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Study on the Effect of Maintenance Conditions of Turnout for Switch Throwing Force

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Abstract

Turnouts consist of complicated and movable structures, therefore the risk of failures is higher than a normal track. Though there are various causes of switch failures, the influence of track irregularities and maintenance conditions for switch failures is still unknown. To avoid the switch failures, it is required to study the influence between switch throwing force and track irregularities and maintenance conditions. In this paper, we make formulae to calculate the switch throwing force depending on the types of track irregularities and maintenance conditions and calculate them in a case as an example. The results showed that the influence of the vertical and lateral displacement of the area near the tip of the tongue rail, the lubricated condition on the slide baseplates and the over tensioning of a stretcher bar are significant in some cases.

Keywords: turnout, switch, tongue rail, switch failure, track irregularities, switch throwing force, stretcher bar.

1 Introduction

Turnouts have complicated and movable structures, therefore the risk of failures such as switch throwing failures is higher than that of normal track. The causes of turnout failures include (1) foreign matter, (2) mutual contact between components, (3) failure of locking device, and (4) increased switch throwing force (STF). While the mechanisms of (1) to (3) are relatively simple, the cause of (4) increased STF is sometimes treated as unknown because it is caused by various competing conditions of the turnout.

Therefore, a simple and quantitative method to determine how the STF is affected by the maintenance condition of turnouts was studied. In this paper, we developed a formula to determine how the STF increases with track displacement and the state of maintenance of track components and attempted to calculate it.

2 Methods

(1) Methods of proceeding with the study
The basic policy of the study is to create a formula for calculating the STF depending on the maintenance conditions of a turnout by extending the formula for calculating the designed STF (simple structural calculation) of the previous study [1]. The final goal is to indicate the items of the turnout maintenance conditions that affect the increase of the STF.

(2) Turnout types
The type of turnout targeted in this study is a low-numbered turnout (No. 8 to 12) that throws the tongue rail at a single point, and the types of points were hinged points and elastic points [2].

(3) Assumed turnout maintenance condition items
a) Track conditions (track displacement, etc.)
 1) Vertical direction (vertical and cross-level displacement)
 2) Lateral direction (lateral and gauge displacement)
 3) Longitudinal direction (misalignment of a tip of tongue rails)
b) Maintenance conditions of turnout components
The maintenance conditions of the turnout components include, for example, 1) adjustment (tension) of a second stretcher bar (SSB), 2) lubrication on slide baseplates, 3) functional condition of ball bearings on slide baseplates and so on. It is focused on 1) and 2) in this paper.
c) Calculation image of STF
Assuming that the designed STF is Q_0 and the increased STFs due to each of the items described above are $Q_1 \sim Q_n$ respectively, the actual STF (Q) including the influence of maintenance conditions of turnouts is calculated by $Q = Q_0 + Q_1 + Q_2 + \cdots + Q_n$. In addition, the STF can be calculated for each of the left- and right-hand tongue rails (Q_l and Q_r; hereafter referred to as $Q_{l,r}$ when both are referred to collectively), and the total STF can be obtained by adding both together.

3 STF formulae for design [1]

(1) The hinged points
The STF of the hinged points is calculated by the frictional force due to the weight of the tongue rail [1]. Equation (2) represent the values for the left- and right-hand tongue rail, respectively.

$$Q_0 = Q_l + Q_r \tag{1}$$

$$Q_{l,r} = \frac{(l+d)^2}{2l} \cdot w \cdot \mu \tag{2}$$

Where Q_0 is designed STF (kN), $Q_{l,r}$ are the STF of left- and right-hand tongue rail (kN), w is a unit weight of the tongue rail (kN/m), μ is a coefficient of friction between the tongue rail and slide base plates (generally 0.2 in lubricated condition), $l + d$ is a length of the tongue rail throwing section (m).

(2) The elastic point
The STF of the elastic point is calculated by the equation (3) described below. The force to deflect the tongue rail (elastic force, $P_{l,r}$) is added to equation (2) in 3. (1) [1]. As a design concept of the elastic point, $P_{l,r}$ is zero when the tongue rail is contact with the stock rail and is maximum value when the tongue rail is opened.

$$Q_{\,l,r} = P_{l,r} + \frac{(l+d)^2}{2l} \cdot w \cdot \mu \tag{3}$$

Where $P_{l,r}$ is elastic force (kN) of left- and right-hand tongue rails, l and d are shown in Figure 1, and others are the same as in 3. (1). Here, $P_{l,r}$ is obtained by giving the amount of deflection y_c as same as the throwing stroke of the tongue rail. Specifically, it is expressed by equation (41) (hereinafter referred to as equation (41)) in Ref. [1] P.481. The calculation model and equation are shown in Figure 1.

$$y_c = \frac{P}{E}\left[A\left(\frac{\ell a^2}{2} - \frac{a^3}{6}\right) + A\left(la - \frac{a^2}{2}\right)b + B\left(\frac{b+c}{2}b^2 - \frac{b^3}{6}\right) + \left\{A\left(la - \frac{a^2}{2}\right) + B\left(\frac{b^2}{2} + bc\right)\right\}c + \left(\frac{Dc}{2}c^2 + \frac{C_I c - D}{6}c^3 - \frac{C_I}{12}c^4\right)\right] \quad \cdots\cdots (41)$$

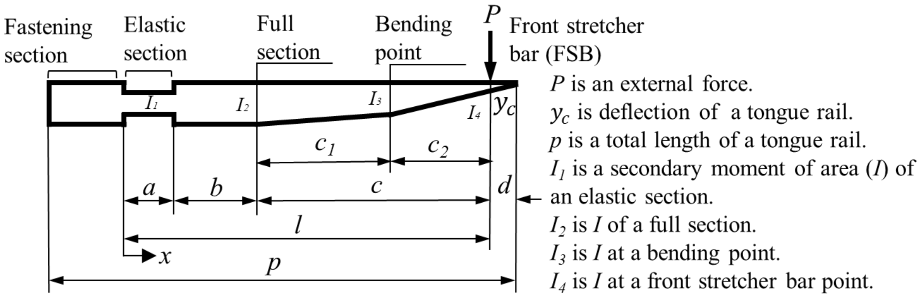


Figure 1: Model for calculating the STF of an elastic point [1]

4 Creating formulae for calculating STFs by track displacements and maintenance conditions of track components

(1) The vertical direction (vertical displacement)
a) A point of action of tongue rail friction force and the STF formula (for the hinged points)
Since the stock rail is strongly fastened to the baseplates, Figure 2 shows the calculation model assuming that the vertical displacement of the stock rail is almost same as that of the baseplates and that the peak position of the baseplates is the point of action of the tongue rail friction force (hereinafter called the “the point of action” or “the supporting point”). In Figure 2, the influence of the contact between a front

stretcher bar (FSB) and the stock rail, which will be described later, is not considered, the rear end of the tongue rail is assumed to be a hinge due to the so-called heeled joint, and the distance from the rear end of the tongue rail to the point of action is x_0, by the moment equilibrium, the formula to calculate the tongue rail STF is,

$$Q_{l,r} = (l + d)^2 \cdot w \cdot \mu \cdot \frac{x_0}{l}. \tag{4}$$

Comparing equation (2), which are designed STF, and (4), the STF increases when $x_0 > l/2$ and decreases when $x_0 < l/2$. That is, the STF increases when the point of action is ahead of the centre of the tongue rail.

b) Effects of the tongue rail lift at the FSB position
The FSB has the function of preventing the tongue rail from lifting (especially due to train vibration) near the tip of the tongue rail. Specifically, the FSB that connects the left- and right-hand tongue rails is located directly below the stock rail (see Figure 3).

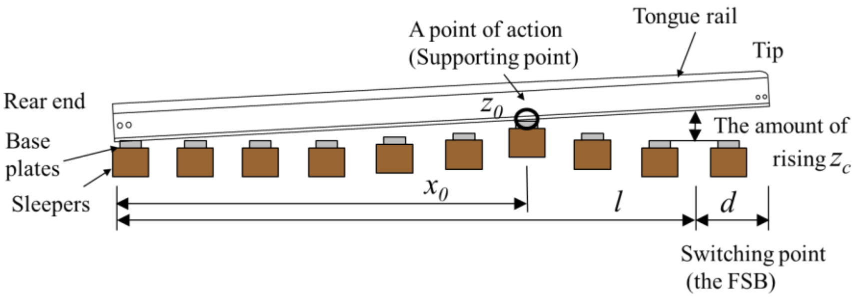


Figure 2: The STF calculation model for vertical displacement
(Ignoring the contact between the stock rail and the FSB)

Figure 3: Anti-jumping function of the FSB

In Figure 2, when the slide baseplate becomes relatively high at the point of action due to vertical displacement, the area near the tip of the tongue rail lifts excessively and the FSB come into contact with the bottom of the stock rail. Since the gap between the stock rail and the FSB is 3 mm by design, if the tongue rail lifts more than 3 mm statically at the position of the FSB, the FSB and the stock rail interfere with each other, causing the tongue rail to deflect downward, which adds frictional force to the STF. This action is known to have a significant effect on increasing the STF [2].

c) The STF when the FSB is in contact with the stock rail
In paragraph a), the effect of the contact between the FSB and the stock rail was ignored, but here the effect of the lifting of the tongue rail at the position of the FSB is considered. The amount of lift of the tongue rail (z_c) at the position of the FSB is determined from the height and deflection angle of the tongue rail at the supporting point in Figure 2 and the dead weight of the tongue rail in front of the supporting

point, and whether this exceeds the design gap of 3 mm or not is used to determine whether to apply Equation (4) or the STF formula considering contact between the stock rail and the FSB, as described later.

d) Calculation of the tongue rail lift at the position of the FSB considering the dead weight of the tongue rail

First, let the height of the tongue rail at the supporting point X in Figure 4 be z_0 (semi-absolute height to the line connecting the front and rear ends of the tongue rail) and the deflection angle be i_0. Once the deflection due to self-weight is ignored here, the amount of the tongue rail lifting z_c at the position of the FSB can be obtained as follows,

$$z_c = z_0 + i_0(l - x_0). \tag{5}$$

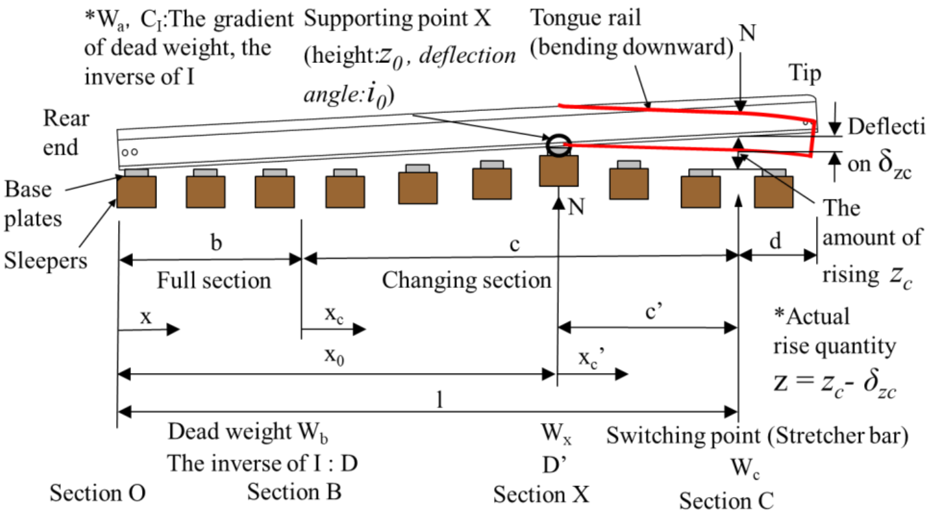


Figure 4: Model for calculating the STF for vertical displacement (Considering the contact between the stock rail and the FSB)

Next, the vertical deflection (δ_{zc}) of the tongue rail due to its own weight at the position of the FSB is calculated assuming a cantilever beam from the supporting point X. To develop the equation, different equations are developed for the sections $0 \le x \le b$ and $b \le x \le l$ in Figure 4. Here, we discuss the latter on the tip side of the tongue rail, which is estimated to have the greatest influence.

Considering the cross-sectional change of the tongue rail, the unit weight is approximated by a first-order equation using the same method as for the moment of inertia of area of the cross-section in the equation (41), and $x_c = x - b$, $W_x = W_a \cdot x_c + W_b$, $c = l - b$ as in Figure 4, the bending moment M in this section is described on the equation (6),

$$M = \frac{W_x + W_c}{2} \cdot (c - x_c) \cdot \frac{c - x_c}{3} \cdot \frac{W_x + 2W_c}{W_x + W_c}. \tag{6}$$

If the inverse of the moment of inertia of area is given by C_I, D as in equation (41), the deflection formula is given by,

$$\frac{d^2z}{dx^2} = \frac{C_I x_c + D}{E} \cdot M. \tag{7}$$

Integrate the equation (7), substituting the boundary conditions of $x_c = 0$ and $i_0 = z_0 = 0$, the formula to calculate the $z(x_c)$ is obtained. Substituting $x_c = c$ into this formula, we obtain δ_{zc}. From the above, the actual amount of lift of the tongue rail (z) at the location of the FSB is $z = z_c - \delta_{zc}$.

e) Calculation of the amount of interference with the stock rail due to the lifting of the FSB and the STF that increases due to the interference

As mentioned above, the design gap $d_c = 3\ mm$ between the FSB (the tongue rail) and the stock rail, the two rails come into contact when the actual lifting of the tongue rail $z \geq 3\ mm$ and the amount of interference (δ_h) is calculated by,

$$\delta_h = z_c - \delta_{zc} - d_c. \tag{8}$$

When $\delta_h \geq 0$, the two rails are in contact and interfere each other. This interference gives a force (*N*) that deflects the tongue rail downward at the position of the FSB, and the reaction force is also applied to the supporting point X, so that a friction force μN acts on each of them (see Figure 4).

Here, *N* is calculated by the equations (9) and (10), using the term for the sectional change in equation (41) and in Figure 4, where $x_c' = l - x_0 = c'$ and $D' = D + C_I \cdot (x_0 - b)$, then,

$$K_z = \frac{D' \cdot c'^3}{2} + \frac{C_I \cdot c' - D'}{6} \cdot c'^3 - \frac{C_I \cdot c'^4}{12}. \tag{9}$$

$$N = \frac{E \cdot \delta_h}{K_z}. \tag{10}$$

Therefore, the STF when the FSB and the stock rail come into contact (interference) can be obtained by adding the terms of μN at the FSB position and the supporting point to the equation (4). The result is obtained by,

$$Q_{l,r} = (l + d)^2 \cdot w \cdot \mu \cdot \frac{x_0}{l} + \mu N \cdot \frac{x_0}{l} + \mu N. \tag{11}$$

f) In the case of the elastic point

In the case of the elastic point, the design is the same as for the hinged points, except that the rear end of the tongue rail is fixed end because it is firmly fastened, and the elastic section must be taken into account. In other words, when the FSB and the stock rail are not in contact, the design deflection force in the left-right direction ($P_{l,r}$ in Eq. (3)) and the friction force (μP_0) due to the reaction force that causes the tongue rail to deflect in the vertical direction at the supporting point on Equation (4). Therefore, the equation (12) is obtained.

$$Q_{l,r} = P_{l,r} + \mu P_o \cdot \frac{x_0}{l} + (l + d)^2 \cdot w \cdot \mu \cdot \frac{x_0}{l} \tag{12}$$

Here, the equation for P_0 is given by the equation (13), which is obtained from K_{z0} by replacing y_c in equation (41) with z_0 in Figure 2, replacing each moment of inertia of area with its vertical value, and replacing the inside of the brackets ([ ]) with the form of P_0 acting on the supporting point X.

$$P_0 = \frac{E \cdot z_0}{K_{z0}} \tag{13}$$

Next, in the calculation of the amount of lifting, there are three sections of the equation $0 \leq x \leq a$, $a \leq x \leq a + b$ and $a + b \leq x \leq l$ due to the presence of an elastic section. In the section of $a + b \leq x \leq l$ which is at the tip of the tongue rail, δ_{zc} is obtained from equations (6) and (7) by setting $x_c = x - a - b$ and $c = l - a - b$, and δ_h from equation (8). Then, if $x_c' = l - x_0 = c'$ and $D' = D + C_I \cdot (x_0 - a - b)$, then equations (9) and (10) give the force (N) to deflect the tongue rail downward. Therefore, the STF when the FSB contacts (interferes with) the stock rail is obtained by adding the two terms of deflection force to equation (11),

$$Q_{l,r} = P_{l,r} + \mu P_o \cdot \frac{x_0}{l} + (l + d)^2 \cdot w \cdot \mu \cdot \frac{x_0}{l} + \mu N \cdot \frac{x_0}{l} + \mu N. \tag{14}$$

(2) The vertical direction (cross-level displacement)

The effect of cross-level displacement is to calculate the load (F) applied to an object (a tongue rail) when it climbs up (or descends down) a slope, taking into account the effect of the slope when the sleeper is inclined in the lateral direction (Figure 5). According to the laws of physics, the object itself generates a force to descend the slope and a frictional force when the object moves on the slope.

If the angle which the sleeper makes with the horizontal plane is θ and the weight of the object is W, then $\theta = \tan^{-1}(\text{a cross level displacement}/\text{ a gauge})$, and $F = W \sin\theta + \mu W \cos\theta$.

Therefore, replacing μ in equation (3) with $\sin\theta + \mu\cos\theta$,

$$Q_{l,r} = P_{l,r} + \frac{(l+d)^2}{2l} \cdot w \cdot (\sin\theta + \mu\cos\theta) \tag{15}$$

is obtained. Note that although the cross-level is described as a displacement, it is also a cant quantity in a curved turnout.

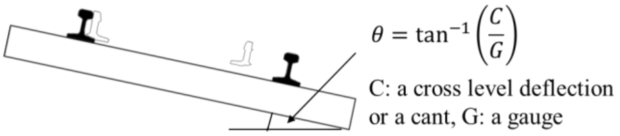


Figure 5: Image of effect on the STF by the cross-level and the cant

(3) The lateral direction (lateral displacement)

a) In the case of hinged points

When lateral displacement occurs on the stock rail, if the rail is convex on the tongue rail side (a track centre side), it is necessary to deflect and throw the tongue rail starting from the convex point (called the maximum lateral displacement point in this paper). Conversely, when the stock rail is convex outward from the track, although a contact gap between the stock rail and tongue rail is generated, the STF is not affected. Therefore, this paper focuses on lateral displacement (semi-absolute displacement to the line connecting the front and rear ends of the tongue rail) in which the stock rail is convex toward the tongue rail.

As with the vertical displacement, the tongue rail changes its cross-section in the longitudinal direction, so the deflection calculation formula to be applied depends on the position (x_0) of the point of maximum lateral displacement. In this study, the simple and reliable equation (41) is applied mutatis mutandis for cross-sectional changes. In the case of the hinged points, the rear end of the tongue rail is a hinged structure, and from there, the full section, the changing section and the FSB (throwing) position are in that order (see Figure 6).

Therefore, there are two formulae for calculating deflection: from the rear end of the tongue rail to the full section ($0 \leq x_0 \leq b$) and from the changing section to the FSB position ($b \leq x_0 \leq l$) as shown in Figure 6. Assuming that the elastic force added by the lateral displacement is P_a, the amount of lateral displacement (= deflection) at the x_0 point is y_0, and the deflection angle is $i_0 = y_0/x_0$, the formula for obtaining the deflection y_c at the position of the FSB is given by equation (16).

$$y_c = y_0 + i_0(l - x_0). \tag{16}$$

Next, making the deflection equation from the point of maximum lateral displacement to the position of the FSB is calculated applying the equation (41), and calculate the value of P_a, which the deflection is y_c. This formula is almost the same as the equation (13) described for the vertical displacement, with the differences being the use of the lateral value for the moment of inertia of area and the deflection being y_c in the equation (16). If, $x_c' = l - x_0 = c'$ and $D' = D + C_I \cdot (x_0 - b)$, then equations (17) and (18) are obtained,

$$K_y = \frac{D' \cdot c'^3}{2} + \frac{C_I \cdot c' - D'}{6} \cdot c'^3 - \frac{C_I \cdot c'^4}{12}, \tag{17}$$

$$P_a = \frac{E \cdot y_c}{K_y}. \tag{18}$$

P_a is simply added to the designed STF since it is the force that occurs when the opposite tongue rail is open, due to the characteristics of the elastic point (the elastic force becomes zero when the tongue rail is in contact with the stock rail). That is, $Q_{l,r} = Q_0 + P_a$.

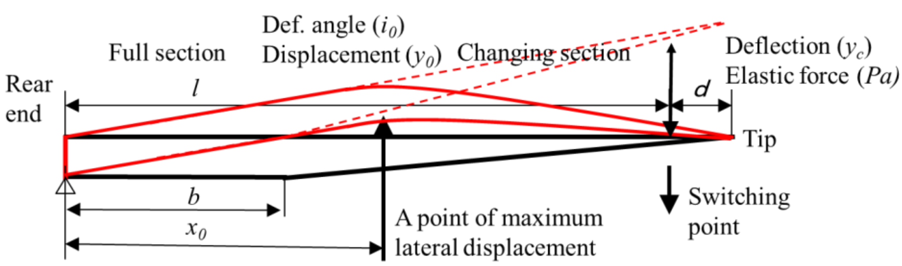


Figure 6: The STF calculation model for lateral displacement (the hinged point)

b) In the case of an elastic point

In the case of an elastic point, the difference compared to the hinged points is that the rear end of the tongue rail is fixed end, and an elastic section is added (see Figure 7).

Therefore, the deflection equation can be divided into three parts: between the fixed end of the tongue rail and the elastic section ($0 \leq x_0 \leq a$), the full section ($a \leq x_0 \leq a + b$), and between the changing section and the FSB position ($a + b \leq x_0 \leq l$)) as shown in Figure 7. As in section a), if the elastic force added by the lateral displacement is P_a, the amount of lateral displacement (= deflection) at the x_0 point is y_0 and the deflection angle is i_0 (due to the virtual load P_0 is obtained applying equation (41)), the amount of deflection y_c at the position of the FSB is obtained by equation (19).

$$y_c = y_0 + i_0(l - x_0) \tag{19}$$

Next, the deflection equation from the point of maximum lateral displacement to the position of the FSB is calculated according to Equation (41), and P_a is obtained by the deflection value being y_c. This formula is the same as the one in section a). If $x_c' = l - x_0 = c'$ and $D' = D + C_I \cdot (x_0 - a - b)$, then,

$$K_y = \frac{D' \cdot c'^3}{2} + \frac{C_I \cdot c' - D'}{6} \cdot c'^3 - \frac{C_I \cdot c'^4}{12} \tag{20}$$

and P_a can be obtained by

$$P_a = \frac{E \cdot y_c}{K_y}. \tag{21}$$

P_a is simply added to the design STF, therefore, $Q_{l,r} = Q_0 + P_a$.

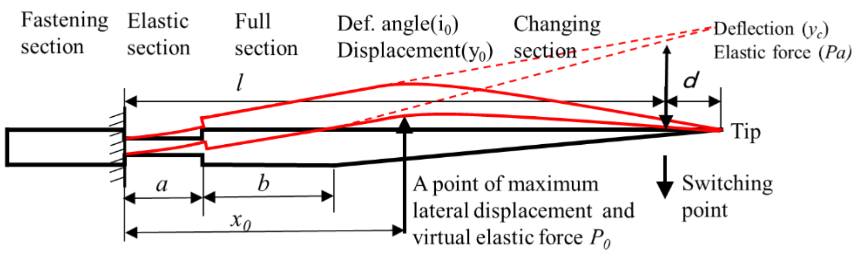


Figure 7: The STF calculation model for lateral displacement (an elastic point)

(4) The lateral direction (gauge displacement)

The displacement of the gauge can basically be expressed as the lateral displacement of the left- and right-hand stock rails, but the direction of the tongue rail at the fixed end of the elastic point is more easily expressed in terms of the gauge. Figure 8 shows the relationship in which the direction of the tongue rail changes due to the change in gauge at the fixed end, and the deflection increases at the position of the FSB.

$$y_{c1} = (y_1 - y_2) \cdot \frac{(l_f + l)}{l_f} \tag{22}$$

where y_1 *and* y_2 are the amount of gauge displacement at the first and second fixed ends (mm), l_f is the distance between the first and second fixed ends (mm), and y_{c1}

is the amount of deflection at the position of the FSB that is added by the gauge displacement at the fixed end (mm).

When y_c is replaced by y_{c1} in Equation (41), P_a is the additional elastic force. As in the previous section, P_a is simply added to the designed STF, and $Q = Q_0 + P_a$.

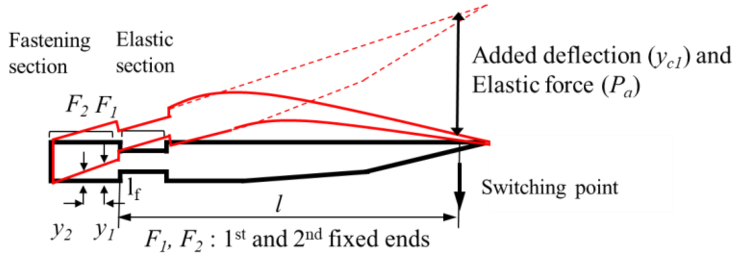


Figure 8: Model of the effect on the change of gauges at fastening section

(5) The longitudinal direction (misalignment of a tip of tongue rails)
The influence of the tongue rail tip misalignment on the increase in STF is negligible based on the results of several experiments conducted in papers [3] and [4], etc. Therefore, it is neglected in this study. It should be noted that the tongue rail tip misalignment has a significant effect on the mutual contact between the various components, as described in 1. (2) at the beginning of this paper.

(6) Adjustment state of a second stretcher bar (SSB)
An SSB is a component that hinges the left- and right-hand tongue rails together near the middle of the elastic point to increase the rigidity of the entire structure (see Figure 9). This component improves the contact gap between the tongue rail and the stock rail. It is known that this spacing adjustment increases the STF, and this paper attempts to create a simple calculation formula. The basic idea of the calculation is to give the spacing adjustment amount as the amount of tongue rail deflection at the SSB position and apply the formula for the effect of displacement as described in section 4(3)b).

Figure 9: Example of the SSB

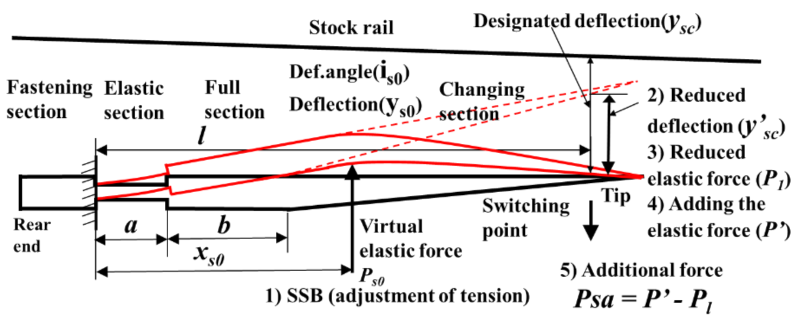


Figure 10 The STF calculation model by a spacing adjustment of the SSB

In general, the SSB is installed at the changing section ($a + b \leq x \leq l$). In Figure 10, if the distance from the fixed end of the tongue rail to the position of the SSB is

x_{s0}, the amount of spacing expansion (tension) of the SSB is y_{s0}, the deflection angle of the tongue rail at the same position is i_{s0}, the virtual force to deflect the tongue rail at the same position when the SSB is expanded to y_{s0} is P_{s0}, the designed stroke of the tongue rail at the position of the FSB is y_{sc} and the designed tongue rail deflection force is $P_{l,r}$, then,

a) Stretch the FSB y_{s0}.

b) The tongue rail throwing stroke, i.e., the deflection of the tongue rail at the FSB position, is reduced by y'_{sc}. Here, $y'_{sc} = y_{s0} + i_{s0}(l - x_{s0})$, where i_{s0} is obtained by applying formula (18) of lateral displacement.

c) As a result, the design deflection force that throws the entire length of the tongue rail is reduced by the amount of deflection y'_{sc}, so if the deflection force when the throwing stroke is $y_{sc} - y'_{sc}$ is P_c, then $P_c = E(y_{sc} - y'_{sc})/K_c$ (K_c is the value in [ ] of equation (41)) and $P_1 = P - P_c$, which is the reduction in deflection force.

d) In actuality, the tongue rail is thrown at the position of the FSB to obtain the stroke of the tongue rail, so the force P' is required to throw the tongue rail y'_{sc} with the FSB position as the fixed end, which is calculated as in equations (19) - (21).

e) From the above, an increasing deflection force $P_{sa} = P' - P_1$ is obtained.

(7) Maintenance (lubrication) condition on slide baseplates

The maintenance condition of the slide baseplates can be expressed by the coefficient of friction (μ) due to the lubrication condition. In the design and study of turnouts, $\mu = 0.2$ is generally used for the lubricated condition and $\mu = 0.5$ for the non-lubricated condition [5]. In practice, however, various conditions are assumed, including the effects of weather and other factors. The formulae are calculated by entering the value of μ into Equation (2) for the hinged points, and Equations (3) and (41) for the elastic point.

5 Results

Based on the ideas described in Chapter 4, the STF is estimated for each condition. Calculations were performed by Japan Industrial Standard (JIS) 50N rail, No.10 elastic points (with 70S rails), which are commonly used on conventional lines. The tongue rail is 7.95 m long and the NS-AM type switch machine (the maximum STF of 3.94 kN [6]) is used. Although the maximum STF of the switch machine has a rated load of 4.9 kN near the contact point [6], the maximum STF including the midway of the stroke is used to evaluate the STF in this study.

(1) The vertical direction (vertical displacement)

Figures 11 and 12 show the calculation results of the effect of vertical displacement on the amount of interference between a FSB and a stock rail and the STF obtained after determining whether interference exists or not, respectively.

Figure 11 shows that the amount of interference is small when the vertical displacement is less than 5 mm and increases when the vertical displacement is 5 mm or more. Here, the amount of interference is small when the peak is closer to the tip of the tongue rail, because the effect of the deflection angle at the supporting point is reduced.

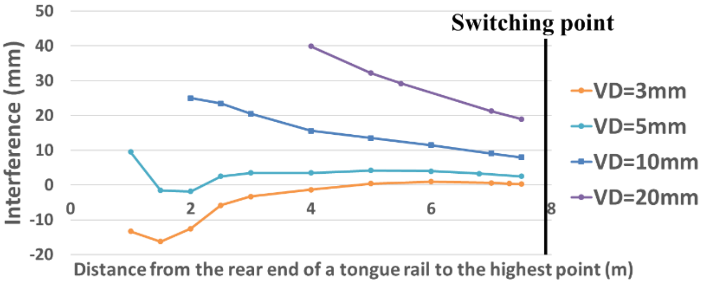


Figure 11 Interference between the FSB and a stock rail due to vertical displacement (VD)

Next, Figure 12 shows that if the supporting point is located 2-3 m near the FSB position, the estimated STF will exceed the limit of the switch machine. It is important to note that even a height of 3 mm may affect the STF. On the other hand, when the supporting point is located near the middle of the tongue rail, even a height of about 10 mm is sufficient margin for the limit of the STF. The reason for this result is that the vertical deflection force (N) due to the interference between the FSB and the stock rail becomes stronger when the supporting point and the FSB are close to each other.

Although cases of contact between the FSB and the stock rail are frequently observed in the field, the results of this estimation indicate that the risk of increased STF should be evaluated based on the position and height of the supporting point, rather than contact itself or not.

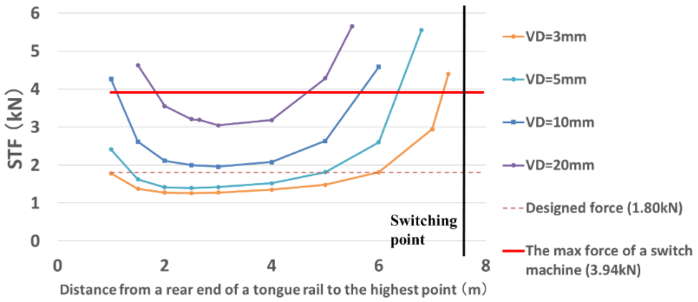


Figure 12: Estimated effect of vertical displacement on the STF

(2) The vertical direction (cross-level displacement)

Figure 13 shows the calculation results of the effect of cross-level displacement. The increase in STF is as small as 5% for a cross-level displacement of 20 mm, which is within the allowable range, and 30% for a maximum cant of 120 mm, which includes the displacement at the curved turnout. It means that the cross-level displacement and the cant are less influence on the STF.

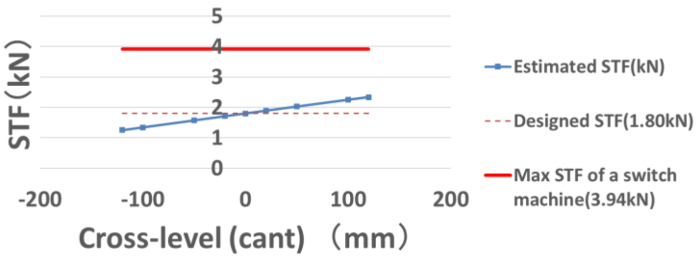


Figure 13: Estimated effect of cross-level displacement on the STF

(3) The lateral direction (lateral displacement)
Figure 14 shows the calculation results for the influence of the lateral displacement. The STF is high when the maximum lateral displacement is less than about 3 to 4 m from the FSB position, especially, even with a displacement of 3 mm, less than about 2 m. On the other hand, it can be evaluated that the maximum displacement of up to 10 mm near the middle of the tongue rail is not a problem because there is enough margin between the maximum displacement and the limit of the STF.

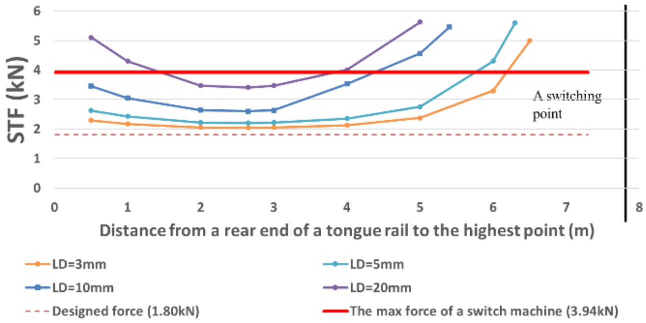
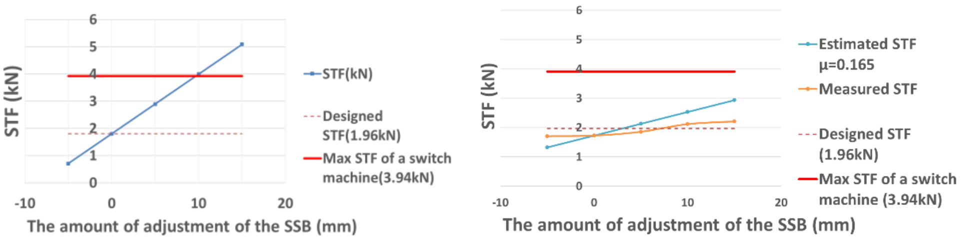


Figure 14: Estimated effect of lateral displacement on the STF

(4) The lateral direction (gauge displacement)
The calculation results for gauge displacement in the fixed section show that even when the difference between y_1 and y_2 is 10 mm, the increase in STF is slight at 3%, indicating that the effect on STF is small for a normal turnout. It should be noted, however, that the effect of the maximum deflection on the contact gap is about 5 mm, which is not negligible.

(5) Adjustment state of the FSB
Figure 15 (a) shows the calculated results of the effect of the adjustment state of the SSB. The result shows that the maximum STF of the switch machine is exceeded when the adjustment amount exceeds 10 mm.
Figure 15 (b) shows the calculation and measurement results [7] of a JIS 60k Rail No. 10 turnout, where the effect of the SSB tension has been measured in the past, for reference. The increase in the STF is small. The measured values are relatively consistent with those in past tests.



(a) JIS 50N-70S Rail (b) JIS 60k-80S Rail with measured results

Figure 15: Estimated STF by the adjustment of the SSB

(6) Maintenance (lubrication) condition on slide baseplates
Figure 16 shows the calculation results of the effect of the maintenance (lubrication) condition on the slide baseplates. It can be seen that the margin between the maximum STF and that of the switch machine becomes small when the friction

coefficient is around $\mu = 0.5{\sim}0.6$, which is generally considered to be an unlubricated condition, and it affects the inability to throwing.

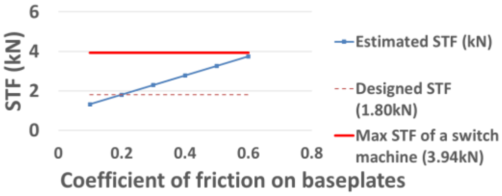


Figure 16: Estimated effect for the STF by the friction coefficient on the baseplates

6 Conclusions and Contributions

In order to examine the effect of the maintenance conditions of the turnout for the STF, we make formulae to calculate the STF depending on the types of track irregularities and maintenance conditions and calculate them in a case as an example. The results showed that the influence of the vertical and lateral displacement of the area near the tip of the tongue rail, the lubricated condition on the slide baseplates, and the over tensioning of the FSB are significant in some cases. In the future, it will be necessary to confirm the validity of the calculation formulae using actual measurements data. In addition, the effects of the maintenance condition of each turnout component, such as the condition of the ball bearing baseplates, should also be examined.

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