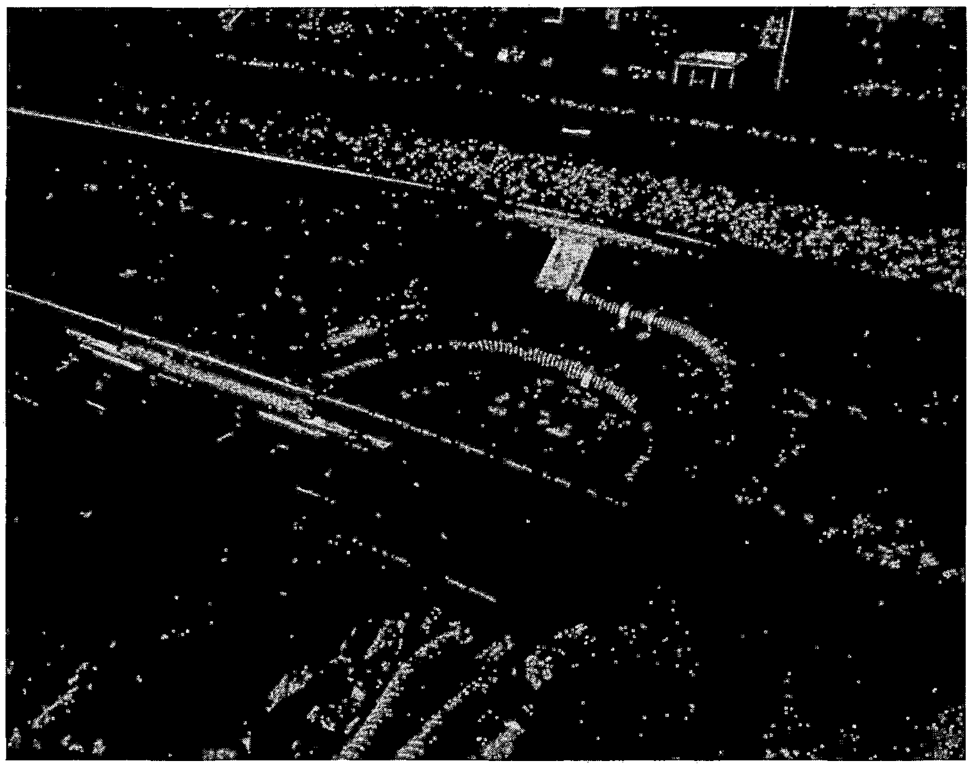
Above: Wheel Inspection System with Hoop Magnets in Place. Right: Wheel Inspection System with Wheel Being Tested with Transverse Magnet in Place

Meanwhile, FRA research and development continues to seek other promising avenues of advanced technology that will enhance the quality of wheel inspection-detection practices.

Stuck Brake Detector Feasibility--Most trains are processed through a classification yard where an incoming train's cars are separated and reassembled, making up other trains for various onward destinations. This process entails temporary use of hand brakes to hold the cars in their desired yard position. When a new train is finally assembled and its air brake system activated, the hand brakes are released. On occasion, one or more hand brakes in a long train may inadvertently have been missed or not fully released. A malfunction may also occur in an individual car's air brake system and cause a stuck or partially braked wheel.

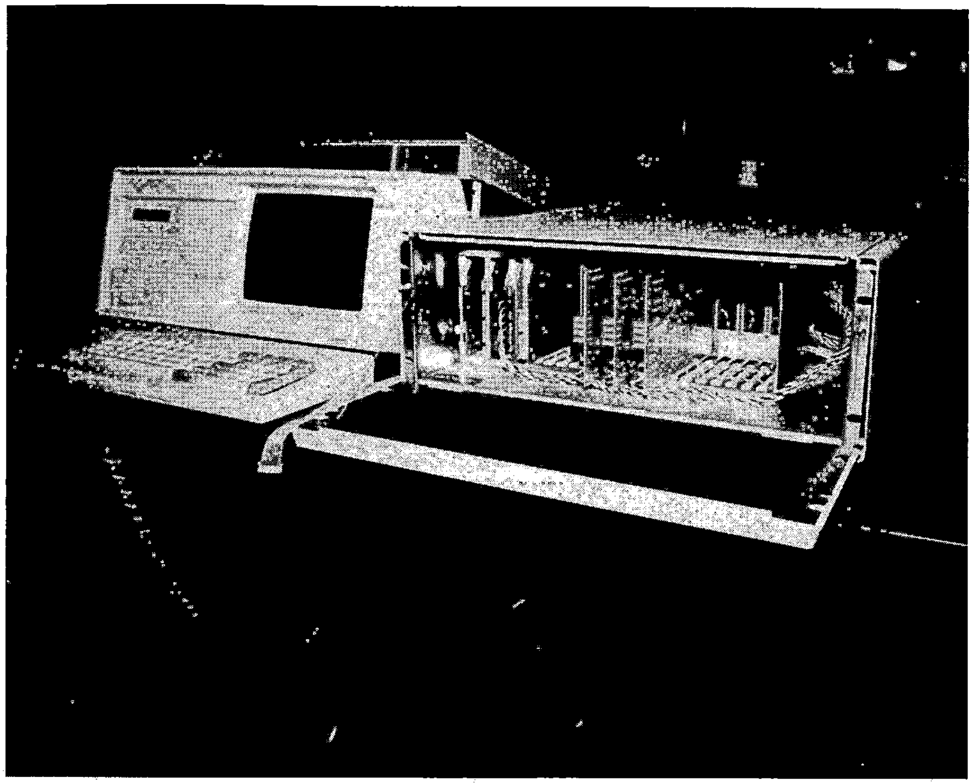
Stuck or dragging brakes on a car in a train can easily go undetected. This can result in severe thermal damage to the dragging wheel and may even create a derailment situation. The "flats" worn into a dragging wheel can, when the wheel is again free wheeling, create undesirable high impact forces that are inflicted on the track structure resulting in further damage.

Because of the adverse safety impact of stuck brakes, research was undertaken to determine the feasibility of developing a wayside automatic stuck brake detector to warn train operating personnel. A prototype Stuck Brake Detector was developed and successfully demonstrated on the departure track of a major east coast classification yard.



Stuck Brake Detector Installation with 18-inch Sensor Rails

The system can detect freight car hand brakes that are inadvertently on, partially left on, or malfunctioning air brakes. The goal is a reliable stuck brake detector system commercially available that will detect and alert railroad personnel to take the necessary remedial action before stuck brakes cause damaging overheated wheels or derailments. A typical application would have departing trains pass over the Stuck Brake Detector installation and have the rolling resistance of a stuck wheel place longitudinal forces against the parallel 18 inch sensor rails that will in turn through a computer and voice synthesizer (see photo) generate a voice radio transmission alerting the train crew and yard supervisors of the faulty car number(s) or acknowledge that there are no stuck brakes. This type of system would be similar to other wayside detectors now in use.

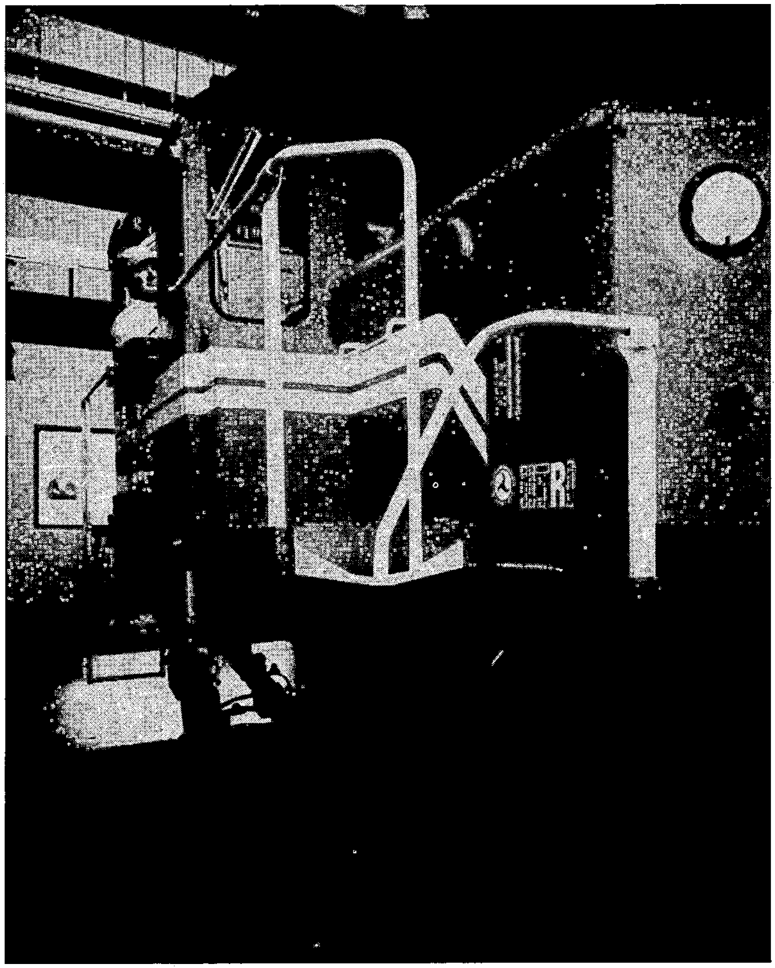


Computer and Voice Synthesizer for "Proof of Concept"
Stuck Brake Detector

Research and Locomotive Evaluator/Simulator (RALES)--In response to the need to be able to conduct controlled experiments involving train handling, human engineering in the locomotive cab, and locomotive engineer training and performance factors, it was necessary to develop a system that in every appearance to the human would be just like the real world but without the real world risks of conducting experiments in the unpredictable operating railroad environment.

Following several years of development and construction, initially by the FRA and then in a joint venture with the Illinois Institute of Technology Research Institute (IITRI), the RALES facility was completed in early 1984. RALES is a state-of-the-art locomotive and train handling simulator designed for training and research applications. It has motion, sound, and visual subsystems which are computer controlled. Any known set of operating conditions for any type of train or route can be simulated.

In the following photograph, the locomotive engineer is shown looking down the track which is displayed on a large parabolic screen in front of the SD40-2 locomotive cab. The cab is mounted on a motion base with six degrees of freedom for movement on longitudinal, vertical, and lateral axes. The control room is located on the other side of the window to the rear of the cab. It contains: computer interface controls; communications; TV monitors for activities inside the cab, train action indicators, and the scenes on the parabolic screen; and, remote controls for the simulated train.



Research and Locomotive Evaluator/Simulator

Railroads, railroad suppliers, and Government agencies have been using the facility for training to upgrade the skills of locomotive engineers, evaluating locomotive engineer train handling performance, human factors and engineering testing of prototype equipment which may be proposed to be placed in the locomotive cab, and developing performance standards for train control equipment.

Although Government-owned, RALES is operated and maintained by IITRI at its Chicago, Illinois, facility under a care, custody and control type of contract with FRA, with user fees charged for its use.

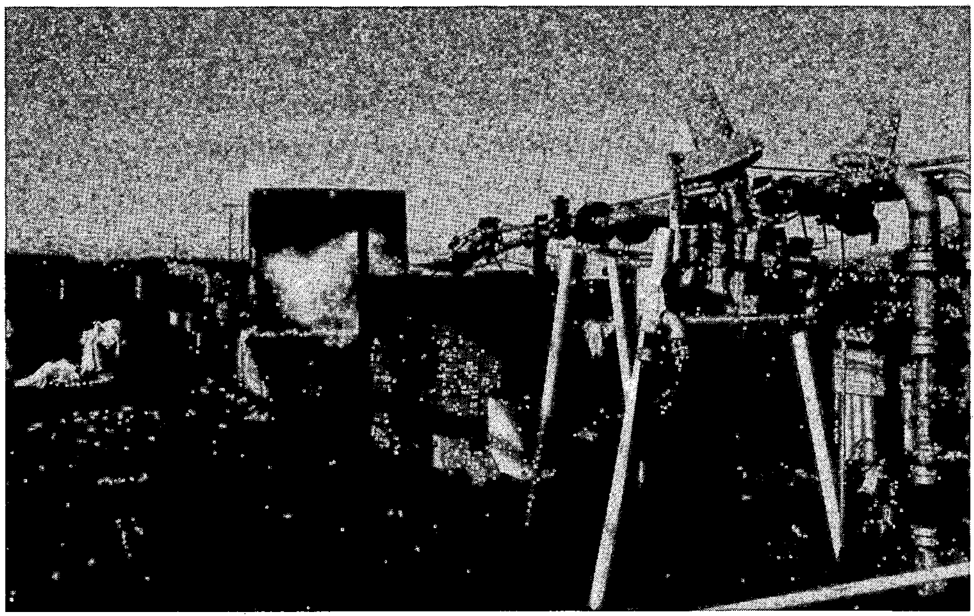
Commuter Car Bearing Failure Analysis--Hollow axle and roller bearing assemblies used on commuter cars in the Metro North M-2, New Jersey Arrow III, and SEPTA Silverliner IV fleets had been experiencing failures in the early eighties.

In several cases, the failures resulted in wheel bearing seizure, axle burn-off, and wheel loss, posing potentially serious hazards to commuter passengers and the wayside public. A research task force was created in 1982 to investigate the possible failure causes and to develop preventive measures. The necessarily brief initial study found that hollow axle assemblies were more susceptible to certain failure mechanisms than experienced by solid axles.

Additional studies performed a more detailed tribological and metallurgical examination of failed hollow axle bearing assembly components in order to increase understanding of the failure mechanisms. Of the various cause possibilities surfaced, the lack of a sufficient interference fit and a low clamping force between the wheel bearing and axle due to hollow axle resilience appeared to be one highly likely cause for the observed higher rates of failure on hollow axles compared with solid axles. Based upon this early knowledge and the relative failure rate expeience, the commuter carriers began to transition the commuter car fleets to solid axles. It had been assumed that use of solid axles would reduce the probability of the commuter car bearing failure problems, however, two solid axle bearing assembly failures subsequently did occur and were studied to determine the failure mechanisms. Examination of the components revealed evidence of a failure mechanism similar to the hollow axle failures. Investigation of assembly records revealed a pattern in the bearing press record which was strikingly atypical. A third wheelset in which this pattern appeared was pulled from the Arrow-III fleet and was found to have a failure in progress.

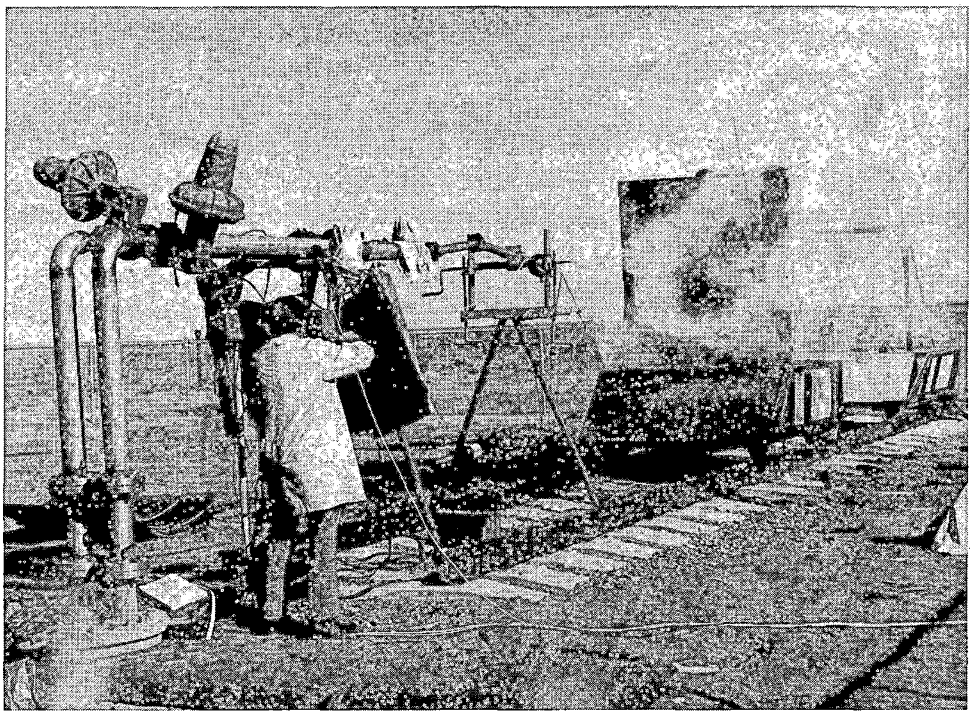
As a result of the bearing failure analyses to date, all involved commuter carriers have tightened quality control in the fitting of axle and bearing assemblies and in the inspection practices. In addition, a comprehensive roller bearing research program consisting of surveys and laboratory tests was begun in recognition of an even broader problem also involving roller bearing performance in the increasing demands of today's high speed, high capacity freight service.

Protection During Hazardous Materials Handling--Even though the Office of Hazardous Materials Transportation, Research and Special Programs Administration, is responsible for the overall regulatory control of hazardous materials transportation, each modal agency is responsible for ensuring appropriate provisions for safe handling of hazardous materials as well as the enforcement of the regulations. In this arena, FRA research has made major contributions to the improvement of the design of tank cars and their components to reduce the likelihood of catastrophic accidents and assure safe transportation. Other research in the area has focused on the emergency response to hazardous materials incidents, when and if they occur, and the safety of spent nuclear fuel casks while in the railroad environment.



Torch Fire Test Facility Simulating an Accident Torch Fire Exposure

Most of the FRA tank car research involves simulating worst case, derailment accident-type situations that can expose a hazardous materials tank car to intense fire and/or puncture of its tank shell. To provide for this in a controlled laboratory setting a Torch Fire Test Facility was designed, fabricated, and used to conduct tests of simulated torch fires such as from a point source, i.e., valve or punctured hole feeding a flammable material, and pool fires as when lying within or being surrounded by fire. In torch testing, a four-foot square test sample is impinged by the flame. Nozzle distance from the sample determines if it is a torch or pool fire simulation.



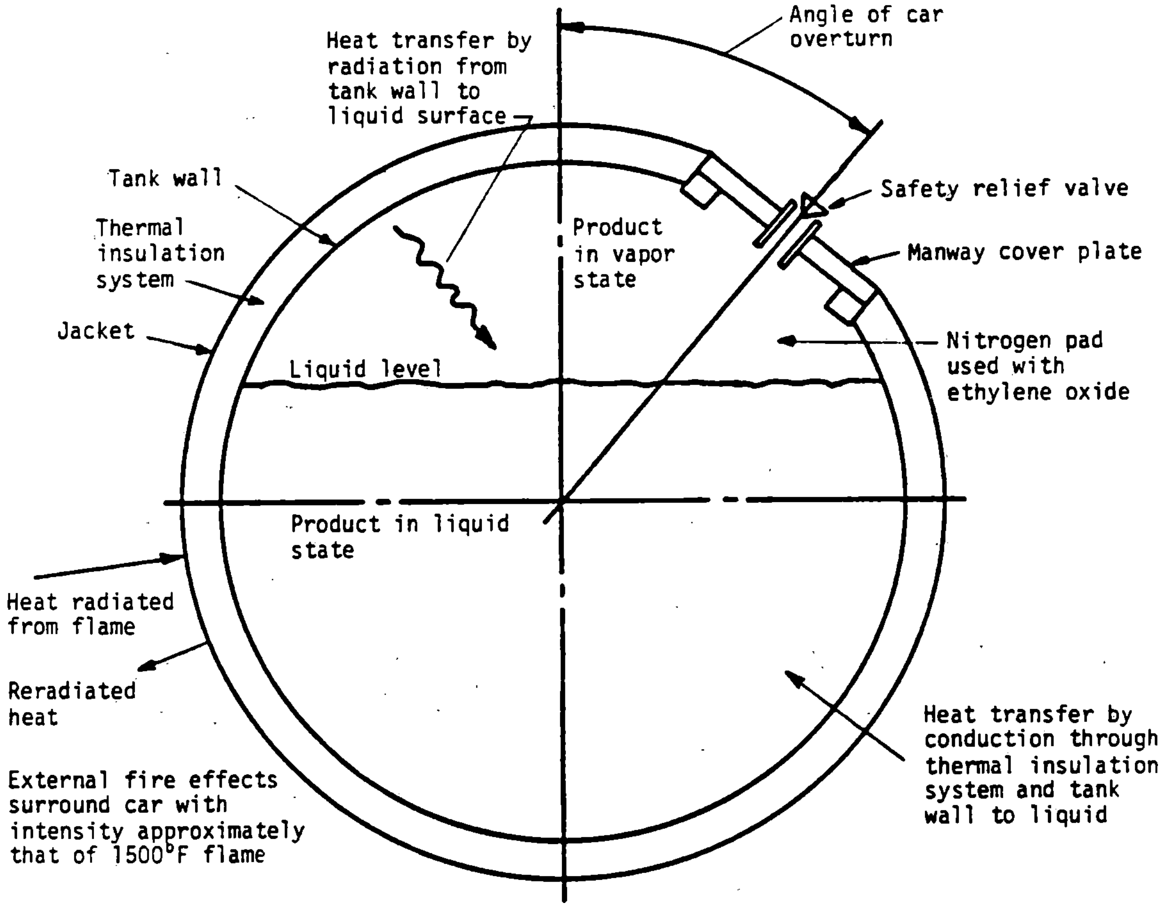
Torch Fire Test Facility Simulating Fully Engulfing Pool Fire

A major research project was completed that defined the characteristics and requirements associated with tank car safety relief valve sizing. The situation giving rise to this research were several accidents in which a tank car did not remain upright. In this circumstance, the tank car safety relief valve may not have been able to release vapor because of the flow of liquid hazardous material from the valve.

An analysis was conducted on the temperatures, pressures, and liquid level experienced by tank cars that become engulfed in fire. The study findings resulted in a revision of the DOT regulations concerning the use of both thermal insulation and safety relief valve sizes required for tank cars carrying hazardous materials.

Based upon a common interest and availability of resources, a joint research project was conducted with the Air Force Rocket Propulsion Laboratory to develop guidelines for emergency response personnel responding to accidents involving chemicals and propellants. Both an accident management guide and a post accident guide were published and are available to the public.

In cooperation with the Department of Energy, a safety assurance test project was performed with the purpose of subjecting a spent nuclear fuel cask to fires typical of those found in a railroad accident environment. An obsolete cask was modified to represent current cask design. This cask was subjected to simulated pool and torch fire tests using the FRA's Torch Fire Test Facility.



Conditions Considered in the Analysis of Tank Cars Subjected to Fire

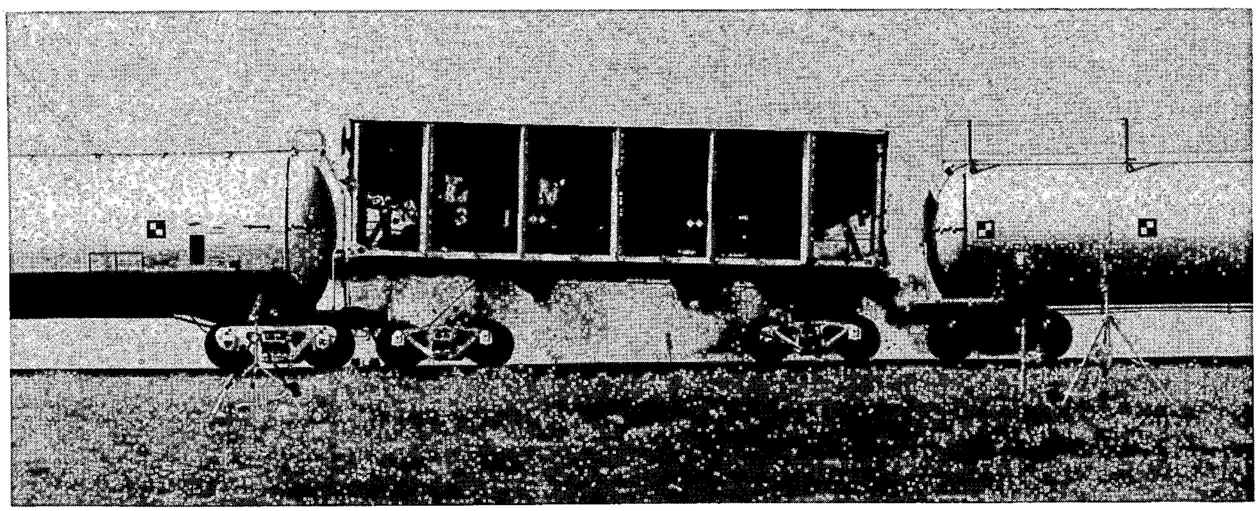
Based on these tests, it was decided to test cask size calorimeters in a fully engulfing pool fire (see photo on following page). Three 5-foot diameter, 21-foot long calorimeters, with a weight of 11 tons, were subjected to a 30-minute fire in a 30 foot by 60 foot open pool fire test facility. These tests defined thermal boundary conditions for use in future analytical analyses in connection with cask design.

Another safety assurance test project was completed in the determination of the thermal effectiveness of proposed new insulation systems for tank cars. Three alternative insulation systems composed of ceramic and mineral fibers, and designed especially for chlorine tank cars, were tested. Since chlorine vapors react unfavorably with steel at 483° F., testing was to determine the insulation effectiveness in keeping the internal tank wall temperature below 483° F. when subjected to a standardized fire exposure. As a result of these tests, the chlorine industry will be afforded the opportunity to use a superior insulating system to that presently in use.

Pool Fire Test of a Calorimeter

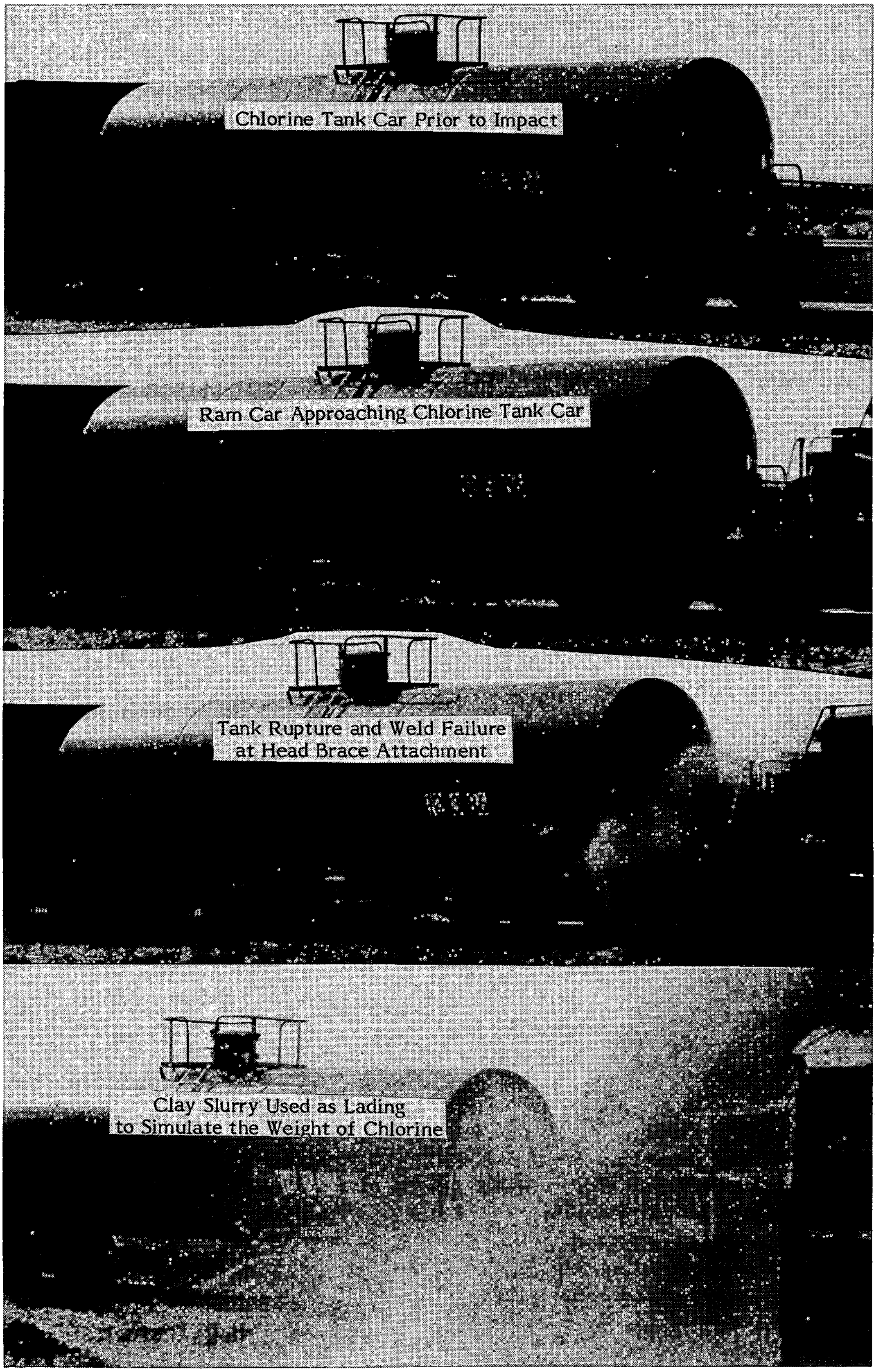
Testing of insulation systems for cryogenic hazardous materials carrying tank cars as well as both current and alternative insulation systems for aluminum tank cars has also been successfully completed.

Major tank car safety research undertakings in the late seventies resulted in the regulatory requirement for certain of the most dangerous classes of hazardous materials carrying cars to be equipped with head shields and shelf couplers. In a derailment situation, the shelf-coupler is to prevent cars from becoming uncoupled through vertical movement of the couplers while the head shield protects the end of a tank car from puncture by a separated coupler or other protrusion. See photograph below illustrating this action.



Early Tank Car Safety Testing at the Transportation Test Center

As a result of prior research, head shields and shelf couplers are required on all tank cars with a capacity of 18,500 or more gallons that carry certain designated hazardous materials. Although considered hazardous, chlorine tank cars typically have a capacity below 18,500 gallons. Because of this, a follow-on research test project was undertaken at the Transportation Test Center to determine the puncture resistance of chlorine tank cars as compared to tank cars equipped with the required head shield. Scale model, full-scale tank head, and actual tank car puncture tests were conducted. Test specifications required the test car to be impacted at 18 miles per hour or greater with a ram car equipped with a raised coupler as a simulated accident condition. In the first actual chlorine tank car impact test, the tank head weld ruptured instead of the head brace weld. On cars equipped with head shields, the head brace weld is designed to "break away" at the tank/center sill interface during any severe impact. When the unyielding weld was eliminated, the chlorine tank car was able to survive the impact without a head shield. The picture series to the right illustrates the initial test in which the tank head weld ruptured. Clay slurry was used as the lading to simulate the weight of chlorine.


Chlorine Tank Car Prior to Impact
Ram Car Approaching Chlorine Tank Car
Tank Rupture and Weld Failure
at Head Brace Attachment
Clay Slurry Used as Lading
to Simulate the Weight of Chlorine

A prohibition against trailer-on-flatcar (TOFC) and container-on-flatcar (COFC) transportation of hazardous materials applies to portable tanks, intermodal (IM) portable tanks, multi-unit tank car tanks and cargo tanks designed for highway use. Notwithstanding this prohibition, provision for specific approval can be given under conditions approved by the FRA. In recognition of increasing shipper interest and in the belief that more complete safety criteria for TOFC and COFC service of tanks transporting hazardous materials needs to be established, research began in 1985 to investigate tank vulnerability while in TOFC and COFC service.

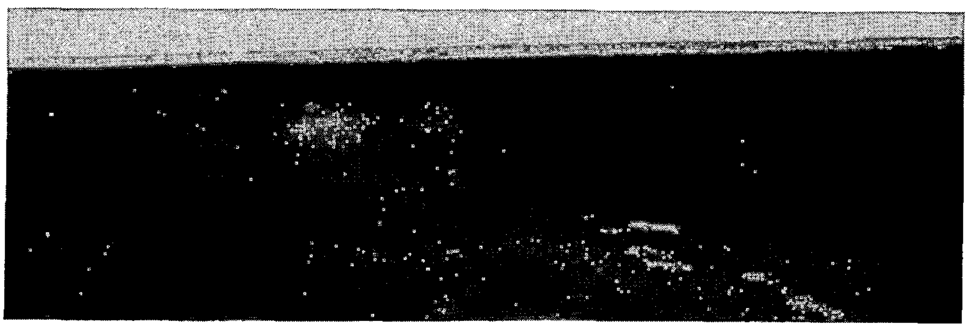
Tank TOFC/COFC service of hazardous materials involves many of the same safety issues as transportation in a traditional railroad tank car. These safety issues include pressure relief, identification, special commodity and special handling requirements. In addition to the safety issues associated with railroad tank cars, TOFC/COFC service involves additional or different safety issues such as securement of the container to the flatcar or on the trailer, and securement of the highway cargo tanks to the flatcar.

Accordingly, simulated derailment tests were conducted at the Transportation Test Center on various configurations of highway cargo tanks and IM portable tanks in trailer-on-flatcar (TOFC) and container-on-flatcar (COFC) service in order to obtain quantitative dynamic data on the performance of the TOFC versus the COFC configurations . A series of tests were conducted at speeds ranging from 20 to 60 miles per hour. The test area was a section of tangent (straight) track with a switch installed. In early testing, the switch was thrown under the test cars to simulate a broken rail type of derailment. For the final test, a turnout was constructed. In the final test run, the switch was thrown back and forth rapidly so that the test cars would pile up as in an accordion type derailment. This final test run was conducted at 60 m.p.h. The picture series illustrates the resulting action.

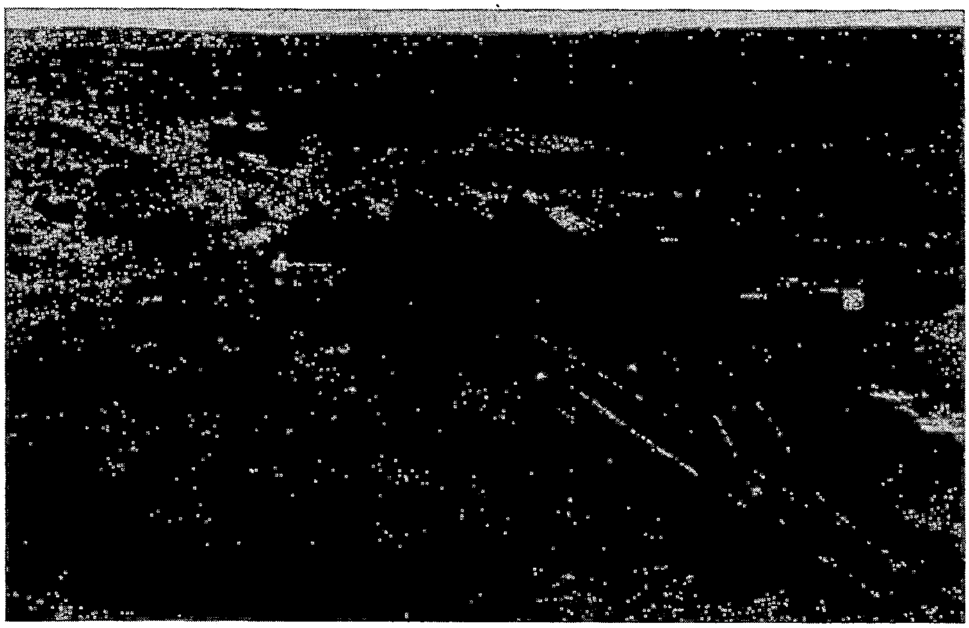
Intermodal Consist Entering Test Area
(Locomotive has uncoupled and run ahead from the moving consist)

Tank Car and First Intermodal Car Entering Test Area Turnout

Intermodal Cars in Test Area



Intermodal Cars Have Derailed/Overturned



Aftermath of the Test--Turnout in Foreground

The Track Safety Program, also in support of the safety rulemaking process and enhanced voluntary safety practices focuses its research on improving the safety of track and bridge structures, signal and train control systems, the relationships between track and the dynamic response of rail vehicles, special track provisions for highspeed passenger service and all other elements of the railroad right-of-way having influence on the safe operation of trains. The program elements and research objectives are:

Track and Components--Provides sound technical information, analytical procedures, and guidance that will improve the reliability of track structural components and associated signal and train control systems and determine their safe operating limits.

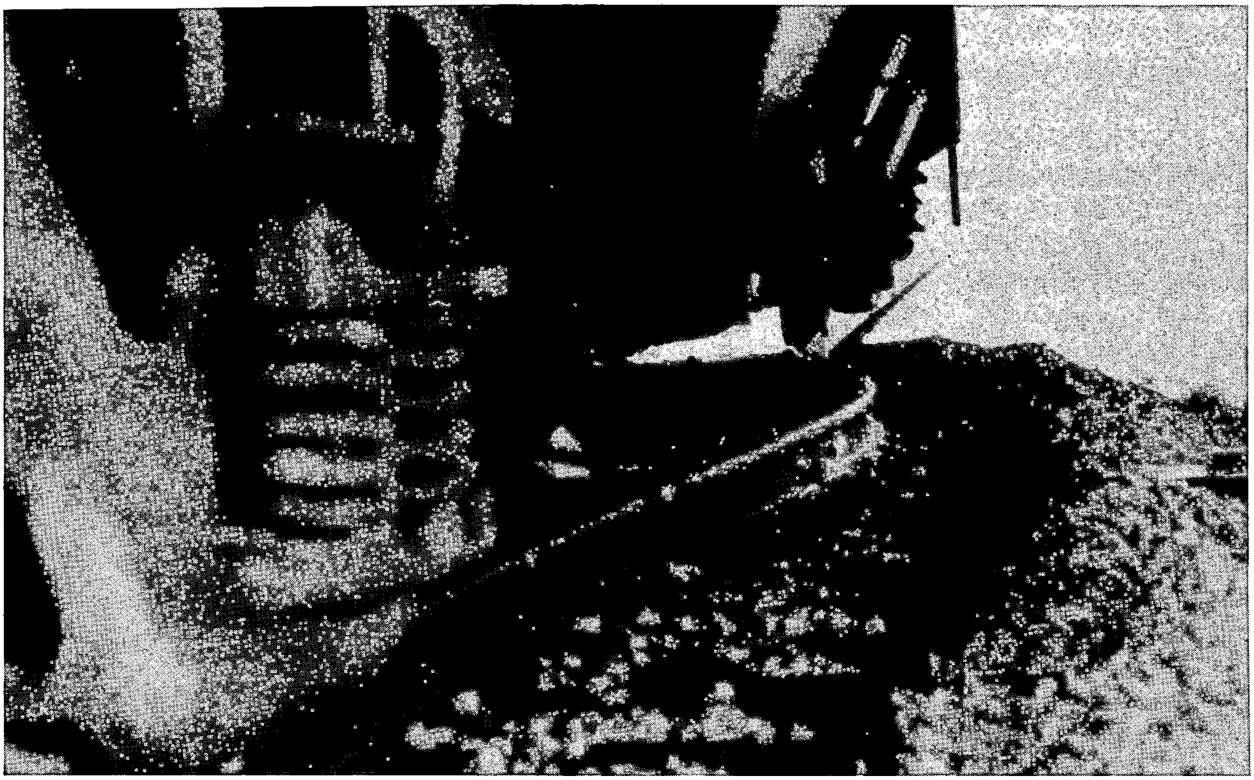
Inspection-Detection--Provides the inspection equipment, techniques, and methodologies necessary to ensure early and reliable detection and warning of unsafe track conditions.

Track-Train Interaction--Provides for the collection of historical information, analysis, and production of factual test data that accurately portrays the effect of the dynamic interaction that occurs between a train, its locomotive and cars, and the track and bridge structures over which they ride.

Safety Testing--Provides for the operation and maintenance of train equipment at FAST to permit rail system testing under controlled environments through: (1) time-accelerated degradation rate testing of track and its components; (2) measurement of the influence and effect of track degradation on vehicle performance and safety operating limits, and (3) measure the effect of train operation on the track structure performance and safety limits.

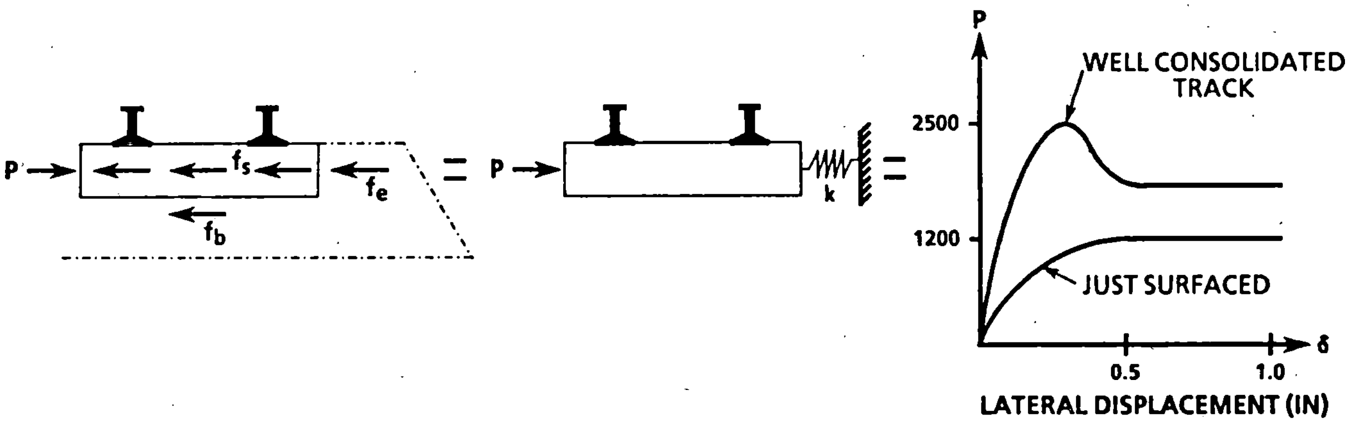
Examples of the accomplishments in this program over the 1981-1987 time frame include the following.

Track Buckling--The increased use of continuous welded rail (CWR) track in the United States has resulted in a large number of accidents attributable to train derailments induced by thermal buckling of railroad track. In an effort to improve on the safety of CWR track, several experimental and analytical investigations have been conducted. Results to date indicate that increased emphasis is needed on track lateral resistance and rail neutral temperature variation influences.



Track Buckled Beneath Railcar

Track lateral resistance is the reaction offered by the ballast to the rail tie structure against lateral movement. The lateral resistance has three components: tie end, tie bottom, and tie sides. Measurement of track lateral resistance is by a single tie push test mobilizing a tie laterally through the ballast and determining its load deflection.



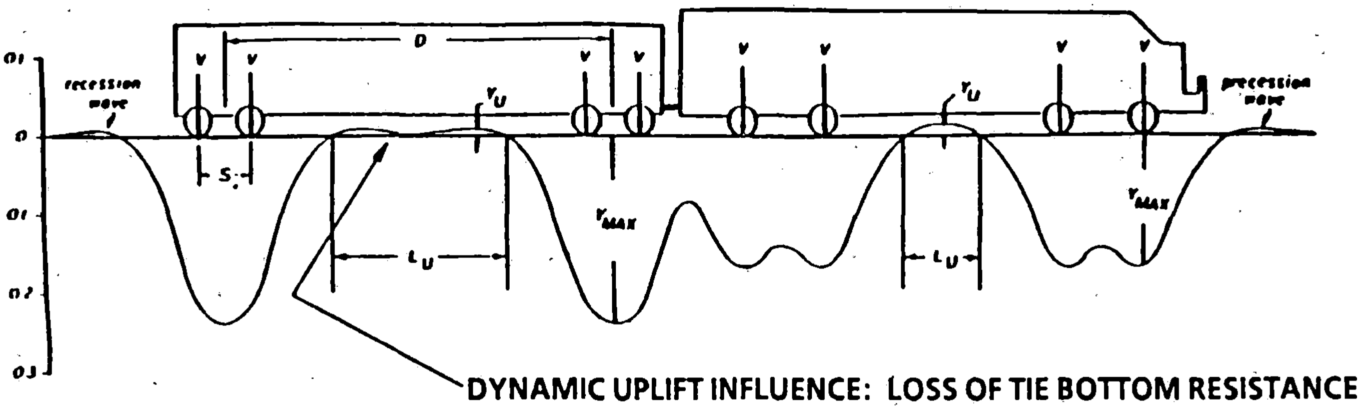
Track Lateral Resistance--Single Tie Push Test

The measurement of track resistance is very important for the analytical determination of "safe" allowable temperature increase limits and for monitoring lateral resistance recovery after track maintenance to aid in the proper determination of train "slow order" requirements. Recent study has shown the approximate percentage resistance of tie end or shoulder (20 percent), tie bottom (35 percent), and tie sides or cribs (45 percent). It is important to note that although the shoulder contribution is only 20 percent, during dynamic uplift (track lift observed when a large distance exists between the two trucks at the end of long cars) all or part of the tie bottom and side resistance is lost. The shoulder then becomes critical in providing adequate lateral resistance for buckling prevention.

APPROXIMATE % RESISTANCE CONTRIBUTION

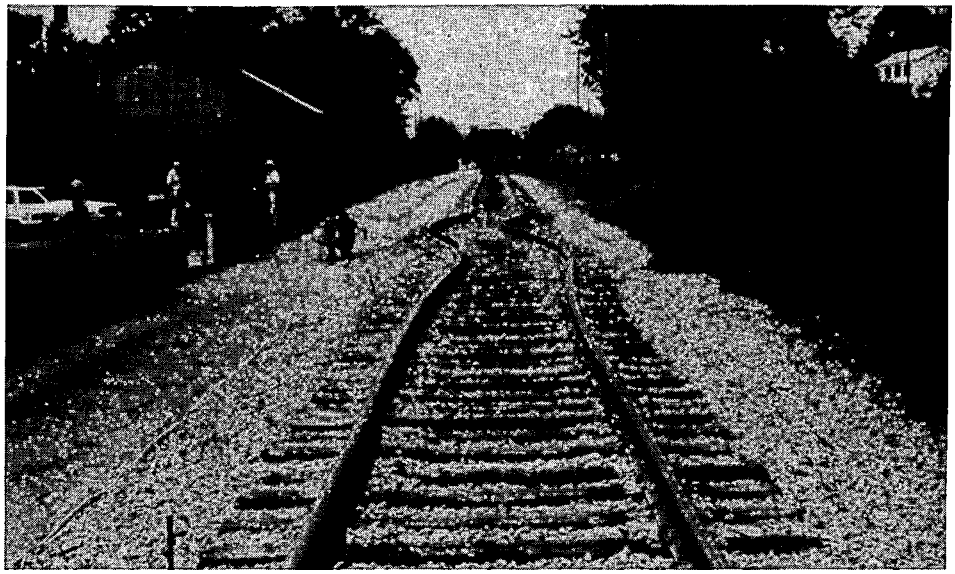
TIE ENDS (SHOULDER)	TIE SIDES (CRIBS)	TIE BOTTOM
20%	45%	35%

NOTE IMPORTANCE OF 20% SHOULDER CONTRIBUTION UNDER DYNAMIC CONDITIONS

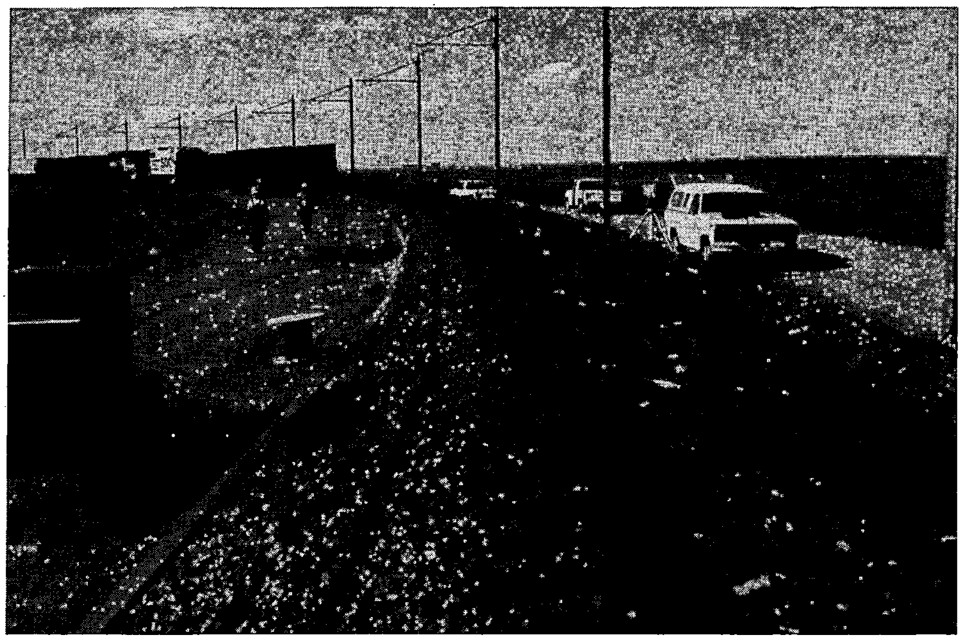


Track Resistance Distribution and Dynamic Uplift Implication

Rail neutral temperature is defined as the temperature at which the net longitudinal force in the rail is zero. Typically, it is the rail laying or anchoring temperature. Test data indicates 20- to 40-degree Fahrenheit shifts in rail neutral temperatures are not uncommon. These variations are important because they directly influence the longitudinal force in the rail. For example, a 40^{o} F. change in a 132 pound rail's neutral temperature can change the force level by 100,000 pounds. Major causes of neutral temperature (zero longitudinal force) change are: unconstrained rail or track movement; maintenance actions; and, CWR installation in cold temperatures. A low rail neutral temperature exposed to a normal climatic temperature increase can create compressive forces sufficient to lead to track buckling. A high rail neutral temperature experiencing a prolonged drop in the ambient temperature could produce tension forces sufficient to lead to a rail pull-apart. One of the major problems in controlling neutral temperature variation is the nonavailability of a technique or device to nondestructively and accurately measure the longitudinal force existing in the rail.



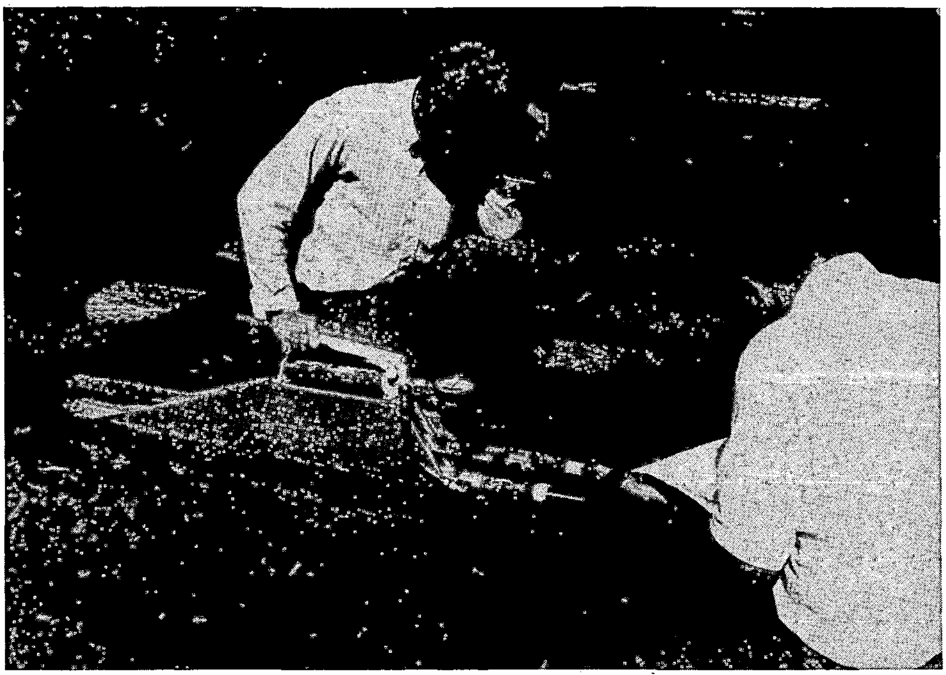
Static Track Buckling Test on Major Eastern Railroad



Dynamic Track Buckling Test at Transportation Test Center

Research is well underway in problem definition and in developing the technical information for improving the buckling safety of CWR track. This includes dynamic buckling analyses, ballast resistivity characterization, neutral temperature variation behavior assessments, and rail longitudinal force measurement. This will lead in the future to safety limits and guidelines for track buckling prevention.

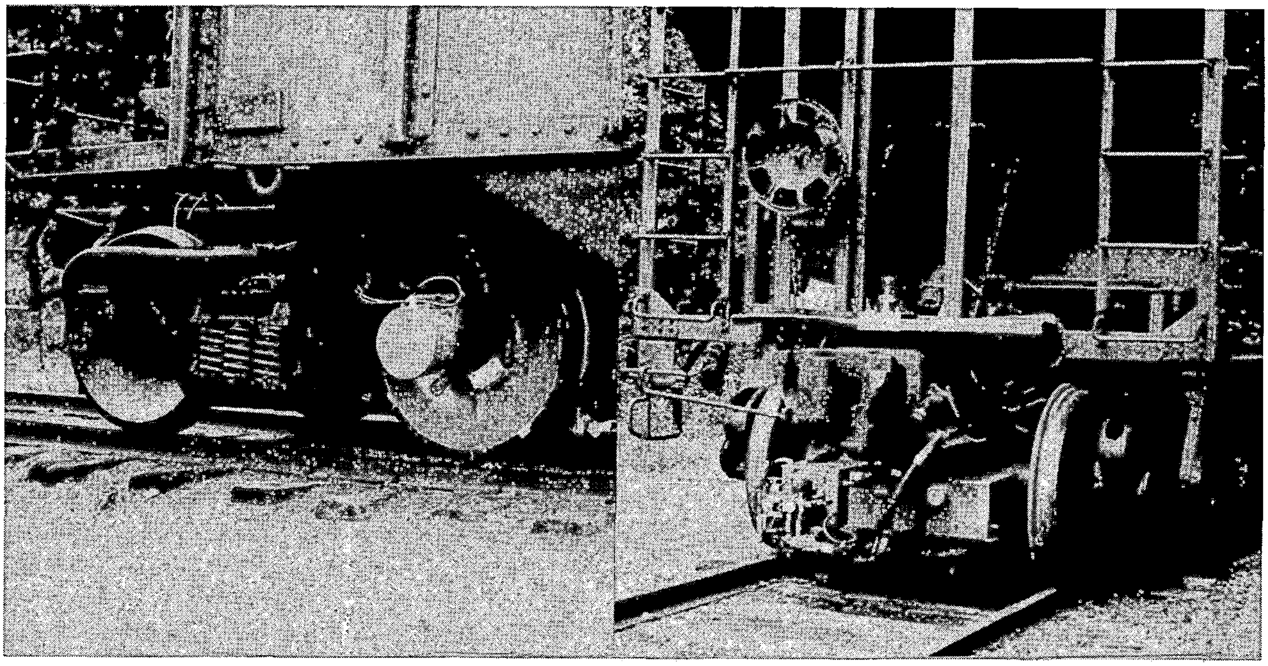
Rail Restraint--Track in the United States consists of the two rails set at a standardized gage of 4 feet 8 1/2 inches and maintained within specified tolerances. This research has as its objective the understanding of the relationship between the stiffness of the rail fastener system and the ability of the track to withstand gage widening forces generated by traversing rail vehicles and to develop performance-based safety tolerances based on these characteristics. Insufficient restraint can result in wheels dropping to the inside of the rail and derailment.



Field measurement of rail restraint

Safety-adequate rail restraint characteristics for low speed (less than 25 miles per hour) track have been defined as a result of early field tests. In order to facilitate future field inspections for determining a track's rail restraint strength, a prototype hand held, field portable measuring device, the Lightweight Track Loading Fixture, was fabricated and successfully tested. To accommodate even more comprehensive track coverage, a continuous survey device, the Gage Restraint Measurement System (GRMS), capable of measuring rail restraint characteristics while traveling at speeds up to 15 mph was also designed, fabricated, and successfully tested. In order to determine the dynamic lateral restraint of a rail, lateral and vertical loads, indicative of the railroad operating environment, must be applied to the rail and the resistance to movement measured.

The gage variation from the static unloaded state is critical to the characterization. The GRMS measures the lateral spring rate of railhead movement from a moving platform without derailment or destruction of the track. The track gage spring rate identifies degraded ties and fasteners as soft spots. The GRMS truck is located under one end of a 100-ton hopper car (see photo at right). Its mechanical subsystem applies a lateral force to the track at the wheel/rail interface by means of a telescoping axle. This is compared to the measurement of the unloaded gage measuring system.



Left: Split-axle truck showing enclosed slip ring housing and instrumented wheel of split axle. Right: Split axle truck under hopper car showing junction boxes.

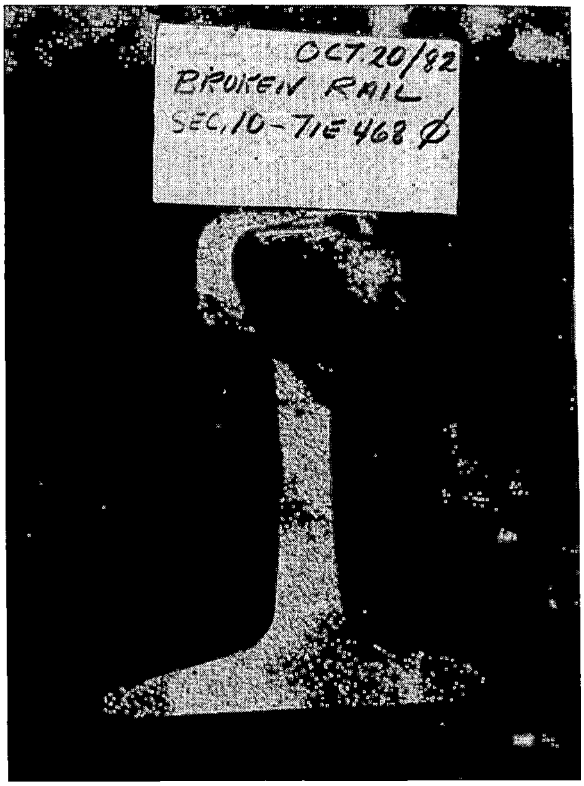
Rail Integrity--The increasing cost of maintaining track and the ever increasing physical demands being placed upon the track structure, caused by the higher average vehicle weight and increased volume over fewer lines, requires the establishment of a rail inspection rationale that provides for the timely detection and removal of rail defects in order to further improve safety and prevent derailment. To study this problem, the principles of fracture mechanics were applied as the primary approach to controlling fracture and fracture fatigue failures in rail in order to approach a more rational basis for determining inspection frequencies.

Rail defect occurrences can be found in three broad categories: Rolling Contact Fatigue (RCF), Manufacturing Defects (MFG), and Maintenance or Service-Induced Defects (MSI). RCF defects are detail fracture and vertical/horizontal split heads and are characterized by long formation periods. Understanding this fatigue type of defect has been the focus and principle thrust of the research to date.

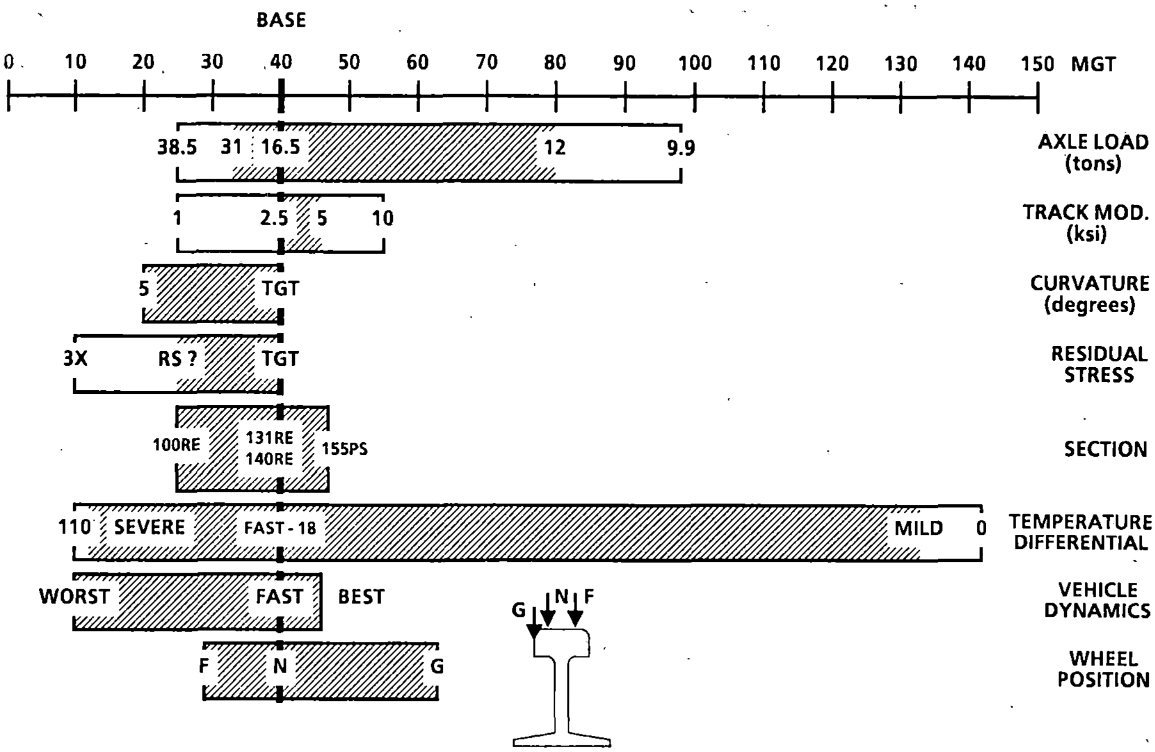
A prototype inspection strategy has been developed from crack initiation and flaw growth studies, residual stress determinations and analytical model calculations.

Field experiments conducted at the Facility for Accelerated Service Testing, Transportation Test Center, near Pueblo, Colorado, have provided the only actual accurate measurements of detailed fracture growth and correlation with millions of gross tons (MGT) of exposure.

In the photo on the following page can be seen a detailed fracture which had grown to 80 percent of the rail head area. The Detail Fracture Life Sensitivity figure illustrates the variables involved and their potential for impact on defect growth as measured in millions of gross tons (MGT) of traffic.



Broken Rail Removed from FAST Track



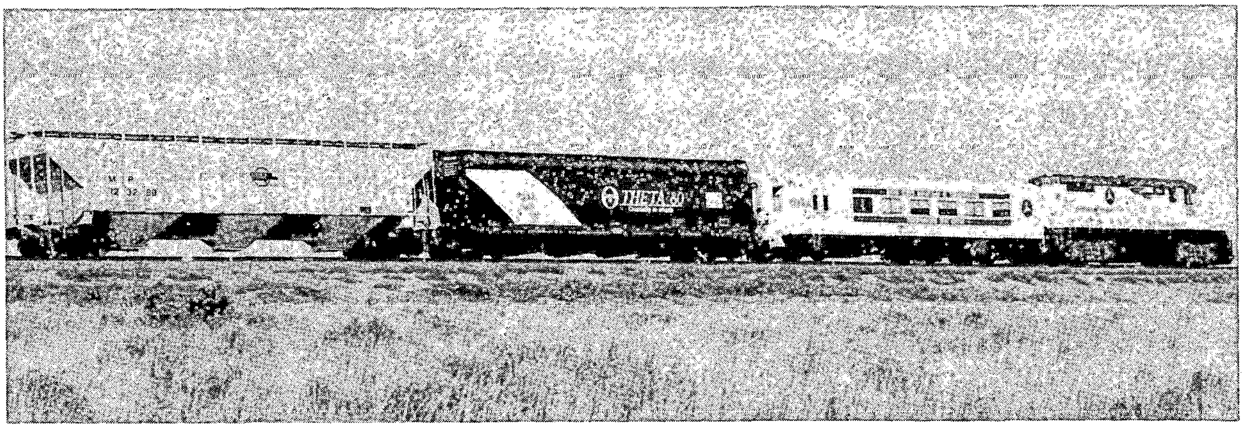
Detail Fracture Life Sensitivity

Rail Flaw Inspection Technology--In an effort to improve the effectiveness of internal inspection for rail defects and flaws, a research project using advanced technology developed under the aerospace program shows promise for application to the railroad environment. Electromagnetic acoustic transducers have been developed for rail flaw inspection and could offer the advantage of non-contact inspection, getting around problems of rust, scale, and grease on the rails. The potential of improved detection because of changed ultrasonic beam patterns available is being explored.

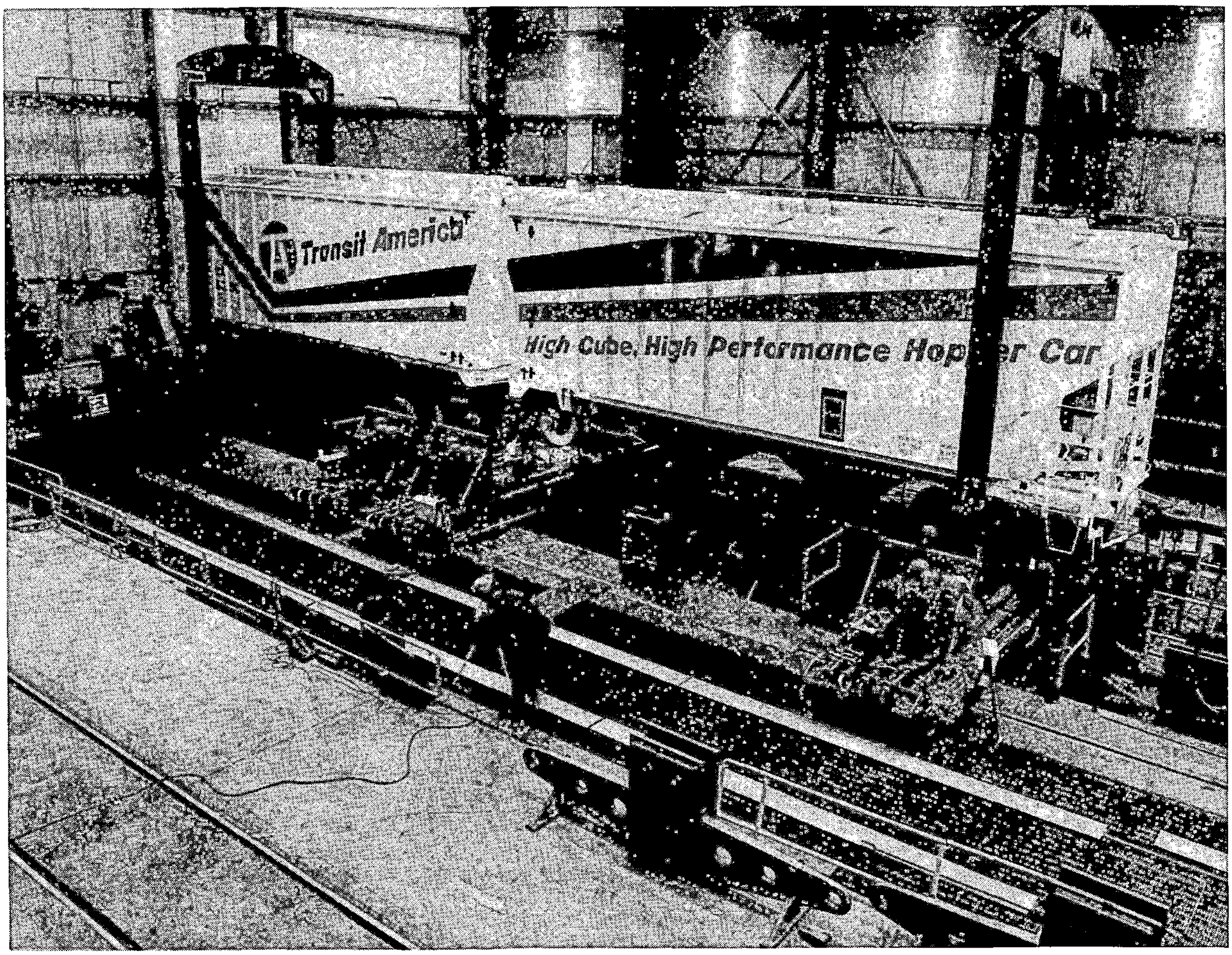
Concrete Tie Safety Inspection Criteria--Concrete ties offer the potential of longer service life with greater track stiffness, a smoother ride, and less variation in track gage. In upgrading the Northeast Corridor track between Washington and Boston, many miles of concrete ties were installed. After a relatively short time, minute cracks were detected in the ties. A research project was set up to evaluate the safety consequences of the cracking and to find countermeasures to keep the cracks from developing. The research revealed the cracking was due to very high dynamic impact loads caused by deteriorated wheel treads on high speed passenger cars and freight trains. An improved rail/tie pad material was used to attenuate the impact loads and thus stop the growth of cracks. A detection device for finding wheels producing high impact loads was developed and is in use on several railroads as a way of identifying wheels which need maintenance attention.

Vehicle Track Interaction--This ongoing program has promoted safety research and information exchange among the industry, suppliers, domestic and foreign governments, and users of the Nation's railroads through cooperative research and testing, principally in those areas affected by the interaction between the railroad vehicle and the track upon which it is moving. Since 1980, more than 43 major technical reports have been published and distributed throughout the industry to convey the results of mutually supported testing. In addition, technical papers regularly published in scientific journals and railroad industry publications have presented to the public the newly discovered technologies in areas such as track stability, track geometry limits, vehicle operating limits for curving, hunting, braking and brake shoe performance, and the hazardous rock-and-roll phenomenon. Train derailment cause finding, train handling and the make-up of train consists were also research report topics enjoying a high level of interest among the railroad community. Mathematical modeling of dynamically induced forces, accelerations and other parameters have been developed to aid future designers and operators in calculating safe limits of performance for railroad vehicles and train consists over various classes of track. Recent significant accomplishments in the vehicle track interaction area include:

1. The static and dynamic performance of two prototype covered hopper cars, furnished by industry suppliers with new design features incorporated, were tested and their performance compared (see photo on following page) to that of a representative "baseline" car. In both instances the safety performance of the new designs showed significant improvement. Laboratory testing (see photo on following page) of the prototype articulated covered hopper car was conducted and the results compared to on-track tests. The tests verified the capability of the laboratory test equipment (the Vibration Test Unit) in safety testing of the increasingly popular articulated car type.



Safety performance of a prototype high-cube covered hopper car
is tested for comparison with a baseline car.
Data Collection Car is between locomotive and test car.



A prototype articulated covered hopper car, with new safety features
incorporated, is tested on the Vibration Test Unit
in the Rail Dynamics Laboratory, Transportation Test Center.

2. Realistic coefficients of friction for frequently used types of brake friction materials were established for use in developing idealized train brake systems. Five friction materials were evaluated over a range of load and environmental conditions.

3. Test data has been developed concerning alternate types of track structures, in particular, concrete ties and wood ties with premium fasteners. These data permit more accurate evaluation of track designs for various traffic conditions.

4. The strain-life approach to characterizing the fatigue behavior of materials and its application to the railroad environment was evaluated and presented for use in railcar and component design. This approach provides an additional tool for predicting safe limits of vehicle performance.

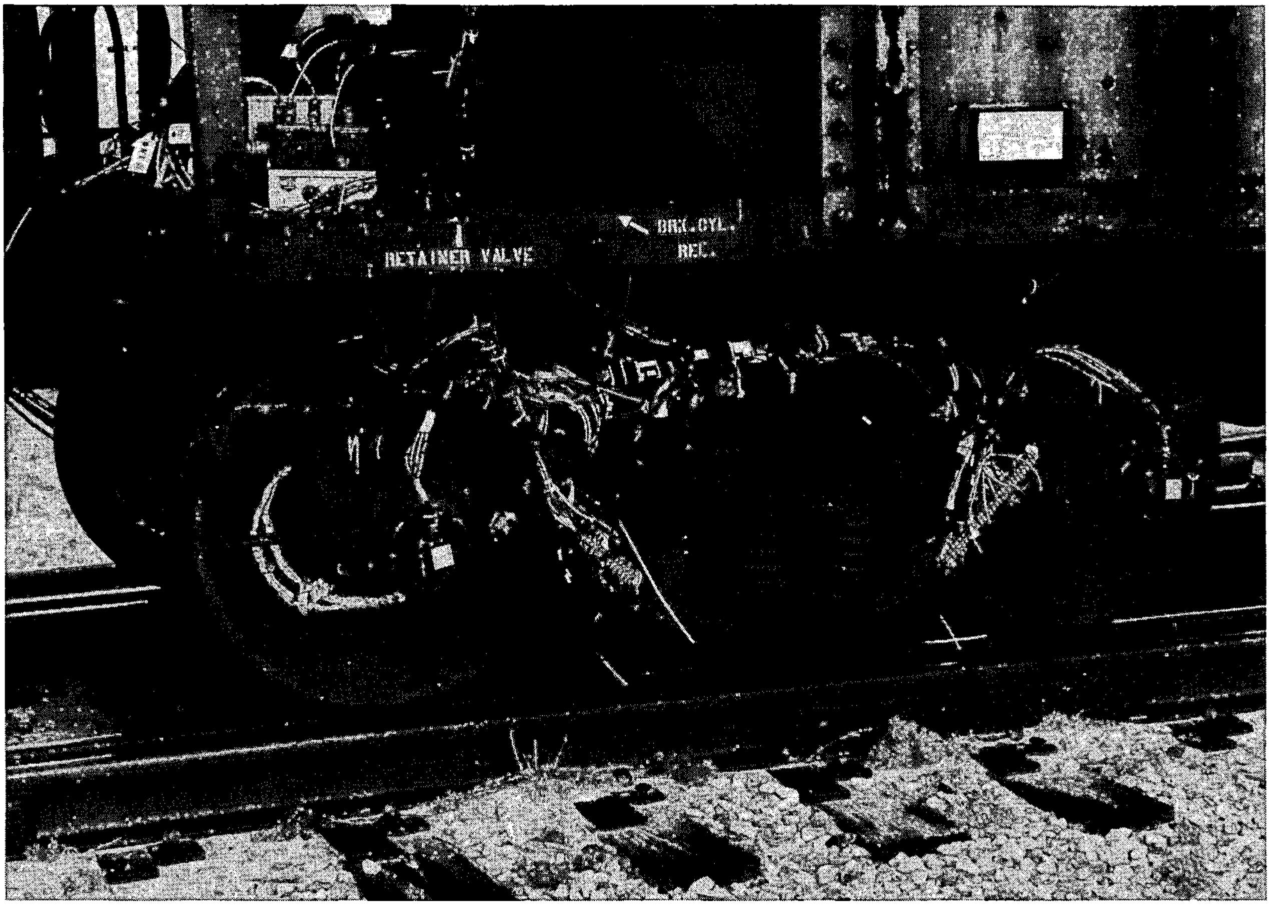
5. Fatigue life data were developed for a series of railcar component shapes and sizes. Data for this ferrous series was not previously available and was determined to be critically needed by a special industry/academic Fatigue Task Force.

6. A computer model, the Train Operating Simulator (TOS), was developed. This model has been widely accepted for use by railroads, suppliers, the National Transportation Safety Board, and FRA for prediction of train responses to varying operating conditions. The TOS model is used in railroad accident investigations as well as for making operating and maintenance predictions.

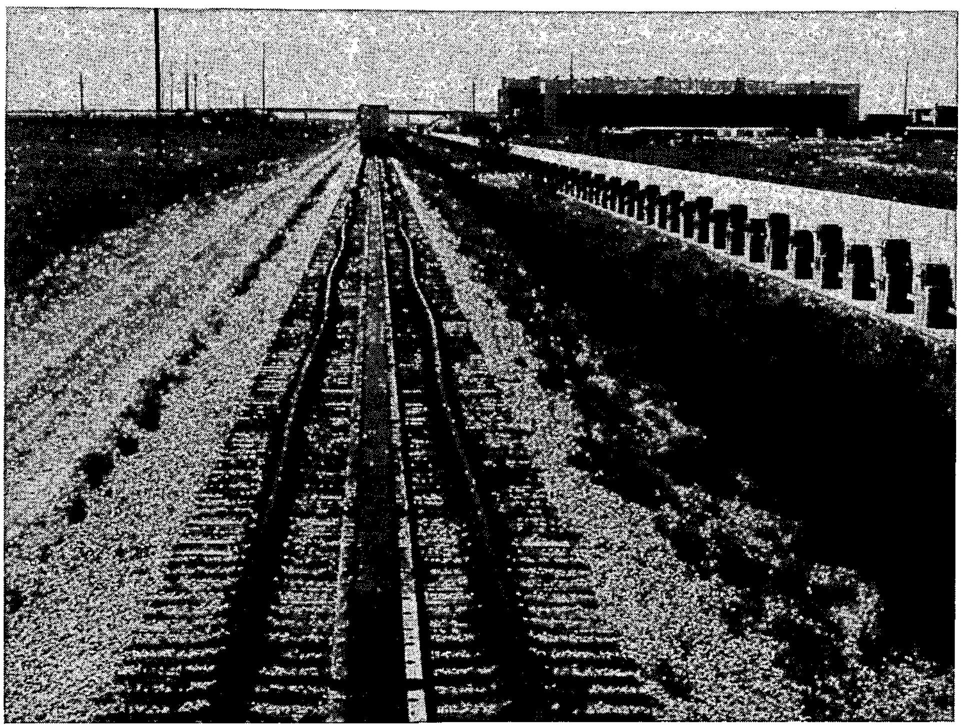
7. Definition of a "Crosslevel Index" that when applied to lower class track (speeds under 30 m.p.h.) limits the likelihood of the "harmonic roll" type of derailments.

8. Development of a track survey device which measures the Crosslevel Index using instrumentation mounted on a standard locomotive.

9. Definition of a track surface specification which would limit derailments resulting from wheel unloading, coupler separation, and car body-truck separation produced by track twist and other track surface variations.



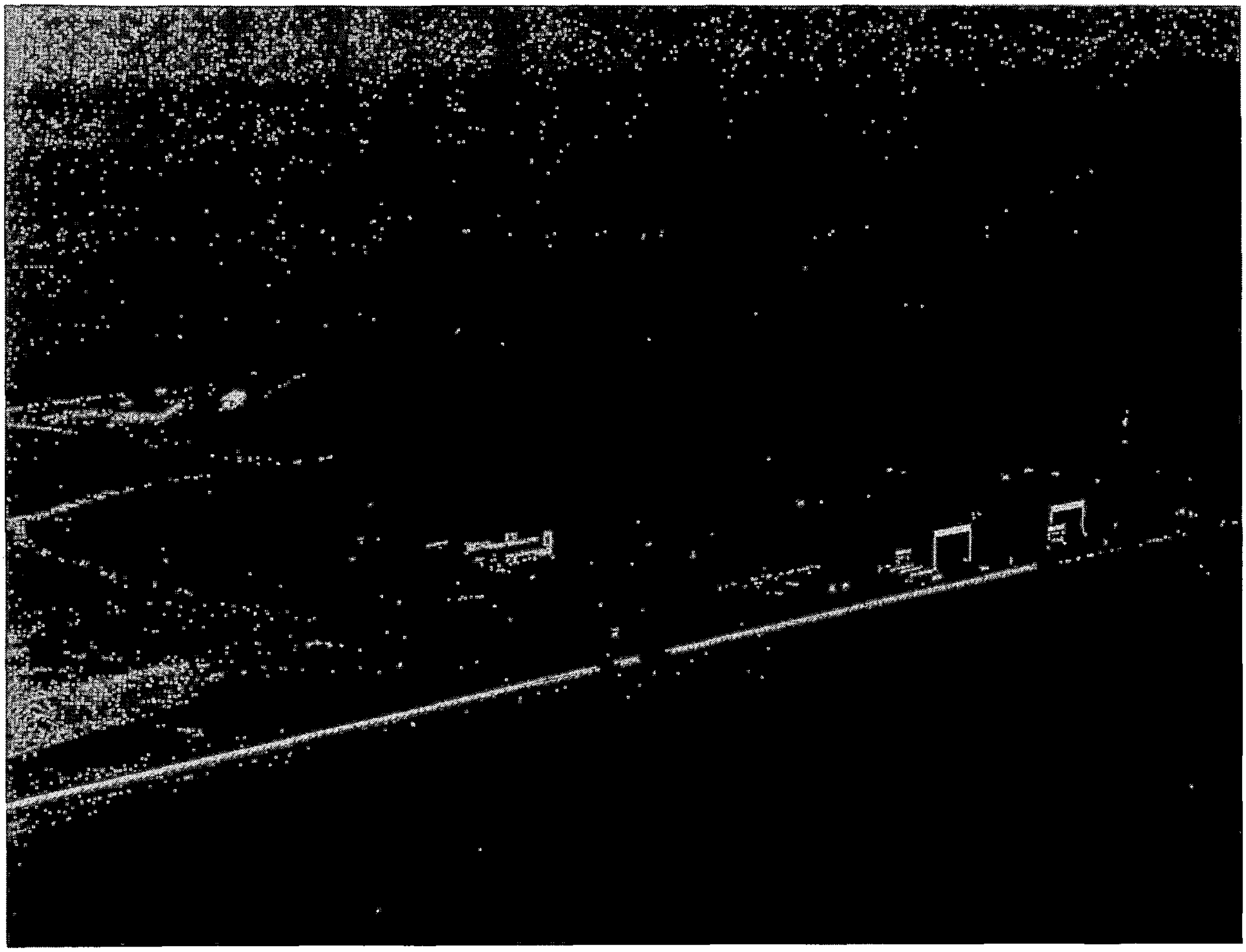
Typical Instrumented Truck Used in Vehicle Track Interaction Testing



Perturbed Test Track Used for Vehicle Dynamics Testing
in Vehicle Track Interaction Studies

Facilities

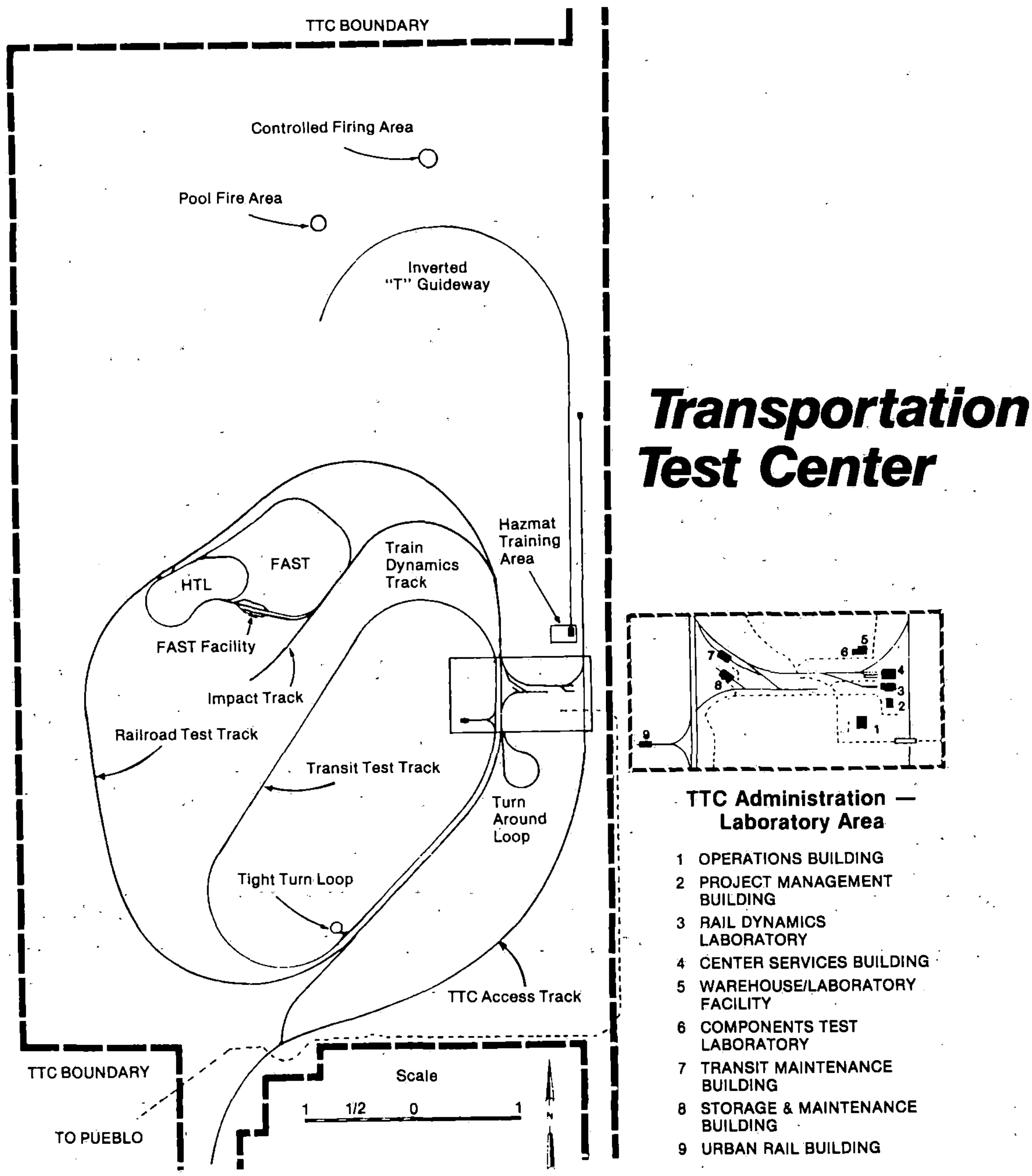
Transportation Test Center



The Facility and Grounds

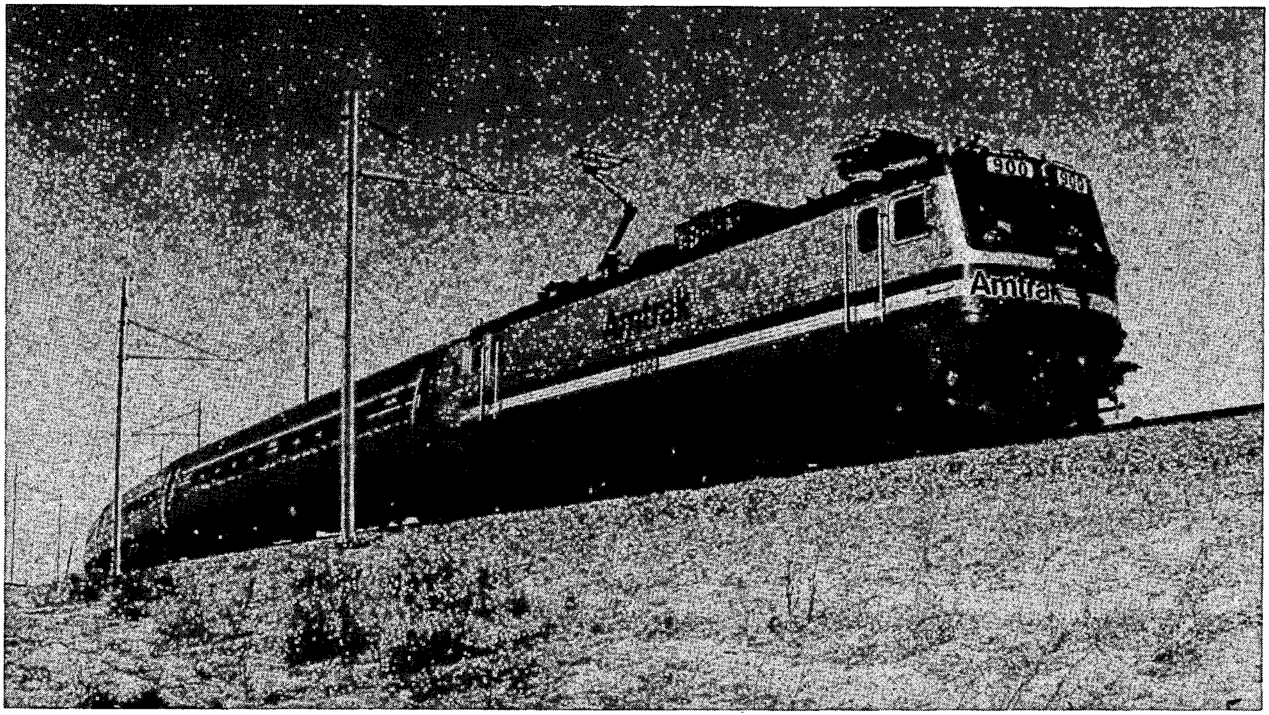
The Transportation Test Center was constructed as a result of the High Speed Ground Transportation Act of 1966, as a facility to support the development of advanced high speed intercity ground transportation systems, urban transit systems and general railroad systems. It was constructed on 52 square miles of land leased from the State of Colorado and is located about 25 miles northeast from Pueblo, Colorado. This remote location permits a variety of tests to be conducted with minimum disruption or impact to the environment or surrounding population.

The initial emphasis was on facilities for testing the new advanced concept of intercity passenger equipment being developed under the 1966 Act. A capability to test Tracked Air Cushion Vehicles, Linear Induction Motor Vehicles, and a variety of high speed conventional track vehicles was developed and constructed.



Not shown: 80 miles of paved and unpaved roads.

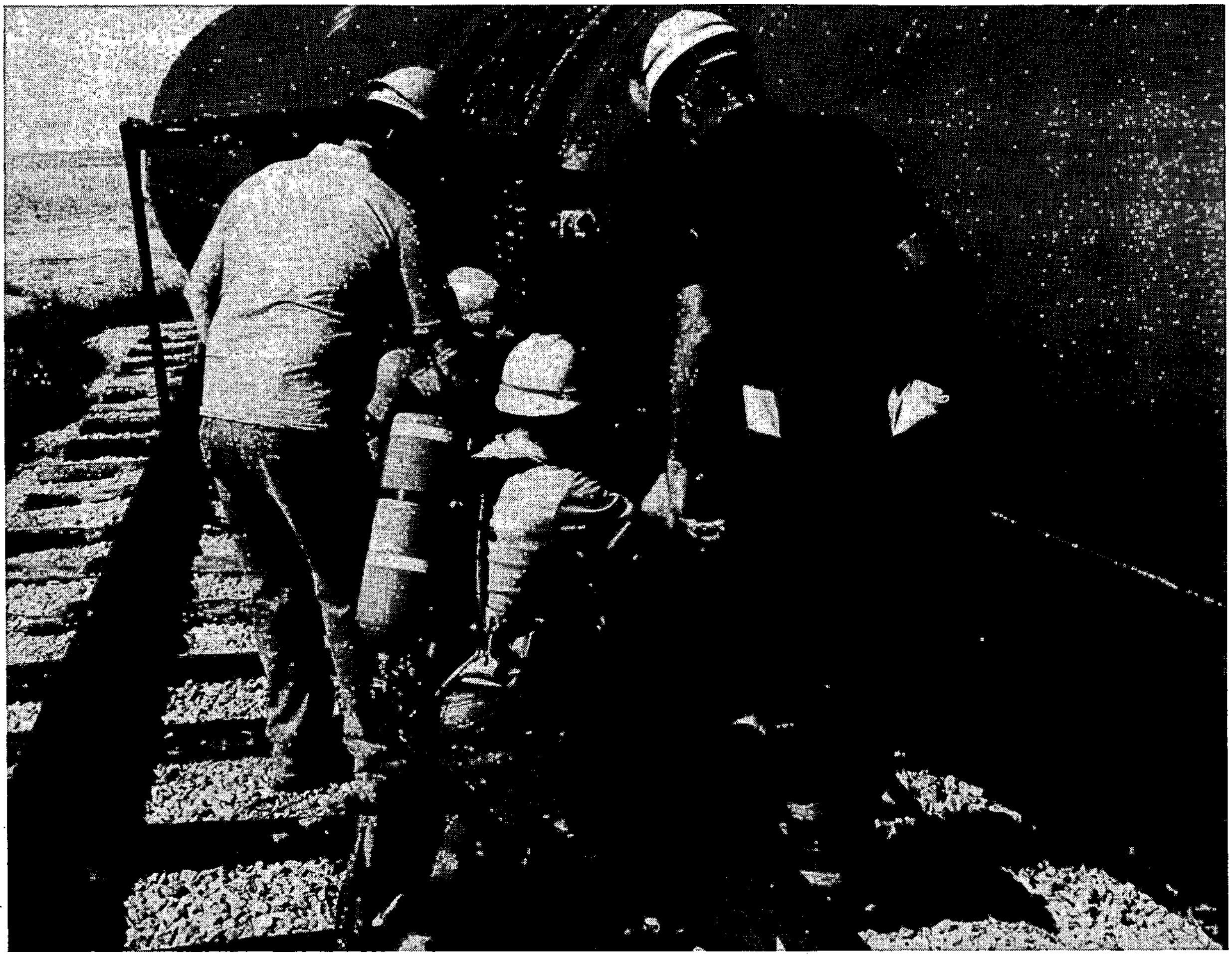
In 1975, as the initial demonstration of the advanced vehicles was being completed, emphasis shifted away from advanced concepts to supporting the solution of the then current industry problems and economic condition of the freight railroads. New facilities and tracks were proposed and constructed for purposes of evaluating conventional track and equipment problems. Among the most notable of these new facilities was the Facility for Accelerated Service Testing (FAST) dedicated in 1976 and a laboratory test facility, the Rail Dynamics Laboratory (RDL) which was built to evaluate vehicle dynamic characteristics.



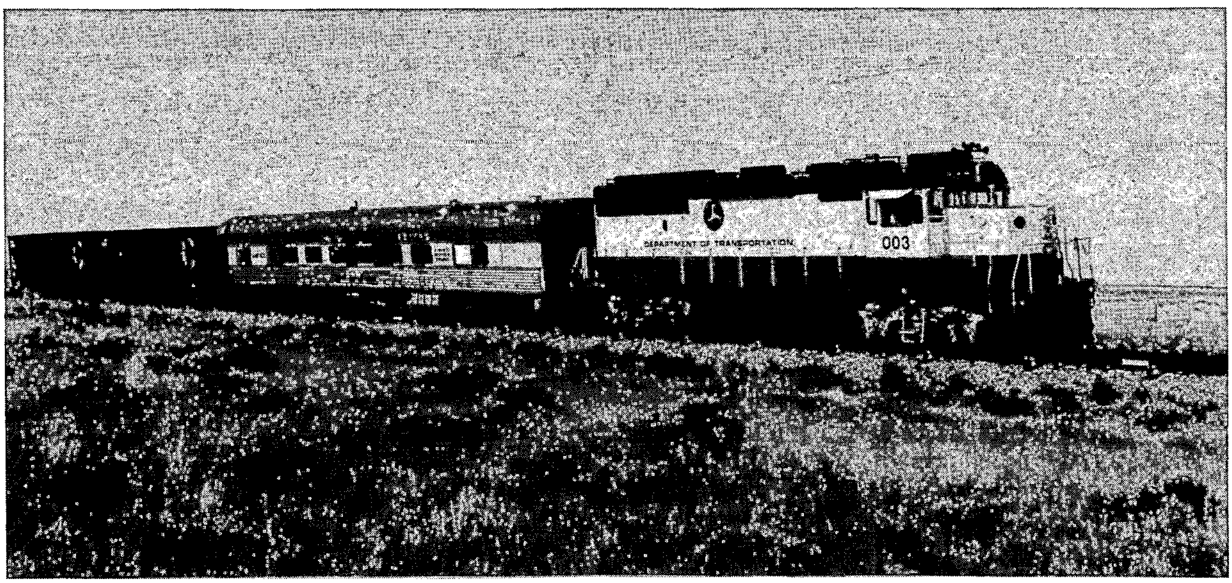
High Speed Electrified Test Track

During the 1970's, the Test Center was managed by the FRA and the transit test facilities by the Urban Mass Transportation Administration. By 1982, as part of the privatization activities underway throughout the Government, the FRA awarded a contract to the Association of American Railroads (AAR) for the Care, Custody and Control of the Test Center. The contractor was responsible for marketing the capability of the Center, not only to the transit industry and railroads, but to other transportation and non-transportation users. The FRA thus became only one of many users of the facility's capability over the years, funding specific projects along with other Government and private sector customers. By way of comparison, the pre-1982 share of operational funding was about 95 percent FRA and 5 percent other. For 1988, this is expected to be about 40 percent FRA and 60 percent other, with a substantial amount of commercial business.

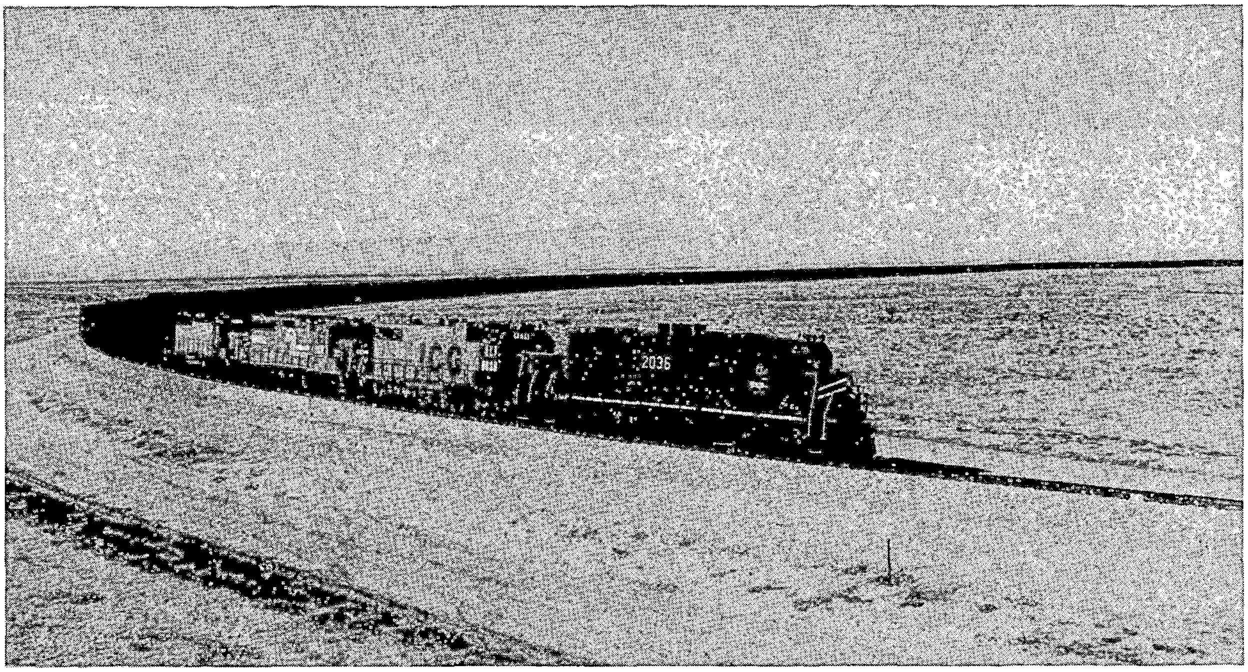
The AAR also added some capability on their own by starting a hazardous material training facility and, cooperatively with the FRA, installed a facility that had been donated by an industry firm to the DOT for testing fatigue characteristics of freight car bodies. This device is called the Simuloader. Today, the Transportation Test Center still shows some evidence of the facilities that were developed for the advanced ground transportation systems, but it is very evident that the major thrust and usage is to solve the current and anticipated problems of the railroad industry.



AAR Hazardous Materials Training Center at TTC



Cooperation: DOT Locomotive with AAR Research Car on TTC Test Track



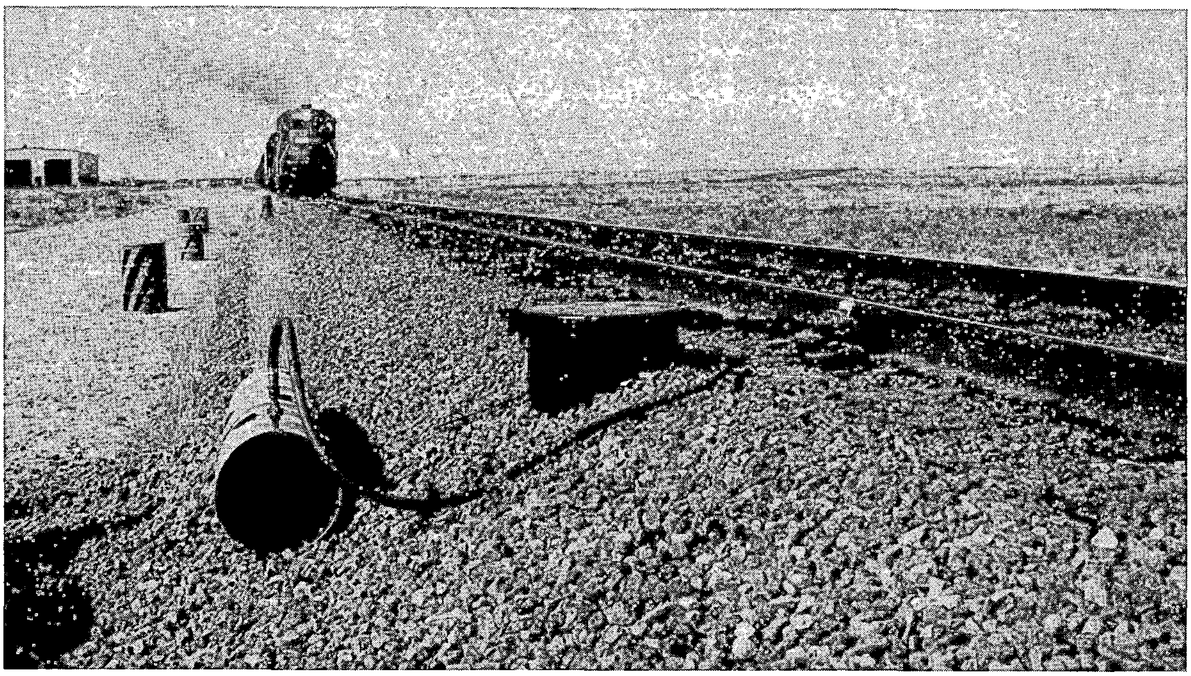
FAST Train with Shared Power from Four Cooperating Railroads

Facility for Accelerated Service Testing (FAST)--The purpose of FAST is to investigate wear and fatigue failure phenomena in conventional railroad track and rolling stock. The program was conceived as a joint effort between the Federal Railroad Administration and the railroad transportation and supply industries. Sponsorship was through donation of rolling stock and track material from the private sector and cash funding for the operation of the program from the Government.

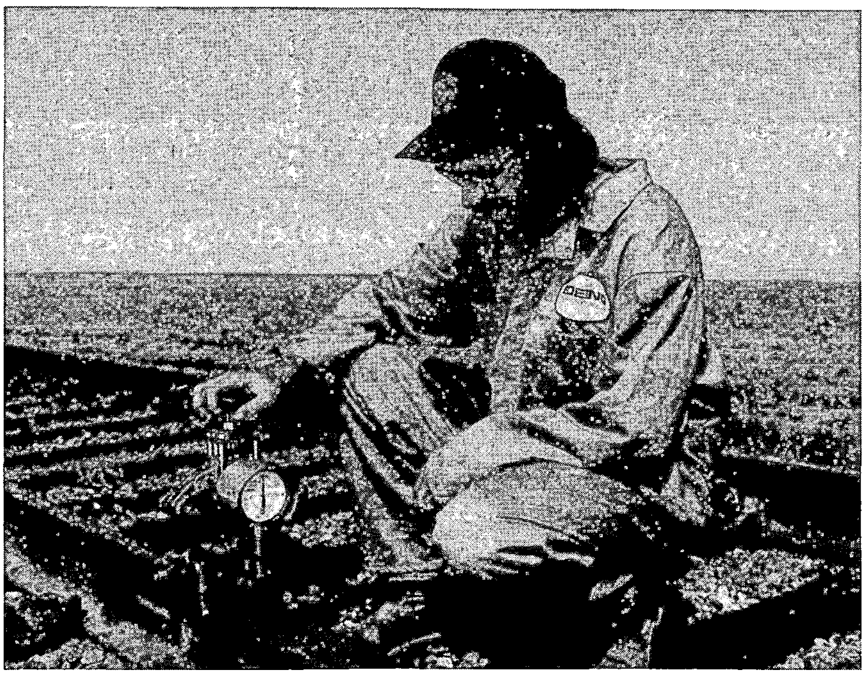
To facilitate this testing, a closed loop test track was constructed, 4.8 miles in length. Over this track, a train consist of predominately loaded 100-ton hopper cars was to operate 16 hours per day, to rapidly accumulate mileage on the cars and tonnage exposure to the track. After less than a year of planning and construction, the first train rolled over the track in September of 1976. The 16-hour operation was conducted mostly during the night, leaving daylight hours for measurement of the track and rolling stock and data collection for the various experiments conducted on particular cars and track sections.

In 1978, an organization of Experiment Managers and Monitors was formed to oversee the various experiments being conducted. The Experiment Managers were persons knowledgeable in the subject matter being investigated and drawn from the rail industry and their consultants. Experiment Monitors were personnel employed at the Center and able to monitor an experiment's progress on a day-to-day basis. This system continued until 1982 when operation of the Test Center was passed from the Federal Railroad Administration to the Association of American Railroads. At this time, the operation of FAST became a contractual program, being performed for the FRA by the AAR. The FRA's support was shifted at about the same time to safety issues with the industry's interest focused on economic questions. The experiment management nature also changed at this time with full-time AAR/TTC employees acting as Experiment Supervisors overseeing the progress of the experiments. Working under a full-time program manager, this arrangement exists to this day.

As the FAST program matured, it became apparent that the time and track space required to conduct experiments had been significantly reduced. During this time, FRA and the AAR decided that a shorter test track would significantly reduce costs and increase efficiency. In 1985, a cutoff track known as the High Tonnage Loop (HTL) was constructed by the AAR at FAST. Operation over this track was initiated in July of 1985. The new track is 2.7 miles in length requiring only 270 miles of train operation to accumulate a million gross tons of traffic exposure instead of the 480 miles of travel previously required over the original 4.8 mile track.

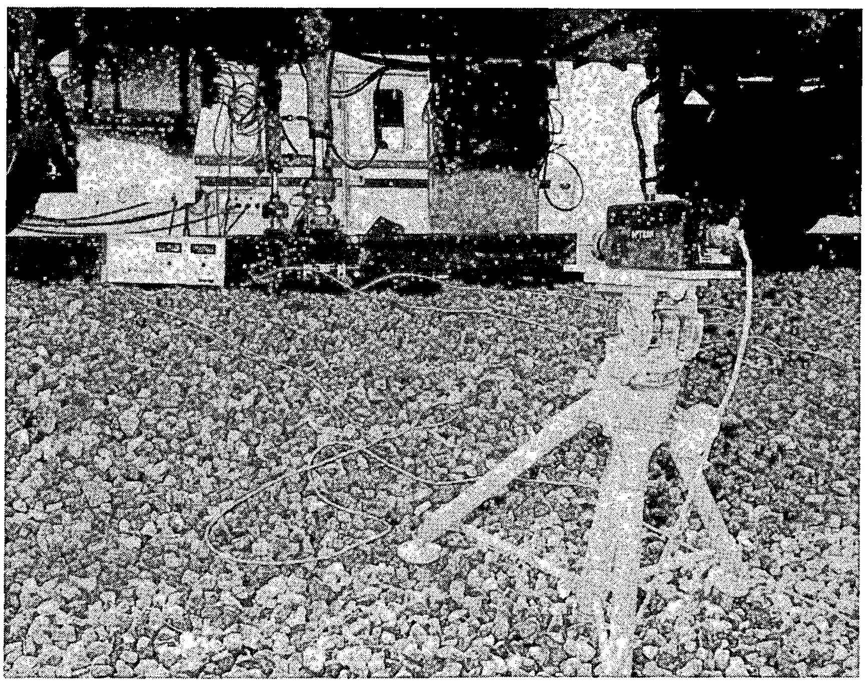


Measuring Rail Lubrication Quantity on FAST Track



Rail Wear Measurements on FAST Track

Track Gage Measurement on FAST Track

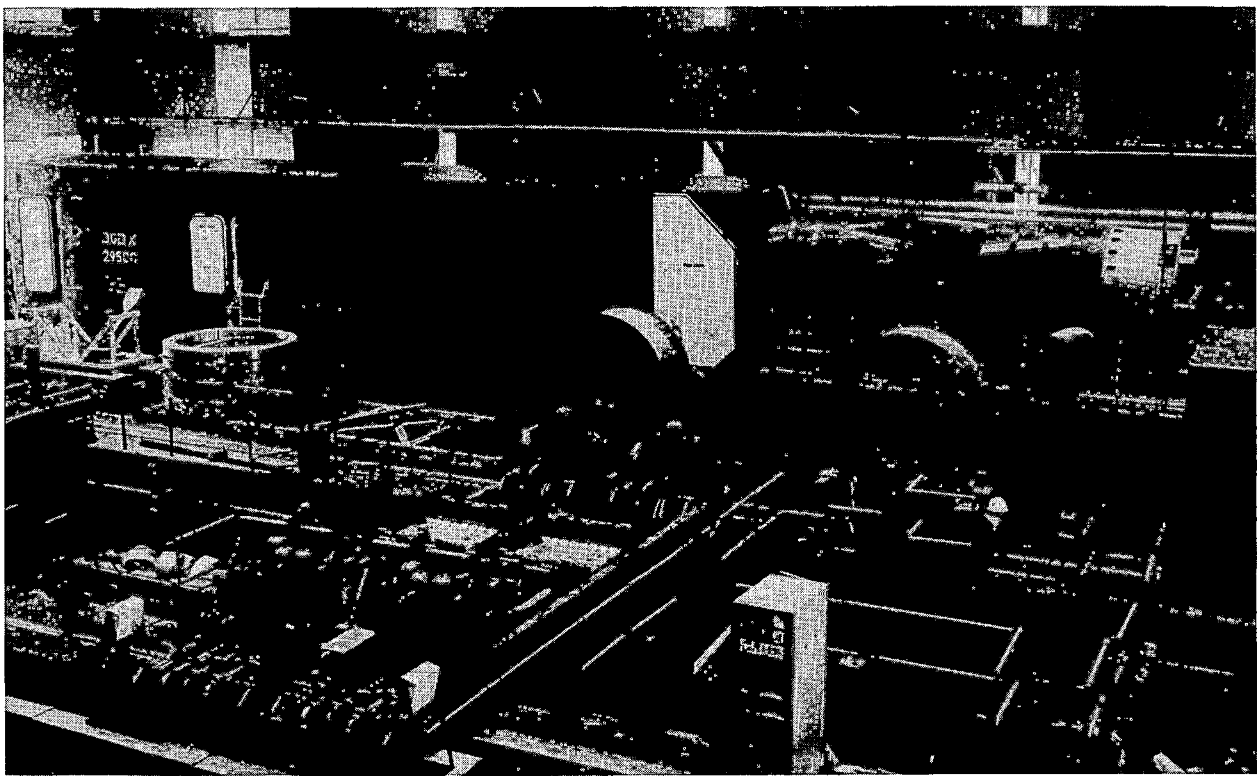


Measuring Track Modulus on FAST Track

In early 1988, a major change is scheduled for the FAST program. At that time, operation of the 100-ton (33,000 lb. wheel load) consist will cease and be replaced with a consist of 315,000-pound gross weight cars (39,000 lb. wheel load). This change is in response to pressures in the rail industry to improve the loaded to empty weight ratios on rolling stock. The implications of the safety and economic impacts of an increase in gross car weight are unknown. In the latter years of the 1980's, this test program keeps the FAST program at the leading edge of expanding the technical knowledge in heavy haul railroad operations.

Rail Dynamics Laboratory--This 55,000-square-foot building houses a Vibration Test Unit, a Roll Dynamics Unit, the Simuloader, and associated data-collection systems, instrumentation, and handling equipment.

Vibration Test Unit (VTU): This hydraulic shaker will impart virtually any combination of motions to a full-scale freight car or other equipment under test. Computer-monitored input permits it to simulate theoretical or actual conditions. The VTU offers many possibilities for evaluating the effect of track irregularities on empty or loaded vehicles. It can analyze suspension systems, structural stresses on rail cars and trailers, failures, and the sensitivity of materials or loads to shock and vibration. The instrumentation and data recording capabilities of the VTU offer up to 128 channels to the main data acquisition system and an additional 103 channels to the control system.



Vibration Test Unit of the Rail Dynamics Laboratory

Roll Dynamics Unit (RDU): This unit is designed to simulate the relative motion of both powered and unpowered vehicles. It can impart rotary motion to the wheels of a vehicle or be driven as a dynamometer by a powered vehicle. The data that it collects support studies of acceleration, adhesion, braking, and truck hunting. The data also validate engineering simulations of phenomena associated with motion and vehicle performance. The RDU will accommodate virtually all existing and planned rail vehicles, including locomotives and transit cars, and can be adapted for non-rail vehicles. Its extensive instrumentation will record up to 128 channels of data simultaneously.

Simuloader: This unit is designed to apply loads of different frequencies directly to the railroad car body to study the fatigue characteristics of the structure.

The Rail Dynamics Laboratory is equipped with bridge cranes, communications networks, and other essential support systems. It has the facilities to support the offices of a team of 15 to 20 persons for any period of time.

Transit Test Track (TTT)--This 9.1-mile track contains six representative types of track construction. It is equipped with a third rail throughout that will provide from 400 through 1,500 volts. Two miles of the track are equipped with a type of catenary system representative of that used in modern city light rail systems. The catenary system is adjustable as to both wire height and voltage. Connected to the TTT is an electrified tight-turn loop, a complete circle with a radius of 150 feet.

Railroad Test Track (RTT)--Longest of TTC's tracks (14.7 miles), the RTT provides a facility on which to generate vehicle dynamic data, to evaluate wheel-rail dynamics, and to do other testing under controlled conditions--at speeds of up to 160 miles an hour. The track is maintained to high commercial railroad standards. The RTT is completely electrified with a heavy duty catenary system the height of which may be adjusted to suit the vehicle being tested. Voltages of 12,500, 25,000, or 50,000 are available. An associated balloon loop permits trains to be turned.

Other Laboratories and Test Tracks--A variety of other laboratories, buildings, and test tracks are available including a Center Services Building for maintenance and repair, and a Component Test Laboratory for mechanical, metallurgical, and chemical analyses, and instrumentation calibration.

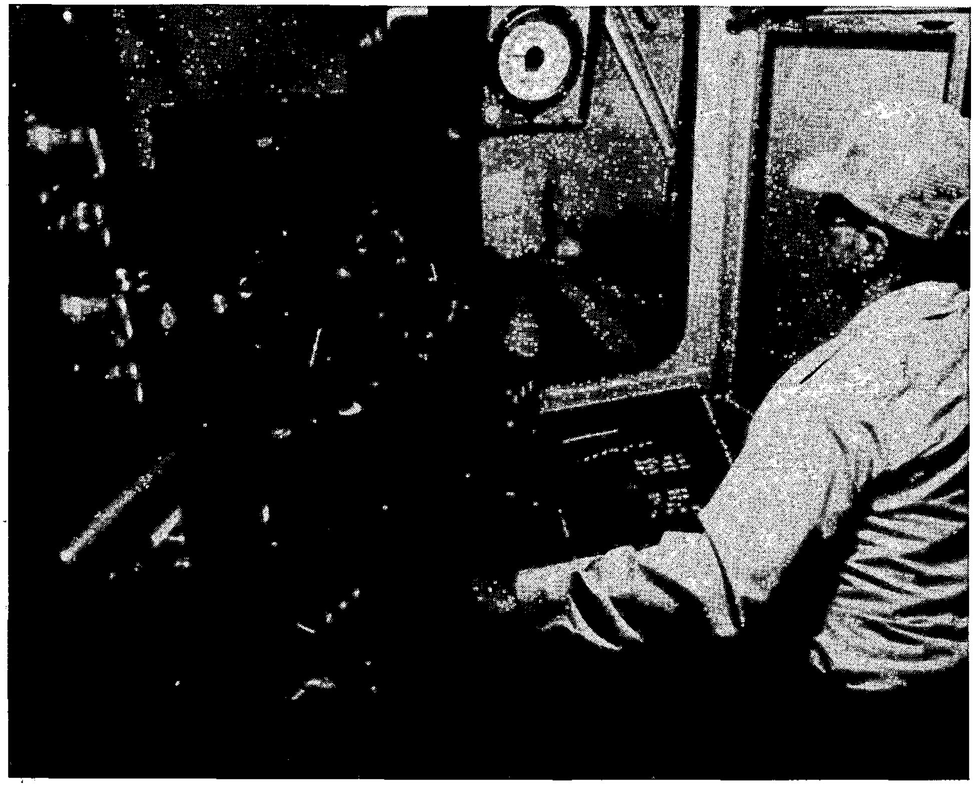
Research and Locomotive Evaluator/Simulator (RALES)

In the early 1970's, several studies were conducted to gain insights into improving the training of locomotive engineers, understanding the individual tasks required of train crews and dispatchers, and improving safety inside the locomotive cab. One conclusion from these efforts was that more definitive and valid results could be obtained if an appropriately designed locomotive and train handling simulator were available. Thus, a primary goal of FRA's R&D program in the railroad human factors area became the design and construction of the most versatile and realistic train handling simulator that current technology could achieve.

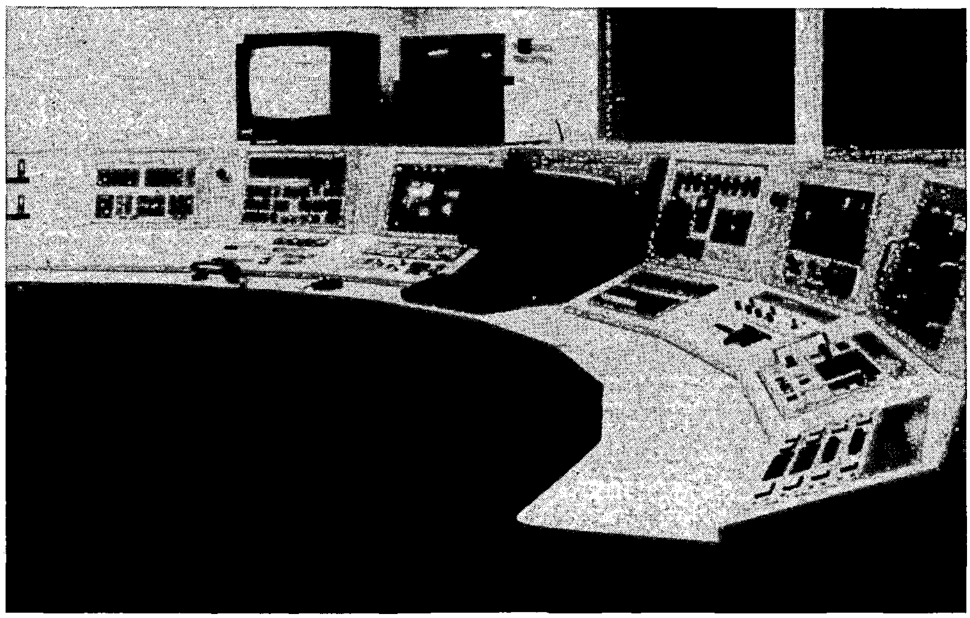
The definition of performance requirements for the simualtor began in 1974 leading to the development of competitive concept designs in 1978. In 1979, construction began. The simulator was completed in 1984 under contract to the Illinois Institute of Technology Research Institute (IITRI) in Chicago, Illinois. This contract was somewhat unique in that it provided not only for completing construction of the simulator but also for the operation and maintenance by IITRI for a period of ten years after construction was completed. It is operated as a private facility with all users paying a users fee.

Railroads, suppliers, and the Government have been users of RALES for both training and research. One large railroad has recently contracted for the construction of a similar facility of their own. Also, as a result of the knowledge gained from RALES, two other simulators have been built which do not have locomotive cabs or motion bases and can be either portable or used in a classroom environment.

Briefly described, RALES is a full-scale SD 40-2 locomotive cab mounted on a motion base with full sound and visual subsystems. Its functions are computer simulations of real trains and locomotives. It can simulate any train consist likely to operate under all operating conditions. Shown below are pictures of the inside of the cab and of the experiment operators control console.



Locomotive Cab Interior with Motion Picture Screen in Background



RALES--Experiment Operator's Control Console