TWIST FAULTS

Produced by Civil Engineering Conference
For use by all Railway Civil Engineering Staff

CEC/DG/010
Issue 1
February 2002

Note

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AMEC Rail
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Balfour Beatty Rail
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First Engineering
Grant Rail Ltd
GT Railway Maintenance Ltd
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In conjunction with Railtrack Plc (in Railway Administration)

Printed by Heron Press, Kings Norton, Birmingham. Telephone: 0121 433 5100
February 2002

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Scope

This booklet has been produced for the guidance of track staff at all levels. It is intended to give general information on the causes, associated risks, identification, avoidance of twist faults; how twist is measured; and what preventative and remedial actions are required.

Introduction

The presence of twist faults on railway infrastructure may create a risk to safety of the line and has the potential to cause serious incidents. Derailments caused by twist have resulted in prosecution of renewals and maintenance companies by the HMRI.

It is essential that all staff play their part in eliminating the occurrence of twist faults.

Photograph - derailment risk twist fault in S&C

What is Twist?

Twist is the term used to describe the variation in cross-level measured across the four foot over a given distance along the track.

Cross-level for a twist on Railtrack Infrastructure is measured over a 3 metre distance, this equates to approximately 5 sleepers. The dimension relates to the 10-foot wheelbase of older four-wheeled single axle wagons with rigid suspensions. On London Underground twist is measured over a 2 metre distance. (See Appendix 2).

Twist in both cases is reported as a gradient e.g. 1 in 200. (See page 8).

Twist typically occurs at;-

- Cant change in the transition of a curve. This is an example of a design twist and will have a maximum gradient of 1 in 400. Correctly maintained cant gradient is an acceptable form of twist that forms an essential part of the design of a railway curve.
- At a track fault. These may be detected by visual inspection, measurement of the cross level or by a Track Recording vehicle (TRV) and this type of fault is referred to as a twist fault.
- During track renewal construction work for example at run-ins and run-outs of new work, or where bottom ballast has been poorly compacted, or at particularly wide joints which suffer high wheel impact.

Twist faults present a derailment risk to all traffic irrespective of speed. Short wheel based four wheel wagons are most susceptible.

The measurement of twist should be considered in two ways, static twist and dynamic twist.

- **Static twist** can be measured with a cross-level gauge. It gives the twist measurement of the track whilst unloaded and so does not allow for sleepers voiding.
- **Dynamic twist** is the twist that will occur under the passage of a train when the track is loaded. A Track Recording Vehicle, TRV, measures dynamic twist.

It is important to allow for the effects of voiding when calculating twist. The use of void meters and a cross level gauge allows the dynamic twist to be calculated.

Twists are measured across the four-foot and can be calculated by taking the difference between two readings taken 3 metres apart. (5 sleepers). These readings in millimetres are then used to calculate the twist gradient. This is a simple calculation and will be explained later.

Photograph - derailment caused by twist

Where are Twist Faults Likely to Occur?

- Within wetbeds and slurry spots

Photograph - wetbeds causing twist

- At broken rails or broken fishplates
- At dipped IBJ's or where two different types of IBJ are used parallel to each other (e.g. 4 hole & 6 holes) or where track type changes.
- Where a joint is dipped or staggered

Photograph - dipping joint

- Where broken or damaged sleepers are present
- At breather/adjustment switches
- Where embankment movement occurs
- As a result of settlement and mining subsidence.
- At sites of weak formation, e.g. ash ballast or fen soils.
- Run-in and run-outs to structures, waybeams and level crossings
- Near hard-spots, eg tunnel mouths, viaducts, shallow ballast under bridges.
- Voiding sleepers and sites where poorly consolidated ballast exists.
- Voids caused by decay on way-beam and longitudinal timbers.
- On renewals sites during construction activities.
- Where trackside drainage trenches have recently been exposed.
- Due to wear at crossing noses.
- An area where mechanical tamping is restricted.
- Where drainage is defective.
- As a result of tunnelling activities under the track e.g. pipeline thrustbore.
- Twist induced during maintenance activities
- Due to settlement on Slab track. (Remedy with thicker pads).
- Where tamping starts and ends.

Design Twist in Transition Curves

In a transition curve the cant is increased/decreased by a calculated amount over a given distance. This is where the high rail gradually rises relative to the low rail by a designed amount. For example the design twist or cant change starts at C=0mm and rises to the value of cant in the regular curve, e.g. C=150mm on high-speed track.

The cant in transitions should be shown by markings in steps of 5mm. In some locations cant plates are fixed to the high side of the sleeper at regular intervals. In other locations cant may be marked with black paint on a yellow background. Track staff should use these markings for reference when completing tamping and maintenance activities. All markings should be of such a size so as to be clearly legible from the cab of an on track machine in normal operating mode.

Design twist or cant change can be checked using a suitable track gauge. This should be done by appropriately trained track staff and always completed following tamping and maintenance activities.

Any variations in the design twist are needed to calculate the twist error in the cross-level. This is demonstrated in the examples shown later.

Photograph- transition curve with cant marking

What does a Twist Fault Look Like?

Visually it may be difficult to see the presence of a twist fault in the track. By careful observation you may notice that one rail is dipping lower than the other. This variation in levels may be static (unloaded) or dynamic (during the passage of a train).

Twist Gradients

Twist may occur at any of the locations noted previously. The following section of this guide will advise you how to determine whether or not the twist fault presents a risk to traffic.

Twists are reported as a gradient.

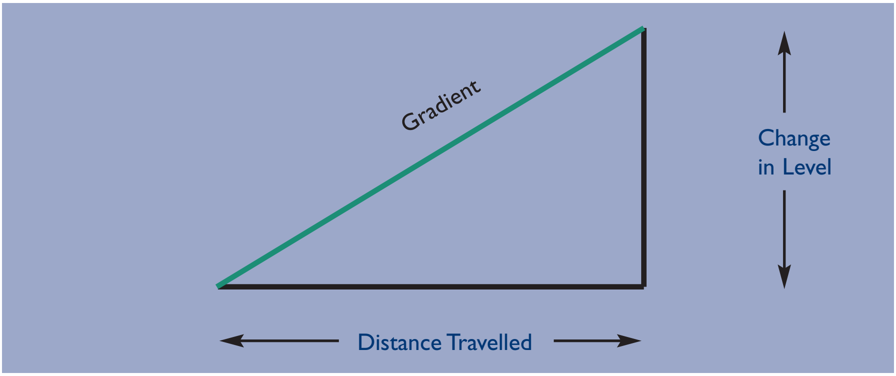
- Twist gradients above 1in 301 are low risk.
- Twist gradient between 1 in 200 and 1 in 300 do present a risk and remedial work should be planned to mandated timescales.
- Twist gradients between 1 in 91 and 1 in 199 require immediate action to mandated timescales
- Twist gradients worse than 1 in 90 require traffic to be stopped.

If a twist fault is suspected it should be measured by using an appropriate cross level gauge, (calibrated in accordance with the manufacturers instructions) to measure variations in the relative rail levels across the four foot. Examples of how to calculate twist for both straight and curved track follow. If voiding under sleepers occurs, this must also be measured and included in the twist calculation.

Photograph - twist fault measured at a Level Crossing

How a Twist Gradient is calculated

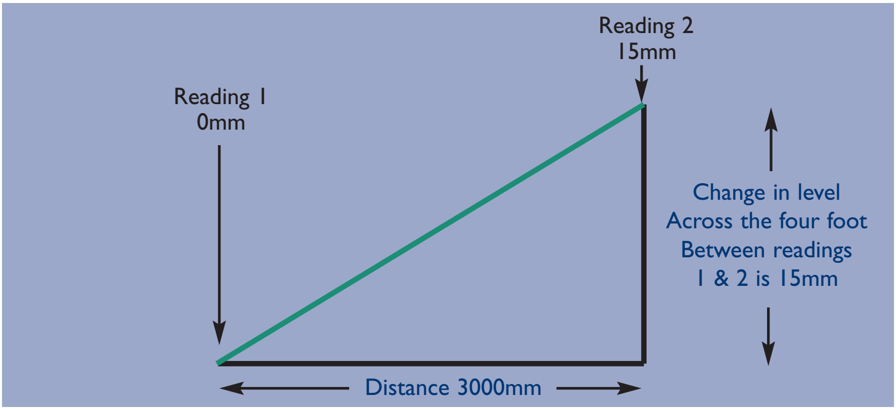
A gradient can be expressed as a ratio, eg. 1 in 100 means a rise of 1 unit over a distance of 100 units.



Gradient is calculated using a simple equation.

$$\text{Gradient} = \frac{\text{Change in Level}}{\text{Distance Travelled}} \qquad \text{eg. Gradient} = \frac{1}{100} \qquad \text{Gradient} = 1 \text{ in } 100$$

On Railtrack infrastructure a distance of 3000mm (3 metres) is normally used as distance travelled (approximately 5 sleepers). The cant is measured and noted at the two points 3000mm apart. The change in level (difference between the two readings in mm) is then divided into 3000mm to give the twist value.



$$\text{Gradient} = \frac{\text{Change}}{\text{Distance}} \qquad \text{Gradient} = \frac{15\text{mm}}{3000\text{mm}} \qquad \text{Gradient} = \frac{1}{200}$$

So Twist Reported as 1 in 200

Checking the Accuracy of the Cross Level Gauge Before Use

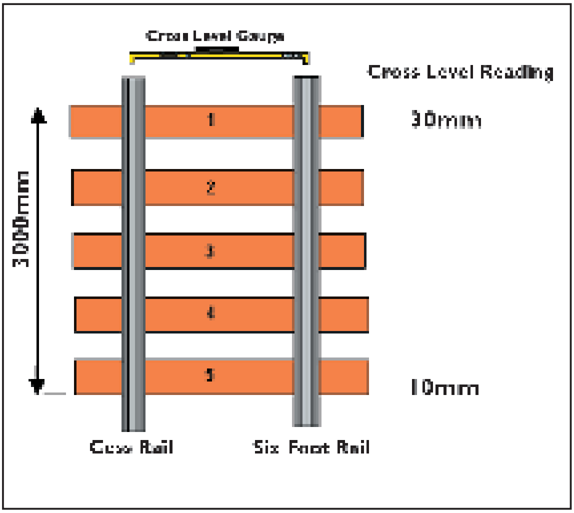
The cross level gauge should be routinely checked for damage and accuracy. This is done by taking the reading at a location on a section of straight track and then repeat the measurement with the cross level gauge rotated through 180 degrees. If two different values of cross-level are obtained then the gauge is out of adjustment, it should be returned for correction.

IT IS IMPORTANT TO CHECK YOUR CROSS-LEVEL BEFORE USING IT

Photograph - measuring cross-level

A variety of track geometry trolleys and machines are available which will also measure twist faults. These machines can be used to measure cross levels continuously through the site.

EXAMPLE 1 - Measuring Cross Level on the Same Rail



At sleeper number 1 = 30mm (6 ft rail high)

At sleeper number 5 = 10mm (6 ft rail high)

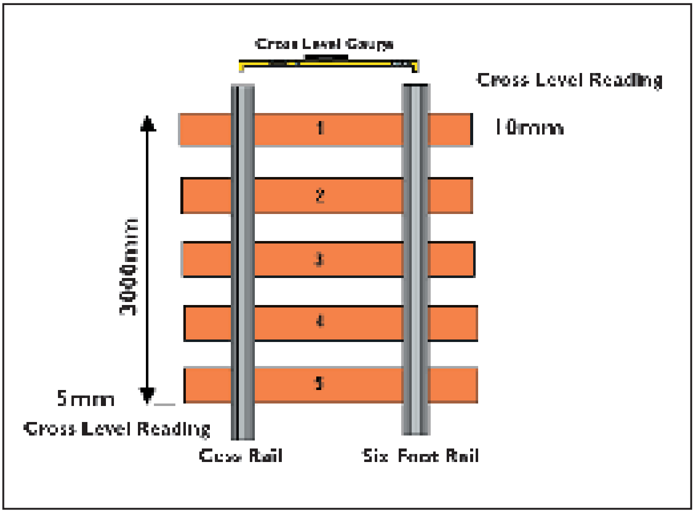
Difference between two readings = 30mm-10mm = 20mm

Therefore TWIST=20mm in 3,000mm

$\frac{20}{3000} = \frac{1}{150}$ or Gradient = 1 in 150

When the high rail is the same at both sleepers, the difference between the two readings is found by subtracting one from the other. The gradient is found by dividing the interval by the difference between readings i.e. 3000mm ÷ 20mm = 150 (hence 1 in 150 gradient)

EXAMPLE 2 - Measuring Cross Level on Different Rails



At sleeper number 1 = 10mm (6 ft rail high)

At sleeper number 5 = 5mm (cess rail high)

Difference between two readings = 10mm+5mm = 15mm

Note that the two cant/cross level readings have been added together to establish the change of cant/difference because the high rail at sleeper number 1 has become the low rail at sleeper number 5.

Therefore TWIST=15mm in 3,000mm

$\frac{15}{3000} = \frac{1}{200}$ or Gradient = 1 in 200

For a gradient 1 in X, the lower the numerical value of X, the more severe the twist.

The table below gives sample values of twist over a 3000mm base. A more comprehensive table can be seen in appendix 1.

Twist 1 in x	Measured changes in cross level in 3m (3000mm)
90	33mm
110	27mm
150	20mm
200	15mm
230	13mm

Twist 1 in x	Measured changes in cross level in 3m (3000mm)
250	12mm
300	10mm
430	7mm
600	5mm
1000	3mm

Use of the Void Meter

Only static twist can be measured with a cross-level, dynamic twist must also be considered.

Voids can be detected by watching the vertical movement of sleepers under traffic, sounding on timber sleepers and by observation of worn powdery ballast (or grey slurry when wet) on the ends of concrete sleepers. The presence of voids can result in a dynamic twist. Accurate measurement of voiding should be undertaken using void meters.

Since voids cannot be assumed to be constant, void meters should be placed to check all sleepers near a suspected twist fault to find the worst case of voiding.

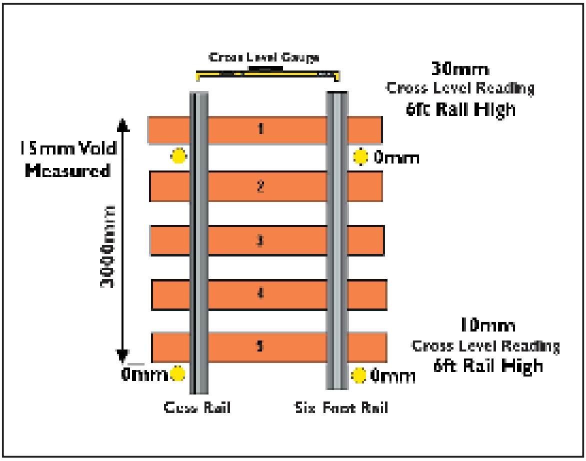
Photograph of Void Meter

EXAMPLE 3 - With void meters

Void meters are installed under both rails at sleeper 1 and 5 as shown. Measurements were then taken:

At sleeper number 1 = 30mm (6 ft rail high) with cross level gauge, 15mm deflection with void meter under the cess rail. No voiding under the six foot rail.

At sleeper number 5 = 10mm (6 ft rail high) with cross level gauge, 0 mm deflection with void meter under either rail.



Difference between two readings = (30mm+15mm)-10mm = 35mm

Therefore TWIST = 35mm in 3,000mm.

This equates to 1 in 85. This gradient is severe and would require the line to be blocked. (See table on page 17)

Why is twist measurement important?

A twist fault can cause a flange climbing derailment at all speeds. A twist fault is a condition where there is a difference in cross-levels between rails over a short distance. Twist faults may cause unloading of one or more of the wheels causing them to lose contact with the rail. Once contact with the running surface is lost the wheel can flange climb and derail the vehicle. Modern vehicles with softer suspension are less prone to twist than older type four wheel freight wagons. However there is still a serious risk of a derailment occurring as a result of twist and it is essential that twist faults are corrected.

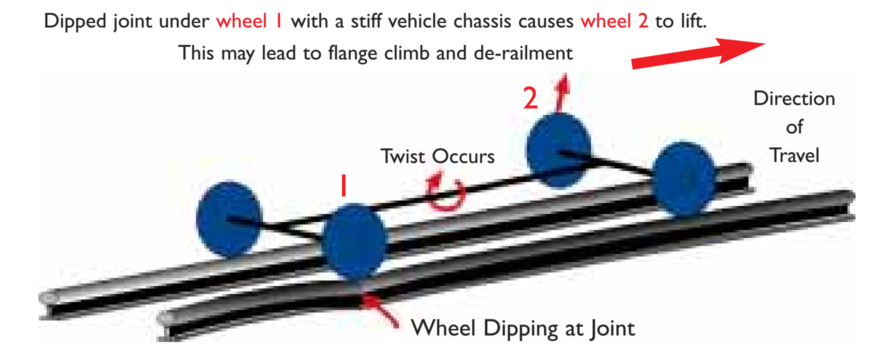


Diagram showing how flange climb derailment may occur.

Twist on Track Renewals Sites

It is common to inadvertently apply twist faults during track renewal activities. These twist faults must be removed prior to the hand back of the line to traffic. A competent person must carry out detailed cross level measurements and ensure that the track meets design and construction requirements after tamping and repair activities. Twist faults that exceed the maximum tolerances (referred to in RT/CE/S/102) must be removed prior to handback of the line to traffic.

Twist on renewal sites during the works can cause derailment of on-track plant and ballast trains. This will almost certainly delay relaying activities and causes possession over-runs. A competent person must assess the track to confirm its adequacy prior to engineering equipment being allowed to pass over the site.

Good consolidation of ballast during relaying activities is essential. Failure to consolidate may result in twist faults occurring after the line has been opened to traffic. Sites should be monitored following relaying activities, any twist faults occurring should be corrected with appropriate urgency according to the severity of the twist.

Methods to avoid twist faults during renewals activity: -

- When blanketing and traxcavating, ensure bottom ballast is applied evenly, well compacted in layers and with gentle gradient changes.
- When machine ballast cleaning aim for an even distribution of returned ballast and ensure that blockages in the machine do not lead to uneven return.
- Ensure that run-in and run-outs to new work are adequately packed before running plant and ballast trains into the site.
- Do not undermine the track when excavating trenches particularly for drainage. Cross drains and start / finish of digs should be at right angles to the track
- Ensure that when steel sleepers are installed, sufficient tamping is completed to allow the troughs (on the underside of the sleepers) to fill with ballast.

Photograph - Twist fault on renewals site caused by settlement of unconsolidated ballast which subsequently caused a derailment.

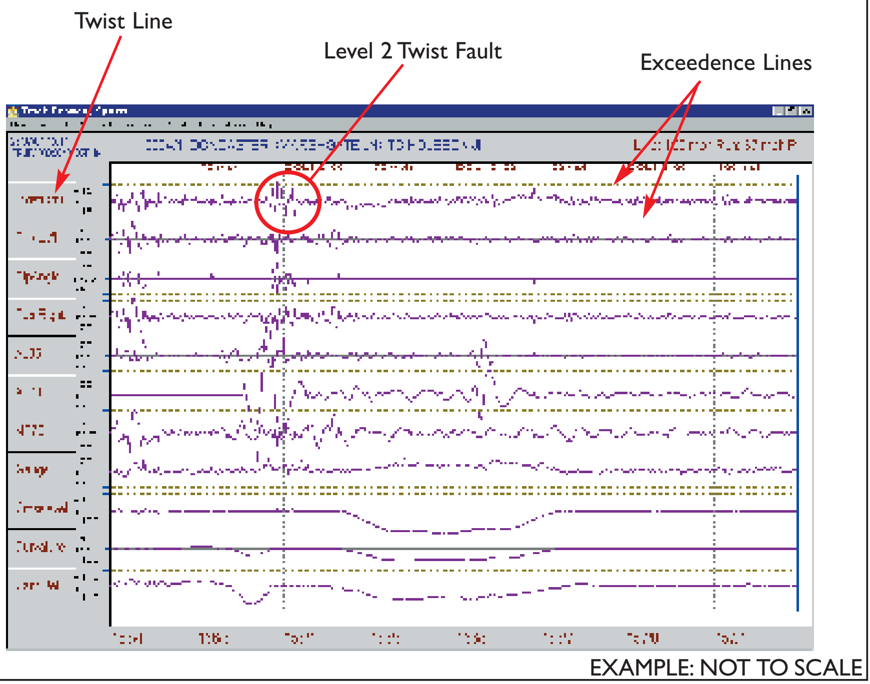
The condition illustrated in the photograph is not specific to renewal sites. Settlement may also occur on maintenance sites where formation is disturbed. For example, removal of wet beds and replacement of sleepers if ballast consolidation is poor.

Twist and the Track Recording Vehicle (TRV)

Use of the Track Recording Vehicle (TRV) is an effective method of measuring dynamic twist. The data provided by the TRV is useful to P-way Engineers for identifying existing twist faults and predicting potential twist sites. The TRV must be considered as an audit tool to identify twist faults missed by other inspection methods.

Twist is one of many characteristics recorded by the TRV and plotted on the chart. The chart is used to assess line safety and track quality. Level 2 twist faults are shown on the top of the chart.

The 3m twist is plotted at half of full scale. The lines at each side of the twist trace show the limit above which constitutes a level 2 fault. Use of the chart enables P.way Engineers to visualise the general condition of all lines recorded by the TRV.



The computers on-board the TRV monitor and process all the data collected by the measuring systems. In addition to twist these systems record data for top, alignment, cant deficiency, dynamic gauge, cross-level and curvature and others listed in the left hand column of the chart.

When the measurements reach a pre-determined threshold they are also recorded in a report format. (Bench marks for these thresholds are laid out in Industry Specifications) Measurements above these thresholds are called exceedences and are categorised as "level 1" and "level 2" dependant on the severity.

Level 1 Exceedence (L1)

The threshold for a L1 is set at a level, that indicates an isolated undesirable feature in the track to which attention needs to be given. The level 1 is an increased risk but not at a level that requires immediate action. A twist fault in the L1 category has a twist gradient of between 1 in 300 to 1in 201. Proactive treatment to L1 faults should prevent a L2 twist exceedence developing.

Level 2 Exceedence (L2)

If the twist value exceeds the threshold for a L1, then it is recorded as a level 2 fault, this must be considered as a serious exceedence. The responsible staff must rectify L2 faults to minimum action timescales.

The report below is a typical example of an immediate action report form. The twist faults are represented by **TW3M** shown in the channel column. Level 2 exceedence reports are available to engineers immediately after the TRV run. Repair must be instigated in accordance with mandated timescales.

TRACK RECORDING for RAILTRACK plc by SERCO RAILTEST Ltd
TRACK RECORDING VEHICLE [TRU] [SL_DTGS V3.06] AREA [ECML SOUTH - 2B]
ACTION REPORT page 001 Date 9-11-2001 WUNL: Networker ZONE [North Eastern Zone]
JOURNEY: DONCASTER <MARSHGATE JN> TO HOLBECK JN 0054/1 PWME [A M E DONCASTER]
PWSS: RSM DONCASTER ELRX: DOL1 2100 FILE [TRUD30309040102B]

Location Miles yds ch	Level	Dist AWSm	Channel		Peak Value		Line Speed	Action	Sign-off
ELRX: DOL1 2100									
156m 811y(36)	L2 (20)	791	GAUGE	=	27.1mm		[70]		> : [illegible] : 15 / 11 / 01
156m 861y(39)	L2 (-20)	836	LTOP	=	-22.3mm		[70]	10 Days	> : [illegible] : 17 / 11 / 01
156m 848y(38)	L2 (-15)	825	ALIG35	=	-16.3mm		[70]	10 Days	> : [illegible] : 13 / 11 / 01
156m 863y(39)	L2 (15)	838	**TW3M**	=	17.3mm	(1:173)	[70]	10 Days	> : [illegible] : 14 / 11 / 01
156/3 - 156/4	SD1(3.6)	0	ALIG35	=	5.7mm		[70]		> : [illegible] : 13 / 11 / 01
156m 880y(40)	L2 (15)	854	ALIG35	=	21.9mm		[70]	10 Days	> : [illegible] : 11 / 11 / 01
156m 876y(39)	L2 (15)	850	**TW3M**	=	17.5mm	(1:171)	[70]	10 Days	> : [illegible] : 14 / 11 / 01

Signature PWSM R James. Date returned to PWME 17 / 11 / 01

Signature PWME [illegible] Date received from PWSM 18 / 11 / 01

Information shown on the Level 2 report includes Engineers Line Reference (ELR) and track I.D. The mileage and yardage of the fault is shown on the left-hand side. A twist fault is describes as TW3M indicating it is recorded over a 3 metre distance, the value of the twist may be shown either as a gradient or in mm (e.g. 1 in 150 or 20mm for 3m twist). The time-scale for the action required be shown depending on the severity of the twist (e.g. 36 hours or 10 days). When remedial work is completed the report should be signed off and dated by the person responsible for the repair. Notes should also be included which detail the nature of the repair. All repairs signed off should be reviewed and countersigned by the P-way Section Manager and P-way Engineer.

The table below suggests the minimum action in place at date of this publication. (Current minimum action needs to be checked against latest Standards.)

To assist track staff in locating "Level 2" twist faults, the TRV drops a marker trace of red paint in the four foot approximately 22 metres after the fault is detected.

Exceedence Level	Irregularity	Time-scale	Action 1	Action 2	Action 3
2	Dynamic twist of 1 in 90 or worse	Stop all traffic and correct immediately	TRV Train captain contacts signalman to block line	Signalman blocks line and informs infrastructure control	Team attends immediately to instigate repair
2	Dynamic twist of between 1 in 91 and 1 in 125	Correct within 36 hours	Level 2 exceedence report to area staff	Team repairs within time-scales	-
2	Dynamic twist of between 1 in 126 and 1 in 199	Correct within 10 working days	Level 2 exceedence report to area staff	Team repairs within time-scales	-
1	Dynamic twist of between 1 in 200 and 1 in 300	No immediate action. Section Manager to observe	P-way Engineer review cause & considers L2 preventative work	Team completes preventative work L2 avoided in next run	-

The Future of the TRV

The UK rail industry is presently reviewing TRV requirements. New technology computers, video and remote data technology will improve the accuracy of data recorded and the speed in which it is processed. This will impact on the way that twist faults are reported in the future.

Removing Twist Faults

It is essential that remedial measures taken give a permanent fix ensuring the fault does not reoccur. If the twist fault is in a slurry spot for example, merely lifting and packing is unlikely to be sufficiently durable. It will be necessary to dig out the slurry spots, replace with fresh compacted ballast and ensure drainage is working adequately. It is the root cause of a track fault that must be treated.

Site circumstances will dictate the nature of remedial work to be completed. This may include:

- Manual lifting and packing
- Measured shovel packing
- Dig out and make good wet beds
- Hand held stone blowing
- Machine Tamping or Stone blowing
- Rail end straightening

Manual lifting and packing may adequately repair a twist fault caused by localised settlement of the track bed. Following the repair a twist gradient worse than 1 in 400 should not be present in the track. (A difference in rail level of 7mm over 5 sleepers)

The use of hand held stone blowing or on-track machine stone blowing may produce a more durable correction to twist fault than tamping and both methods have the advantage over measured shovel packing of not requiring the cribs or area between sleepers, to be opened out for the work to be undertaken.

Most twist faults will be repaired under traffic within a safe system of work. Whilst carrying out these repairs great care should be taken to ensure that temporary variations in cant or cross level are not worse than 1 in 200 or 15mm in 3000mm. Repairs should be carried out in such a way that the twist fault is reduced and removed. Care should also be taken when lifts greater than 25mm are required to correct twist faults, a TSR may need to be imposed. Where lifting is carried out it may be necessary to return to the site after a short time under traffic to remove the effects of any settlement. Repair to twist faults during hot weather may affect the stability of the track and the critical rail temperature. More information can be found in the Railtrack Company Specification RT/CE/S/011

Your P-way Engineer or responsible manager should be informed if:

- A lift of more than 25mm is required
- When remedial work is necessary during hot weather.

When remedial work is carried out it is essential to ensure that fastenings are correctly tensioned, rails are seated, defective fastening and sleepers are replaced. Adequate ballast must be provided prior to lifting and correct ballast profiles should be left on completion.

More detailed information on maintenance methods can be obtained from the Civil Engineering Conference Track Maintenance Handbook Parts one and two CEC/C/0005 or equivalent P W I Textbooks.

References

Additional information relating to twist and twist faults can be found in your area track technical library:

- Track Maintenance Handbook - Part 1 - Plain Line CEC/C/0005
- Track Maintenance Handbook - Part 2 - Switch and Crossing CEC/C/0005
- Track Construction Standards RT/CE/S/102
- Track Inspection Requirements RT/CE/S/103
- Track Maintenance Requirements RT/CE/S/104
- Continuous Welded Rail (CWR) Track RT/CE/S/011
- London Underground E8404 A3
- PWI British Railway Track, Volume 4

Appendix One

The table below relates to unloaded measurements taken over 3000mm, allowance must be made for voids and design twist (see page 3 and 6).

Difference (mm)	Gradient	Action
5	>1 in 600	No Action
6	1 in 508	Monitor & Repair
7	1 in 435	Monitor & Repair
8	1 in 381	Monitor & Repair
9	1 in 339	Monitor & Repair
10	1 in 300	Monitor & Repair
11	1 in 277	Monitor & Repair
12	1 in 254	Monitor & Repair
13	1 in 230	Monitor & Repair
14	1 in 218	Monitor & Repair
15	1 in 200	10 days
16	1 in 191	10 days
17	1 in 179	10 days
18	1 in 169	10 days
19	1 in 160	10 days
20	1 in 150	10 days
21	1 in 145	10 days
22	1 in 139	10 days
23	1 in 133	10 days
24	1 in 127	10 days
25	1 in 122	36 hours
26	1 in 117	36 hours
27	1 in 110	36 hours
28	1 in 109	36 hours
29	1 in 105	36 hours
30	1 in 102	36 hours
31	1 in 98	36 hours
32	1 in 95	36 hours
33	1 in 92	36 hours
34	1 in 90	Close Line
35	1 in 87	Close Line
36	1 in 85	Close Line
37	1 in 82	Close Line
38	1 in 80	Close Line
39	1 in 78	Close Line
40	1 in 76	Close Line
41	1 in 74	Close Line
42	1 in 73	Close Line
43	<1 in 71	Close Line

Appendix Two
Twist on London Underground

Dynamic twist on London Underground is also measured by a Track Recording Vehicle TRV over a 2 metre base (2000mm). As with other railway track exceedences can be located manually by use of a cross level gauge. In this case measurements being taken over a 2 metre base. Allowance must be made for dynamic movement.

Tolerances for track category					Minimum Action	Notes
Exceedence	A	B	C	D		
All Lines except defined lines						
Level 3	25mm	25mm	25mm	25mm	Inspect within 24 hour repair within 48 hours	1
Level 2	20mm	20mm	20mm	20mm	Inspect and rectify within 8 weeks	
Level 1	12mm	13mm	15mm	18mm	Plan maintenance if required	
The Defined Lines are: All of the District Line The Piccadilly Line - Baron Court to Northfields and Hanger Lane Junction All of the Jubilee Line The Metropolitan Line - Finchley Rd to Wembley Park						
Level 3	20mm	20mm	20mm	20mm	Inspect within 24 hour repair within 48 hours	1
Level 2	18mm	18mm	18mm	19mm	Inspect and rectify within 8 weeks	
Level 1	12mm	13mm	15mm	18mm	Plan maintenance if required	
Note 1: If the 2 metre twist is over 25mm impose 10mph speed restriction and correct within 24 hours. 25mm over 2000 mm equates to a 1 in 80 twist gradient.						

The latest version of London Underground E8404 A3 Track Geometry and Condition Standards Manual should be consulted.

Notes

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