METHOD OF ESTIMATION OF CLIP-BOLT INTERMEDIATE FASTENINGS FAILURES

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ABSTRACT

The authors solve the problem of determination of operational risks relating to elements of a railway track under increasing over time changes in the track geometry due to weakening or breakdown of clip-bolt intermediate fastenings. To evaluate fastenings' failures a method is offered based on the use of a parameter of rails' displacement under train load. The parameter can be obtained by using automated diagnostic devices type KVL-P, ADK-I and «ERA» and similar to them. The article provides calculation of rail head displacement value, depending on the number of defective fastenings. The conditions for method' s application are stipulated.

Keywords: railway, railway track, operational risks, failures of rail clip- bolt fastenings, evaluation method.

Background. *The problems of safe operation and technical condition of tracks involve various forms of participation of engineering services. One of their constant concerns is protection from track geometry changes increasing over time due to weakening or breakdown of intermediate clip-bolt fastenings (hereinafter – CB). This problem is solved in accordance with the principles set out in the «Concept of integrated control of reliability, risk, life cycle costs on the railways» (URRAN) [1]. And here the most important issues are prevention, timely warning of impending danger at the site of a track where a threat to train movement has occurred or could occur.*

When it comes to changes in track geometry due to defects in intermediate CB-fastenings, the original data to assess the likelihood of track elements failures becomes primarily a parameter such as rail head displacement, characterizing the difference between the size of a track under train load and without it. Displacement parameter can be obtained using automated diagnostic tools KVL-P, ADK-I and «ERA» and others, but methodically there is a need for more precise estimates, design schemes to identify sections of the tracks recommended for dragging or replacement of intermediate rail fastenings of CB type.

Objective. *The objective of the authors is to present an assessment method applied in case of clip-bolt intermediate fastenings failures.*

Methods. *The authors use general scientific and engineering methods, mathematical apparatus, analysis, comparative method, graph construction.*

Results. *The aim of calculation at the first stage is determination of rotation angle of a short rail in CB fastening subjected to transverse and vertical forces of rolling stock (Pic. 1).*

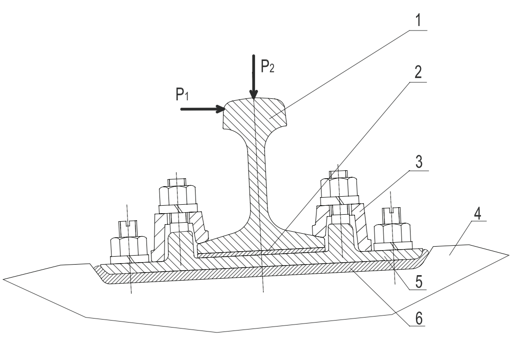
CB fastening belongs to the category of rigid, and rail rotation takes place due to deformation of under-rail rubber gasket 2, the characteristic of which corresponds to GOST [Russian standard] R56291–2014 [2].

Relative deformation of the gasket under the action of train load of 23 tons per axle, after a 10-fold statistical compression Δ *does not exceed 30%. Let's take yielding of the gasket under the action of train load* $\Delta = 1/20 = 0,2$ *(mm / t).*

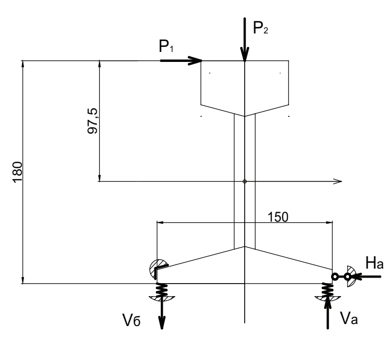
To determine rail rotation angle we take a simplified calculation model, which allows us to estimate the ultimate value of steel filaments' movement.

The following assumptions are taken into account:

- *pad deformation (p. 6 Pic. 1) is considered insignificant and therefore is not taken into account;*
- *a piece of rail R65 with the length of 50 cm is used, installed with CB fastening on a concrete sleeper;*
- *loads meet GOST 32698–2014 (Intermediate fastening of a railway track. Safety requirements and*



Pic. 1. Impact forces P1 and P2 in the area of clip-bolt fastening with the rail R65:
1. Rail R65. 2. Gasket under the rail. 3. Clip. 4. Concrete sleeper. 5. Baseplate. 6. Gasket under baseplate.



Pic. 2. Calculation model: ***P_1= 5,22 t – horizontal force; P_2 = 10,25 t – vertical force; H_a – horizontal reaction; V_a – vertical reaction at the point «a»; V_b – vertical reaction at the point «b».***

control methods) and are equal to P_1 = 5,22 t and P_2 = 10,25 t.

Pic. 2 shows the calculation model, used to determine reaction and movement of the rail.

From the equilibrium condition $\sum M_a = 0$; $\sum M_b = 0$; $\sum Fx = 0$ we get:

$P_1 \cdot 180 + P_2 \cdot 75 - V_a \cdot 150 = 0$;

$P_1 \cdot 180 - P_2 \cdot 75 - V_b \cdot 150 = 0$;

$P_1 - H_a = 0$.

Hence H_a = 5,22 t; V_a = 11,39 t; V_b = 1,15 t.

Under the influence of these forces the spring (b) is not extended on design conditions of the support, and the spring (a) is compressed with yielding δ = 0,2 (mm / t).

In this case, the rail rotates around the support (b) to an angle ϕ_b and a spring in the support (a) is compressed to a value $\Delta_a = \delta \cdot V_a = 0{,}2 \cdot 11{,}39 = 2{,}27$ (mm).

Accordingly, rotation angle will be:

$\phi_a = \Delta_a / 150 = \Delta_h / H_r$,

where H_r = 180 mm is a height of a rail R65.

Since rail displacement Δ_h is determined by movement of the inner surface of the rail head, then

$\Delta_h = \Delta_a \cdot 180/150 = 2{,}27 \cdot 1{,}2 = 2{,}7$ (mm) ≈ 3 (mm).

From the above calculation it follows that R65 rail rotation under the action of applied forces in CB fastening occurs due to deformation of the under-rail gasket, displacement of the rail head is less than 3 mm.

There is a reason to believe:

• In the place of CB fastening with standard tightened moment of screws of clip bolts rail displacement has a limit $\Delta_h \approx 3$ (mm).

• In case of rail displacement with $\Delta_h > 3$ (mm) it can be stated that in the intermediate fastening clip bolts are not tightened enough or it is broken.

• There is an opportunity using the value of rail displacement to evaluate the condition of CB fastenings.

* * *

However, to quantify inoperable fastenings, it is necessary to establish a relationship between the magnitude of rail displacement and the number of broken or badly tightened fastenings along the string length.

For this it is necessary to determine the angle of rail twisting with one, three, five and seven consecutive inoperable fastenings from vertical and horizontal forces acting on the rail.

Pic. 3 shows the calculation scheme for rail rotation evaluation with one inoperable fastening. To simplify the calculation we take fixations adjacent to the broken fastenings as rigid fixations. Then the rotation angle in the section with a broken fastening will be:

$\phi = M \cdot L / 2G \cdot I_{fast}$,

where M is a torque in a cross-section of application of a horizontal force (kg · cm);

L is distance between intermediate supports (cm);

G is torsion rigidity of R65 rail;

I_{tor} is moment of torsion inertia of R65 rail.

Values G and I_{tor} are taken from GOST R51685–2000* [3].

Torsion moment in the rigid fixation:

$M = P_2 \cdot h_2 = 5{,}22 \cdot 10^3 \cdot 9{,}75 = 51 \cdot 10^3$ (kg·cm).

We determine rotational angles in cross-sections of defective fastenings.

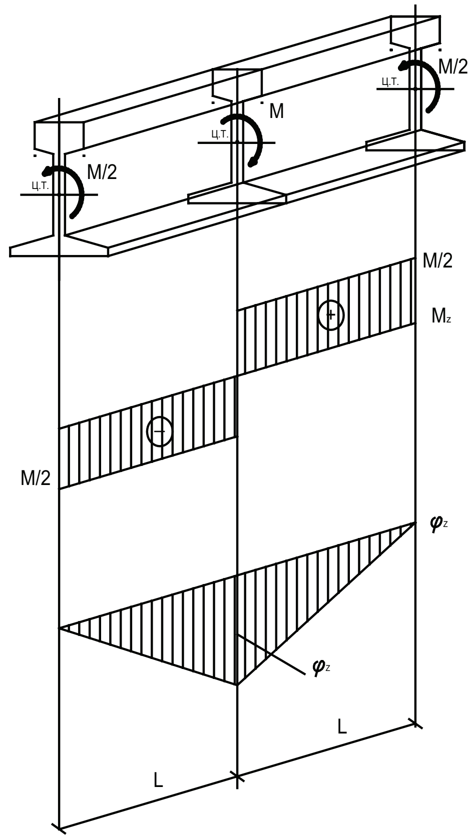
• In case of one broken fastening:

L = 50 cm;

$\phi_1 = 51 \cdot 10^3 \cdot 50 / 2 \cdot 8 \cdot 10^5 \cdot 288 = 5{,}5 \cdot 10^{-3}$ (rad).

• In case of three broken fastenings:

L = 100 cm;



Pic. 3. Calculation scheme for evaluating the rotation of the rail with one inoperable fastening.

$\phi_3 = 51 \cdot 10^3 \cdot 100 / 2 \cdot 8 \cdot 10^5 \cdot 288 = 11 \cdot 10^{-3}$ (rad).

• In case of five broken fastenings:

L = 150 cm;

$\phi_5 = 51 \cdot 10^3 \cdot 150 / 2 \cdot 8 \cdot 10^5 \cdot 288 = 16{,}6 \cdot 10^{-3}$ (rad).

• In case of seven broken fastenings:

L = 200 cm.

$\phi_Z = 51 \cdot 10^3 \cdot 200 / 2 \cdot 8 \cdot 10^5 \cdot 288 = 22 \cdot 10^{-3}$ (rad).

Naturally horizontal movement of the rail head will be:

$\Delta_h = h \cdot \phi_Z$.

Let's determine horizontal movement of rail heads in the places of defective fastenings.

• In case of one broken fastening:

L = 50 cm;

$\Delta_h = 180 \cdot 5{,}5 \cdot 10^{-3} = 1$ (mm).

• In case of three broken fastenings:

L = 100 cm;

$\Delta_h = 180 \cdot 11 \cdot 10^{-3} = 2$ (mm).

• In case of five broken fastenings:

L = 150 cm;

$\Delta_h = 180 \cdot 16{,}6 \cdot 10^{-3} = 3{,}00$ (mm).

• In case of seven broken fastenings:

L = 200 cm;

$\Delta_h = 180 \cdot 22 \cdot 10^{-3} = 4$ (mm).

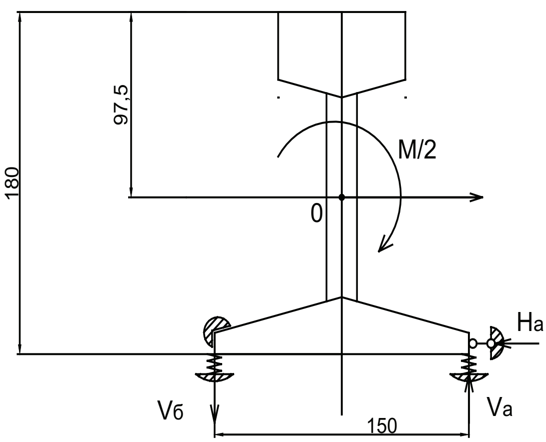
The results represent the minimum values of rotation angles and horizontal displacements of R65 rail as fixations of rails were considered absolutely rigid.

In fact, the rail in the fixation rotates due to deformation of the gaskets. Therefore, further, considering gaskets' deformation we define rail rotation as in elastic fixations.

Table 1

Rotation angles and horizontal displacements of rail string heads

№	The number of defective fastenings, pcs	The distance from the applied force to the fixation, L, cm	The rail rotation angle, ϕ_Z, rad.	The rail head displacement, Δ_h, mm
1	1	50	$5,5\cdot10^{-3}$	1,41
2	3	100	$11,0\cdot10^{-3}$	2,41
3	5	150	$16,6\cdot10^{-3}$	3,41
4	7	200	$22,0\cdot10^{-3}$	4,41



Pic. 4. Calculation scheme for determining the value of rail deformation in the fixation.

Pic. 4 shows the calculation scheme for determining the value of rail deformation in the fixation.

We determine the force in the fixation using the equation

$V_a \cdot b = M/2;$

$V_a = M/2\cdot b = 51\cdot10^3/2\cdot15 = 1,7\cdot10^3$ *(kg) – a force, acting on springs.*

Spring displacement caused by action of the force P on it:

$\Delta_a = \delta\cdot V_a = 0,2\cdot1,7 = 0,34$ *(mm).*

Rail rotation angle:

$\phi_Z = \Delta_a / b = 0,34 / 150 = 0,0023$ *(rad)* $= 2,3\cdot10^{-3}$ *(rad).*

Rail head displacement:

$\Delta_h = \Delta_a\cdot180/150 = 0,34\cdot1,2 = 0,41$ *(mm).*

Rotation angles and horizontal displacements of rail heads of the string depending on the number of defective fastenings are shown in Table 1.

Conclusions

With regard to the calculations it was revealed the following:

• In case of regulatory operation of the track section it is difficult to determine the failure of 1-2 intermediate rail fastenings type CB accounting only on shift of rail head under load (displacement parameter), since it is very small and amounts to only 1,41 mm.

• To use as a criterion the limit value of rail head shift, it is necessary that the failure occurs at least at three intermediate fastenings of CB type, while the horizontal value of rail shift exceeds 2,41 mm.

• The limit value method based on rail head displacement, is applicable to the diagnosis of the track and when scheduling preventative maintenance.

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