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## INTRODUCTION

### Background

In November 1985, TRB's Committee on Guided Intercity Passenger Transportation (A2M05) established a subcommittee to study high-speed and super-speed safety issues. The task of the subcommittee was to compile engineering and operational data, and other information on these issues. Such data could serve as source material for industry and government in establishing safety requirements for high-speed rail passenger operations above the current maximum allowable limit of 110 mph (Federal Railroad Administration [FRA] Class 6 track). Institutional differences between foreign countries operating high-speed passenger services and the United States (for example, public versus private ownership) would also be identified to the extent that such differences affect the applicability of foreign practices to U.S. railroads.

Subcommittee members were chosen based on their knowledge and experience in various technical areas related to high-speed rail passenger operations. The subcommittee members were divided into four task groups by the following subject areas: permanent way; rolling stock; communication, signal, and electrification systems; and operations. Each task group identified specific issues in each subject area where data on current practices should be collected from railroad administrations around the world that operate high-speed systems.

Letters of introduction and a statement of the subcommittee's purpose were sent to railroad administrations in seven foreign countries (West Germany, France, Japan, United Kingdom, Italy, Spain, and Sweden). Responses from all of them indicated their willingness to cooperate and provided the names of some specific individuals to contact in each organization. It was apparent, however, that the correspondence process would be time-consuming. The four task groups subsequently turned their efforts to preparing detailed questionnaires, incorporating specific issues that had been identified in each subject area. The four questionnaires were assembled and sent to the seven foreign railroad administrations. At the same time, a request was made to Mr. Jean Bouley, Secretary General of the International Union of Railways (UIC), for his assistance in encouraging responses from the various European railroad administrations and helping to establish a dialogue with the appropriate officials.

Mr. Bouley was very helpful in establishing communications with the Europeans who could provide the information sought by the subcommittee. Ultimately, three members of the subcommittee met with their European counterparts at a meeting arranged by Mr. Bouley at the UIC's Office for Research and Experiments (ORE) headquarters in Utrecht, Netherlands, on August 31 and September 1, 1988, to obtain the information that had been requested in the questionnaires.

While the subcommittee's work was underway, concerns about the possible necessity for additional safety requirements for proposed high-speed rail systems were growing within the FRA. In particular, progress toward selecting a high-speed rail passenger system in Florida, as well as a project promoted by the northeastern states looking for higher-speed operations between New York and Boston, added urgency to FRA's need to define safety requirements to apply to high-speed railroad operations. FRA, therefore, provided funding to expedite preparation of this report as part of its larger effort to collect data to support new safety requirements.

## Purpose and Scope of Report

The purpose of this report is to present certain information on infrastructure, rolling stock, and communication, signal, and electrification systems of European rail systems now operating passenger services at high speeds. In the context of this report, high speed is defined as 125 mph (200 km/hr) and above.

Material gained through the subcommittee's day-and-a-half meeting in Utrecht (see *Background*) makes up the bulk of this report. French National Railways (SNCF) also responded in writing to the subcommittee's questionnaire. Most of the material obtained and reported here relates to SNCF, to the German Federal Railway (DB), and to a lesser extent, to British Rail (BR). The meeting participants, who are identified in Appendix A, provided information on their own experience and asked not to have their comments attributed as official statements of their respective administrations. The participation in this meeting by officials of UIC and ORE was especially helpful because of the number of instances in which current European practice is governed by UIC Codes.

Where current practice varies from country to country, no attempt has been made to present comparisons. Rather, a range of values found acceptable by different railroad administrations is presented. Only significant differences in existing practices between countries are highlighted and contrasted. Direct comparisons between current European practice and FRA's existing regulations or Association of American Railroads (AAR) specifications have not been attempted.

## Differences Between European and U.S. Railroad Regulatory Agencies

Any comparison of European and American railroads must begin with an understanding of the differences in the institutional framework within which each functions. The American railroad system, of course, functions primarily as private enterprise with private ownership of most railroad property and equipment. Through various railroad reorganization programs, some rail lines are owned by state or local government agencies, but even in the majority of these cases, operations are performed by private corporations.

Through a number of laws (primarily the Federal Railroad Safety Act of 1970 and the Rail Safety Improvement Act of 1988) and court decisions, the FRA has been given jurisdiction over all areas of railroad safety involving public and private railroads operating in both interstate and intrastate service. This jurisdiction does not apply to light rail or rapid transit systems within urban areas that are not physically connected to the general railroad system of transportation. Proposed high-speed rail systems, irrespective of their use of new technologies not usually associated with traditional railroad practice, would be under the jurisdiction of the FRA with regard to matters of safety.

In addition to FRA's regulations, which have the force of law, there are also voluntary guidelines that will affect the construction and operation of high-speed rail systems, including Amtrak's equipment specifications and AAR and American Railway Engineering Association (AREA) specifications and recommended practices. Less formally, the inertia of customary design and operating procedures will also affect new U.S. systems.

The railroads represented at the meeting in Utrecht--French, German, and British--are government-owned or controlled, a fact that dramatically alters the relationship between the railroad administration and government safety officials as perceived by Americans.

In France, for example, SNCF may propose to the Ministry of Transport that large projects be undertaken with certain conditions of safety specified. The Ministry's Bureau of Safety will review the proposed project, discuss it with the railroad, and usually approve it through a letter agreement with SNCF. The ministry does not promulgate specific regulations, as FRA does, but certain safety-related regulations issued by SNCF are subject to its approval. Similarly, in Germany, DB's constitution stipulates the railroad's responsibility for the safety of vehicles, equipment, and operations. Each chief engineer is responsible for upholding the railroad's own safety standards as well as for their further development.

In the United Kingdom, Acts of Parliament apply to railroad operations in some specific cases. Generally, however, the system is similar to that of France and Germany in that under the terms of the Health and Safety Act, British Rail and the Ministry of Transport reach agreement on specific safety issues through an exchange of written correspondence.

To summarize, in each of these countries the railroad itself has the prime responsibility for safety, while the government has responsibility to oversee and to approve or disapprove the railroad's actions. In each case the government has regulatory power, but does not exercise it through detailed regulation as is the case in the United States. Further, in these European countries, local governments have no jurisdiction over operation of the national railroad network except through specific agreements for local service.

Throughout this report references are made to UIC Codes as they relate to current design, construction, and operation of existing European high-speed systems. These codes, published and updated at unspecified intervals by the UIC, generally cover material similar to that found in the following American publications: AAR Mechanical Division's *Manual of Standards and Recommended Practices, Field Manual* and *Office Manual of the Interchange Rules* of the AAR Mechanical Division, AREA *Manual for Railway Engineering* and *Portfolio of Trackwork Plans*, AAR *Signal Manual of Recommended Practices*, and AAR *Communications Manual of Recommended Practices*. UIC Codes that are obligatory in nature are designated with the letter "O" and usually cover requirements for rolling stock and financial activities. Codes that provide only recommendations are designated with the letter "R" and usually address permanent way, operations, or commercial activities. Thus, one source document for each specific topic is provided to users, with the individual paragraphs or sections of a particular code designated O or R. Although the railroad administrations that are UIC members have no statutory obligation to adhere to the UIC Codes, they generally do so to a large extent. The UIC Codes are public documents, but many ORE reports carry a "right-of-use" restriction making them accessible only to member railroads. (In the United States, the AAR and FRA are recipients of UIC publications.)

## Organization of the Report

The major sections of this report deal with characteristics of European high-speed rail systems as follows: operations, vehicles, infrastructure, signal systems, communications, and electric traction systems.

## OPERATIONS

This section briefly discusses the different operating philosophies of SNCF, DB, and BR; the European approach to safety; safety considerations of the interfaces between rolling stock and infrastructure; and emergency procedures.

### Operating Philosophy

High-speed European operating philosophies have been established as a result of an analysis of national transportation and social policy demands and future objectives. Land availability and environmental impacts, as well as cost/benefit analyses, have also led to decisions on dedicated or mixed rail service line development. These factors are the principal reasons for the difference in the design and operating approaches taken by France (SNCF), West Germany (DB), and the United Kingdom (BR). SNCF's existing and newly planned high-speed lines (TGV) are utilized solely by passenger trains with a maximum speed of 186 mph (300 km/hr). The TGV-North line, to be built from Paris to Belgium and the Channel Tunnel, is designed for 200-mph (320-km/hr) operation. Mixed service operation is not forbidden; however, high-speed services are naturally capacity-constrained because the high-speed passenger train frequency requirements are incompatible with slower-speed passenger or freight service.

The DB's new high-speed lines (Intercity Express [ICE]) have been designed and scheduled to accommodate 155-mph (250-km/hr) passenger trains and preferential freight service. BR, utilizing upgraded existing lines, intends to introduce 145-mph (234-km/hr) intercity passenger service on mixed usage trackage.

It is generally accepted that capital costs of new or upgraded high-speed lines for mixed traffic will be greater than those of lines dedicated solely to high-speed passenger service. Factors affecting capital costs include the need for the following:

- Additional sidings with interlockings for access and egress to provide required capacity;
- Greater clearances, lesser gradients, reduced curvature, and stronger bridges; and
- A signal and control system to accommodate the different braking characteristics of the various vehicles using the line.

Maintenance of the track structure also becomes a paramount operating cost issue. High-speed lines of conventional ballasted concrete-tie track in mixed service incur greater costs to maintain comfort and safety at the required levels than do dedicated high-speed lines.

### The European Approach to Safety

Safety concerns of European high-speed rail systems are approached on the basis of designing and operating these systems in such a manner as to avoid unsafe conditions. This approach is described as "designing safety into the system" as opposed to issuing safety-related regulations. Great emphasis and importance are attached to eliminating potential causes of accidents. These design features include such elements as integrity of track structure and vehicle dynamic stability to ensure against derailments; signal and control systems that ensure train separation to prevent collisions; avoidance of highway grade crossings to preclude highway vehicle/train accidents; isolation and protection of high-speed system infrastructure from intrusions; and, in some cases, separation of high-speed from conventional train operations. It is not considered essential to provide a double-track line for high-speed operation.

### Safety Considerations of Rolling Stock/Infrastructure Interfaces

The interface between rolling stock and infrastructure has been and continues to be a basic issue in the planning for the high-speed thresholds crossed by the European systems. Early in the planning process, groups were established to coordinate rolling stock and infrastructure interface. They agreed on areas to be studied and researched to ensure a balanced approach to performance criteria.

Basically, the results of this work have been incorporated into acceptable limits for lateral accelerations and forces for comfort and safety. These limits are directly translated into vehicle weights, axle loads, and truck dynamics. It is on this issue that a significant distinction exists between SNCF and DB. SNCF has reduced vehicle axle loads (now at 17 metric tons) as speeds have increased, with the objective of maintaining the same level of dynamic forces at 200 mph (320 km/hr) as earlier developed by heavier axle loads at 125 mph (200 km/hr) on similar ballasted track structure. SNCF's maximum allowable carbody lateral accelerations for conventional lines have been established at 0.15 g for cars and 0.20 g for locomotive units. On the TGV high-speed lines, carbody lateral accelerations are normally limited to a range up to 0.07 g with exceptions to 0.125 g primarily for enhanced passenger comfort. However, reduced dynamic loading of the track structures is also realized by this approach.

DB has maintained the UIC standard 22.5-metric-ton axle-load limit on its newest dual service passenger/freight locomotives. As a result, these locomotives have initially developed greater dynamic forces into the track structure than vehicles with lower axle loads at comparable speeds. Consequently, DB favors a more costly ballastless track for higher speeds and is thus devoting considerable resources to the development and application of new types of track construction.

### Emergency Procedures

All the high-speed rail systems incorporate public address systems on the vehicles and at stations for disseminating passenger information. Train crews are instructed and given practical training in routine and emergency public address system announcements as well as hands-on practice of procedures to protect, evacuate, and rescue passengers in case of accident.

This type of practical training is also provided by the railroad and by the car builders to nonrailroad fire departments and other emergency organizations located along the high-speed routes. Some railroad administrations furnish detailed local maps to regional fire and rescue groups to expedite their access to train accident sites.

# VEHICLES

This section provides information on the European high-speed rail experience related to vehicle stability, vehicle safety features, and typical strength requirements.

## Vehicle Stability

Vehicle stability criteria are defined in UIC Publication C-138.

Operational stability is considered the most important safety issue in new vehicle design. As previously noted, the primary responsibility for safety rests in the hands of the railroads, which have based their technical approach to safety on their own operating experience. Speeds have been gradually increased, starting with experience gained at conventional speeds. As experience is gained at each plateau of higher speed, a railroad administration reviews the safety of its operation and either continues the status quo or modifies its rules on the basis of the added experience.

Tests of high-speed rail equipment have demonstrated the relationships between vehicle stability and track geometry, but the limits of safe vehicle stability have not yet been reached in test situations. Many test runs have already been made at speeds up to 255 mph (410 km/hr), and more will be conducted at even higher speeds in the near future.

In actual practice, the allowable deviations in track geometry are governed by considerations for passenger comfort. Experience has consistently shown that the limitations on original design and maintained track geometry (and, therefore, on speed) imposed by providing passenger comfort are always stricter than those required for safety alone. However, extremely high-speed equipment tests have helped to establish the maximum allowable wheel/rail forces. Through both computer simulation and actual measurements during acceptance testing, it must be demonstrated that these wheel/rail force limits are not exceeded.

In general, the guidelines issued by ORE and UIC are followed by the European high-speed rail systems. For high-speed rolling stock, the design parameters (such as vehicle accelerations, vehicle and truck excursions, dynamic stability, and ride quality) are reduced 10 percent below UIC values for conventional speed regimes.

Initial testing of a new vehicle is carried out on a dynamic stability test machine or roller rig similar to that operated by the AAR at the Pueblo Transportation Test Center. Maximum lateral and vertical forces are specified by the railroad administration on the basis of values suggested by the UIC publication. Additional parameters that are defined for the tests include discrete singular maximum values of lateral and vertical accelerations and the permissible sequential values of these accelerations. These values are set forth in UIC Publication C-138.

One railroad begins its vehicle acceptance through an analytical review of the design on paper before starting to construct a prototype. The roller rig testing starts with delivery of the prototype. Instrumentation is installed to detect the earliest indication of truck (bogie) instability as speed is increased. The testing is conducted with both new and worn (250,000 mi [400,000 km] of service) wheel tread contours. For acceptance, stability must be demonstrated at a speed 10 percent higher than the maximum design speed. Maximum excursions of truck yaw, pitch, and roll are included in evaluation of ride quality and dynamic stability.

Vehicle Safety Features

Vehicle structural design considerations are detailed in UIC Code 566 OR. This publication contains many obligatory provisions. General carbody design characteristics are prescribed. In addition, the code prescribes static levels of compression, draft, and vertical forces, both individually and combined, and their points of application that the vehicle must be able to resist. The *dynamic* load requirements for carbody design are now under study in preparation for the issuance of a code applying exclusively to high-speed train sets.

UIC Code 566 OR also covers certain vehicle components and fastenings. These requirements give both static and dynamic forces for which all such components and fasteners must be designed.

Safety considerations for passenger amenities are covered in a series of UIC pamphlets, referenced below. It should be noted, however, that these specifications were initially developed for conventional trains and have not yet been revised specifically for high-speed equipment.

- #560 contains regulations for entrance doors including automatic closing and locking devices. Automatic door closure and locking is required when a train accelerates to a specified low initial speed from a stop. Further, it must not be possible to open the side doors while the train is in motion. This pamphlet also covers intercar doors; compartment, side, corridor, and toilet doors; windows; steps; handles; and handrails. The need for side and end doors to resist the forces of positive and negative air pressure generated by trains passing each other at the operating speed is recognized. (It should be noted that similar requirements are not fully covered by existing U.S. performance specifications for all exterior windows, doors, and other openings.)
- #515 covers passenger coach running gear.
- #564.1 covers window glazing.
- #564.2 covers fire protection and fire-fighting measures.
- #565.1 covers passenger coach interiors.

In developing these codes, the working committees drew on extensive railroad experience gained on regional trains operating throughout Europe.

In such matters as the attachment of interior fittings, flammability, and window glazing, existing U.S. standards and regulations are at least the equal of those followed by the various European high-speed rail systems. In some respects, the practices followed by Amtrak, for example, are already more conservative or stringent than those set forth in the comparable UIC Codes.

On-board diagnostic systems will be installed in the next generation of European high-speed vehicles, so that the operator will be alerted automatically to any unsafe condition that develops on the train, e.g., hot boxes, sticking brakes, open doors.

Typical Strength Requirements

UIC Code 566 OR specifies the following force requirements that the carbody must be able to withstand without permanent deformation and without exceeding the maximum permitted stress levels. (Conversion factors were rounded, so values in pounds [lb] are approximate.)

- Compression (buff)

  449,618 lb (2,000 kN) at buffer level

  449,618 lb (2,000 kN) at automatic coupler centerline

  112,405 lb (500 kN) diagonally at buffer level

  89,924 lb (400 kN) 13.8 in (350 mm) above buffer centerline

  67,443 lb (300 kN) at the level of the side sill

  67,443 lb (300 kN) at the level of the cantrail (side top chord)

- Tension (draft)

  337,214 lb (1,500 kN) at coupler stops

  224,809 lb (1,000 kN) at secondary coupler stops

  337,214 lb (1,500 kN) at pulling face of coupler

- Vertical loading

  An evenly distributed vertical load on the floor equal to

  1.3 x [combined weight of (body and underframe)

  + (2 x number of seats x 176 lb or 80 kg)].

  Simultaneously, a longitudinal compressive force of 449,618 lb (2000 kN) at the coupler centerline.

- Interior fittings

  Baggage racks

  225 lb (1,000 N) vertically and evenly distributed per meter of length

  191 lb (850 N) vertically at any point along the front edge

  Coat hooks

  67 lb (300 N) vertically

  56 lb (250 N) horizontally

No special requirements are set forth for the securement of baggage in the overhead racks of coaches because European practice usually provides storage space for passenger carry-on luggage in semiclosed compartments at the ends of the cars as well as in the floor space between seats when they are placed back-to-back.

There appears to be universal opposition to installation of passenger-restraining devices such as seat belts in high-speed trains.

# INFRASTRUCTURE

The topics discussed in this section are as follows: European infrastructure standards, specifications, and parameters; track structure; track geometry criteria; track buckling preventive measures; right-of-way safety and intrusion prevention (grade crossing and separation policy, fencing, and bridge intrusion detection); stations; and sound barriers.

## Infrastructure Standards, Specifications, and Parameters

The design criteria of European high-speed rail systems are still guided by several UIC and ORE codes that apply to conventional lines; selection of rail section is one example. However, each national network has developed and applied a considerable number of its own criteria for rolling stock, track, and signal and electrification systems. Consequently and contrary to the popular viewpoint, totally unencumbered interchange of trains across national borders remains constrained.

Track centers for new high-speed lines vary from 14 ft 9 in. (4.5 m) on dedicated TGV lines to 15 ft 5 in. (4.7 m) on the DB mixed-use ICE lines. The wider center considers both the increased aerodynamic interaction of passing high-speed movements and excessive dimension loads.

Track design parameters in use on TGV lines are shown in Appendix B. New ICE lines differ somewhat from TGV as they are being constructed using standard and minimal horizontal curve radii of 15 min or 23,000 ft (7,000 m) and 20 min or 16,750 ft (5,100 m) respectively.

The curve-spiral transitions for TGV lines have been established on the basis of acceptable speed/comfort force limits. Although maximum superelevation is 7-3/32 in. (18 cm), unbalance is usually limited to 3-15/16 in. (10 cm) with exceptions to 5 1/8 in. (13 cm).

Bridges on the TGV and ICE lines are basically of prestressed concrete box girder construction with ballasted decks. Special attention during construction is given to the subgrade/structure interfaces in regard to backwall earthwork consolidation and transition slabs. Bridges are designed for stresses in accordance with speed/impact research and test results.

## Track Structure

Generally, BR and DB use monoblock concrete ties with elastomer pads and elastic fasteners, while SNCF uses U41 duo-block ties with bolted elastic fasteners. All have opted for standard UIC 60 kg/m rail (122 lb/yd section equivalent). Concrete ties provide a more stable structure than wood ties do and are projected to have a 40- to 50-yr life with rail at an approximate 750 mgt life span.

On TGV lines granite ballast is placed to a minimum depth of 12 in. (30 cm) under ties, while subballast depth varies from a minimum of 6 in. (15 cm) to a maximum of 20 in. (50.8 cm) or more, depending on condition of the subgrade.

Turnouts in use on TGV routes permit 100-mph (160-km/hr) and 137-mph (220-km/hr) facing-point diverging movements. Movable point frogs permit the maximum carbody lateral acceleration to be kept within 0.15 g for ride comfort through the turnouts.

On new lines it appears that DB will partially convert to ballastless slab track as soon as possible. SNCF states that they have no plans for such applications because of the initial high cost with no perceived immediate advantage in safety or comfort over their standard ballasted concrete tie track.

## Track Geometry Criteria

Appendix C presents (for information only) TGV track geometry data as applicable to this report. The elements of measurement, baselines, and allowable limit criteria have been developed and applied by SNCF from utilization of their Mauzin track geometry car equipment. In North America, Amtrak and other railroads' geometry cars' input and output modes are customized to their own parameters (as are SNCF's) but are generally responsive and adaptive to the FRA track standard geometry categories and track class rejection limits. The TGV parameters should be interpreted and analyzed accordingly. It is to be noted that the 100-ft (31-m) baseline measurements are computed values.

These criteria are established on the basis of passenger comfort requirements and the practical limitations of maintenance equipment and do not constitute safety limits, but SNCF's policy calls for speed reductions if these limits are breached.

Track geometry car runs are scheduled over each track segment at least once in every three months. Individual checks on lateral accelerations are conducted with portable units every week. Regular walking inspections by a supervisor are also performed. Rail flaw detection car schedules are based on tonnage over the line but are generally programmed twice yearly.

## Track Buckling Preventive Measures

Although the European track systems are generally not subjected to the extreme temperature swings that occur in the United States, the operators are acutely aware of this mode of potential alignment failure. They generally apply these preventive measures and procedures:

(1) Rail is destressed if installed above or below the acceptable temperature range (SNCF 68° to 90° F [20° - 32° C]).

(2) Walking inspections by supervisors are conducted in the spring to identify ballast deficiencies and line deviations.

(3) Regular track geometry car inspections are conducted, including lateral loading and acceleration measurements.

(4) Regularly scheduled in-revenue-service cab and rear end inspections are conducted with portable accelerometers.

(5) Trackwork is restrictioned in hot weather, and surfacing is done only at night.

(6) Track stabilization is a required procedure as a part of surfacing operations.

(7) A test train is operated over all new trackwork before the start of revenue operations.

## Right-of-Way Safety and Intrusion Prevention

This subsection addresses issues related to grade crossing and grade separation policy, fencing of rights-of-way, and intrusion detection devices installed on overhead bridges.

### Grade Crossing and Grade Separation Policy

It is generally agreed that high-speed trains should not operate over highway grade crossings. However, the cost of eliminating grade crossings from existing mixed traffic lines is so great that high-speed service would never be initiated on them if removal were a precondition. Therefore, most European authorities have accepted higher-speed service without the elimination of existing grade crossings on the premise that they will be removed as soon as funding permits. According to UIC Code 762 R, highway grade crossings should not be tolerated where rail speeds exceed 125 mph (200 km/hr), and gates with flashing lights and bells should be used where speeds exceed 87 mph (140 km/hr). Crossings on some lines upgraded to 120 mph (193 km/hr) utilize watchmen in addition to gates and lights. In accordance with this UIC Code, the new lines in both France and Germany designed to operate at 155 and 186 mph (250 and 300 km/hr) are being constructed with grade-separated crossings.

At protected crossings flashing lights, gates, and bells are activated 20 to 45 sec prior to a train's arrival in a manner similar to state regulations throughout the United States. Most experts think that providing additional warning time would simply invite impatient motorists to drive around the gates. Most highway warning devices of grade crossings are not connected to adjacent highway traffic signals although a few are so arranged. "Half-gates" are normally used to permit vehicles occupying a crossing to clear it when the gates begin to lower. Some authorities have installed left-hand far-side half-gates with time delay to allow vehicles to clear the crossing. Others have installed island-type barriers between traffic lanes to preclude motorists from driving around gates that are down.

Accident records illustrate the risks involved with existing grade crossings. For example, in late 1988, a TGV train operating in slower-speed territory (60 mph [97 km/hr]) collided with a transformer-hauling trailer that was traveling in violation of its route permit. In this accident, the engineman was the only fatality. The TGV trainsets are configured so that the first and last cars are power cars that carry no passengers.

### Fencing

Six-foot-high (1.83-m) fences are installed on new TGV lines to prevent right-of-way intrusions. Designated rail workers are given citation authority to deal with trespassers.

### Bridge Intrusion Detection

Overhead bridges are equipped with intrusion detection devices to provide warning in the event of a vehicle breaking through a bridge railing and falling onto the track area.

## Stations

On TGV lines, stations have a four-track configuration with through trains operating on the two center tracks. There are no passenger control facilities on the platforms, a condition that has aggravated crowd control problems when loading trains during heavily traveled peak-season operations.

Operation of high-speed trains past high-level platforms in excess of 125 mph (200 km/hr) without stopping or slowing down is common practice. Flashing lights or bells are not used to warn people on the platform of the approaching train.

Sound Barriers

Treatment of the vehicles for acoustic attenuation provides acceptable noise levels for passengers. External noise becomes a far greater problem for wayside locations because of increased wheel/rail noise at higher speeds. Unballasted (slab) track exacerbates this problem, so sound barriers may be needed in urban areas. The Japanese Shinkansen lines have installed wayside barriers along a large portion of the route mileage; however, to date, minimal installations have been required on the European systems.

## SIGNAL SYSTEMS

The basic philosophy of the signal systems for high-speed rail service in Europe is quite similar to that being proposed for the United States. All railway administrations agree that operating trains at speeds in excess of 125 mph (200 km/hr) requires the use of continuous cab signals coupled to an automatic train control system to enforce the speed limits being imposed by the signal system. This practice has been incorporated into UIC Code 734 R. The manner in which this is done varies from one system to another and may also vary within a system under different circumstances. (In the United States, federal regulations require cab signals on all routes operated in excess of 79 mph [127 km/hr]).

In general the Europeans have built new high-speed railroads to supplement existing lines where additional service (or traffic) or higher speeds would have exceeded the capacity for safe and efficient operation of an existing route, or where high speeds simply could not be attained on an existing route due to civil engineering constraints. The result has been high-speed trains using both existing mixed service (freight, commuter, and conventional passenger) lines and new dedicated high-speed tracks with their different respective signal systems. The European desire to operate at higher speeds on existing lines without changing the basic signal spacing (driven by UIC Code 544-1) has resulted in innovative braking systems that stop trains more quickly and in shorter distances than conventional systems.

It must be remembered that the primary function of a signal system is to provide a warning at a distance sufficiently in advance of a danger point to permit a train to stop safely. Because stopping distance varies as the square of the speed, high-speed trains would require very long stopping distances if only conventional braking systems were used. The greatly increased stopping distance would require signal spacing to be increased, thus significantly reducing the capacity of existing lines unless major changes were made to the basic signal system--an unacceptable solution for the European railways. Therefore, they have made significant changes and improvements to braking systems that have not been accepted in the United States, where the choice has been to move signals to accommodate the longer stopping distances in spite of resulting loss of line capacity.

Both European and American signal practices operate on the premise that the braking system must be capable of stopping the train if its propulsion system or electric traction system (in electrified territory) should fail. In the United States, dynamic brakes are specifically *not* considered in calculating braking distances and signal spacing because dynamic brakes require power from the locomotive or electric traction system to function. The Europeans have developed dynamic brake systems that use battery power or residual magnetism. Because these systems can operate without power from the locomotive or the overhead electric traction system, they *can* be used in calculating stopping distances and, thus, signal spacing. Some foreign railways also use electromagnetic track brakes that slide on top of the rail to provide additional retarding force. This track brake's effects are also used in stop-distance calculations when its operation is independent of the locomotive or electric traction system.

After stopping distances have been determined for a particular type of vehicle's braking system on a specific line profile, the Europeans add a 10 percent factor of safety to allow for poor adhesion, improperly adjusted brakes, low air pressure, and other variables. Typical American practice has been to add from 15 to 25 percent as a safety factor. Most European systems are permitted to use emergency braking rates to determine signal spacing, a practice strictly prohibited by U. S. federal regulations for decades.

The automatic train control systems in Europe normally allow from 4 to 8 sec (similar to U.S. practice) for the train operator to react and apply the brakes before the system initiates a penalty brake application. The distance traveled during this reaction time must also be added to the stopping distance to determine the proper signal spacing (an additional 1,760 ft [536 m] at 150 mph [242 km/hr]).

Because UIC Code 544-1 (obligatory) requires certain braking characteristics of trains operating up to 100 mph (160 km/hr) on conventional lines, signals are spaced to accommodate these characteristics. To operate above 100 mph (160-km/hr) on conventional lines signaled for 100-mph (160-km/hr) operation, the cab-signal code change point must be moved in advance of the wayside signal.

In summary, the stopping distances for European high-speed trains that are used to determine signal spacing are appreciably shorter than that of typical American practice because of the additional braking capacity of the high-speed trains (dynamic and track brakes) and a lower factor of safety. In addition, the consideration of emergency braking rates instead of full service braking rates allows further reduction of the stopping distance.

The UIC has had no reason to develop regulatory codes for an international signal system because, with few exceptions, operators and locomotives are changed at the international borders. Each nation's railway has developed its own signal system specifications, which vary significantly among the countries. (UIC Code 512 does address the electrical resistance characteristics of the wheel/axle set, so that signal track circuits can be properly shunted.) The recently issued UIC Code 734 R summarizes the German, Italian, and French systems and provides a basic outline for a suggested uniform European high-speed signaling system. The Union Switch and Signal Company presented a short paper at the 1984 AAR Communications and Signal Division Annual Meeting in Boston that discussed some of the basic differences between European and American signaling philosophies.

Each railroad administration has its own criteria and techniques for the design of its signal system. The number and type of wayside signal aspects, cab-signal aspects, use or non-use of wayside signals, track circuit power (if any), and other characteristics vary from one system to another. The number of cab-signal aspects is also an open issue and ranges from a minimum of 6 up to about 20. Where an absolute stop aspect is provided by the cab signal, the train operator may be permitted to proceed at 20 mph (30 km/hr) after coming to a stop.

Consensus is that cab-signal equipped tracks do not need wayside signals for high-speed trains. Wayside signals are frequently kept on existing lines with mixed traffic to handle trains not equipped with cab signals. Newly constructed dedicated high-speed lines have cab signals only and are not provided with wayside signals.

A stationary wayside marker is sometimes used to denote the beginning and end of blocks instead of a signal. Most European countries do not require that conventional lines be equipped with cab signals. However, trains operating at authorized speeds over 125 mph (200 km/hr) must be controlled by cab signals. European railroad administrations appear willing to accept the possibility of a low-speed train's failure to comply with signal indications in very dense, mixed traffic. In the United States, FRA has repeatedly taken the position that all trains operating in cab-signal territory should be equipped with cab signals. This is also the requirement for the dedicated TGV lines.

Cab-signal systems in the United States do not normally include aspects for civil speed restrictions (curves, bridges, slow orders, etc.) among the indications displayed. The Europeans are committed to enforcing civil speed restrictions within the cab-signal system. Most wayside signal cases are provided with a means to adjust the maximum authorized speed at that point that is to be displayed by the cab-signal system and enforced by the automatic train control system. Speed restrictions associated with curves or bridges are permanently wired into the signal system logic.

To provide for maintenance activities and unforeseen contingencies, virtually all lines handling high-speed trains are equipped with complete bidirectional signals and high-speed crossovers between tracks. Europeans define a high-speed crossover as one through which a train can diverge at speeds in excess of 100 mph (160 km/hr). The highest speed American crossovers in common use allow only 45 mph (73 km/hr). Bidirectional signaling includes the full complement of associated cab signals and wayside signals. Hot box and dragging equipment detectors monitor trains in both directions and display stop signals when tripped. The new generations of high-speed trains are provided with on-board monitors to detect hot journals as they develop instead of relying on wayside detectors.

## COMMUNICATIONS

Voice communication between a high-speed train and a control center or a portable wayside unit is not normally considered to be a critical safety system, but it can become critical under many circumstances. Specific radio frequencies are assigned to particular routes in most of Europe, rather than to the regions or companies as is U.S. practice. Each train is equipped with a multiple frequency high-powered radio in the cab that must be switched manually to the appropriate frequency by the operator. The conductor and other crew members are usually provided with small portable radios or access to the main radio via the trainline intercom system.

The radios are designed so that everyone within range of the transmitter hears both sides of a conversation. This means that a warning message on the operating frequency is heard by everyone as the coverage is continuous over the line with no dead spots permitted. Tunnels or other problem areas are provided with repeaters or auxiliary antennas to ensure reception. These repeaters and auxiliary antennas are not currently able to handle local police, fire, or emergency medical frequencies. However, it was felt that this issue should be seriously reviewed with local authorities who are equally dependent on radio communications for emergencies. Although railroad maintenance forces have been provided with separate radio frequencies, each field supervisor's radio is also equipped to function on the train operation frequencies. This permits field supervisors to communicate directly with nearby trains without the time-consuming need to relay important information through the train dispatcher.

Some railroads also provide a hard-wired wayside telephone system to back up the radio or for use for lower priority communications that would otherwise tie up the radio. It was also noted that high-speed trains are being equipped with commercial cellular telephones, which can be used for emergency communication by railroad personnel.

Some of the new systems will eventually have high-speed radio data links between the control center and the trains to monitor critical functions. Most railroads do not envision radio links because of the shortage of available frequencies. The use of satellites as part of the communications system is not yet being advocated in Europe due to the relatively low position on the horizon for synchronous communications satellites, and the resultant interference from buildings and hilly terrain.

UIC Code 751 addresses a number of the technical parameters associated with railroad radio systems in a manner similar to the Federal Communications Commission regulations in the United States.

## ELECTRIC TRACTION SYSTEMS

Most main lines in Europe are electrified and have been operated electrically for decades. The Europeans are very confident about their electric traction systems and foresee no safety problems associated with high-speed passenger operation with 15- or 25-kv catenary. The circuit breakers and fault detection devices have been proven over the years and function reliably as required. System design parameters are nearly the same as those contained in chapter 33 of the AREA *Manual for Railway Engineering*. The only open issues associated with electric traction systems for high-speed operation have to do with catenary tensions and pantograph spacing for good power collection. Neither of these issues directly affects safety of operation.

The geometry of the overhead catenary system is specified. It is the vehicle designer's responsibility to ensure that the pantograph maintains its proper positional relationship to the contact wire over the entire range of allowable track geometry variations and vehicle dynamics. As part of the acceptance testing of the prototype vehicles, lateral and vertical displacement of the pantograph and motion of the contact wire are observed and measured to ensure minimum loss of contact between pantograph and contact wire. From European railroad high-speed test observations, the minimum spacing between multiple pantographs has been established at 656 ft (200 m) for constant tension catenary.

For a number of reasons, many not related to the electric traction system, most railroads choose to suspend operations when winds reach hurricane force at about 75 mph (120 km/hr).

To minimize damage, modern pantographs are designed to break away from the vehicle if they become entangled in the catenary.

All vehicles using the new Channel Tunnel will be required to use nonflammable coolants in their transformers and in other electrical devices such as thyristor and diode modules. Existing European codes now permit the use of mineral oil, which is a flammable coolant.

## CONCLUSION

The TRB Subcommittee on Safety Parameters and Criteria has prepared this report as a step in communicating information on the design and safe operation of high-speed rail passenger systems. This subcommittee will remain active and alert to the safety aspects of new equipment and infrastructure design and of new developments in operations and maintenance procedures.

## ACKNOWLEDGMENTS

The TRB Committee on Guided Intercity Passenger Transportation and the Subcommittee on Safety Parameters and Criteria gratefully acknowledge the assistance of Mr. Jean Bouley, Secretary General of the International Union of Railways, in arranging for three subcommittee members to meet their European counterparts to gather the information presented in this report. Dr. Alan H. Wickens and Dr. I. Korpanec, Chairman and Director, respectively, of the Office for Research and Experiments, are gratefully acknowledged for their hospitality in hosting the meeting at ORE headquarters in Utrecht, Netherlands, on August 31 and September 1, 1988, and for their valuable contributions to the conduct of the discussions. The representatives of the French National Railways and the German Federal Railway, along with Dr. Wickens representing British Rail, are acknowledged for their generous contribution of time and for their willingness to share their knowledge and experience gained in operating high-speed rail services.

# APPENDIX A

## LIST OF PARTICIPANTS
## MEETING ON HIGH-SPEED RAIL SAFETY FACTORS
## UTRECHT, NETHERLANDS
## AUGUST 31 AND SEPTEMBER 1, 1988

European Participants:

| | |
|---|---|
| Jean Bouley | Secretary General, International Union of Railways (UIC) |
| Dr. A. H. Wickens | Chairman, Office for Research and Experiments, UIC, and Director, Engineering Development and Research, British Rail |
| Dr. I. Korpanec | Director, Office for Research and Experiments, UIC |
| Peter Molle | Head, Rolling Stock Department, German Federal Railway, and Chairman, UIC Committee on Traction and Rolling Stock |
| Dr. E. H. Maak | Head, Civil Engineering Department, German Federal Railway |
| Dieter Metz | Head, Operating Department, German Federal Railway |
| Philippe Roumeguere | Head, Way and Works Department, French National Railways |
| Gerard Coget | Head, Rolling Stock Construction, French National Railways |

TRB Subcommittee Members:

| | |
|---|---|
| Richard P. Howell | Vice President, DeLeuw Cather & Co.; Subcommittee Chairman |
| Richard U. Cogswell | Staff Engineer, Federal Railroad Administration |
| Joseph J. Schmidt | Consultant to the Association of American Railroads |

TRB Staff:

| | |
|---|---|
| Elaine King | Rail Transport Specialist |

APPENDIX B

## TRACK DEDICATED TO TGV OPERATIONS

Specifications for Speeds up to 186 mph (300 km/h)

| | | | |
|---|---|---|---|
| 1. Distance between track centers | : | 14'9" | 4.50m |
| 2. Gauge | standard: | 4'8 1/2" | 1.435m |
| | min. : | 4'8" | 1.422m |
| | max. : | 4'8 3/4" | 1.442m |
| 3. Width of subgrade | double track : | 44'7" | 13.60m |
| | single track : | 26'3" | 8.00m |
| 4. Nominal height of contact wire | : | 16'8" | 5.08m |
| 5. Minimum depth of ballast under ties | : | 1' | 0.30m |
| 6. Concrete ties density | : | 2,692/mile | 1,666/kilometer |
| and distance between ties | : | 23 1/2" | 0.60m |
| 7. Maximum curve superelevation | : | 7 3/32" | 0.180m |
| 8. Permissible unbalanced superelevation | | | |
| | standard: | 3 15/16" | 0.100m |
| | (exceptional): | 5 1/8" | 0.130m |
| | up to 100 mph : | 6 1/4" | 0.160m |
| 9. Maximum gradient | : | 5% | 5% |
| 10. Minimum horizontal curve radius | | | |
| 186 mph (300 km/h) | standard: | 20,000' or 17 min | 6,000m |
| | (exceptional): | 13,000' or 26 min | 4,000m |
| 168 mph (270 km/h) | : | 10,750' or 32 min | 3,200m |
| 137 mph (220 km/h) | : | 6,600' or 52 min | 2,000m |

Note: An exceptional value is permissible only when occurring between two standard values, i.e., a curve of exceptional value may not be immediately followed by another exceptional value.

APPENDIX B
(continued)

11. Vertical curve radius

| Limit | Vertical acceleration | 186 mph(300 km/h) | | 160 mph(260 km/h) | |
|---|---|---|---|---|---|
| | | Radius | Curvature | Radius | Curvature |
| standard (crest & trough) | 1 mph/sec (0.45 m/s2) | 49,900' (15,500m) | 6.9 min | 37,300' (11,600m) | 9.2 min |
| exceptional for crest | 1.13 mph/sec (0.50 m/s2) | 44,900' (13,900m) | 7.7 min | 33,600' (10,500m) | 10.2 min |
| exceptional for trough | 1.35 mph/sec (0.60 m/s2) | 37,400' (11,600m) | 9.2 min | 32,800' (10,000m) | 10.5 min |

12. Maximum variation of superelevation on transition curves

Standard limit: $\frac{41.6}{V/(\text{mph})}$ in inch per 31 ft $\qquad \frac{180}{V/(\text{km/h})}$ in mm/m

Exceptional limit: $\frac{49.8}{V/(\text{mph})}$ in inch per 31 ft $\qquad \frac{216}{V/(\text{km/h})}$ in mm/m

13. Variation of unbalanced superelevation on transition curves

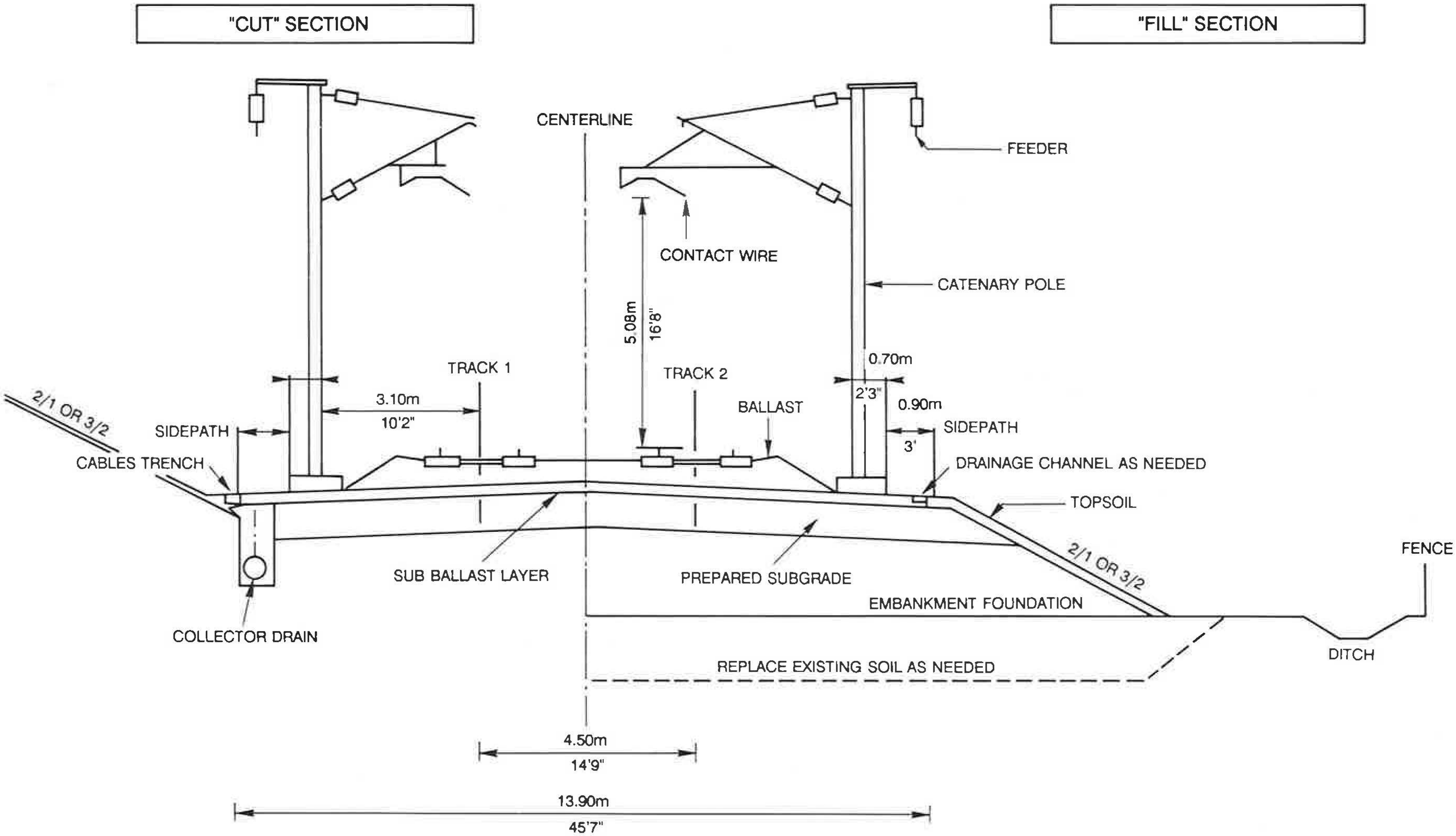
160/186 mph (260/300 km/h)

standard: not to exceed 1 3/16" in the distance covered by the train in one second — 30 mm/s

exceptional: not to exceed 1 31/32" in the distance covered by the train in one second — 50 mm/s

14. Spiral length for minimal curve radius
186 mph (300 km/h) : 1,000 ft 300 m

15. Separation between successive transitions
: 500 ft 150 m




TGV LINE TYPICAL CROSS-SECTIONS

APPENDIX C

TGV Track Geometry: Allowable limits of defects for speeds above 137 mph (220 km/h)

| | Measuring Baseline | Recurrent Defect Limits | | Isolated Defect Limits | |
|---|---|---|---|---|---|
| | | Peak to Peak | Unilateral | Peak to Peak | Unilateral |
| Longitudinal Level | 31 ft (10m)<br>100 ft (31m) | 3/16" (5mm)<br>5/16" (8mm) | ± 3/32" (2.5mm)<br>5/16" (8mm) | 3/8" (10mm)<br>3/8" (10mm) | ± 3/16" (5mm)<br>± 3/8" (10mm) |
| Alinement (Alignment) | 31 ft (10m)<br>100 ft (31m) | 1/4" (7mm)<br>5/16" (8mm) | ± 1/3" (3.5mm)<br>5/16" (8mm) | 1/2" (12mm)<br>1/2" (12mm) | ± 1/4" (6mm)<br>± 1/2" (12mm) |
| Cross Level | 31 ft (10m) | 5/32" (4mm) | ± 3/32" (2.5mm) | | |
| Twist (Warp) | 10 ft (3m) | | ± 3/16" (4.5mm/3m) | | |
| Gauge | | 3/32" (2mm) | | 3/16" (4mm) | |

These defects are generally measured from graphs printed out by the track geometry recording car (Mauzin car). Whether recurrent defects or isolated defects, the allowable limits are measured either by the peak-to-peak value, or the "unilateral" (peak-to-the-average) value.

Note: Refer to text on page 19.