14. APTA PR-M-S-014-06
Standard for Wheel Load Equalization of Passenger Railroad Rolling Stock

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Abstract: This standard contains minimum requirements for wheel load equalization for non-articulated railroad passenger equipment of all types employing two axle trucks. The standard includes requirements for testing to verify compliance with the standard.

Key Words: equalization, wheel load equalization, wheel unloading, suspension

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Standard for Wheel Load Equalization of Passenger Railroad Rolling Stock

1. Overview

This standard establishes static wheel load equalization requirements to provide passenger equipment with wheel unloading characteristics necessary to reduce the risk of low-speed wheel climb derailments.

Several factors can contribute to low-speed derailments, including but not limited to:

- Wheel Flange Angle
- Coefficient of Friction
- Wheel Load Equalization
- Truck Rotational Resistance
- Track Conditions (excessive warp, tight curvatures, gage face wear, etc)
- Vehicle Dynamics
- Operating Conditions

> **Caution:** Experience indicates that low-speed derailments cannot be completely eliminated through equipment design alone. In addition to requiring specific vehicle characteristics, railroads must take a systems approach to minimizing the risk of low-speed derailment, which may require managing friction (providing rail lubrication) in tight curves, maintaining limits on rail gage face wear, and maintaining suitable levels of track cross level and other track parameters.

1.1 Scope

This standard shall apply to railroad passenger equipment of all types used in regular passenger service, originally contracted for after one year after authorized date. This includes locomotive-hauled cab and trailer cars, MU cars, and non-passenger-carrying cars and locomotives that are intended for use in passenger service on the general railroad system of the United States.

1.2 Purpose

This standard provides minimum requirements for wheel load equalization to reduce the risk of low-speed, wheel climb derailments.

2. References

This standard, where applicable, shall be used in conjunction with the following publications. If the following publications are superseded by an approved revision, the approved revision shall apply.

49 CFR 213 Code of Federal Regulations - Track Safety Standards

APTA PR-M-S-015-06 – Standard for Wheel Flange Angle for Passenger Railroad Rolling Stock

3. Definitions, abbreviations, and acronyms

3.1 Definitions

3.1.1 cross level: Cross level is the difference in height or elevation of one rail with respect to the other rail at any cross-section. On tangent track, the difference in height is measured with respect to a horizontal line. On superelevated track it is measured with respect to a line across the top of rails, with the height difference equal to superelevation.

3.1.2 difference in cross level (DCL): The difference in cross level between any two cross-sections along the track.

3.1.3 equalization (wheel load equalization): Describes the degree to which a vehicle maintains uniform vertical wheel loads over vertical track irregularities. As used in this Standard equalization refers to this measure under static conditions. For example, a measure of the equalization capability of a vehicle is the increase or decrease in vertical wheel loads when a single wheel is either above or below a uniform track plane established by the remaining wheels. The lower the change in vertical load associated with a track rise or dip, the better the equalization

3.1.4 hysteresis: mechanical energy loss that occurs under cyclical loading and unloading of suspension systems.

3.1.5 nominal wheel load (NWL): The vertical load on the rail from a wheel when measured on level tangent track, with all the wheels of the vehicle in the same plane, and the vehicle stationary.

3.1.6 short warp: Difference in cross level between any two points within ten feet along a section of track.

3.1.7 truck warp: Difference in height of one of the four wheels of a two axle truck with respect to the plane generated by the wheel-rail contact patches of the other three wheels.

3.1.8 truck wheelbase: The longitudinal distance between the two axle centers on a two axle truck.

3.1.9 warp: Synonym for "difference in cross level".

3.1.10 wheel load (WL): Vertical load of the wheel on the rail.

3.1.11 wheel unloading (WUL): Wheel load difference as a percentage of NWL; [WUL = {(NWL – WL)/NWL}x100].

3.2 Abbreviations and acronyms

APTA	American Public Transportation Association
DCL	Difference in Cross Level
NWL	Nominal Wheel Load
PRESS	Passenger Rail Equipment Safety Standards
WL	Wheel Load
WUL	Wheel Unloading

4. Wheel Load Equalization Requirements

This standard provides upper limits on wheel unloading associated with one wheel being lifted or dropped with respect to the other wheels due to an extreme difference in cross level (DCL). These limits vary with the class of equipment, as described in Sections 4.1 through 4.4 below.

Sections 4.1 and 4.2 present upper limits on wheel unloading for vehicles having a pair of two-axle trucks. Sections 4.3 and 4.4 identify two other vehicle types, equipment with one or more three axle trucks and equipment with shared axle trucks. Limits have not been established for these two equipment types. Limits will be set if the need arises in the future.

All passenger equipment shall be segregated into one of two suspension system classifications. Class G equipment (Section 4.1) is designed to operate over the general railroad system on track with DCL not exceeding 3 inches within any 62 feet of track. Current FRA regulations for track Class 1 permit a DCL of 3 inches within any 62 feet of track. Class R equipment (Section 4.2), while not equalizing as well as Class G, may be superior to Class G equipment with respect to other operating characteristics but requires the maintenance of track warp to a DCL not exceeding 2.25 inches in any 10 feet of track while still maintaining the Class G requirement of DCL not exceeding 3 inches within any 62 feet of track.

The choice of whether to qualify the vehicle as Class G or Class R will involve making a judgment as to the methodology to be used to meet the overall performance goals for the vehicle; Annex A.2 discusses some of the factors to be considered in making this judgment.

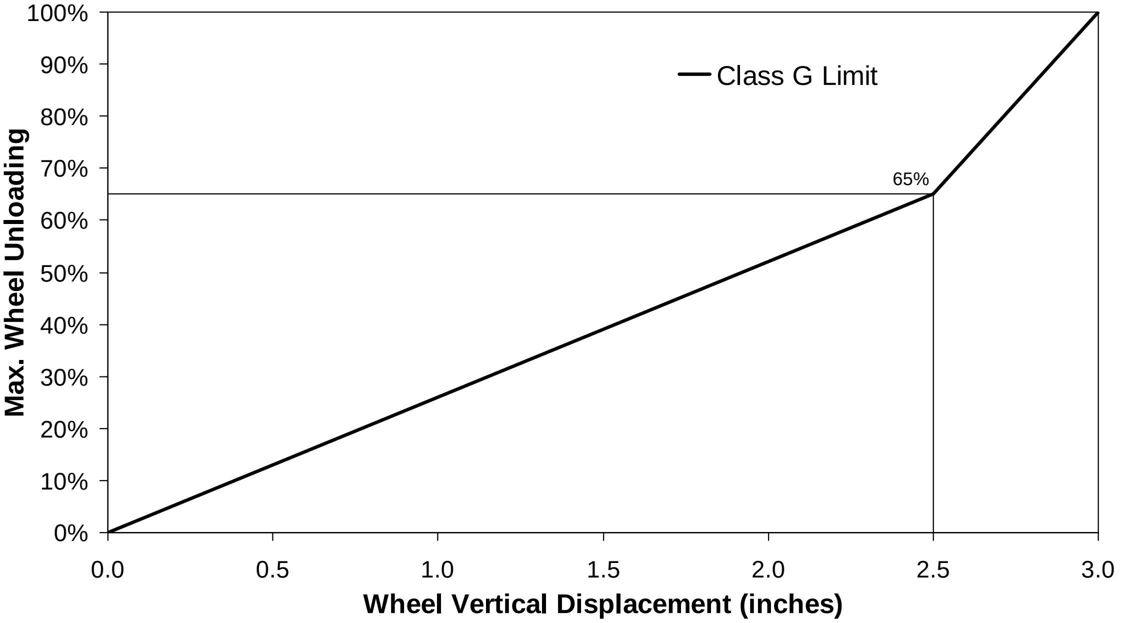
The equalization requirements specified in Sections 4.1 through 4.2 (whichever is appropriate) shall be confirmed by testing under specific conditions as described in Section 5.

4.1 Class G Passenger Equipment

The wheel unloading requirements in this section apply to passenger equipment with two-axle trucks that operates over track with a DCL upper limit of no more than 3 inches within any 62 feet.

For vehicles on level tangent track, vertical wheel loads shall be determined while displacing one wheel vertically (lift or drop) from its position on level track as depicted in Figure 1. At 2.5 inches of vertical wheel displacement, the wheel unloading shall not exceed 65% of the nominal wheel load. At all vertical wheel displacements up to and including 3.0 inches, no wheel tread shall lose contact with the running surface of the rail.

Figure 1 – Wheel Unloading Requirement - Class G



Testing and data reduction shall be done in accordance with Section 5. Hysteresis must be accounted for in testing.

In order to verify the wheel unloading requirements for Class G equipment an analysis which is summarized in Annex B[C1] was conducted to evaluate the relationship between the static wheel unloading requirement and a dynamic wheel equalization scenario.

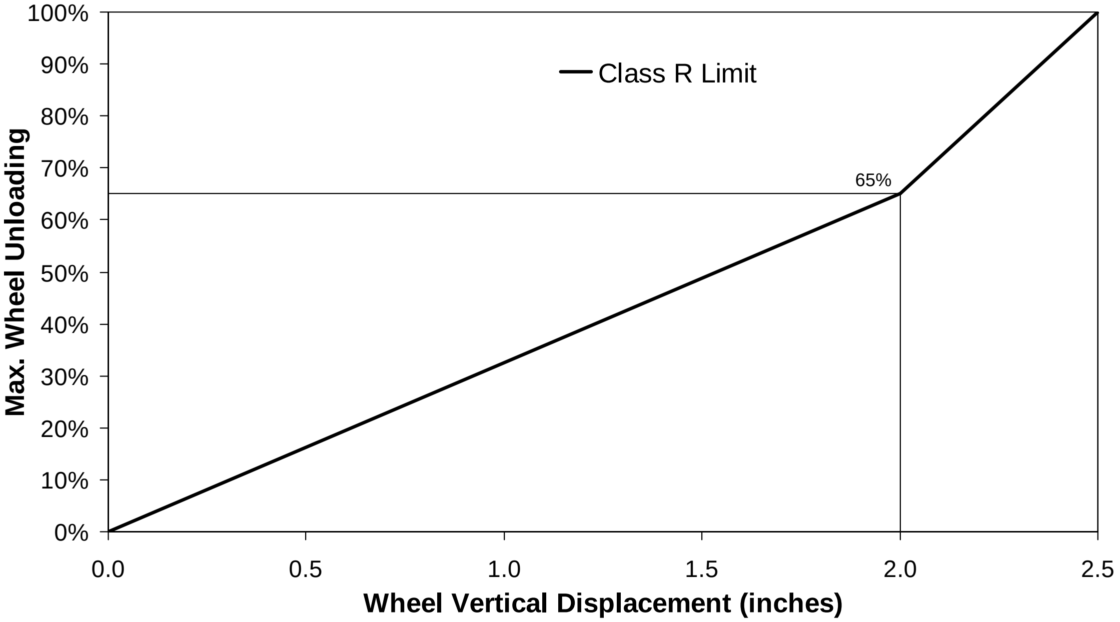
Equipment meeting Class G standards shall be stenciled on the inside of an equipment locker door (closest to the “B” end of the vehicle) “COMPLIES WITH APTA SS-M-014-06, CLASS G”.

4.2 Class R Passenger Equipment

The wheel unloading requirements in this section apply to passenger equipment with two-axle trucks that operates over track with a DCL upper limit of no more than 2.25 inches over any 10 feet of track and no more than 3 inches within any 62 feet of track.

For vehicles on level tangent track, vertical wheel loads shall be determined while displacing one wheel vertically (lift or drop) from its position on level track as depicted in Figure 2. At 2.0 inches of vertical wheel displacement, the wheel unloading shall not exceed 65% of the nominal wheel load. At all vertical wheel displacements up to and including 2.5 inches, no wheel tread shall lose contact with the running surface of the rail.

Figure 2 – Wheel Unloading Requirement - Class R



Testing and data reduction shall be done in accordance with Section 5. Hysteresis must be accounted for in testing.

In order to verify the wheel unloading requirements for Class R equipment an analysis which is summarized in Annex B [C1] was conducted to evaluate the relationship between the static wheel unloading requirement and a dynamic wheel equalization scenario.

> **Caution:** Equipment qualified under the provisions of this section and designated as Class R may at some time need to operate on track other than that for which it was acquired. This may occur during equipment delivery, special train movements, or temporary detours. It will also occur if the equipment is sold for use in another service at a later date.
>
> In any of these instances, notification of the Class R status of the equipment, together with information on where the equipment is to be operated, shall be submitted in writing to an appropriate official of the operating railroad, and confirmation of suitability for operation over the intended route(s) shall be obtained.

Equipment meeting Class R standards shall be stenciled on the inside of an equipment locker door (closest to the "B" end of the vehicle) "COMPLIES WITH APTA SS-M-014-06, CLASS R".

4.3 Passenger Equipment with One or More Three Axle Trucks

The wheel unloading requirements in this section apply to passenger equipment intended for unrestricted operation and equipped with one or both trucks having three axles. If the need develops, this requirement will be addressed in a future revision.

4.4 Passenger Equipment with Articulated, Shared Axle Trucks

The wheel unloading requirements in this section apply to passenger equipment intended for unrestricted operation and equipped with two independent axles having a wheel base greater than 15 feet. If the need develops, this requirement will be addressed in a future revision.

5. Static Test

5.1 Test Conditions

Conformance with the equalization requirements in Section 4 shall be verified by testing for the vehicle load and suspension conditions defined in Table 1.

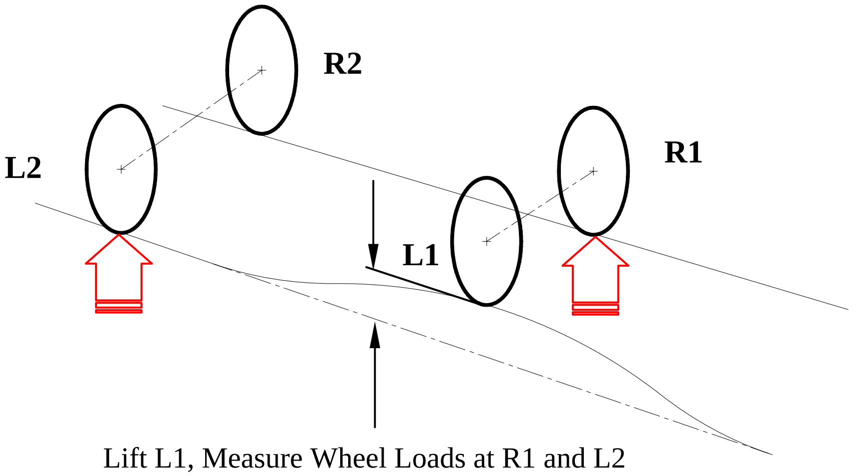
Table 1 – Static Equalization Test

Parameter	Condition
Vehicle Load	Empty (ready to run)
Suspension	Normal Operating [1]
Configuration	If the equipment contains trucks that are nominally the same with regard to equalization behavior, only the more lightly loaded truck need be tested; otherwise, each truck design shall be tested.
Wheels to be Tested [2]	Each wheel in turn on the test truck(s)
Wheel Load Measurement [2]	Wheel Lift - Wheel load shall be measured on the wheel opposite the wheel lifted and on the wheel on the same side of the truck as the wheel lifted as shown by arrows in Figure 3. Wheel Drop - Wheel load shall be measured on the wheel dropped and on the wheel diagonally opposite the wheel dropped.

[1] If air springs are used, they are to be inflated with leveling valves disconnected.
[2] All loads must be applied and measured at the wheel-rail interface.

The test shall be conducted in accordance with the procedure outlined in Section 5.2 and the analysis of the test data shall be performed in accordance with the method described in Section 5.3.

Figure 3 – Measurement of Wheel Loads – Wheel Lifted



Lift L1, Measure Wheel Loads at R1 and L2

5.2 Test Equipment and Procedure

This section outlines a test procedure which shall be used as a guide to conduct the static equalization test described in Section 5.1.

The following instrumentation and equipment can be used to conduct the static equalization test.

- Load measurement devices (measure load between wheel and rail)
- Lifting jacks of sufficient capacity
- Track gage bar with cross level readout
- Displacement measurement device (measure vertical displacement of wheel)

The test procedure shall require verification of the accuracy and ability of the load and displacement measurement devices to discriminate between compliant and non-compliant wheel unloading.

The test procedure outlined below should be used in conjunction with Figure 3 and Table 2. The procedure is an example which describes the steps to be taken when lifting wheel L1 and measuring wheel loads at R1 and L2 as depicted on Figure 3. Measured wheel loads are entered into Table 2 (for Class G).

5.2.1 Place test vehicle on straight, level track. Release brakes and back-off slack adjusters. Chock wheels on truck not under test.

5.2.2 Establish test conditions as per Section 5.1 and note the wheel lift requirements per Section 4, for the Class of equipment.

5.2.3 Measure and record the cross level adjacent to each axle of the vehicle using a suitable measurement device. All wheels must be within 1/16 inch of a ‘virtual’ level rail plane established by all wheels on the car.

5.2.4 Lift wheel R1 and place load measurement device between wheel and rail. Zero the load measurement device before lowering the wheel. Repeat at wheel L2. The entire wheel load shall be supported by the load measurement device. In this condition, all wheels must be within 1/16 inch of a ‘virtual’ level rail plane established by all wheels on the car.

5.2.5 Establish height of ‘virtual’ level rail plane at wheel L1 for use as baseline reference for determining vertical displacement of wheel during test.

5.2.6 Record ‘zero height’ static wheel loads at R1 and L2 (WL_{11}). Note: Need to create Table 2 for R1 and L2 wheel.

5.2.7 Lift wheel L1, by increments shown on Table 2. At each increment record wheel loads at R1 and L2 (WL_{12} to WL_{15}).

5.2.8 Lower wheel L1, by increments shown on Table 2, back to the ‘zero height’ condition. At each increment record wheel loads at R1 and L2 (WL_{16} to WL_{19}).

5.2.9 Repeat steps 5.2.6 to 5.2.8 (i.e. second trial). Note: During second trial wheel loads are designated (WL_{21} to WL_{29}).

5.2.10 This process shall be repeated for each wheel of the truck.

5.3 Data Reduction Technique

This section provides details for data reduction methods and practices to be used in the processing of static equalization test results, for Class G and Class R equipment. The method takes into account the hysteresis effect that could be present in suspension arrangements.

The process is illustrated for one wheel but this approach shall be applied for any other wheel tested and for any other test conditions.

For Class G equipment, Table 2 depicts the method to be applied for recording measured wheel loads and the calculation of wheel unloading. The following bullets describe data entry and calculations for determining wheel unloading at wheel R1 when raising wheel L1 as shown on Figure 3:

- Measure and record wheel loads at wheel R1 (WL_{11} to WL_{19}) as wheel L1 is lifted, in increments from ‘zero height’ up to 3 inches and then lowered back to level track. Repeat this process twice (WL_{21} to WL_{29}) (i.e. two trials).
- Determine the average wheel load (WL_2 to WL_5) based on wheel loads measured at Wheel R1, for both trials, at each incremental vertical displacement of Wheel L1.
- Determine the nominal wheel load (NWL) at Wheel R1 by averaging the wheel loads measured during the test when all wheels are on level track.
- Calculate the average wheel unloading at Wheel R1, at each vertical displacement, based on the average wheel load (WL_2 to WL_5) and the nominal wheel load (NWL). Table 4 is an example of the calculation for Class G equipment.

- Repeat this measurement and calculation process for wheel L2 as wheel L1 is lifted.
- Repeat this entire process for the wheels at each corner of the truck.
  Lift wheel L2, measure and calculate wheel unloading at wheels R2 and L1
  Lift wheel R2, measure and calculate wheel unloading at wheels R1 and L2
  Lift wheel R1, measure and calculate wheel unloading at wheels R2 and L1

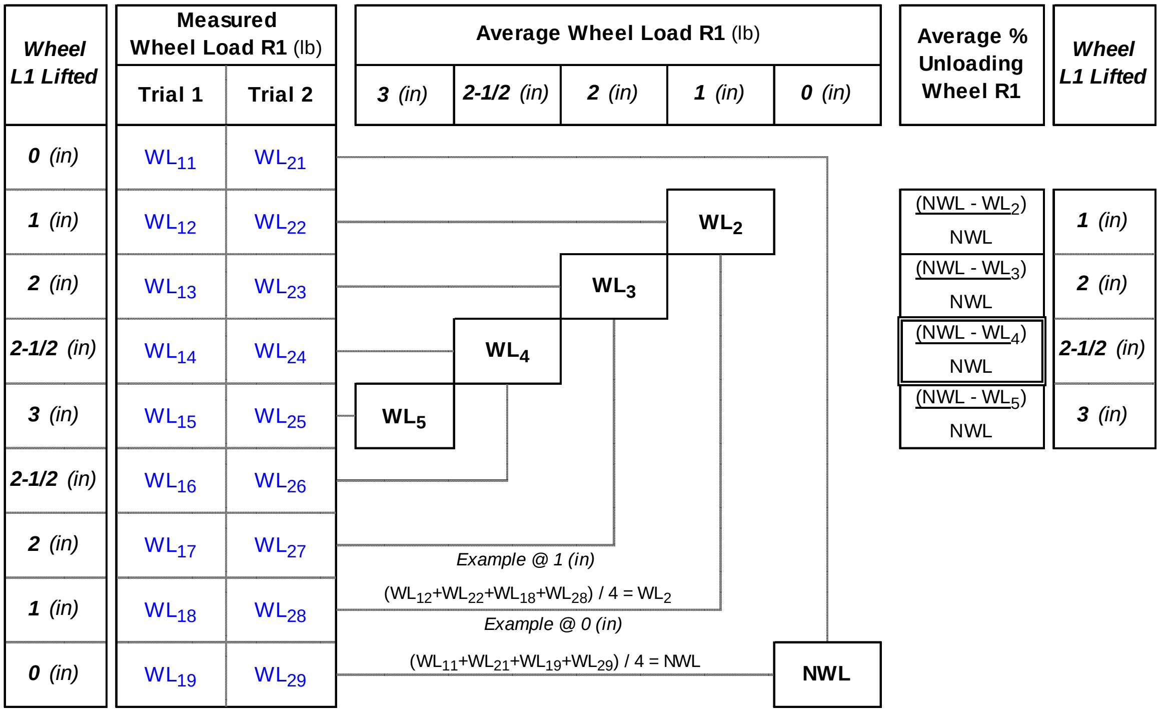
For Class G equipment at 2.5 inches of wheel lift – Wheel unloading per truck corner, based on the lifting of that corner's wheel, shall be computed by measuring the unloading of the remaining wheels, averaging the unloading per each wheel for two consecutive trials, and retaining the highest average. This unloading per truck corner shall not exceed 67%. The average of all four truck corner wheel unloadings shall not exceed 65%.

Table 3 depicts the method for Class R equipment.

For Class R equipment at 2.0 inches of wheel lift – Wheel unloading per truck corner, based on the lifting of that corner's wheel, shall be computed by measuring the unloading of the remaining wheels, averaging the unloading per each wheel for two consecutive trials, and retaining the highest average. This unloading per truck corner shall not exceed 67%. The average of all four truck corner wheel unloadings shall not exceed 65%.

Table 2 – Wheel Unloading Calculation Form – Class G

Wheel R1 Load Equalization (L1 Lifted)



Wheel L1 Lifted	**Measured Wheel Load R1** (lb) **Trial 1**	**Trial 2**
0 (in)	WL_{11}	WL_{21}
1 (in)	WL_{12}	WL_{22}
2 (in)	WL_{13}	WL_{23}
2-1/2 (in)	WL_{14}	WL_{24}
3 (in)	WL_{15}	WL_{25}
2-1/2 (in)	WL_{16}	WL_{26}
2 (in)	WL_{17}	WL_{27}
1 (in)	WL_{18}	WL_{28}
0 (in)	WL_{19}	WL_{29}

Average Wheel Load R1 (lb) *3 (in)*	*2-1/2 (in)*	*2 (in)*	*1 (in)*	*0 (in)*
WL_5	WL_4	WL_3	WL_2	NWL

Average % Unloading Wheel R1	*Wheel L1 Lifted*
$\frac{(NWL - WL_2)}{NWL}$	*1 (in)*
$\frac{(NWL - WL_3)}{NWL}$	*2 (in)*
$\boxed{\frac{(NWL - WL_4)}{NWL}}$	*2-1/2 (in)*
$\frac{(NWL - WL_5)}{NWL}$	*3 (in)*

Example @ 1 (in)

$(WL_{12}+WL_{22}+WL_{18}+WL_{28}) / 4 = WL_2$

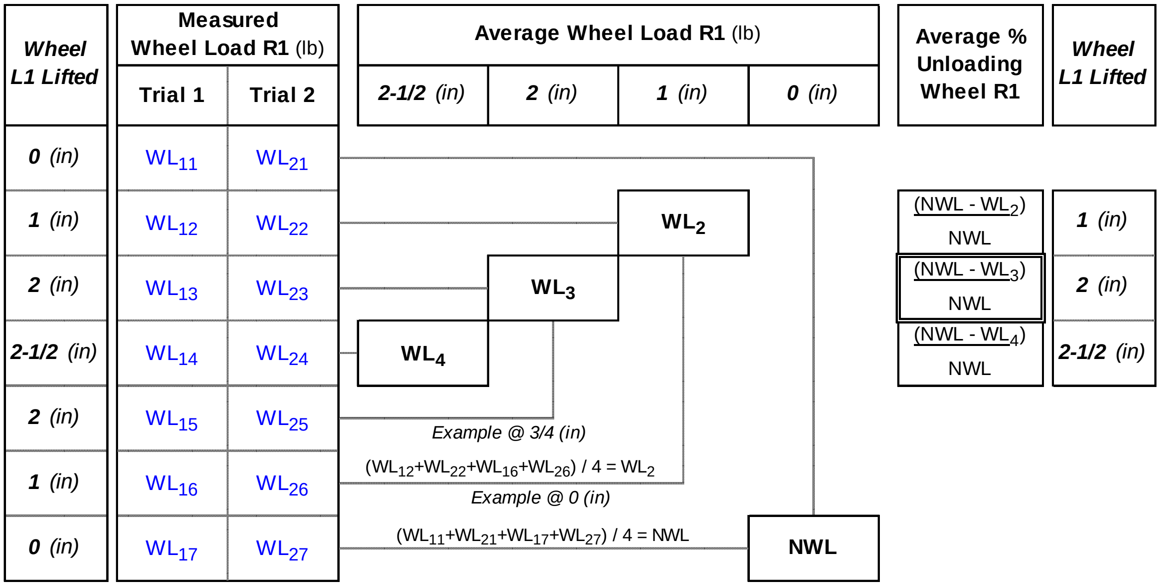
Example @ 0 (in)

$(WL_{11}+WL_{21}+WL_{19}+WL_{29}) / 4 = NWL$

NOTE: For Class G equipment at 2.5 inches of wheel lift – Wheel unloading per truck corner, based on the lifting of that corner's wheel, shall be computed by measuring the unloading of the remaining wheels, averaging the unloading per each wheel for two consecutive trials, and retaining the highest average. This unloading per truck corner shall not exceed 67%. The average of all four truck corner wheel unloadings shall not exceed 65%.

Table 3 – Wheel Unloading Calculation Form – Class R

Wheel R1 Load Equalization (L1 Lifted)



Wheel L1 Lifted	**Measured Wheel Load R1** (lb) **Trial 1**	**Trial 2**
0 (in)	WL_{11}	WL_{21}
1 (in)	WL_{12}	WL_{22}
2 (in)	WL_{13}	WL_{23}
2-1/2 (in)	WL_{14}	WL_{24}
2 (in)	WL_{15}	WL_{25}
1 (in)	WL_{16}	WL_{26}
0 (in)	WL_{17}	WL_{27}

Average Wheel Load R1 (lb) *2-1/2 (in)*	*2 (in)*	*1 (in)*	*0 (in)*
WL_4	WL_3	WL_2	NWL

Average % Unloading Wheel R1	*Wheel L1 Lifted*
$\frac{(NWL - WL_2)}{NWL}$	*1 (in)*
$\boxed{\frac{(NWL - WL_3)}{NWL}}$	*2 (in)*
$\frac{(NWL - WL_4)}{NWL}$	*2-1/2 (in)*

Example @ 3/4 (in)

$(WL_{12}+WL_{22}+WL_{16}+WL_{26}) / 4 = WL_2$

Example @ 0 (in)

$(WL_{11}+WL_{21}+WL_{17}+WL_{27}) / 4 = NWL$

NOTE: For Class R equipment at 2.0 inches of wheel lift – Wheel unloading per truck corner, based on the lifting of that corner's wheel, shall be computed by measuring the unloading of the remaining wheels, averaging the unloading per each wheel for two consecutive trials, and retaining the highest average. This unloading per truck corner shall not exceed 67%. The average of all four truck corner wheel unloadings shall not exceed 65%.

Table 4 - Wheel Unloading Calculation Example – Class G

Wheel R1 Load Equalization (L1 Lifted)

Wheel L1 Lifted	**Measured Wheel Load R1** (lb) **Trial 1**	 **Trial 2**
***0** (in)*	16,103	16,101
***1** (in)*	12,487	12,610
***2** (in)*	8,371	8,619
***2-1/2** (in)*	6,164	5,486
***3** (in)*	3,019	2,560
***2-1/2** (in)*	7,250	6,644
***2** (in)*	9,418	9,921
***1** (in)*	13,555	13,890
***0** (in)*	17,691	17,700

Average Wheel Load R1 (lb) ***3** (in)*	 ***2-1/2** (in)*	 ***2** (in)*	 ***1** (in)*	 ***0** (in)*
2,789.5	**6,386.0**	**9,082.3**	**13,135.5**	**16,898.8**

Example @ 1 (in)

(12,487+12,610+13,555+13,890) / 4 =13,135.5

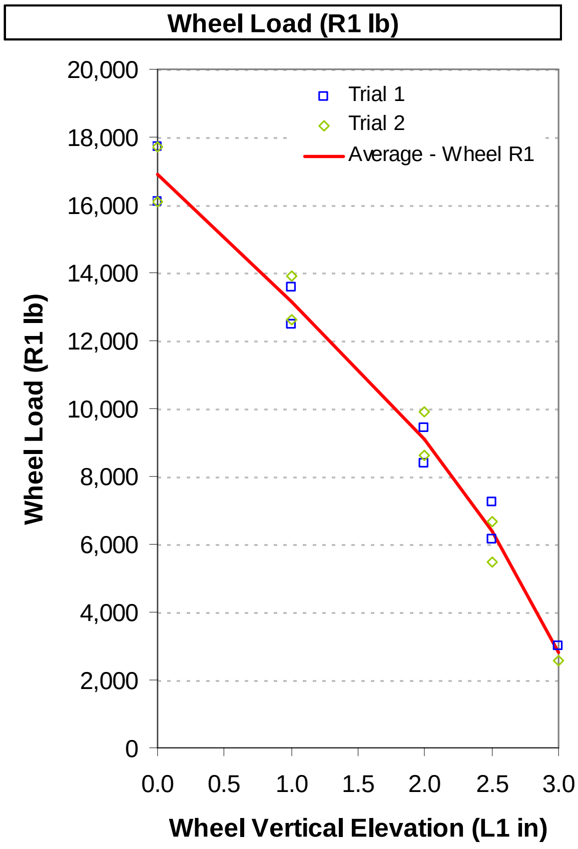
Example @ 0 (in)

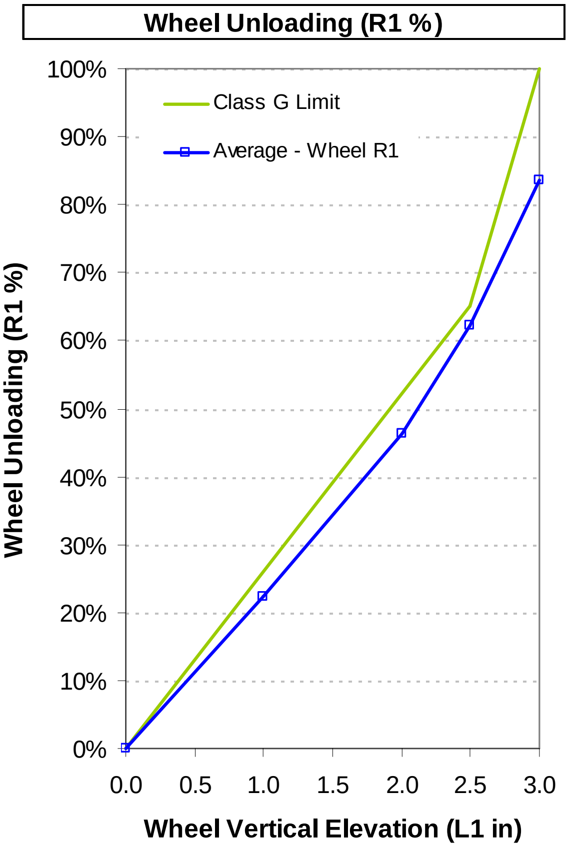
(16,103+16,101+17,691+17,700) / 4 = 16,898.8

Average % Unloading Wheel R1	***Wheel L1 Lifted***
22.3%	***1** (in)*
46.3%	***2** (in)*
62.2%	***2-1/2** (in)*
83.5%	***3** (in)*

Example @ 2-1/2 (in)

(16,898.8-6,386.0) / 16,898.8 = 62.2%





NOTE: For Class G equipment at 2.5 inches of wheel lift – Wheel unloading per truck corner, based on the lifting of that corner's wheel, shall be computed by measuring the unloading of the remaining wheels, averaging the unloading per each wheel for two consecutive trials, and retaining the highest average. This unloading per truck corner shall not exceed 67%. The average of all four truck corner wheel unloadings shall not exceed 65%.

Annex A (informative) Wheel Load Equalization

This annex provides background information discussing the role of wheel load equalization in contributing to derailment risk and it describes some of the tradeoffs that may arise in suspension system design for good equalization and for good performance in other areas. This annex is informative and does not contain requirements that must be evaluated for demonstrating compliance to this standard.

A.1 General

Adequate equalization, together with management of other factors, is important for safe operation of rail equipment, including minimizing the risk of low-speed derailment. Equalization is controlled to a large extent by the vehicle's suspension system. Suspension stiffness, geometry and other factors determine the equalization capability of the vehicle.

The track surface irregularity referred to as "difference in cross level" (DCL) is the parameter of concern as regards equalization. Wheel unloading caused by DCL will increase the risk of low-speed derailment, although other factors are likely to be present and be contributing factors in causing the derailment. Low-speed derailment can occur without wheel unloading provided other factors are present; wheel unloading simply reduces the margin of safety against derailment.

Inertial (dynamic) effects will influence wheel unloading. Typical parameters which control the magnitude of this component of wheel unloading are vehicle speed, rate of change of lift or drop with distance along the track, and the slope of this rate of change . These are predominant parameters which determine whether or not the vertical load change approaches static. The dynamic response of the vehicle to track irregularity is also a factor, which may influence whether or not the wheel vertical load change is approximated as static.

Low-speed derailment is typically classified as either wheel climb or rail rollover derailment. Factors that contribute to wheel climb derailment are vertical and lateral load at the interface between wheel and rail, angle of attack of the wheel with the rail against which the wheel is being driven by the lateral load, friction coefficient between wheel and rail, wheel flange geometry, and rail gage face geometry. Rail rollover derailment is sensitive to vertical and lateral wheel load and to rail anchorage to the ties or slab base. In either type of derailment, equalization can play a significant role through its influence on vertical wheel load.

The ratio of lateral force to vertical force acting at the wheel to rail contact patch of a wheel is a predominant parameter in establishing the risk of low speed derailment resulting from wheel climb. The critical value of this ratio is related to coefficient of friction between wheel and rail and to the maximum angle that the flange makes with the horizontal (the flange angle). The magnitudes of the vertical and lateral forces occurring in operation are functions of DCL, equalization, unbalance on curves, yaw moment between truck and carbody, and possibly other factors such as buff and draft loads at the couplers. When these factors result in a ratio of lateral to vertical force greater than the critical value, and the distance and/or time over which the ratio remains high is sufficient, wheel climb derailment can occur.

The vehicle’s suspension affects equalization by creating resistance of the wheelsets to developing roll angles independently of each other within a truck when subjected to short warp DCL. A second mechanism affecting wheelset load change is associated with roll of one truck that transmits a torsional moment between trucks through the carbody; this moment will result in a variation of vertical load fractions carried by the wheels on both trucks. These two components of equalization, referred to as truck warp and truck-to-truck equalization, may both play a significant role in equalization, or one may dominate[1].·Short wavelength DCL on the order of wheelset spacing within a truck, sometimes referred to as short warp, will typically result in truck warp being the dominant component affecting equalization for passenger car and locomotive suspension arrangements. The relative roles of the truck warp and truck-to-truck components may be reversed for freight car suspension arrangements, due to the relatively good truck warp equalization of the three-piece freight car truck and the relatively stiff vertical suspension of freight cars as compared to passenger cars and locomotives. Relatively long-wavelength DCL, on the order of truck spacing, will typically result in truck-to-truck equalization being the dominant equalization component. One potential source for long wavelength DCL is transition in superelevation when entering or exiting curves (spiral transition).

Maximum static wheel unloading will occur either when one wheel experiences a vertical displacement with the other wheels of the truck remaining in the plane established for level track or when two diagonally disposed wheels experience a vertical displacement with respect to the two wheels on the other diagonal. In the former case both the truck warp and truck-to-truck components of wheel unloading will be present, while in the latter case only the truck warp component will be present. However, the latter case can be expected to produce a truck warp component of wheel unloading equal to that in the former case at approximately one-half the height change of the two diagonally disposed wheels as was experienced by one wheel in the former case. Therefore, rate of change of profile of either rail with distance would be less severe in the latter case than in the former case in order to result in the same truck warp component of wheel unloading in both cases.

Rolling stock design with good equalization capability will lower derailment risk over the range of operating conditions encountered in most, if not all, operations. However, there are tradeoffs associated with design for good equalization. The user must determine whether the track and other conditions on its system will permit equalization capability to be outside the limits set by this standard while still retaining acceptably low low-speed derailment risk. Even with equalization meeting the limits specified in this standard, low-speed derailment risk will only be acceptably low if the other influencing factors are controlled. It is the users’ responsibility to manage all factors that contribute to low-speed derailment in order to operate with acceptably low risk.

Operating conditions in addition to those listed above that may increase derailment risk are:

1. cant excess on curves
2. spiral curve entry and exit

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[1] In the context of this document, tbe term refers to “out of plane” deformation rather than the parallelogram distortion which may occur in freight truck applications

3. buff and draft forces on vertical and horizontal curves
4. traction and braking forces and moments generated in right angle mechanical drives

A.2 Suspension System Design Tradeoffs

The vehicle suspension system, in addition to establishing wheel load equalization performance, has an influence on other vehicle characteristics that in turn affect overall performance. Suspension system design determines ride quality and wheel-rail interface dynamic loads. Suspension system design influences wayside noise and vibration, static steering on curves, high speed stability, dynamic envelope, roll stability and wheel load shifts due to cant deficiency. Suspension system design for controlling the performance measures delineated above may force limits on the level of wheel load equalization that can be achieved.

Truck maintenance and weight considerations may be in conflict with suspension design for controlling the performance measures mentioned above.

Therefore, in order to manage both low-speed derailment risk and other aspects of suspension system performance, it may be prudent to consider tighter limits on track irregularities (DCL in particular).

Annex B (informative)
Static Wheel Unloading vs Likelihood of Low-Speed Derailment

The load equalization standard is in part based on simulations investigating the potential for vehicle derailment as a function of static unloading performance. These calculations were intended to address the following questions:

- How do static jacking test results correlate with the potential for derailment over track twist inputs?
- What level of static jacking performance is required to avoid derailment?

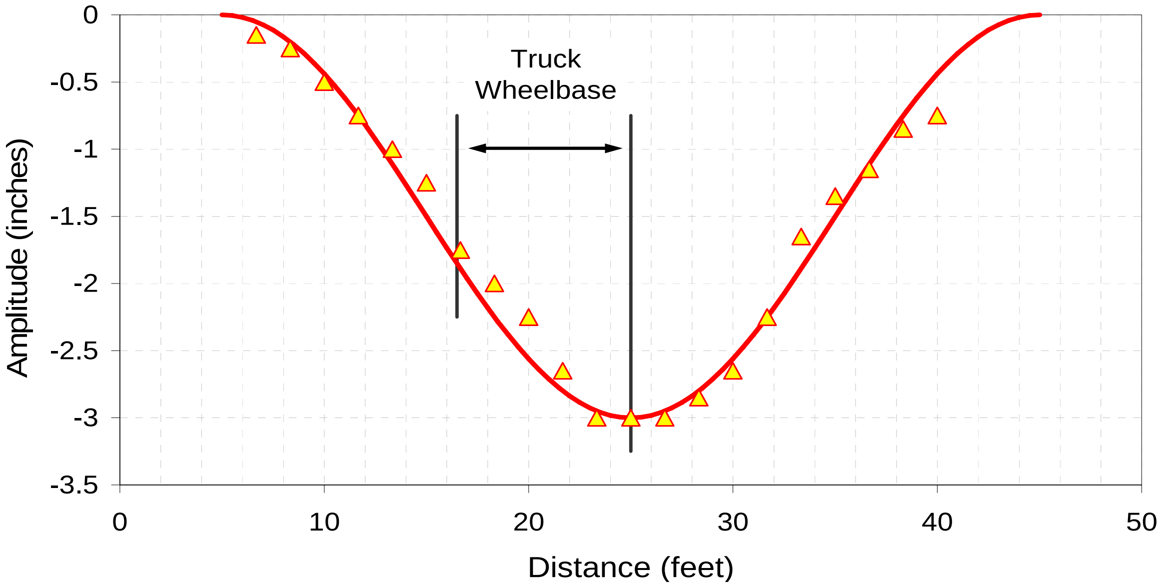
The simulations modeled a generic four-axle car representative of a typical North American passenger coach. Calculations were performed using VAMPIRE®, a generalized multi-body simulation for rail vehicle applications. VAMPIRE® is a U.K. registered trademark of DeltaRail Group Ltd.

Static jacking results were calculated using the VAMPIRE® Static Analysis program. Wheel unloading was obtained by lowering a single-wheel on one truck. The calculation is equivalent to a static jacking test on a full vehicle. Both wheel-to-wheel (truck) and truck-to-truck (vehicle) equalization are considered. Given symmetry of the vehicle, the calculations were performed for a single wheel only. All other wheels would effectively provide the same result.

The dynamic calculations considered a hypothetical low-speed derailment scenario. The track input was a 300-foot radius curve without superelevation. The tight curve causes significant wheel-rail lateral forces and a high angle of attack at truck leading axles. A track dip on the curve outside rail then creates a loss of vertical load on that rail. The combination of a high angle of attack and a single wheel L/V ratio exceeding the Nadal criterion makes derailment likely.

The perturbation shape was defined by a versine as shown in Figure B-1. The data points in the figure correspond to field measurements taken in an experiment determining possible track bump waveforms. The fit between the assumed waveform and the measurements is quite good.

Figure B-1. Track Dip Input

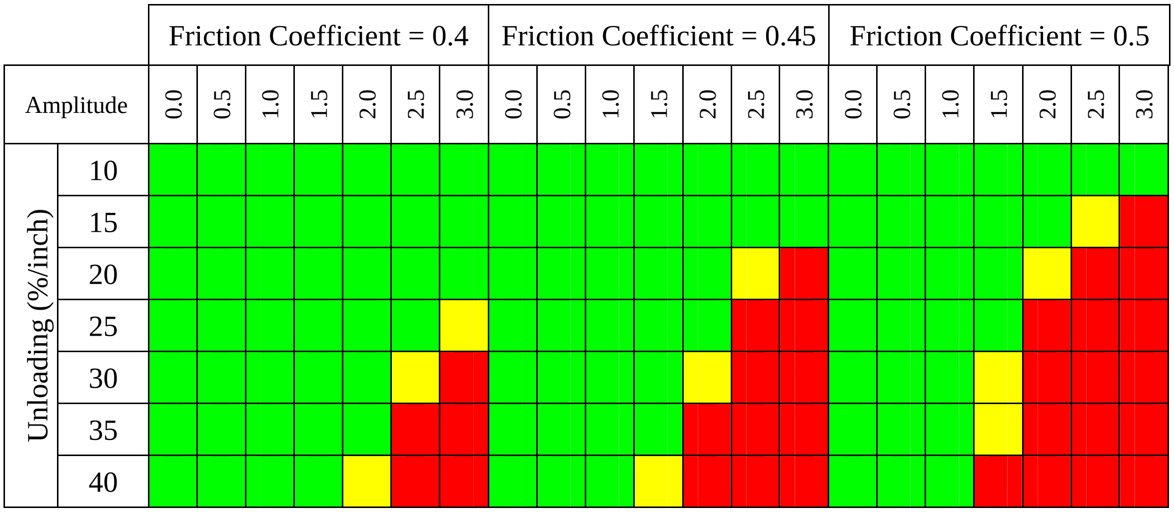


Vehicle dynamic response was predicted using the VAMPIRE® Transient Analysis program. The calculations considered track dip amplitudes ranging from 0.5 inches to 3 inches. Vehicle speed was 5 mph. Previous calculations up to 15 mph indicated the low-speed case was critical. The vehicle wheel profile was a nominally worn contour with a constant 1:20 tread taper and a 72-degree flange. Wheel-rail friction coefficients from 0.4 to 0.5 were assumed at both tread and flange contact.

Qualitative simulation results are summarized in Table B-1. The results are divided into three categories. First is the case where derailment was not predicted and maximum single wheel L/V ratios did not exceed the Nadal limit. Second are cases where derailment was not predicted but maximum single wheel L/V ratios did exceed the Nadal limit. The final case is where derailment was predicted. That is, VAMPIRE® predicted one or more wheels would climb up and over the outside rail of the curve.

As shown, input amplitudes of 2.5 inches or more invariably lead to derailment at friction coefficients greater than 0.4 or static unloading performance worse than 25 percent per inch. A friction coefficient of 0.5 leads to derailment over track dips of 2.0 inches or greater unless static unloading performance is 10 percent or better.

Table B-1. Summary of Simulation Results



		Friction Coefficient = 0.4							Friction Coefficient = 0.45							Friction Coefficient = 0.5						
Amplitude		0.0	0.5	1.0	1.5	2.0	2.5	3.0	0.0	0.5	1.0	1.5	2.0	2.5	3.0	0.0	0.5	1.0	1.5	2.0	2.5	3.0
Unloading (%/inch)	10	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	15	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟥
	20	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟥	🟩	🟩	🟩	🟩	🟨	🟥	🟥
	25	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟥
	30	🟩	🟩	🟩	🟩	🟩	🟨	🟥	🟩	🟩	🟩	🟩	🟨	🟥	🟥	🟩	🟩	🟩	🟨	🟥	🟥	🟥
	35	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟩	🟩	🟩	🟨	🟥	🟥	🟥
	40	🟩	🟩	🟩	🟩	🟨	🟥	🟥	🟩	🟩	🟩	🟨	🟥	🟥	🟥	🟩	🟩	🟩	🟥	🟥	🟥	🟥

Legend No Derailment 🟩 Nadal Limit Exceeded 🟨 Predicted Derailment 🟥

This admittedly limited study suggests a number of conclusions.

1) Derailment in a tight curve at a high friction coefficient over a significant track dip is difficult to prevent regardless of the load equalization ability of the truck and vehicle. This implies track owners must emphasize proper track vertical geometry in tight curves. It is assumed that practical experience has long since proven this.
2) At a wheel-rail friction coefficient of 0.4, acceptable performance over track dip amplitudes up to 3 inches is obtained in a tight curve if static wheel unloading is better than approximately 25 percent per inch. Better means unloading should be less than roughly 25 percent per inch. This supports the Class G wheel unloading definition. Increased wheel-rail friction or greater static wheel unloading creates a potential or likely risk of derailment. Under these circumstances, single wheel L/V ratios exceeding the Nadal limit are predicted. When such values are sustained, actual wheel climb may occur. The wheel-rail coefficient of friction is a critical parameter.

Several issues argue for a conservative interpretation of the results. That is, the predictions should be viewed as potentially underestimating the risk of derailment.

1) The truck wheelbase used was 102 inches. While this is a typical value for North American passenger car trucks, some vehicles have truck wheelbases greater than this. For example, the Acela power car trucks have a wheelbase of 112 inches. A greater wheelbase will increase the amount of track twist encountered by a truck.
2) The analyses did not consider external influences such as increased truck rotational resistance and primary suspension non-linearities. However, factors such as variations in local track stiffness are assumed to be included in the track input. That is, track quality (including the subgrade) presumably creates the geometry deviations resulting in the track dip.
3) The analyses did not consider alignment defects in combination with the track dip. With exception of the vertical dip, track geometry in the curve was otherwise perfect. Typical track roughness or an alignment or gauge perturbation coinciding with the track dip could further increase dynamic response.

Notwithstanding the above issues, it should also be acknowledged that the Nadal criterion is conservative. As noted, wheel-rail coefficient of friction is a significant parameter. In practice, the crucial coefficient of friction is that available to resist lateral sliding between wheel and rail. Longitudinal friction forces at the wheel-rail contact will tend to reduce available lateral friction. This effectively reduces the coefficient of friction to be used in the Nadal equation and thus increases the limit value.

Further information regarding this study is provided in

- Klauser, P. E., “Static Wheel Unloading versus Likelihood of Low-Speed Derailment,” Report 06.912 TR.01, Lockport, Illinois, September 2006.

This report or subsequent revisions may be downloaded from the APTA (American Public Transportation Association) website at www.apta.com.

Annex C (informative) Bibliography

[C1] Klauser, P. E., “Static Wheel Unloading versus Likelihood of Low-Speed Derailment,” Report 06.912 TR.01, Lockport, Illinois, September 2006.