Survey of Techniques and Approaches for Increasing the Lateral Resistance of Wood Tie Track

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This report presents a review of the lateral resistance characteristics of wood and concrete cross-ties together with a survey of techniques, systems and approaches used to increase the lateral resistance of wood tie track to approach that of concrete ties. As part of this activity, the existing wood tie track structure's lateral resistance was compared to concrete tie track, based on extensive testing performed to date in the US and internationally. Different options for increasing the lateral resistance of wood tie track are discussed together with the expected increased lateral track resistance.

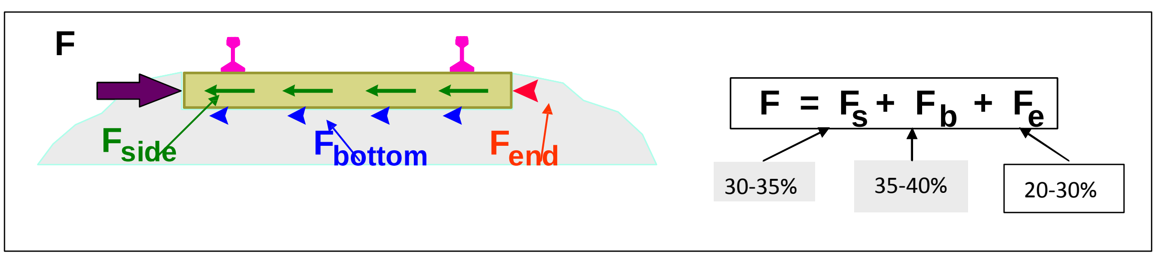
The data and literature examined included extensive single tie push test data performed by the Federal Railroad Administration and the AAR, laboratory test data to include the AAR track lab and overseas, international testing, and studies performed at major international laboratories and centers.

Lateral Resistance of Cross-Tie Track

As noted in Figure 1, the lateral resistance of cross-tie track consists of three basic components [1, 2, and 3]:

- End Resistance - resistance between the end of the tie and the ballast at the end of the tie, primarily the ballast shoulder. (Fe = Fend)
- Bottom Resistance - resistance generated by friction/interaction between the base of the cross-tie and the ballast under the tie (Fb= Fbottom)
- Side resistance - resistance generated by friction/interaction between the sides of the cross-tie and the ballast between the ties, the crib ballast
- (Fs= Fside)

Figure 1 – Lateral Resistance Components (Kish)



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As noted in Figure 1, the bottom resistance or friction represents the largest component of lateral resistance, of the order of 35 to 40%, followed by the side resistance or friction which is of the order of 30 to 35% and the end resistance which is of the order of 20 to 30%.

However, this relationship can change significantly. For example, under a heavy freight car or locomotive, where uplift occurs (Figure 2), the ties can be lifted up from the ballast, reducing the bottom resistance. In this case, the importance of the side and end ballast resistance increases significantly.

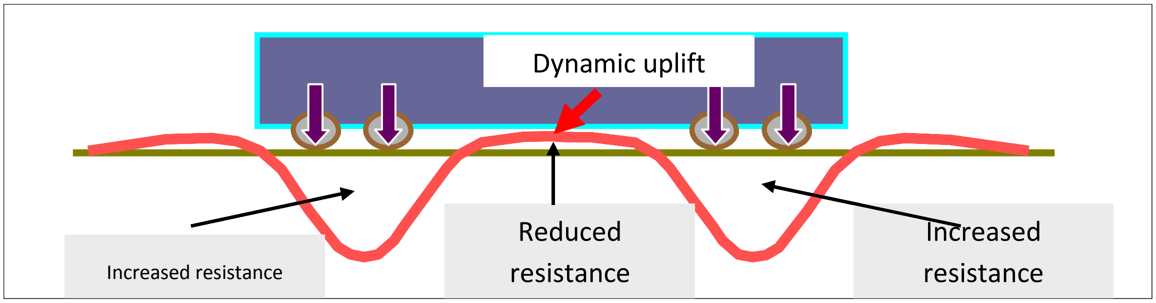


Figure 2: Reduced Resistance Due to Uplift of the rail

Thus it is important to maintain all three components of the ballast resistance. This is particularly the case for cribs and shoulders which are not often maintained to the full dimensions required by the track structure. Thus, adequate shoulders will provide lateral restraint to the cross-ties (and the track superstructure itself), resisting both short term and long term lateral movement of the track, and facilitating maintenance of the track alignment. This is particularly true for continuously welded rail (CWR) track, where inadequate ballast shoulders, and the associated inadequate lateral track resistance, can result in rapid loss of alignment or even buckling of the track structure. Studies have shown that inadequate shoulders can result in a loss of overall track resistance of the order of 20 to 30, and in some cases up to 40+ % [1, 2, 3, 4, and 5].

Similarly, full cribs will provide longitudinal resistance to the movement of the ties, to prevent tie skewing or movement along the track. Tests have shown that half empty cribs can reduce tie longitudinal restraint by the order of 30% or more. This longitudinal restraint is of even more importance on grades, where full cribs (together with adequate longitudinal anchoring) will prevent creep of the rail or movement of the ties under traffic loading. In addition, the cribs also provide supplemental lateral resistance for the track, of the order of 30 to 35%[1] of the total lateral resistance [1,2,3,4,5].

Figure 3 defines the lateral and longitudinal resistance behavior of cross-ties in track.

[1] There is a strong interaction between the crib and base friction lateral resistance.[2]

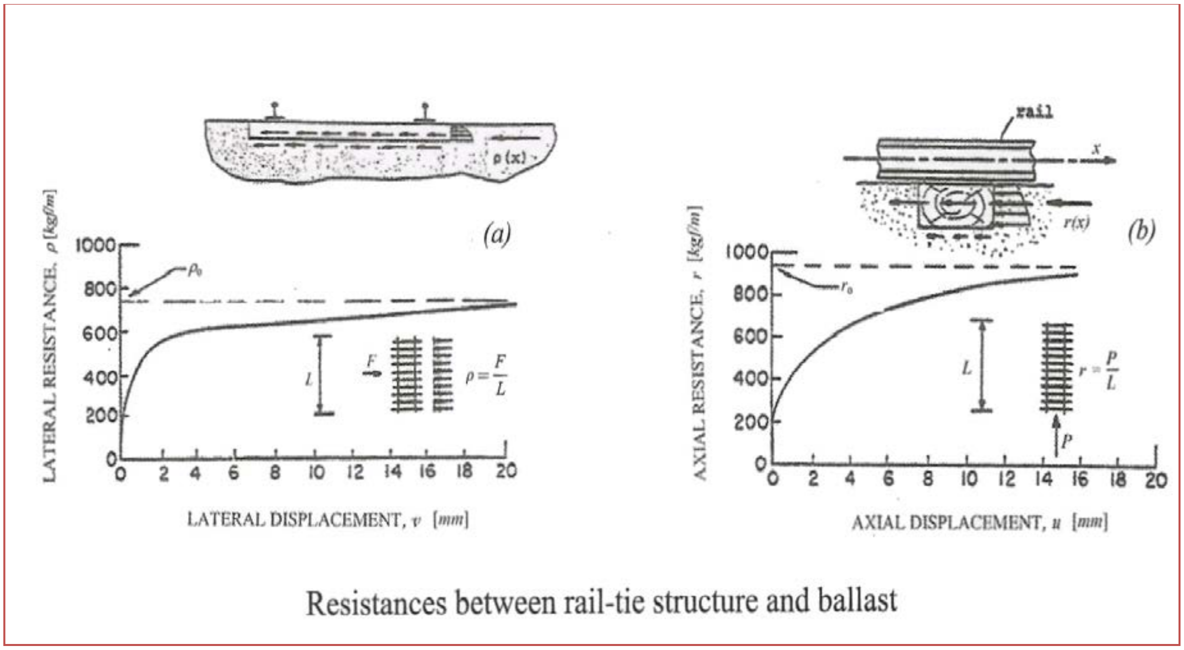


Figure 3: Lateral and Longitudinal track resistance

Focusing on the lateral resistance of the track, the lateral track resistance can be defined in one of two ways:

- Track resistance per foot where the total track lateral resistance is obtained by loaded the track laterally and measuring the lateral deformation curve. The lateral resistance is then the applied force divided between the distance the track is deformed
- Single tie push test where a single tie is separated from the track (by removing the fasteners) and then displaced laterally.

Noting that the single tie push test is significantly easier to perform, it has been adopted as the ‘standard" for lateral resistance measurement in the US.

Figure 4 illustrates the shape of the load- deflection curve obtained from a single tie push test. As can be seen in this Figure for well consolidated track, there is a linear increase in resistance in load until a maximum value Fp is reached. This is termed the Peak Resistance of the tie, after which there is a ‘softening" in the load deflection behavior. This Fp value is usually defined as the tie lateral resistance as was illustrated in Figure 1. For weaker track, there is no corresponding softening behavior, so that the Fp value remains constant through the balance of the load- deflection behavior.

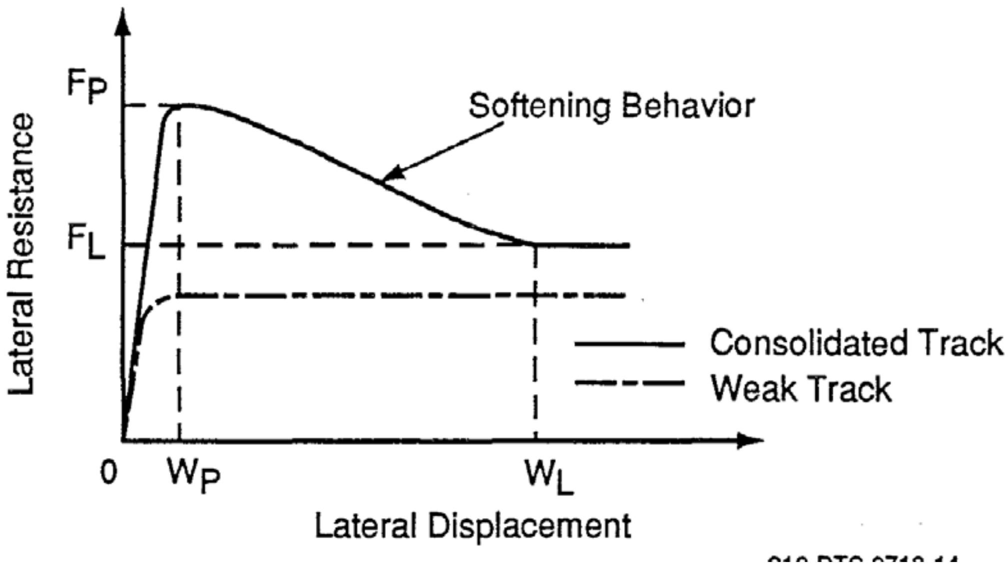


Figure 4: Single tie push test load-deflection curve.

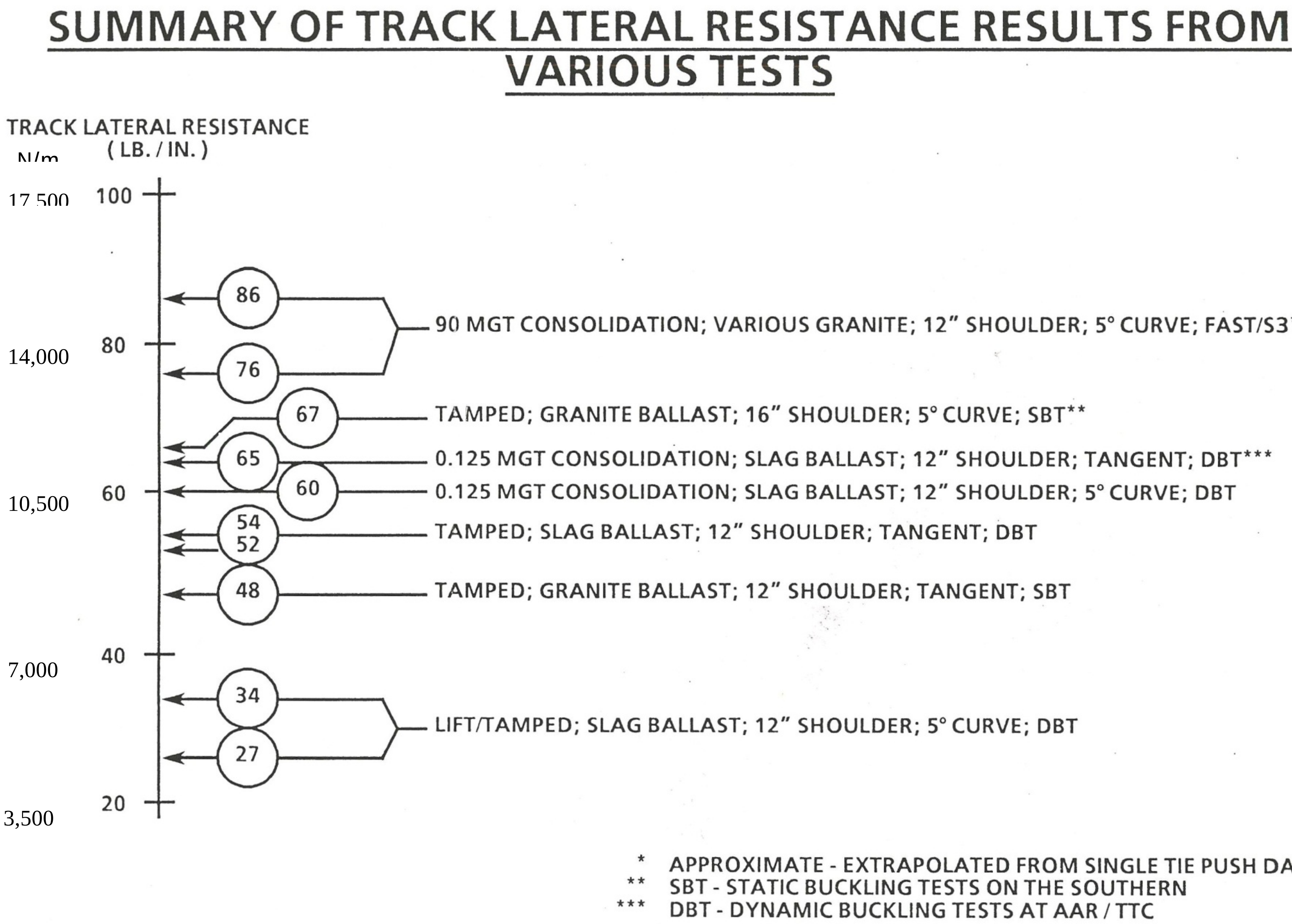
Testing in the US and elsewhere has provided the following ranges of peak lateral resistance values (per tie); note all values are in lbs. of force (Table 1).

TABLE 1: Wood and Concrete Tie lateral resistance (Single Tie Push tests)

	Wood Tie	Concrete ties
Strong	> 2500	> 3000
Average	2000-2500	2500- 3000
Marginal	1500-2000	2000-2500
Weak	<1500	<2000

Strong lateral resistance track refers to track that is well consolidated, with full shoulders and cribs. Weak track generally includes poorly consolidated (or recently disturbed) track often with inadequate shoulders and cribs. This is illustrated in Table 2, where it can be seen that weak or disturbed timber tie ballasted track generates a lateral resistance of 30 to 50 lb./in which for 20” tie spacing corresponds to a range of 600 to 1000 lbs/tie, similar to that shown in Table 1 for disturbed or weak timber tie track.

Table 2: Lateral Resistance as a function of various ballast and track factors (note resistance here is defined in lb/in as compared to lb/tie.)



Figures 5 and 6 show the effect of tie type and maintenance in graphical format. Again note that timber ties in recently disturbed (post-maintenance) ballast generate lateral resistance values of the order of 700 to 800 lbs/tie as compared to concrete ties which generate lateral resistance of the order of 800 to 1000 lb/tie.. For consolidated track, under comparable conditions, timber ties generate lateral resistance values of the order of 1300 to 1400 lbs/tie as compared to concrete ties which generate lateral resistance of the order of 2200 to 23000 lb/tie. European data in Figure 6 shows comparable lateral resistance values.

Figure 5: Lateral Resistance as a function of wood vs. concrete tie and track maintenance

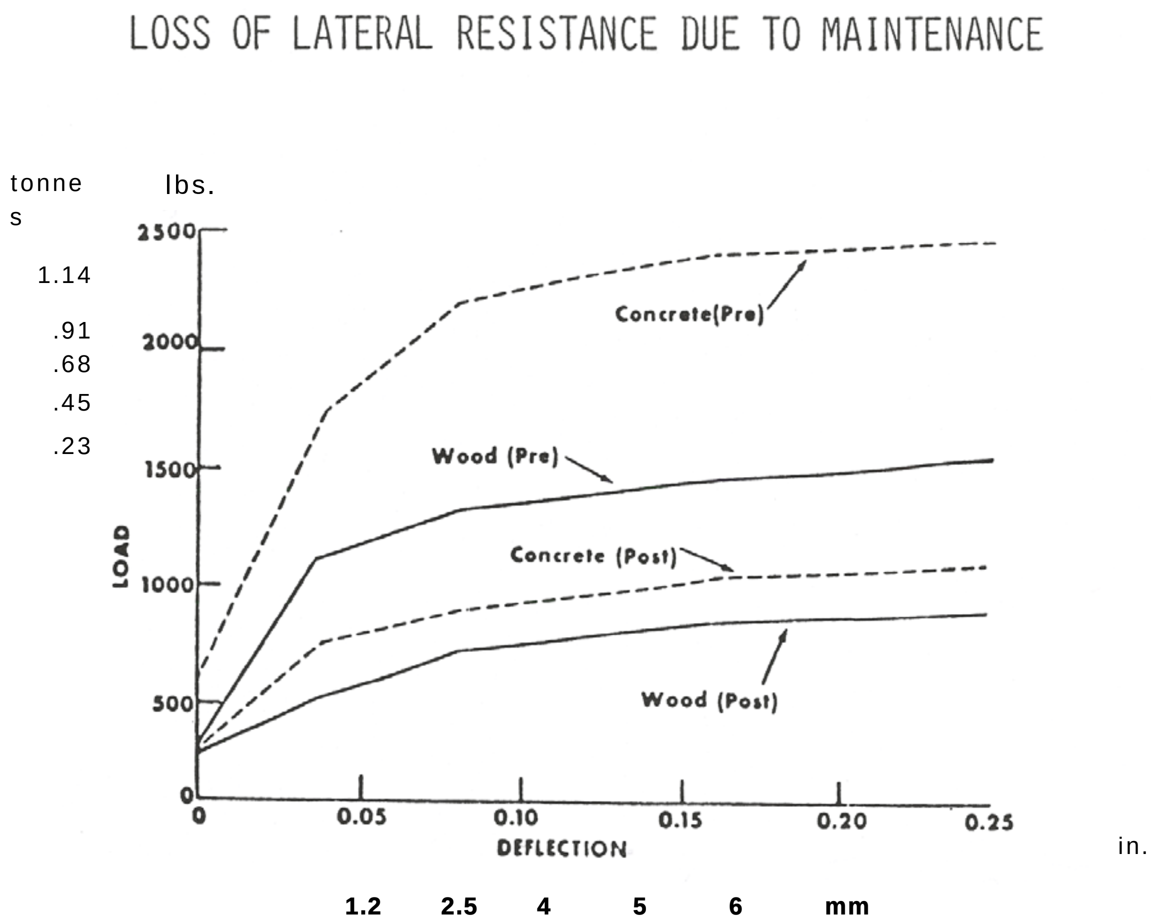
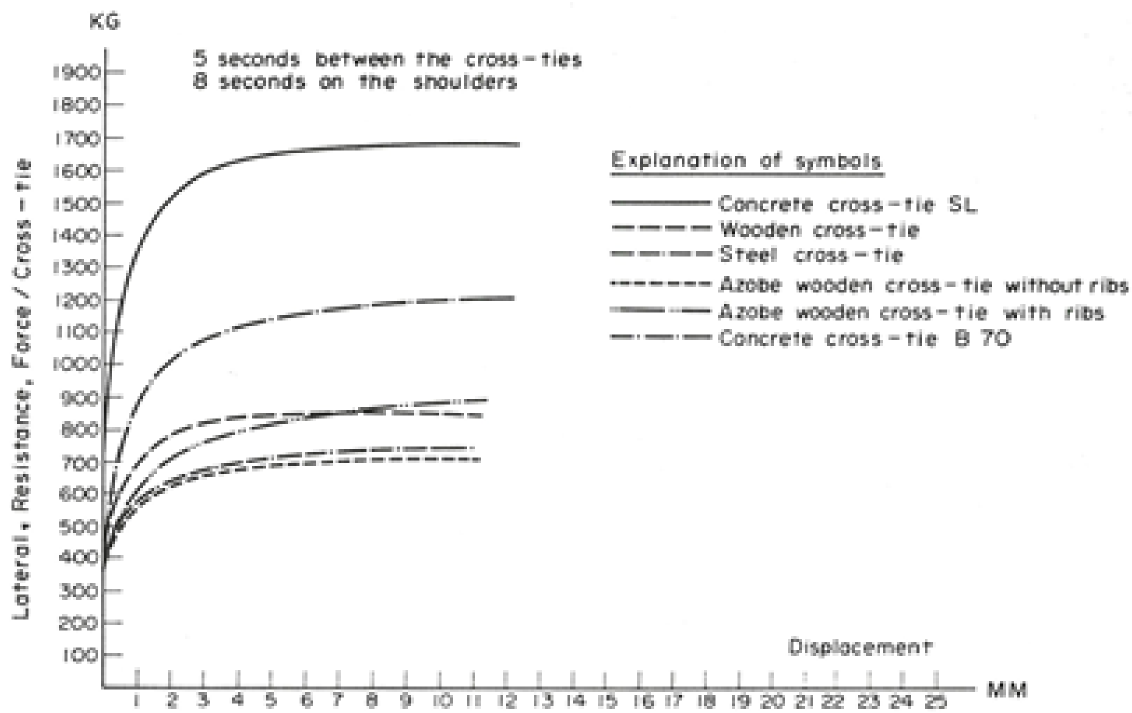


Figure 6: Lateral resistance of different tie types from European Test Data [3] (1 kg = 2.2 lb)



Comparison Between Various Ties. Ballast Compression Time T = 5/8.

Similar differences are observed between wood and concrete ties in their longitudinal resistance as shown in Table 3.

Table 3:: Longitudinal Resistance of wood vs. concrete ties (per tie basis)

LONGITUDINAL RESISTANCE* (LBS PER TIE)

	WOOD TIE**		CONCRETE TIE***	
MGT	TANGENT	CURVE	TANGENT	CURVE
0	2588	2763	3106	3316
.5 to 1	3030	3476	5060	5805
1 to 2	3194	3814	5334	6369
Average (all cases)	3180		5310	

* Defined to be longitudinal force necessary to displace tie .08 inches (Reference 5)

Increasing Lateral Resistance

Table 4 presents different techniques for increasing the lateral resistance of cross-ties in ballast track together with their relative influence of on the lateral resistance of the track [3].

TABLE IV The Influence of Various Factors on the Lateral Resistance of the Track (the assessment of factors marked with an asterisk also applies to the axial resistance)

	Very Good	Good	Little (or no) influence	Poor	Very Poor
*Tie weight (concrete ties)		×			
*Tie width		×			
Tie height	×				
Tie length		×			
Discontinuous ties (block-type ties)	×				
Friction at the bottom of ties (grooves)	×**	×			
Safety caps	×				
*Increase of the size of the ballast		×			
Admixtures added to the ballast		×			
Lateral raising of the track benches	×				
Increased width of the track benches			×		
Increased thickness of the ballast under the bottom of the tie			×		
Increased thickness of the ballast above the bottom of the tie	×				
Tie spacing		×*	×		
Transverse inertia of the rails		×			
Tightness of fastenings (stiffness of the track panel)			×		
* Raising of track level					×
*Shovel packing					×
*Tamping				×	
*Compacting	×				
*Train speed			×		
*Load (heavy of loaded track)		×			
Temperature			×		

*Observation applicable to the axial resistance of the track

As can be seen from this Table, there are several design features that can provide significant benefit in increasing lateral track (and tie) resistance.

These include:

- Increased ballast shoulder width and height (track "benches").
- Compacting/consolidation of ballast
- Discontinuous ties
- Increasing Tie Height, width and/or length and tie weight
- Safety caps
- Decreasing tie spacing
- Increasing fastener rotational resistance
- Friction at bottom of ties (grooves)

The first two techniques are the most commonly employed techniques both in the US and internationally, and they are effective, however they focus on the ballast as opposed to the ties. Thus they are equally applicable to increasing the resistance of wood tie track as concrete tie track. Virtually all major US railways increase shoulder width on CWR track in curves or in buckling prone territory, to increase lateral resistance. They also use ballast consolidators to increase lateral resistance of disturbed ballast, such as after maintenance operations such as tamping, tie insertion, etc. In Europe, the use of track benches, to increase the height of the ballast shoulder above top of tie has been used and found to be effective [3].

The use of discontinuous ties applies primarily to two-block concrete ties and is not applicable to wood ties.

Increasing the tie height or length can be of potential interest, but has a cost impact in direct proportion to the percentage increase in the amount of wood in the tie. While the UP used 9' ties for many years (and still uses them for some applications), the most common length of tie is 8 1/2''. Standard cross-tie height is 7", though ties used in less demanding applications are 6" in height. This will be discussed further in the next section on techniques to improve lateral resistance of wood ties.

Deceasing tie spacing from the standard 19.5" spacing also represents an economic cost-benefit trade off, however the amount of decrease may be limited by the requirements for maintaining sufficient crib spacing to allow for maintenance such as tamping, tie removals, etc.

Use of end or safety caps will be discussed in detail in the next section on techniques to improve lateral resistance of wood ties.

The effect of increased fastener rotation resistance will be discussed in detail in the next section on techniques to improve lateral resistance of wood ties.

The effect of increasing friction on bottom of ties will be discussed in detail in the next section on techniques to improve lateral resistance of wood ties.

Techniques to Improve Lateral Resistance of Wood Ties

Increasing tie length or height

Increasing the tie height or length has been shown to increase lateral resistance of the tie in ballast, but has a cost impact in direct proportion to the percentage increase in the amount of wood in the tie. While the UP used 9' ties for many years (and still uses them for some applications), the most common length of tie is 8 1/2''. Standard cross-tie height is 7", though ties used in less demanding applications are 6" in height. This is primarily an economic question relating to the increase in cost of the ties plus any costs due to changes in tie handling equipment versus the benefits associated with the increased costs. This requires a detailed cost benefit analysis which is beyond the scope of this report. However, cost increases are primarily linear with change in either length of height. Lateral resistance increase in linear with length for that percentage of lateral resistance due to side pressure (30-35%) but this can be significant for curves and other areas where lateral track geometry related maintenance costs are high.

Deceasing tie spacing from the standard 19.5" spacing also represents an economic cost-benefit trade off, however the amount of decrease may be limited by the requirements for maintaining sufficient crib spacing to allow for maintenance such as tamping, tie removals, etc.

Increasing base or side friction on wood ties

The effect of increasing friction on bottom or sides of ties has in fact been an issue addressed with several types of concrete tie designs, where there was limited friction between the tie top/side and the ballast. Generally, this has not been the case for traditional hardwood or softwood ties, where the ballast particle pressure at the interface with the tie caused 'indentations' in the wood, resulting in a good frictional contact.

However, studies in Europe with the use of ribs or indentations under timber ties result in reported improvement in lateral resistance [3]. While this approach has not been used in the US on timber ties, it has been used effectively on plastic and composite ties to increase lateral resistance though increasing base friction with the top of the ballast under the tie or side friction with the ballast in the cribs (see Figure 7).

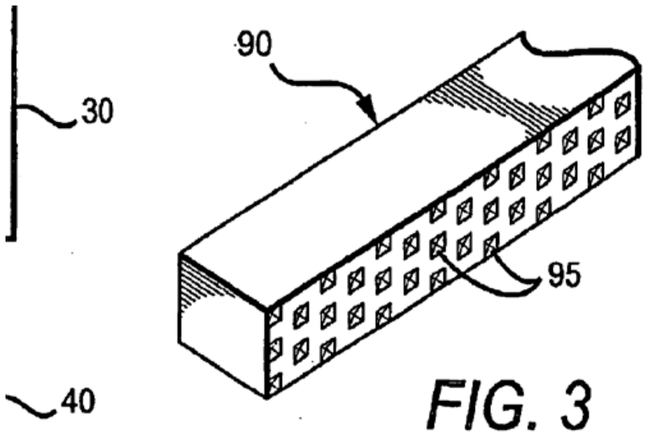


FIG. 3

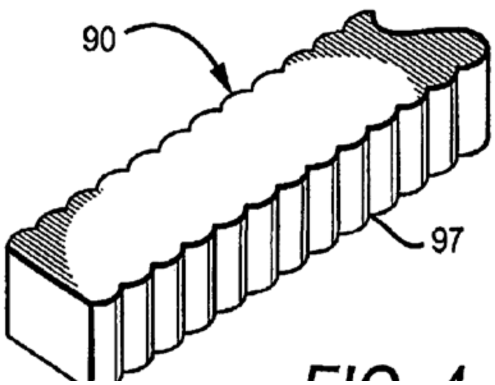


Figure 7: Indentation in Rubber or Composite Ties

Tie End or Safety Caps

Use of end or safety caps (also referred to as sleeper anchors) on timber ties likewise has been used extensively in Europe to improve lateral resistance of wood ties. Figures 8 and 9 show several different end cap configurations used in Europe.

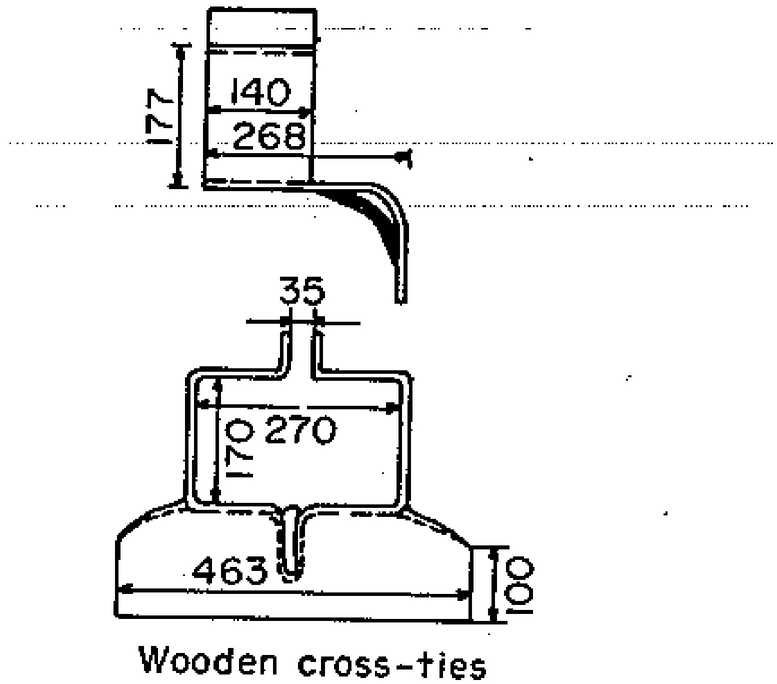


Figure 8: End or Safety Caps for Wood Cross-Ties

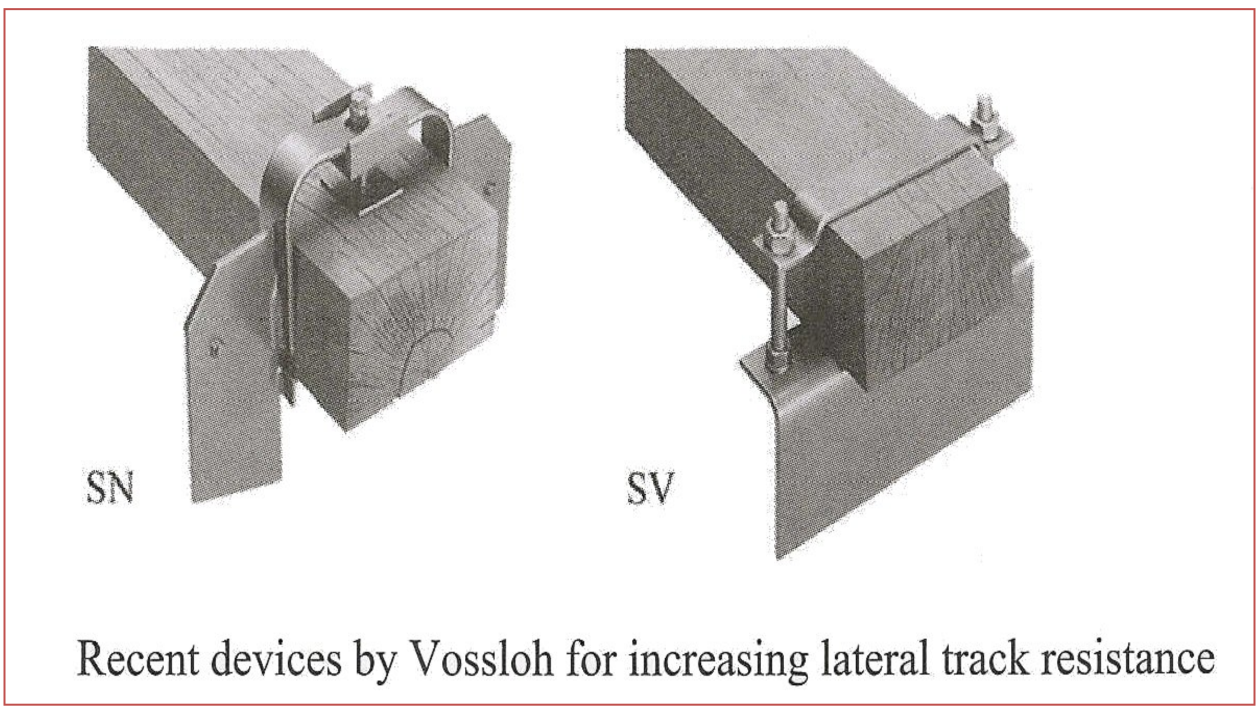


Figure 9: Vossloh Design Sleeper Anchor for Timber Ties

As noted in Figure 10, European practice is to add a safety cap every second or third tie.

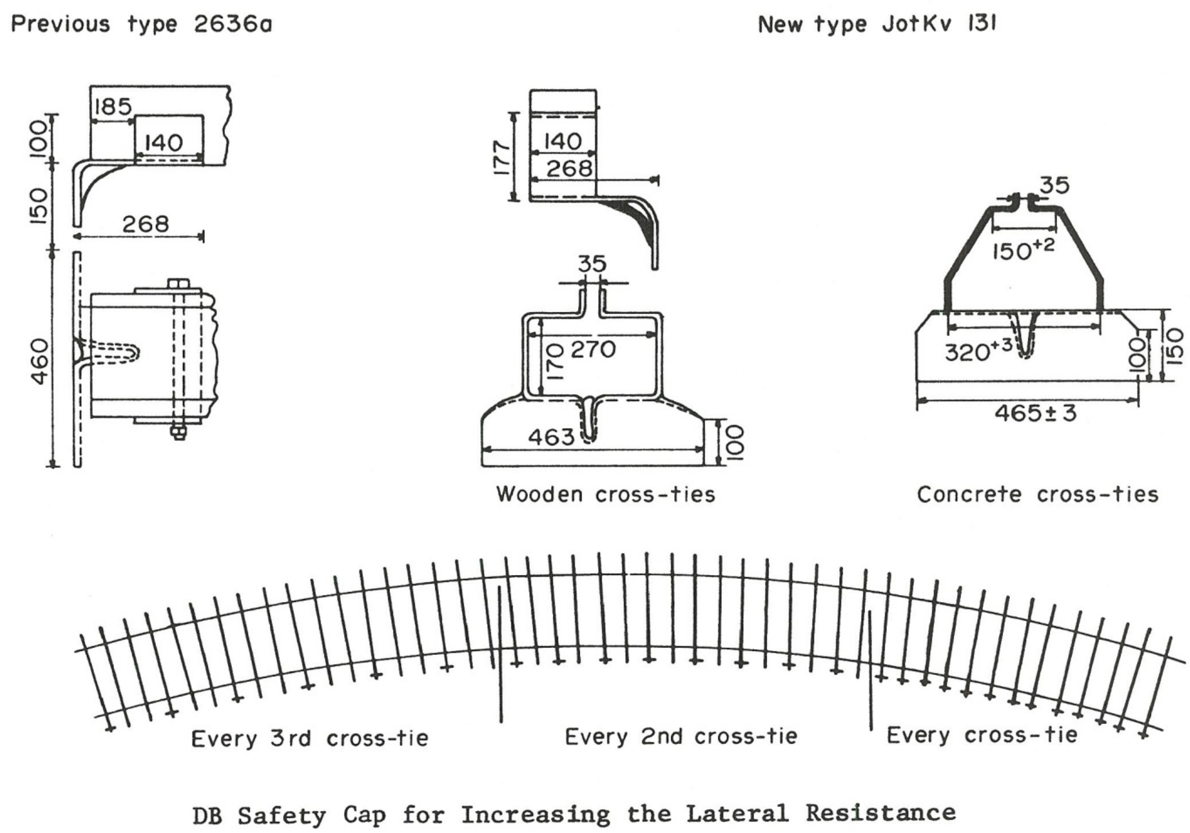


Figure 10: Use of tie safety caps on every tie, every second or third tie

As can be seen in Figures 11 European tests on lateral track resistance of ties equipped with safety caps show a significant increase in lateral resistance of the order of 50% for non-compacted or disturbed ballast. This corresponds to an increase from 600 kg or 1300 lbs. per tie without end caps about 900 kg or almost 2000 lb with end caps. Note, however that for these tests, there is only a relatively small improvement in using safety caps on every tie as opposed to every second tie, as noted in Figure 10. Figure 12 shows that reducing the number of safety caps to every third tie results in an approximate 15% reduction in lateral resistance from the every second tie design configuration (for compacted ballast). Thus, as noted previously, it is not necessary to place safety caps on every tie in a curve or in a buckling prone location, but rather every second or third tie is sufficient (and more economical).

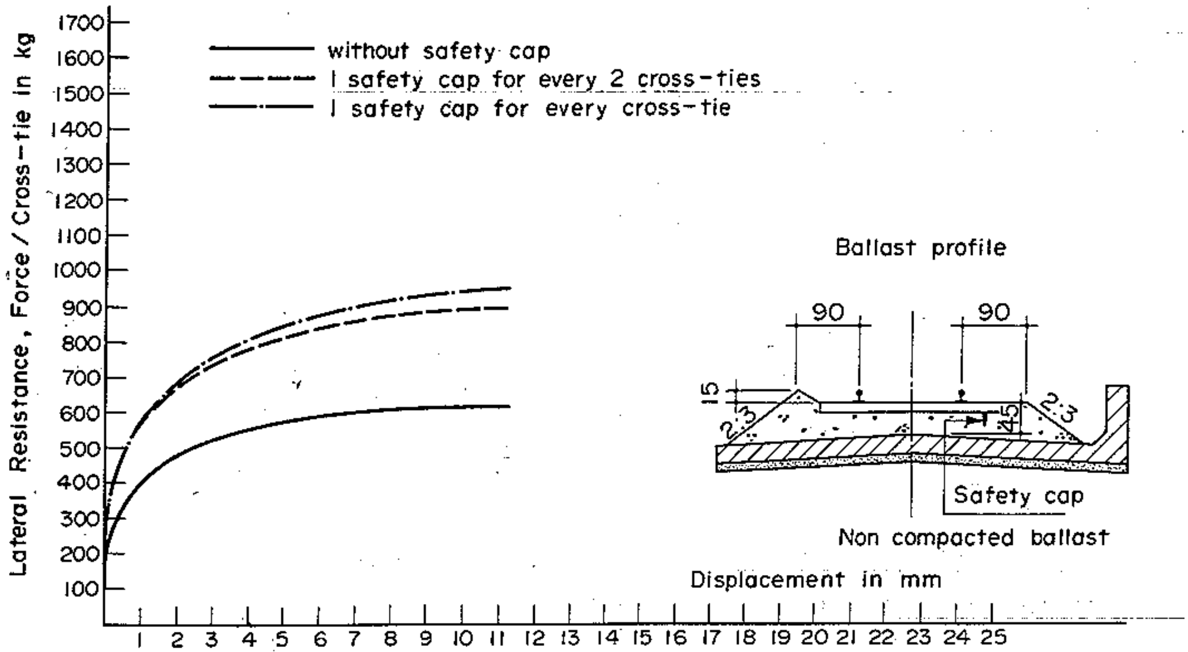


Fig. 13 Influence of Safety Caps. Wooden Cross-Ties.

Figure 11: Lateral Resistance of track with and without safety caps (non-compacted ballast) [3]

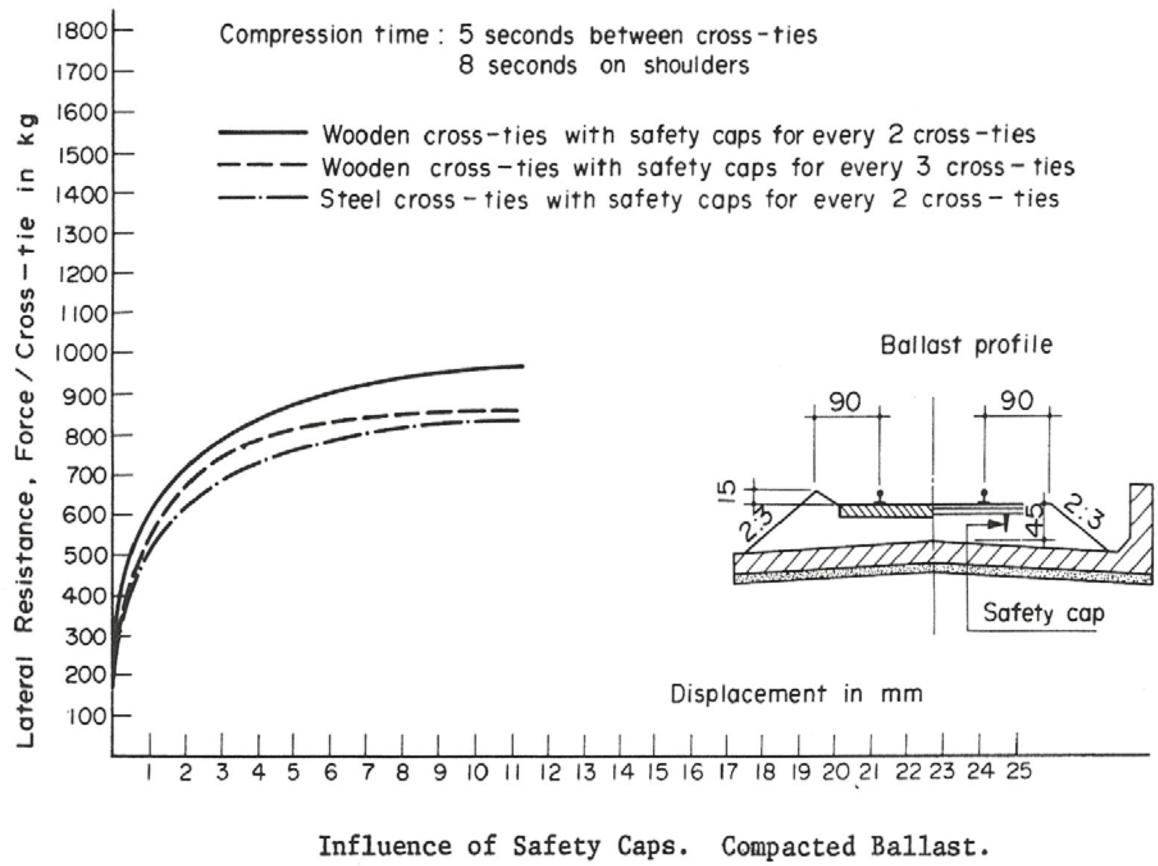


Figure 12: Effect of safety Caps on Compacted ballast [3]

Increased Fastener Rotational Resistance

Several studies have examined the effect of fastener rotation resistance, s, which is the proportionality constant between the resistance moment (per unit length of rail) and the rotation of the rail axis [7,8]. This includes both theoretical analyses and experimental determination.

Both the analytical and test results show that when the torsional stiffness of the fasteners is virtually, non-existent, such as the case with cut spike fasteners, the cross-ties act merely as spacers and a bending moment of the rail-tie structure is carried by the bending stresses of the two rails. However, when the fasteners exert a resistance against rotation (s >0) the bending moment is carried not only by the bending stresses of each rail, but also by the axial forces in the rails, as shown in Figure 13. Thus, in general, the both the gage and the fastener resistance will have an effect on the lateral response when s>0. This is illustrated in Figure 14 which shows the effect of the torsional fastener stiffness, represented by s, on the lateral track displacement $\hat{v}$. As can be seen from this figure, the lateral displacements for s = 20 ton-m/rad are less than a tenth of the corresponding values for s = 0. Also, the lateral displacements for s = 50 are less than one half of those for s = 20.

Thus, based on Figure 14 the effective track lateral bending stiffness (EI) increases with increasing fastener rotational s. This in turn indicates, that increased lateral resistance of wood tie track can be accomplished by using elastic fasteners with rotational or torsional stiffness greater than traditional cut spike track (which approaches s= 0). It should be noted, that this behavior will not be seen in a single tie push test, where the tie is disconnected from the fasteners and rails, but is seen when the track superstructure is evaluated as a single entity (corresponding to the first of the two methods of determining lateral track resistance discussed at the beginning of this report, track resistance per foot where the total track lateral resistance is obtained by loaded the track laterally and measuring the lateral deformation curve, and the lateral resistance is then the applied force divided between the distance the track is deformed.)

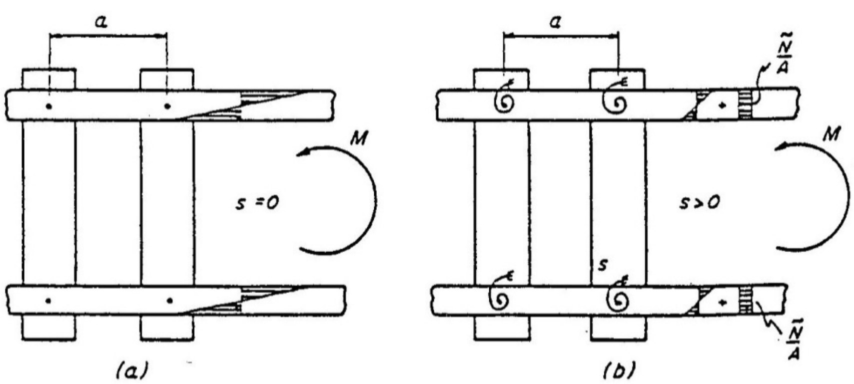


Figure 13: Effect of rotational fastener stiffness, s, on rail stresses.

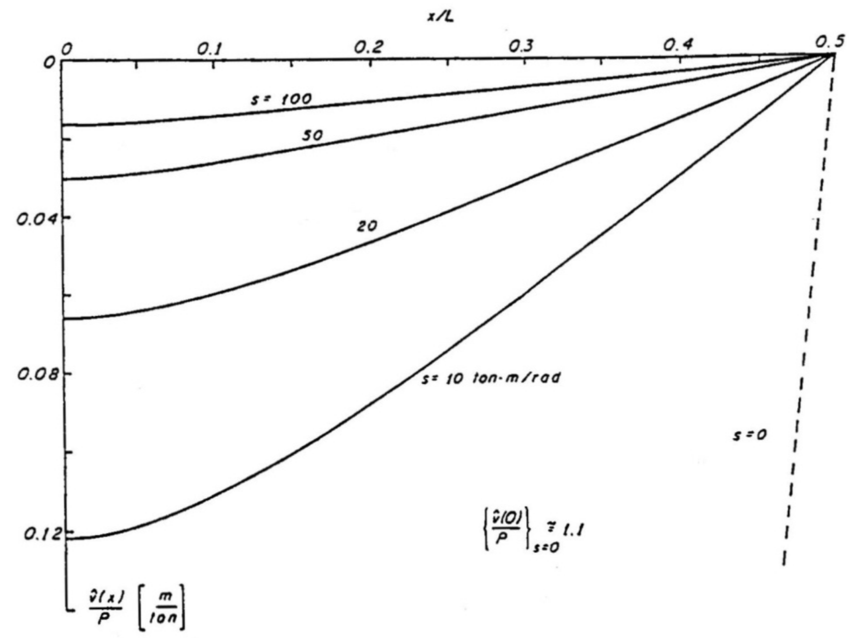


Figure 14: Effect of torsional stiffness of fasteners on track lateral displacements

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