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Satbayev University

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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INFLUENCE OF APPENDIX POINT LOAD TRAINING ON MAGNITUDE OF SIDE POWER

Abstract. An alternative method of restoring the force factors acting on the rail during operation is proposed. The method is based on the use of influence matrices that bind the forces acting on the rail with stresses in the places where the strain gauges stick. As elements of the basic set of power factors restored by the proposed method, the vertical force (FZ), lateral force (FY) and moment (M) from the displacement of the vertical force away from the center of the rail head are selected.

Key words: rail, stress, strain, vertical and lateral forces, stress-strain state, influence matrix.

In the general case, the resultant force acts on the rail head on the wheel side at the point of contact, which is usually laid out on the vertical, lateral and longitudinal components. The method of measuring (restoring) lateral forces acting from a wheel on a rail, stated in [1], does not specifically describe the positions of the contact point on the surface of the head, i.e. points of application of vertical force relative to the center of the rail head, thereby implying the independence of the values of lateral forces on the rail obtained by the Schlümpf method from the position of the conditional center of the contact patch on the rail head.

This paper outlines the method for determining the force factors (including lateral forces) acting on the rail during operation, allowing you to perform the appropriate field tests at any position of the contact point in a pair of "wheel-rail". In the course of the work, mathematical models of a fragment of a rail-sleeper grid on sleepers with elastic intermediate rail fastenings in a ballast layer, models for carrying out virtual gauge (calibration) rail loads were built. The constructed computational models allow, by computation, to obtain mathematical matrices (influence matrices) necessary to restore vertical and lateral loads from the wheel to the track, as well as to obtain the value of the displacement of the contact point in a pair of “wheel-rail”.

Calibration tests were carried out by stepwise loading of the rail section of the track with vertical and horizontal jacks (rods). During the tests, the readings of strain gauges (figure 1), mounted directly on the rods of the loading jacks, and the readings of the strain gauge circuit on the rail neck (figure 2), collected by the Schlumpf method, were recorded.The rail was loaded with a vertical force F_Z in the middle of the head and when the point of application of force was displaced from the center of the head inward (force F_B) and out (force F_Z) by 25 mm in the path curve. A comparison of the experimental values of the lateral forces F_Y in the rods with the restored values of the lateral forces according to the Schlumpf method is presented in figure 3.

As a result of the experiments, graphs of the lateral force on the rail head were obtained obtained by the Schlumpf method and directly from the loading jacks (figure 1-3), with a different position of the point of application of vertical force on the rail head.

From the results obtained in the experiment:

- when a vertical force is applied in the middle of the rail head a relatively acceptable degree of deflection of the restored lateral force is observed according to Schlumpf's indications;

- when a vertical force is applied with a deviation from the center of the rail head and in the absence of lateral force, a non-zero lateral force is restored according to the indications of Schlumpf's scheme;

- when a vertical force is applied with a deviation from the center of the rail head by 25 mm in/out of the curve, there is a substantial discrepancy between the lateral force restored by the Schlumpf method and the lateral force applied.

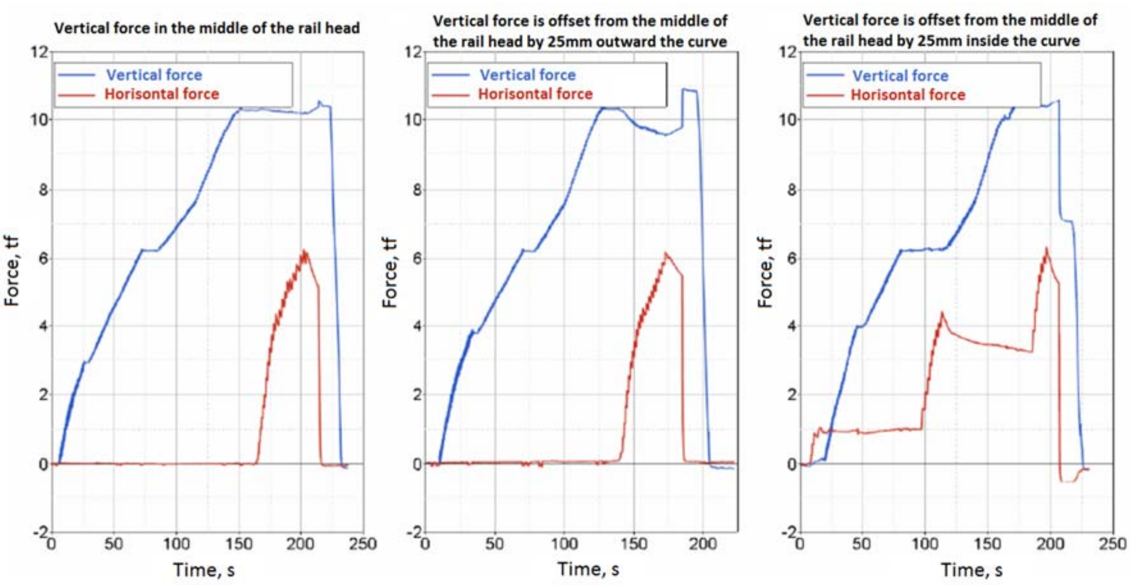

Figure 1 – Change of forces in loading rams jacks at different positions of the point of application of vertical force, tf

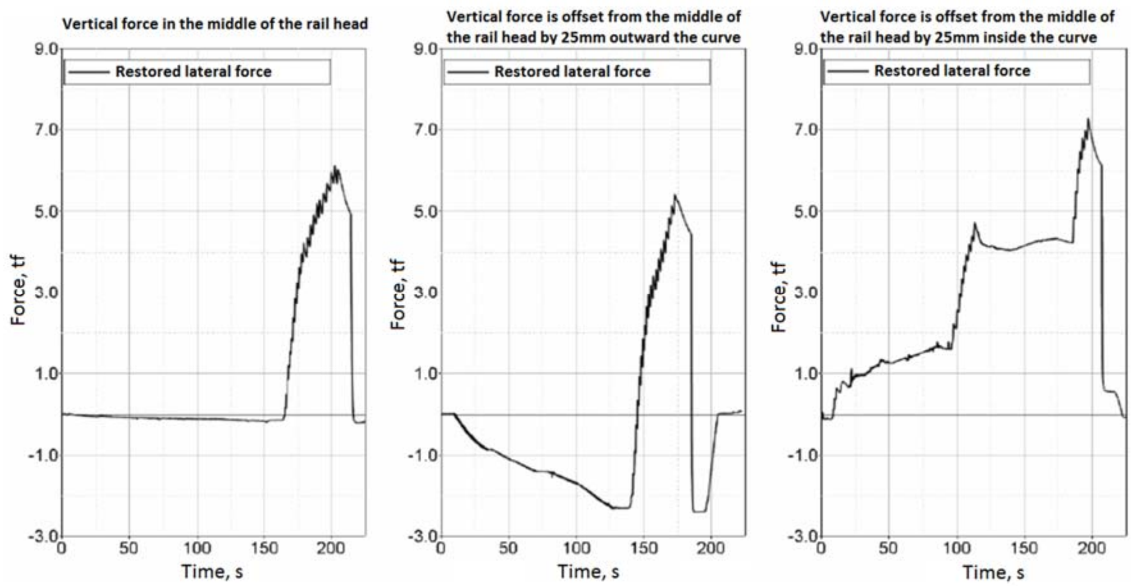

Figure 2 – Change of lateral forces restored by the Schlumpf method at various positions of the point of application of vertical force, tf

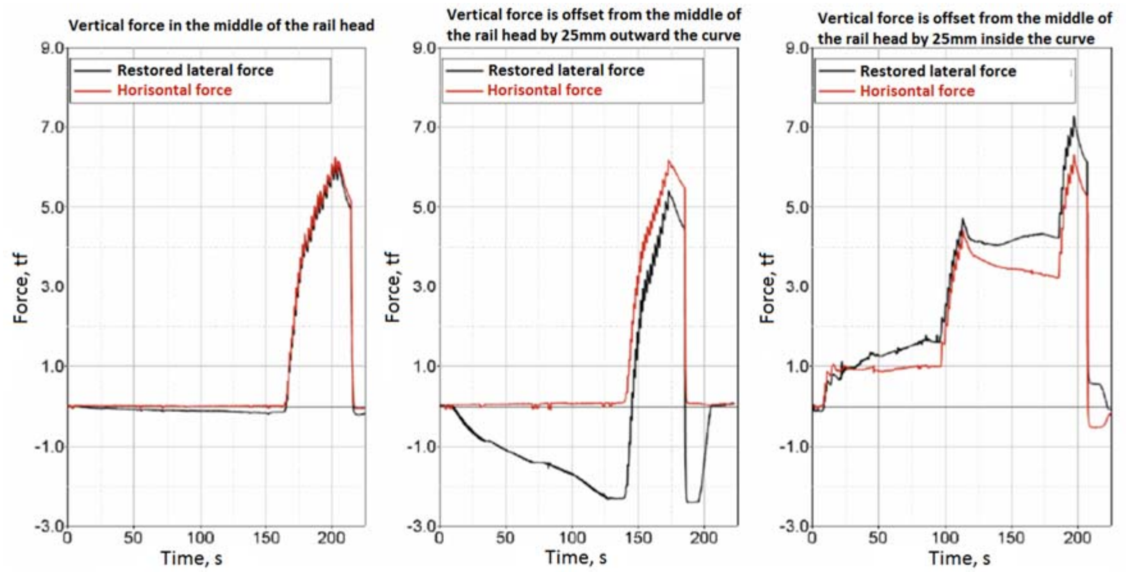

Figure 3 – Change of forces in the jack, creating lateral loading of the rail, and lateral forces reconstructed by the Schlumpf method at different positions of the vertical force application point

The findings of the results of experimental studies require the establishment of the limits of applicability of the Schlumpf method as a means for restoring forces from the wheel to the rail. For this purpose, calculated finite element models of a rail loaded with vertical ($F_Y = 120\ kN$) and lateral ($F_Y = 45\ kN$) concentrated forces in various combinations in sections above the support and between the supports were developed.

The stress-strain states of the rail were studied at different positions of the point of application of vertical force to its head: along the axis of the rail and displaced from the axis by d=24.5 mm. The values of stresses in the control points on the rail neck, corresponding to the installation sites of strain gauges for determining lateral forces from the wheel to the rail in accordance with GOST 55050-2012, were recorded. A diagram of the rail section with the location of the points of application of concentrated forces and control points is shown in figure 4.

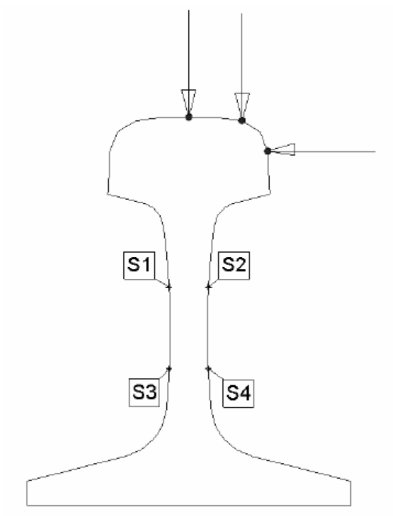

Figure 4 – Scheme of the rail section with the location of points of concentrated application forces and control points

The data obtained show a clear dependence of the distribution of the bending moment along the height of the neck both on the position of the point of application of the vertical force and on the factor of the presence of a support under the loaded rail section.

The stress values at the control points for loading the rail between the supports at the same time with vertical force without displacement and lateral force made the difference (S1-S2) - (S3-S4) = $48.6MPa$. Considering the value of $51.3MPa$, it can be concluded that relatively close values of bending moments in the control sections of the neck, i.e. close values of lateral force. In this case, the lateral force was absent in the loading scheme.

Table 1 shows the stress values at the test points on the rail neck in accordance with GOST 55050-2012. Changes of the bending moment along the rail neck height, in general, can be associated with the application of a lateral force to the rail head or with a displacement of the vertical force on the rail head away from the rail axis. Therefore, the method of restoring lateral forces from the wheel to the rail by the Schlumpf method can be used only in cases of absence relative to a significant displacement of the center of the contact patch from the rail section axis.

Table 1 – Values of normal vertical stresses (MPa) at the control points on the rail neck for various design schemes

Design parameters	Control points				S1-S2	S3-S4	S1-S2-S3+S4
	S1	S2	S3	S4			
$\left.\begin{matrix}F_z \neq 0\\ F_y = 0\end{matrix}\right\}$ between supports d = 0	-35.1	-35.2	-17.7	-17.7	-0.003	0.002	-0.01
$\left.\begin{matrix}F_z \neq 0\\ F_y = 0\end{matrix}\right\}$ above the support d $\neq$ 0	7.1	-115.2	1.2	-101.8	122.4	102.9	19.2
$\left.\begin{matrix}F_z \neq 0\\ F_y = 0\end{matrix}\right\}$ between supports d $\neq$ 0	24.9	-95.7	16.8	-52.5	120.6	69.3	51.3
between supports d $\neq$ 0	-54.1	-15.7	-61.1	26.1	-38.4	-87.1	48.6

In this case, it is necessary to choose the cross section of the rail above the sleeper as the measuring one. The data and conclusions obtained as a result of computational and experimental studies are in complete agreement [2-9]. The identified limitations of the Schlumpf method for restoring lateral forces from a wheel to a rail require the development of a more universal method that takes into account possible deviations of the center of the contact patch from the axis of the rail section.

The need to introduce an additional factor that takes into account the displacement d of the point of application of forces from the contact of the wheel with the rail is shown by the experiment described above. It would be logical to associate this factor with the difference in the values of the forces F_{B} and F_{H} - by the vertical forces when the point of its application moves inwards and outwards of the path curve, respectively. Taking into account the deviations from the center of the rail head d, we obtain the physical meaning in the form of the momentum $\text{M} = (F_{\text{B}} - F_{\text{H}}) \cdot d$. The vertical force applied at any point of the rail head over the cross section with load cells can be replaced by a force F_{Z} in the middle of the rail head and a moment M.

To obtain a connection between the readings of the load cells and the loads, calibration experiments are carried out. From a technical point of view, four loading options would be appropriate: 1) A vertical force in the middle of the rail head; 2) Simultaneously with the vertical force in the middle of the rail head F_{Z}^{T2} and the lateral force F_{Y}^{T2}; 3) A vertical force shifted d outwards from the center of the rail head F_{ZH}^{T3}; 4) Vertical force, shifted by d inward from the middle of the rail head F_{ZB}^{T4} the results of the load cells are recorded in table 2. Using linear superposition, we obtain the matrix [G] for the desired strength factors (table 3).

Table 2 – Indications of strain gauges

Number of the strain gauge	$F_Z^{T1} = \cdots tf$	$F_Z^{T2} = \cdots tf$ $F_Y^{T2} = \cdots tf$	$F_{Z_{\text{н}}}^{T3} = \cdots tf$	$F_{Z_{\text{в}}}^{T4} = \cdots tf$
1	s_1^{T1}	s_1^{T2}	s_1^{T3}	s_1^{T4}
2	s_2^{T1}	s_2^{T2}	s_2^{T3}	s_2^{T4}
3	s_3^{T1}	s_3^{T2}	s_3^{T3}	s_3^{T4}
4	s_4^{T1}	s_4^{T2}	s_4^{T3}	s_4^{T4}

Table 3 – Matrix coefficients [G] with 4 calibration experiments

Number of the strain gauge	$F_Z = 1\ tf$	$F_Y = 1\ tf$	$M = 1\ tf \cdot mm$
1	$g_{11} = s_1^{T1}/F_Z^{T1}$	$g_{21} = (s_1^{T2} - g_{11} \cdot F_z^{T2})/F_Y^{T2}$	$g_{31} = (s_1^{T3}/F_{Z\text{н}}^{T3} - s_1^{T4}/F_{Z\text{в}}^{T4})/d/2$
2	$g_{12} = s_2^{T1}/F_Z^{T1}$	$g_{22} = (s_2^{T2} - g_{12} \cdot F_z^{T2})/F_Y^{T2}$	$g_{32} = (s_2^{T3}/F_{Z\text{н}}^{T3} - s_2^{T4}/F_{Z\text{в}}^{T4})/d/2$
3	$g_{13} = s_3^{T1}/F_Z^{T1}$	$g_{23} = (s_3^{T2} - g_{13} \cdot F_z^{T2})/F_Y^{T2}$	$g_{33} = (s_3^{T3}/F_{Z\text{н}}^{T3} - s_3^{T4}/F_{Z\text{в}}^{T4})/d/2$
4	$g_{14} = s_4^{T1}/F_Z^{T1}$	$g_{24} = (s_4^{T2} - g_{14} \cdot F_z^{T2})/F_Y^{T2}$	$g_{34} = (s_4^{T3}/F_{Z\text{н}}^{T3} - s_4^{T4}/F_{Z\text{в}}^{T4})/d/2$

In matrix form, we can write:

$$\{S(t)\} = \begin{Bmatrix} s_1(t) \\ s_2(t) \\ s_3(t) \\ s_4(t) \end{Bmatrix} = \begin{bmatrix} g_{11} g_{21} g_{31} \\ g_{12} g_{22} g_{32} \\ g_{13} g_{23} g_{33} \\ g_{14} g_{24} g_{34} \end{bmatrix} \cdot \begin{Bmatrix} F_Z(t) \\ F_Y(t) \\ M(t) \end{Bmatrix} = [G] \cdot \{F(t)\}$$

By calculating the pseudo inverse to [G] matrix $[G]^+ = ([G]^T \text{x} [G])^{-1} \text{x} [G]^T$ obtain the possibility of determining (restoring) force factors according to the indications of strain gauges:

$$\{F(t)\} = \begin{Bmatrix} F_z(t) \\ F_Y(t) \\ M(t) \end{Bmatrix} = [G]^+ \cdot \{S(t)\}.$$

In case of technical difficulties in loading the rail with a vertical force on the inside of the head, the first three calibration tests are sufficient. Then the coefficients of the matrix [G] will be made of table 4.

According to the results of the performed computational studies, a technique is proposed for the experimental determination (restoration) of the force factors acting on the rail during operation.

Table 4 – Matrix coefficients [G] with 3 calibration experiments

Number of the strain gauge	$F_Z = 1tf$	$F_Y = 1tf$	$M = 1tf \cdot mm$
1	$g_{11} = s_1^{T1}/F_Z^{T1}$	$g_{21} = (s_1^{T2} - g_{11} \cdot F_z^{T2})/F_Y^{T2}$	$g_{31} = (s_1^{T3}/F_{Z\text{н}}^{T3} - g_{11})/d$
2	$g_{12} = s_2^{T1}/F_Z^{T1}$	$g_{22} = (s_2^{T2} - g_{12} \cdot F_z^{T2})/F_Y^{T2}$	$g_{32} = (s_2^{T3}/F_{Z\text{н}}^{T3} - g_{12})/d$
3	$g_{13} = s_3^{T1}/F_Z^{T1}$	$g_{23} = (s_3^{T2} - g_{13} \cdot F_z^{T2})/F_Y^{T2}$	$g_{33} = (s_3^{T3}/F_{Z\text{н}}^{T3} - g_{13})/d$
4	$g_{14} = s_4^{T1}/F_Z^{T1}$	$g_{24} = (s_4^{T2} - g_{14} \cdot F_z^{T2})/F_Y^{T2}$	$g_{34} = (s_4^{T3}/F_{Z\text{н}}^{T3} - g_{14})/d$

At each instant of time t, the power factors to be restored are determined by the formulas:

$$F_Z(t) = 0.009582 \cdot s_1(t) + 0.007845 \cdot s_2(t) + 0.009878 \cdot s_3(t) + 0.00804 \cdot s_4(t),$$

$$F_Z(t) = 0.00123 \cdot s_1(t) + 0.002916 \cdot s_2(t) + 0.001529 \cdot s_3(t) - 0.00275 \cdot s_4(t),$$

$$M(t) = 0.182746 \cdot s_1(t) + 0.038209 \cdot s_2(t) - 0.18386 \cdot s_3(t) - 0.04411 \cdot s_4(t).$$

wheres_1, s_2, s_3, s_4, are the readings of the strain gauges.

Figure 5-6 show the recovered proposed method of implementing the vertical and lateral forces superimposed on the recording of the load cells on the loading jacks (rods). It can be seen that the method gives errors in determining the lateral force (at the time of reaching the maximum values of the experiment) with the application of vertical force:

- In the middle of the rail head 0.28%;
- With a deviation from the middle of the rail head by 25 mm outwardly, the curve path is 4.22%;
- With a deviation from the middle of the rail head by 25 mm inside the curve path 2.58%.

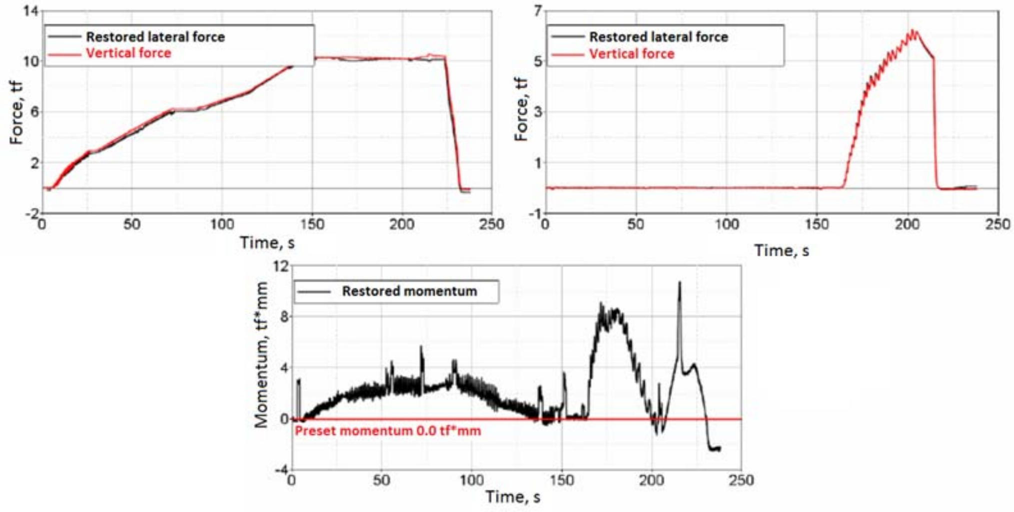

Figure 5 – Calibration loading T1. Power factors and reconstructed using the influence matrix

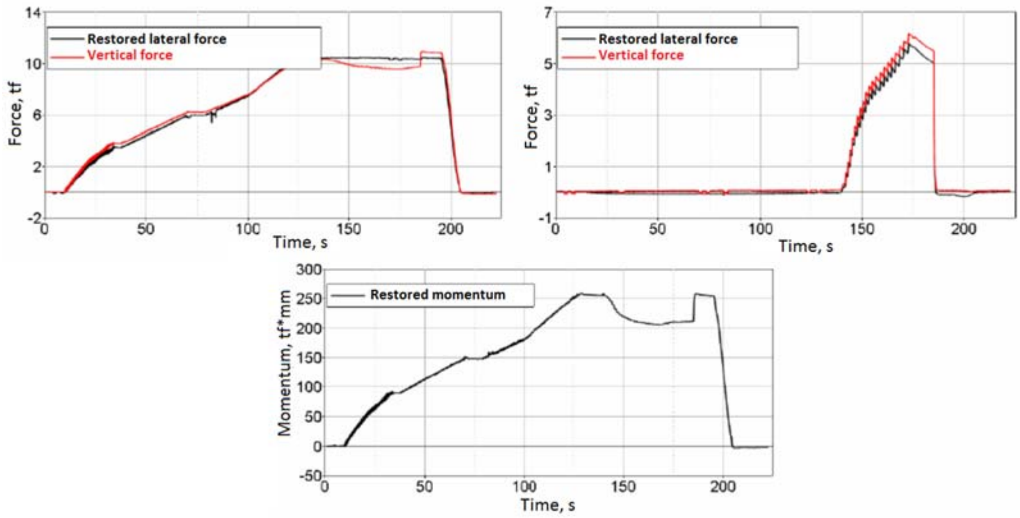

Figure 6 – Calibration loading T2. Power factors and reconstructed using the influence matrix

Conclusions can be drawn from the results of the above studies:

- When a vertical force is applied in the middle of the rail head, the applied lateral force is restored according to the indications of the Schlumpf scheme;
- When a vertical force is applied with a deviation from the center of the rail head and in the absence of lateral force, a nonzero lateral force is restored according to the indications of the Schlumpf scheme;
- When a vertical force is applied with a deviation from the center of the rail head by 25 mm inside / outside of the curve, the lateral force is not restored according to the Schlumpf scheme indications.

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ПОЕЗД САЛМАҚ КҮШІНІҢ ТҮСУ НҮКТЕСІНІҢ БҮЙІР КҮШТІҢ ШАМАСЫНА ӘСЕРІ

Аннотация. Пайдалану кезінде рельске түсетін күш факторларын қалпына келтірудің балама әдісі ұсынылған. Әдіс тензорезистор желімделген орындардағы рельске түсетін кернеу мен күшті байланыстыратын әсер ету матрицасына негізделген. Ұсынылған әдіс бойынша қалпына келтіруде, күш факторларының базистік жиынтығының элементі ретінде таңдалды: көлденең күш (FZ), бүйірлік күш (FY) және рельс басынан көлденең күштің ортадан шетке қарай ауысуынан пайда болатын момент (M).

Бұл жұмыста «доңғалақ- рельс» жұптаса отырып түйісу нүктесінің кез келген жерінде дала сынақтарын өткізуге мүмкіндік беретін және пайдалану кезінде рельске әсер ететін, күш факторларын (соның ішінде бүйірлік күштер) анықтау әдістемесін сипатталады.

Жылжымалы құрам рельстің бойымен қозғалған кезде жүктемелерді алуға (қалпына келтіруге) арналған әмбебап тәсіл әзірленді. Ұсынылған тәсілдегі жүктемелер рельс деформацияларымен анықталады (қалпына келтіріледі). Зерттеу нәтижелерін рельс жолының жүктелуін бағалау және нормативтік-құқықтық базаны жақсарту үшін пайдалануға болады

Жұмыс барысында балласты қабаттағы серпімді аралық бекітпелері бар шпалдағы рельс- шпал торының фрагменттерінің математикалық үлгілері, рельсті виртуалды калибрлеу (таралау) жүктеуге арналған модельдер жасалды.

Құрылған есептеу модельдері доңғалақтан рельс жолына тік және бүйірлік жүктемелерді қалпына келтіруге, сонымен қатар «доңғалақ-рельс» жұбының түйісу нүктесінің ығысу көлемін алуға қажетті математикалық матрицаларды (әсер ету матрицаларын) алуға мүмкіндік береді.

Зерттеу нәтижелері бойынша қорытынды жасалды: рельс басының ортасында тік күш қолданылған кезде, Шлюмпф диаграммасына сәйкес қолданылатын бүйірлік күш қалпына келтіріледі; рельс басының ортасынан ауытқумен тік күш қолданылғанда және бүйірлік күш болмағанда, Шлюмпф диаграммасына сәйкес нөлдік емес бүйірлік күш қалпына келтіріледі; рельс басының ортасынан ішке/ сыртқа 25 мм ауытқумен тік күш қолданылған кезде, бүйірлік күш Шлюмпф диаграммасына сәйкес қалпына келтірілмейді.

Түйін сөздер: рельс, кернеу, деформация, көлденең және бүйір күш,кернеулі-деформациялық кезең (КДК), әсер ету матрицасы.

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ВЛИЯНИЕ ПОЛОЖЕНИЯ ТОЧКИ ПРИЛОЖЕНИЯ ПОЕЗДНОЙ НАГРУЗКИ НА ВЕЛИЧИНУ БОКОВОЙ СИЛЫ

Аннотаия. Предложен альтернативный способ восстановления силовых факторов, действующих на рельс в ходе эксплуатации. Способ основан на использовании матриц влияния, связывающих действующие на рельс силы с напряжениями в местах наклейки тензорезисторов. В качестве элементов базисного набора силовых факторов, восстанавливаемых предлагаемым способом, выбраны вертикальная сила (FZ), боковая сила (FY) и момент (M) от смещения вертикальной силы в сторону от середины головки рельса.

В настоящей работе излагается методика определения силовых факторов (в том числе боковых сил), действующих на рельс в ходе эксплуатации, позволяющая выполнять соответствующие натурные испытания при любом положении точки контакта в паре «колесо-рельс».

Выработан универсальный подход к получению (восстановлению) нагрузок на рельсовый путь при движении по нему подвижного состава. Нагрузки в предлагаемом подходе определяются (восстанавливаются) по деформациям рельса. Результаты проведенных исследований могут быть использованы для проведения работ по оценке нагруженности рельсового пути и совершенствования нормативной базы.

В ходе работы построены математические модели фрагмента рельсошпальной решетки на шпалах с упругими промежуточными рельсовыми скреплениями в балластном слое, модели для проведения виртуальных калибровочных (тарировочных) нагружений рельса.

Построенные расчетные модели, позволяют расчетным путем получать математические матрицы (матрицы влияния), необходимые для восстановления вертикальных и боковых нагрузок от колеса на рельсовый путь, а так же получать величину смещения контактной точки в паре «колесо-рельс».

Из результатов исследований сделаны выводы: при приложении вертикальной силы в середине головки рельса прикладываемая боковая сила восстанавливается по показаниям схемы Шлюмпфа; при приложении вертикальной силы с отступлением от середины головки рельса и при отсутствии боковой силы по показаниям схемы Шлюмпфа восстанавливается ненулевая боковая сила; при приложении вертикальной силы с отступлением от середины головки рельса на 25 мм внутрь/наружу кривой не восстанавливается боковая сила по показаниям схемы Шлюмпфа.

Ключевые слова: рельс, напряжения, деформации, вертикальные и боковые силы, напряженно-деформированное состояние, матрицы влияния.

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