A European Standard for Rail Fastenings for Heavy Axle Loads.

David Rhodes, Technical Director, Pandrol Ltd., Station Road, Addlestone, KT15 2AR, UK
(Convenor of CEN Working Group TC256/WG17)

Presented at the International Heavy Haul Association Special Technical Session, Kiruna, Sweden, June 2007

Summary: This paper describes the development of European standard EN13481-8, which sets out the performance requirements for rail fastenings which are to be used on tracks carrying trains with heavy axle loads i.e. axle loads greater than 260kN. The standard takes particular account of proposals to run such trains on track aligned for faster lighter trains. The critical loading case arises when heavy freight trains travel at low speeds on curves for which the super-elevation and rail pad resilience have been selected to suit fast passenger trains.

Index terms: Rail fastenings, Heavy Haul

1. NOTATION AND UNITS

α	Angle of applied load (deg)
M	Moment about centre of rail seat (kNm)
P	Maximum Load Applied (kN)
P_L	Lateral component of P (kN)
P_V	Vertical component of P (kN)
X	Position of load application below centre of gauge corner radius (mm)

2. INTRODUCTION

During the 1990s, the European Committee for Standardisation (CEN) developed technical standards describing test methods and performance requirements for rail fastenings. The work was initiated following the publication of Directive 93/38/EEC (the "Utilities Directive") which set out procurement procedures for water, energy, transport and communications enterprises in Europe. Amongst other things, this Directive required that the technical performance specifications in public tender documents issued by such organisations were based on European standards, where such standards existed. In the railway industry, most technical standards had been set by individual national railways, and so a number of working groups were set up to create new European standards, under the guidance of CEN Technical Committee 256 ("Railway Applications").

Standards for rail fastenings were developed from earlier work carried out by ERRI[1] by Working Group 17 of TC256. The technical work was complete by 2000, and the standards were eventually published in 2002[2,3]. A single set of requirements was set for all "main line" tracks, assuming typical axle loads of up to 22.5 tonnes and maximum axle loads of 26 tonnes, on the basis of a minimum curve radius of 150 metres (or 400 metres where very resilient rail pads were used).

3. THE EUROPEAN HEAVY AXLE LOAD CASE

At about the time that the technical work on the rail fastenings standards was completed, discussions were taking place about the possible introduction of freight trains with heavier axle loads in several European countries, most notably in Great Britain, Finland and Sweden. The iron ore line between Luleå and Narvik was already operating with axle loads near to the limit of the scope of the standards which were being developed, and it was becoming evident that rail fastening systems which were compliant with those standards were not necessarily durable enough for the application.

Clearly, one option open at the time was the adoption of standards used elsewhere in the world for Heavy Haul railways – for example, the AREMA specification[4] used in North America. There were two reasons, in particular, why this could not be accepted as a European standard without some careful consideration. Firstly, there was concern that the AREMA specification reflected American practice in terms of bogie and track alignment design, and maintenance, which was different from European practice. Secondly, there was concern about applications where heavy axle load freight trains might operate on mixed traffic infrastructure in Europe where the alignment, superelevation and track modulus were optimised for faster, lighter trains.

Another option was based on work done by Railtrack (now Network Rail) in the United Kingdom, who had been preparing designs for concrete and steel sleepers suitable for use with axle loads of 30 tonnes[5]. The VAMPIRE vehicle-track interaction model had been used to predict track forces under a freight vehicle with 150 kN static wheel load, running with 142 mm cant excess in a 1500 metre radius curve i.e. the case of a heavy freight train operating on track designed for fast passenger trains.

In 2000, CEN TC256 Working Group 17 set up a Task Group to review existing standards and research reports from around the world, to consider the case for heavier axle loads in Europe and to propose and evaluate a new test standard. The Task Group included representatives of the national railways of Finland, Sweden, Norway and Great Britain and of rail fastenings manufacturers in Germany and the UK.

4. SERVICE EXPERIENCE

The concrete sleepers and rail fastenings used on the Swedish section of the iron ore line are identical to those used on other main line tracks in Sweden, with self tensioning spring clips, one-piece glass-reinforced nylon insulators and natural rubber rail pads having a static stiffness of about 50 MN/m. Although the design pre-dates the publication of the standard, this assembly is broadly compliant with the requirements of EN13481-2. The pad gives an impact attenuation of more than 50% which is beneficial in applications elsewhere on the network, where trains are running at up to 200 km/hr, but has limited value under slower, heavier freight trains. Under heavy axle loads, the soft pad generates large vertical displacements of the rail, which result in rapid wear of the nylon insulators. This, in turn, precipitates deterioration of the pad and if no remedial maintenance work is done the result is wide track gauge and loss of control of rail inclination.

In similar applications in North America, the standard rail fastening may have similar clips and shoulders, but these would normally be used with a stiffer pad (usually made from thermoplastic polyurethane – TPU) and a two-part insulator having a softer nylon face against the rail, and a cast iron cover plate between the clip and the nylon to distribute the load. Other technical improvements have been made to rail fastening insulators for Heavy Haul applications in recent years[6] but the comparison of experience on the iron ore line in Sweden, and freight routes in North America, indicates that compliance with EN13481-2 is not sufficient to ensure durability of all rail fastening components in the Heavy Haul environment.

As well as assessing the condition of rail fastening components in track, measurements were made of rail displacements under passing traffic in a wide range of conditions on both Heavy Haul lines and European main line railways. From the vertical, lateral and rolling displacements of the rail in service it is possible to derive test loads which may be applied to a short section of rail in a laboratory test in order to simulate the operational conditions[7,8]. In trying to understand this process, it is important to consider that the vertical bending stiffness, lateral bending stiffness and torsional stiffness of the rail are all quite different, and that as a consequence the proportion of the vertical wheel load applied to a single rail seat is different from the proportion of the lateral load, and different again from the proportion of the rail overturning torque. In the laboratory test, the three variables are taken into account by varying the magnitude of the load applied to the rail, the angle at which it is applied, and the height above the sleeper top at which it is applied. In order to test the durability of the rail fastening, it is important is that the displacement of the rail foot, relative to the top of the sleeper, is representative of behaviour in track. The loading configuration required to achieve this appears to be rather different from the more "intuitive" loading configuration that might simulate wheel-rail contact.

It has been found that the track loading condition which applies the most damaging forces to the rail fastening occurs when a heavily loaded train runs around a curve with high cant excess – i.e. when the train is running at a speed well below the balance speed of a curve with super-elevation. With most designs of freight rolling stock, the highest stresses occur in the fastening of the low rail. In general, the forces imposed on the fastening of the high rail, under conditions of high cant deficiency, are less severe because on a mixed traffic line the fastest trains are unlikely to be the heaviest trains, and in any case track alignment is usually designed such that the maximum cant deficiency case is less severe than the maximum cant excess case.

5. DEFINITION OF DURABILITY TEST PARAMETERS

The parameters for the inclined repeated load test, used to assess the durability of the fastening system in the laboratory, became the focus of most of the attention of the Task Group. The standards require 3 million applications of the load to the rail, and following the test the condition of the fastening system is assessed by a combination of physical tests and visual inspection of the components.

Finally, three options were considered:

1. Increasing the load by 33%, in line with the proposed increase in typical axle loads from 22.5 tonnes to 30 tonnes, but keeping all other parameters the same as EN13481-2.
2. Adopting the Railtrack load model.
3. Adopting the AREMA Chapter 30 loads.

The maximum applied load, P, the angle of load application, α, and the distance of the load application below the gauge corner of the rail, X, are all defined in the test procedures (Figure 1), but it is more informative to resolve these into the vertical load component, P_V, the lateral load component, P_L, and the rail overturning moment, *M*. In Table 1, these parameters have been calculated for an assembly with 60E1 rail on a 10mm rail pad (except for the AREMA test, which is based on 136RE rail on a 6.35mm ($^1/_4$ inch) rail pad. The rail overturning moment is the net moment about a point on the sleeper surface, directly below the centre line of the rail.

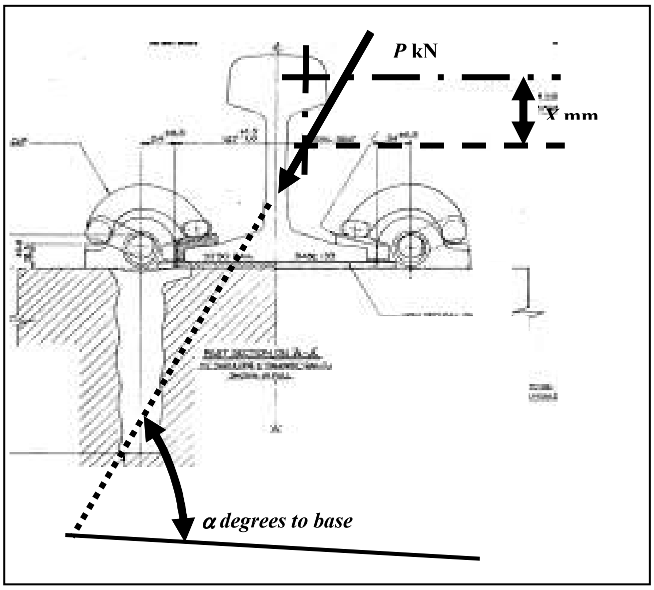

Figure 1: Configuration of inclined repeated load test

	P (kN)	α (deg)	X (mm)	P_V (kN)	P_L (kN)	M (kNm)
EN13481-2 (Soft pads)	70	26	15	62.9	30.7	3.24
EN13481-2 (Med. Pads)	75	33	15	62.9	40.8	4.78
EN13481-2 (Hard pads)	83	33	15	69.6	45.2	5.30
EN13481-2 + 33% (Soft pads)	93	26	15	83.6	40.8	4.31
EN13481-2 + 33% (Med. pads)	100	33	15	83.9	54.5	6.39
EN13481-2 + 33% (Hard pads)	111	33	15	93.1	60.4	7.08
Railtrack 30 tonne (Soft / Med.)	100	40	75	76.6	64.3	4.20
Railtrack 30 tonne (Hard pads)	108	40	75	82.7	69.4	4.53
AREMA Chapter 30	173	20	0	162.6	59.2	7.01

Table 1: Parameters for inclined repeated load tests.
(Note that the EN13481-2 tests for soft pads assume a minimum curve radius of 400 metres, whereas those for medium and hard pads assume a minimum curve radius of 150 metres)

Several interesting factors emerge from Table 1:

Firstly, in the European tests the vertical load component for track with hard pads is generally a little more than half of the wheel load. A quasi static analysis of a "beam on an elastic foundation" gives a value of around 28 - 30% for a Heavy Haul railway (depending on rail size, sleeper spacing and ballast / formation stiffness), so these test parameters include a 100% increment in load to take dynamic effects into account. This is broadly in line with recommendations of work in Europe[9] which was the basis for the standard for concrete sleeper design[10]. The AREMA Chapter 30 load is much higher, being being approximately equal to the static wheel load, reflecting the 200% dynamic increment recommended in that standard. The implication is that AREMA has taken into account the possibility of much more severe defects in the wheel and rail running surfaces than its European counterparts, and that in this respect the AREMA fastening test is incompatible with European sleeper design practice. It was, therefore, excluded from further consideration.

Secondly, lateral load components for track with hard pads are around 40% of the static wheel load for most cases, and are very similar for analysis based on either EN13481-2 or AREMA Chapter 30. However, the Railtrack proposal – based on a case with severe cant excess – demands a higher lateral load than any of the other tests.

Finally, the moment applied to the rail, as a function of static wheel load, is similar for tests based on EN13481-2 and AREMA Chapter 30, but is somewhat lower for the Railtrack 30 tonne test. This is simply because it is necessary to increase the value of *X* in order to maintain a stable test configuration with such a high lateral load component.

6. EVALUATION OF DURABILITY TEST PARAMETERS

The Task Group evaluated the different durability test proposals by carrying out a total of nine tests, which are summarised in Table 2. Note that all of the fastening systems and pads which were tested are fully compliant with EN13481-2, and are used successfully in European main line applications. The results of tests 1, 2, 6 and 7 are particularly significant, because the two fastenings which were tested had also been evaluated in track in a curve on the Swedish iron ore line, south of Gällivare. In both cases, the track trials were carried out with soft rail pads. It had been found that the ePLUS fastening had a significantly longer service life than e2000, and that the principle mechanism of failure of e2000 was initiated by severe wear of the insulator. In that respect, the failures observed in the laboratory test were similar to those observed in track. The test with 100kN applied at 40 degrees did discriminate between these two fastening

	P (kN)	α (deg)	X (mm)	Lab'	Fastening	Pad	Comments
1	93	26	15	GB	e2000	Soft	PASSED (Insulator & pad deformed)
2	93	26	15	GB	ePLUS	Soft	PASSED (No damage)
3	93	26	15	DE	W14	Soft	PASSED (Pad deformed)
4	93	33	15	DE	W14	Soft	FAILED (Pad failed)
5	93	33	15	DE	W14	Med.	PASSED (Pad deformed)
6	100	40	75	GB	e2000	Soft	FAILED (Insulator failed)
7	100	40	75	GB	ePLUS	Soft	PASSED (Pad slightly deformed)
8	100	40	75	DE	W14	Hard	PASSED
9	100	40	75	GB	FC1500	Med.	PASSED

Table 2: Inclined repeated load tests

configurations, but the test with 93 kN applied at 26 degrees did not. Referring back to Table 1, it should be noted that the 100kN / 40 degree test applies a lower vertical load, and almost identical rail overturning moment, to the 93 kN / 26 degree test, but it applies a much higher lateral load.

As a result of this study, the Task Group recommended that the test based on the Railtrack analysis of the 30 tonne axle load case should be adopted as the European standard for rail fastenings for Heavy axle loads.

7. OTHER TEST REQUIREMENTS

The Task Group also reviewed other tests required by EN13481, and considered whether those requirements should be amended if fastenings were to be used in track carrying heavy axle loads.

It was concluded that requirements for torsional resistance, impact attenuation, electrical insulation, clamping force and dimensional tolerances should not be changed. Requirements for rail longitudinal restraint and for the pull-out resistance of cast-in components should be reviewed, and the requirements for testing in service should be amended to ensure that such testing would be carried out under representative conditions.

On the question of longitudinal restraint, there was already a difference in approach between the European standard, and the AREMA test method. Both tests require a longitudinal force to be applied to the rail, and the displacement to be recorded as the rail tends to slip through the fastening. This is especially important in designing track with continuous welded rail, which must withstand thermal forces, but additional forces arise in service as a result of traction and braking. The European test[11] identifies the longitudinal force at which the rail begins to slip through the fastening, whereas the American test demonstrates that gross, continuous slip does not occur at a prescribed proof load. In effect, the existing European standard EN13481-2 required no slip at all with an applied longitudinal force of 7 kN, and AREMA Chapter 30 required that gross continuous slip did not occur with an applied longitudinal force of 10.7 kN. Studies which had been carried out for Finnish Railways prior to 2000 indicated that with a combination of extreme temperature and maximum braking force of a heavy freight train, the longitudinal force in the rail was very close to 7 kN, leaving no margin of safety. At the same time, the figure in EN13481-2 was under review for high speed applications – especially those where eddy current braking might be used – and it had been proposed that the minimum force for the onset of slip should be increased to 9 kN. As a result, the Task Group recommended that the minimum longitudinal restraint should be increased from 7 kN to 9 kN for the heavy axle load case as well. Taking the different test procedures into account, this requirement is, in fact, very close to the AREMA Chapter 30 requirement.

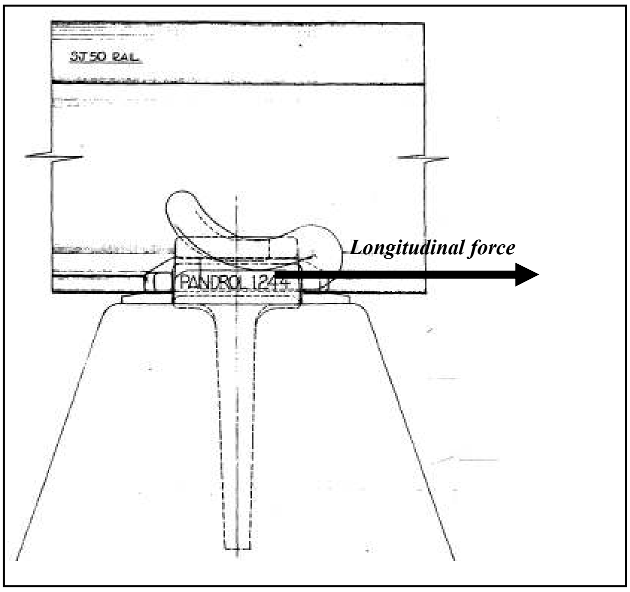

Figure 2: Configuration of longitudinal restraint test.

On the question of pull-out resistance, EN13481-2 requires that an upward force of 60 kN should be applied to any insert in a concrete sleeper as a proof load test as shown in Figure 3. AREMA prescribes a similar test, with a load of 53 kN. As this value is, in any case, about four times greater than the clamping force of a single rail clip and an order of magnitude greater than the weight of the sleeper which might be lifted out of the ballast, hanging on the insert, the Task Group recommended that no change should be made in this requirement.

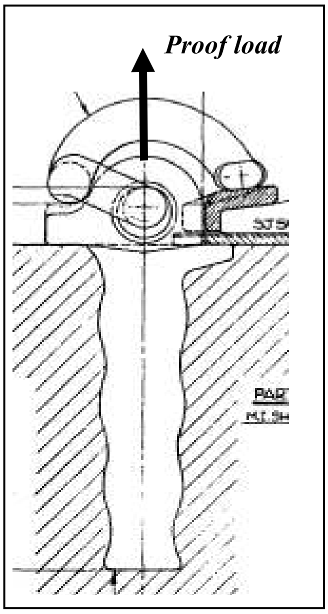

Figure 3: Configuration of fastener pull-out resistance test.

8. CONCLUSION

The Task Group recommended changes to the requirements for inclined repeated load tests and longitudinal restraint tests when rail fastenings are tested for applications with heavy axle loads. These requirements have now been published by CEN as a separate part standard[12], and at the next revision they will be incorporated into the main suite of CEN rail fastening standards.

Acknowledgements: The author wishes to acknowledge the support of CEN TC256/SC1 and the contributions of the other members of the Task Group in 2000: Stein Olav Lundgreen (Jernbaneverket, Norway), Quentin Phillips (then with Railtrack, UK), Kari Ojanpera (then with Finnish Railway Administration), Paul Nilsson (then with Banverket, Sweden) and Roland Buda (then with Vossloh Rail Fastenings, Germany).

9. REFERENCES

[1] **Study of fastening system characteristics and test methods**. ERRI D170 RP5, European Rail Research Institute, Utrecht, September, 1994.

[2] **Railway Applications – Track – Performance requirements for fastening systems.** EN13481 Parts 1 to 7. Comité Européen de Normalisation, Brussels, 2002.

[3] **Railway Applications – Track – Test methods for fastening systems.** EN13146 Parts 1 to 8. Comité Européen de Normalisation, Brussels, 2002.

[4] **Manual for Railway Engineering – Chapter 30 – Ties.** American Railway Engineering and Maintenance-of-Way Association, 2006.

[5] Allen, R.J. **Requirements for Railtrack's next generation sleeper systems.** Railtrack memo, London, December, 1998.

[6] Rhodes, D. **Recent developments in rail fastening insulators for Heavy Haul applications.** Proc. 6th International Heavy Haul Conference, Cape Town, 1997, pp 734 – 740.

[7] Rhodes, D., Leeves, G.G. and Cox, S.J. **Measurement of strains and displacements in track, under traffic.** Proc. 4th International Heavy Haul Conference, Brisbane, 1989, pp 311 – 315.

[8] Cox, S.J., Barker, J.T. and Wang, A. **Track fastening testing – Making the link between track conditions and laboratory tests.** Proc. 6th International Heavy Haul Conference, Cape Town, 1997, pp 741 – 751.

[9] **Study of different values which need to be taken into account with respect to the definition of the properties of concrete sleepers.** ORE D170 RP4, Office for Research and Experiments of UIC, Utrecht, September, 1991.

[10] **Railway Applications – Track – Concrete sleepers and bearers.** EN13230 Part 1, Annex E. Comité Européen de Normalisation, Brussels, 2002.

[11] **Railway Applications – Track – Test methods for fastening systems.** EN13146 Part 1 (*"Determination of longitudinal rail restraint"*). Comité Européen de Normalisation, Brussels, 2002.

[12] **Railway Applications – Track – Performance requirements for fastenings systems.** EN13481 Part 8 (*"Fastening systems for track with heavy axle loads"*). Comité Européen de Normalisation, Brussels, 2006.