ROAD AND RAILWAY CONSTRUCTION

RAIL FASTENINGS
History and types
The functions and requirements of the fastenings are the followings:

- to transfer loads and rail forces from rails to the sleeper,
- to damp vibrations and impacts caused by traffic as much as possible,
- to retain the track gauge and rail inclination within certain tolerances,
- easy to install and maintain,
- to provide sufficient clamping force on rails to make continuously welded rail work,
- to provide electrical insulation between the rails and sleepers, especially in the case of concrete and steel sleepers.
A rail fastening system is a means of fixing rails to railroad ties (United States) or sleepers (international). The terms rail anchors, tie plates, chairs and track fasteners are used to refer to parts or all of a rail fastening system. Various types of fastening have been used over the years.
The earliest wooden rails were fixed to wooden sleepers by pegs through holes in the rail, or by nails. By the 18th century cast iron rails had come into use, and also had holes in the rail itself to allow them to be fixed to a support. 18th century developments such as the flanged rail and fish bellied rail also had holes in the rail itself; when stone block sleepers were used the nails were driven into a wooden block which had been inserted into a recess in the block. The first chair for a rail is thought to have been introduced in 1797 which attached to the rail on the vertical web via bolts. By the 1820s the first shaped rolled rails had begun to be produced initially of a T shape which required a chair to hold them; the rails were held in position by iron wedges (which sometimes caused the rail to break when forced in) and later by wooden wedges, which became the standard. In the 1830s Robert L. Stevens invented the flanged 'tee' rail (actually a distorted I beam), which had a flat bottom and required no chair, a similar design was the contemporary bridge rail (an inverted 'U' shaped with bottom flange and used on longitudinal sleepers); these rails were initially nailed directly to the sleeper.
Types of rail fastening systems

According to structural design

Direct

Elastic

According to flexibility

Inelastic

Indirect
Difference between rigid and elastic fastening systems

The rail fastenings must permanently hold down the rail firmly, ensuring at the same time resilience of the track in the upward direction, and good lateral stability. The elastic downward pressure is essential for the smooth control of the rail’s upward movement and high creep resistance. A rigid rail fastening does not meet these requirements. Even minor temporary deformations of the base reduce the firmness of rail restrain. A permanent deformation of the base completely eliminates the holding down force and, thus, also the creep resistance. Furthermore, the spike or screw support is gradually loosened and pressed aside by impacts exerted on the fastening by the sagging and tilting movements of the rail. Therefore, such rigid rail fastenings with spikes or coach screws are not suitable for use with long welded tracks.
Difference between rigid and elastic fastening systems

In an elastic rail fastening the screws are tightened so that an initial tension is developed via the elastic clip or the spring washers. As shown in the figure, this initial tension maintains the influence of the force on the fastening, even if the spring is pressed in farther due to the wheel load. The result is a fastening which is permanently effective under the influence of different forces. The force takes a pulsating course fluctuating around the value of the initial tension. The holding down force significantly influences the creep resistance between rail and sleeper. Therefore, it is of particular importance to guarantee a minimum holding down force by choosing an appropriate rail fastening.
Difference between rigid and elastic fastening systems

Rigid fastening system

Elastic fastening system

Shock load

Pulsating load

Pulling force in the screw

Time
Rigid, indirect “K” fastening with a rigid clamp. Rail is mounted to a baseplate first, and then the baseplate to a sleeper by screws. Screws and nuts are underlaid by elastic washers. Currently, these fastenings are replaced by elastic ones.

Elastic, indirect “KS” fastening with an elastic Skl24 clamp made by Vossloh. The function is the same as for K fastening. The fastening is used on older sleepers which do not allow direct fastening.
Elastic, direct W14 fastening with a Skl14 clamp made by Vossloh. The most common fastening on main Czech tracks. One screw connects a rail to a sleeper directly, a screw is screwed into a pre-installed plug in a sleeper.

Elastic, direct Nabla fastening. The clamp has a plate shape. One screw connects a rail to a sleeper directly. The fastening is used especially in Spain and France.
Modern rail fastening systems
Vossloh System W 14

Pre-assembly
All the fastening components can be manually or automatically pre-assembled in the sleeper factory. The rail is applied at the construction site. Fastening components can be lost neither during transport nor during track laying.

Assembly
The sleeper screw is loosened by 2-3 turns. The tension clamp is pushed on the rail foot and tightened with torque of approx. 250 Nm. A simple work step which requires no special training. Assembly can be carried out using simple commercially available screwing machines or automatic screwing aggregates.

Exchangeability
All components are exchangeable.

Protection against tilting
Any uplifting or tilting of the rail which occurs during tamping of the track or when running through narrow track curves is absorbed by the middle bend after it has overcome the small air gap (between the middle bend of the tensioning clamp and rail base). Permanent deformation of the outer spring arms is therefore excluded.

Different rail sections on the same sleeper
Different rail sections, e.g. UIC 60, UIC 54 and S 49, can be used on the same sleeper with the same track gauge through simple exchange of the angled guide plates.

Track adjustment
A track adjustment of ± 10 mm in steps of 2.5 millimetres is available as standard.

Electrical insulation
The rail fastening system W 14 is completely electrically insulated. No additional insulating components are required between the clamping element and the rail base.

Track maintenance
The Vossloh rail fastening system requires no regular maintenance.

Neutralisation
No fastening elements have to be removed from the sleeper with continuous welding of the rail (CWR). The sleeper screws merely have to be loosened but not disassembled.

Height adjustment
The Vossloh rail fastening system W 14 can be adjusted in height by using height regulation plates. This is also referred to as anti-frost wedge fastening in many countries.
Highly elastic rail fastening system for concrete sleepers on main lines.

**Features:**

Skl 21 tension clamp with 2.5 mm fatigue strength
Highly elastic intermediate pads with stiffnesses > 50 kN/mm allow high vertical deflection of rail
Rail tilting protection by middle bend of the tension clamp and specially designed angled guide plate
The highly elastic pad is protected against overstrain by the tilt protection of the angled guide plate
Vossloh System W 21 HS

Highly elastic rail fastening system for concrete sleeper on high-speed lines.

Features:

- Skl 21 tension clamp with 2.5 mm fatigue strength
- Highly elastic intermediate pads with stiffnesses > 30 kN/mm allow high vertical deflection of rail
- Rail tilting protection by middle bend of the tension clamp and a special design of the angled guide plate
- The highly elastic pad is protected against overstrain by the tilt protection of the angled guide plate
The rail is held laterally in position by guiding rips which are integrated in the bearing element. Vertical and horizontal loads are taken up by the bearing element.

The patented rail fastening system has a high vertical static and dynamic elasticity combined with low building height, which is achieved by compact steel-rubber bonding.

The system is developed for direct fixing on concrete slab to reduce the vibrations generated from the wheel and transmitted by the rail. This is realized by the noise and vibration attenuation properties of the compact steel-rubber bonding of this rail fastening system.

Reliable, safe and maintenance-free, long spring deflection, high tensioning force, high creep resistance, effective protection against tilting.
Highly elastic rail fastening system for ballast tracks and concrete sleepers.

**Features:**

- Skl 30 tension clamp with high toe load combined with high fatigue strength of 2.2 mm
- For application in main lines with elastic rail pads
- All components can be preassembled at the switch or sleeper plant
- High toe load
- Rail tilting protection by middle bend of the tension clamp and specially designed angled guide plate
- Electrically insulated
- Gauge adjustment ± 5 mm by replacing of angled guide plates
Highly elastic heavy-haul rail fastening system for ballast tracks and concrete sleepers.

Features:

Skl 30 tension clamp with high toe load combined with high fatigue strength of 2.2 mm
All components can be preassembled at the switch or sleeper plant
Rail tilting protection by middle bend of the tension clamp and specially designed angled guide plate
Electrically insulated
Gauge adjustment ± 10 mm by replacing angled guide plates
High curvature of tension clamp protects sleeper screw
Abrasion plate (AP) reduces wear
Vossloh System 300

Worldwide leading Fastening System for super-high-speed on slab track. Vossloh has experience in super-high-speed the 70’s of last century. Providing high elasticity and high reliability proven by most comprehensive references. Our System 300 is in many countries the standard for super high speed on slab track.

The rail fastening system 300, which can be pre-assembled, is suitable for all methods of slab track installation.

The highly elastic intermediate plate substitutes for the elasticity of the ballast bed.

A steel pressure distribution pad, which supports the rail through the interposition of conventional rail pads, is used to improve the load distribution on the intermediate plate. The rail is held laterally in position by plastic angled guide plates.

The rail is permanently tensioned by spring-actuation as a result of the long elastic spring deflection of the tension clamp Skl 15.

The rail fastening system 300 can be adjusted by 30 mm in height and by 20 mm in the track gauge.
Vossloh System DFF 300

Single support as a highly-elastic rail seat for slab tracks. Repair system for slab tracks.

Slab tracks meet all the requirements for combined high-speed and heavy load traffic.

A highly elastic intermediate plate substitutes for the elasticity of the ballast bed. A steel load distribution plate with a rail pads on top is used to improve the load distribution on the intermediate plate.

Plastic angled guide plates, which form a precise gauge true channel, are embedded in a steel base plate. The rail is permanently tensioned by spring-actuation as a result of the long elastic spring deflection of the tension clamp Skl 15. The base plate itself is secured to the concrete slab of the track construction with 4 sleeper screws and plastic dowels of alternatively with anchor bolts.

The DFF 300 rail fastening system can be adjusted by at least 60 mm in height and by 46 mm in the track gauge. It is designed to fit as well directly onto the concrete slab as acting as single support both by interposition of a plastic intermediate plate.

In the case of repair or rehabilitation, the DFF 300 system can be placed between two failed or damaged rail seats points and used as a replacement fastening support.

The tension clamp Skl B 15 is available for bridge structures and other requirements with a reduced creep resistance.
Vossloh System 336

Rail fastening systems for ballastless concrete and steel structures. They ensure an effective reduction in vibration emissions by means of an elastically supported rail.

The system is suitable for standard-gauge railways as well as for urban light railways and can be adapted to local conditions as a result of their high flexibility.

Reliable, safe and maintenance-free, long spring deflection, high tensioning force, high creep resistance, effective protection against tilting.
Exchangeability
All components are exchangeable.

Electrical insulation
The W-Tram fastening system is completely electrically insulated as the angled guide plate, rail pad, dowel and base plate are all made of plastic. No additional insulating components are required between the clamping element and the rail foot.

Track maintainance
The Vossloh fastening system requires no regular maintainance.

Neutralisation
No fastening elements have to be removed from the rail support with continuous welding of the rail (CWR). The sleeper screws merely have to be loosened but not disassembled.

Height adjustment
The Vossloh rail fastening system W-Tram can be adjusted in height by means of height regulation plates.

Elasticity
The Skl 14 is used as standard for nominal stiffnesses of up to 50 kN/mm. The Skl 21 is used for high elasticities with stiffnesses of <50 kN/mm.

Rail tensioning and creep resistance
The rail is permanently tightened by the spring-actuation of the two torsion spring arms of the tension clamp with a spring deflection of approx. 13 mm and a hold-down force of approx. 2 x 10 kN. The requisite high creep resistance of the rail, which prevents the dangerous fracture gap in continuous welded rails, is obtained hereby.

Protection against rail tilting
Any uplift or tilting of the rail which may occur during tamping of the track or when running through narrow track curves is absorbed by the middle bend after it has overcome the small air gap (between the middle bend of the tensioning clamp and rail base). Permanent deformation of the outer spring arms is therefore excluded.
The PANDROL FASTCLIP FE system utilizes the proven technology of the original FASTCLIP assembly to create a lower-cost assembly which still retains the features that have provided railways and contractors with reduced installation, de-stressing and maintenance costs for many years. The fastening system remains captive, as before. It is delivered to site pre-assembled on each tie, and is fully compatible with automated track machinery.
Clip and Toe Insulator
- Nominal toe load of 2,250 lbs (1,000kg) per clip
- Integral toe insulator to reduce rail contact stresses and provide electrical resistance

Cast Shoulder
- Made from spheroidal graphite cast iron
- Shoulder stem does not weaken pre-stressed concrete
- Typical extraction strength of 2000 lbs (9kN)
- Does not deform under loading, the

Plastic Seal Plate
- Provides a simple seal within the tie mold
- Minimizes grout leakage around the shoulder during tie manufacture
- Reduces mold pocket wear, thereby increasing useful life of molds

Collar
- High lateral stiffness and durability give excellent gage retention
- Excellent electrical insulation
- Easily replaced in-situ if required
- Different widths available for dual-rail/gagewidening where required.

Studded EVA Rail Pad
- Specially designed rail pad provides medium stiffness and high impact attenuation, preventing high dynamic forces being transmitted to the ties and ballast, protecting them from damage and reduced life cycle.
Studded and grooved rubber pads are also available.
FEATURES OF ASSEMBLY

Fully Pre-Assembled
As with all FASTCLIP assemblies, all the components leave the tie factory fully preassembled on the tie, offering huge savings in manpower, reduced distribution and handling costs during tracklaying, de-stressing and rail change out. Note that the same clip remains captive on the tie for rail change operations. Loss of parts on site is also eliminated.

Dual-Rail / Gage-Widening
Assemblies allowing for a change of rail size, or track gage, are available, simply by the use of different thickness collars.

Threadless
The PANDROL FASTCLIP FE system has no threaded components, reducing the effect of corrosion of these parts, and problems which may be caused by cross-threading, the ingress of foreign matter, and water freezing in holes in the tie.
Replaceability of Components
PANDROL FASTCLIP FE is virtually maintenance free, with the component materials carefully selected to optimize the useful life of the rail fastening assembly and tie as a whole. However, should you need to replace a component, it is a simple procedure to withdraw the clip, without the need to unscrew bolts.

Rail Tensioning / Creep Resistance
By design, PANDROL FASTCLIP FE generates 2,250 lbs. (1000kgf) nominal toe load per clip. The correct tensioning is automatically achieved when the clip is driven into the working position, due to the shoulder geometry. It is not reliant on the correct torque being applied, as is the case with other systems anchored by threaded bolts.

Anchorage
Cast-in shoulders hold the rail at correct gage and correctly set the FASTCLIP deflection. The shoulders are cast into the tie during the manufacturing process.

Electrical Insulation
The FASTCLIP FE assembly provides excellent electrical insulation properties. The cast shoulders are electrically isolated from the rail by the collars. The spring clips are electrically isolated from the rail by the toe insulators.

De-stressing / Neutralization
All components remain captive during the destressing procedure. The clip is simply withdrawn back to the parked position to release the rail. Under-rollers, side-rollers and Vortok Stressing Rollers are available for use if required.
Installation on Site
Ties arrive on site with all components held captive and the clips set at the parked position. Once the ties are placed and the rail has been threaded, clips are simply pushed from the parked to the working position. Correct toe load is achieved automatically.

Mechanized Installation
The PANDROL FASTCLIP system has proved ideal for mechanized installation. Railways and Contractors have easily adapted existing track laying machines to install the system. Clip application units can be incorporated into a track laying train (no manpower required), or run as free standing units (1 man required).
Nabla C8
Nabla C8 on timber sleeper
Nabla C8 on timber sleeper
Laboratory tests of rail fasteners
The clamping force, exerted by the fastening system, is of major importance for the transmission of the load to the sleeper. A certain minimal value of the clamping force should always be present. Furthermore, the effect of the upward movement of the rail, causing a vertical tensile load on the fastening anchors, should be taken into account. To quantify this a quasi-static test was carried out on the combination rail, fastening and sleeper. In this test, the rail is supported while the sleeper is hanging on the fastening. The sleeper is loaded via an auxiliary beam.
Loading procedure

$P_1$: force, at which pad can just be removed;

$P_2$: force, for which:
- either $P + mg/1000 \leq 2 \text{ kN} \ (m = \text{mass sleeper+fastening+frame}),$
- or sleeper makes contact with the rail;

$P_0$: force, at which $d = 0$, to be determined after the test from the load/displacement characteristic;

$P_3$: $1.1P_0 - mg/1000$. 
Longitudinal restraint test

In considerations about creep, relaxation, temperature effects, pull apart of broken rail and braking forces it is useful to know the relation between the longitudinal load on the fastening and the displacement in the longitudinal direction. Especially the maximum load is of importance.

The figure shows the measuring principle. The sleeper is secured by a rail fastening assembly to the supporting structure. The position of the working line has been chosen in such a way as to minimise the bending moment on the fastening.
The prescribed way of loading is indicated in the figure. It concerns a static test without vertical loading. The load step is $2.5 \pm 0.3$ kN. At some crucial moments (increasing the load, slip through) the measuring signals were recorded at a higher sampling rate.
Vertical stiffness test

To determine the static vertical load of the complete fastening the test assembly, supported horizontally, is loaded by a vertical force of $80 \pm 1\ kN$ with a rate of $50 \pm 5\ kN/min$. After one minute the load is removed. The loading/unloading cycle is repeated two times. During the third cycle the vertical displacements are measured at the four corners of the rail. From this, the average maximum displacement $d\ [mm]$ of the rail is calculated. Finally, the vertical stiffness $k$ is determined as the quotient of the load interval between $5\ kN$ and $80\ kN$ and the corresponding mean vertical displacement $d\ [mm]$. The unit of $k = \text{MN/m} (=\text{kN/mm})$. 

![Diagram of vertical stiffness test setup]

- $P$: Applied load
- Rail
- Rail pad
- Sleeper
Cyclic loading test

The laboratory test to assess the effect of repeated loading is the means of assessing the potential long-term performance of the fastening in the track. The cyclic repeated loading is meant as a simulation of the repeated loading of passing trains. The test assembly, consisting of a short length of rail, fastening system and one (half) sleeper, was fixed in the test rig. The bottom plane of the sleeper acted as reference plane for the force directions.
To create two forces simultaneously with one hydraulic actuator, the test specimen is tilted over a certain angle $\alpha$ by inserting a stiff wedge between sleeper and the supporting structure. In this way two force components are present, one parallel and the other perpendicular to the bottom plane of the sleeper.

A servo-hydraulic actuator applies the constant amplitude cyclic force. The actuator load is introduced on the machined railhead by means of a load application head provided with a concave surface to concentrate the load on the right reference point. The other side of the actuator is connected to a hinge to enable the free movement of the railhead.
**Static preload**
repeat procedure 10 x requirements during last 3 cycles:
- tolerance $\alpha : \pm 0.5^\circ$
- tolerance $X : 1$ mm
- do displacement measurement

**Dynamic loading**
3 x $10^6$ cycles
min. load: (2.5 - 5.0) kN
max. load: see table 2 (in text)
frequency : (3-5) Hz
displacement measurement after:
$5 \times 10^4$, $5 \times 10^5$ en $3 \times 10^6$ cycles.
determine average permanent displacements
Before starting the dynamic load the rail is quasistatic preloaded and unloaded 10 times.

In this test six measurements are taken, four vertical at the edges of the railfoot and two horizontal at the railhead, parallel to the railfoot. The cyclic loading test itself takes about two weeks in case of continuous operation. To present the information of the mean residual displacement more clearly, the data containing the residual displacements of the rail after $3.10^6$ cycles can be presented according to the transformation scheme next figure.
Vertical displacement rail:
\[ w = \frac{1}{4} (d_1 + d_2 + d_3 + d_4); \]

Lateral rotation rail:
\[ \tan \varphi = \frac{1}{2} (d_1 + d_2 - d_3 - d_4) / b; \]

Lateral displacement railhead:
\[ v_{\text{head}} = \frac{1}{2} (d_5 + d_6); \]

Lateral displacement railfoot:
\[ v_{\text{foot}} = \frac{1}{2} (d_5 + d_6) - h \tan \varphi. \]
Action forces
Wheel forces
- $F_z$ (vertical)
- $F_y$ (lateral)
- $F_x$ (longitudinal)

Action forces on one fastener:
- $\beta F_z$ (vertical)
- $\beta F_y$ (lateral)

$\beta = 0.35 \ldots 0.65$
From moving vehicles transferred forces (F_y and F_z) unto rails are picked up by not only one fastener, but also more fasteners on more sleepers, so a part of the forces is transferred to fastenings. The reduction factor is based on experimental measurements and calculations, varies between: β=0.35...0.65.
Momentum equation to the tilting point:

\[ \beta \cdot F_y \cdot m = \beta \cdot F_z \cdot \frac{d}{2} + F_{out} \cdot d \]

In the Equation „d” distance between rail spikes.
From the previous equation anchor force can be expressed unto the inner fastener ("$F_{out}$": anchor force):

$$F_{out} = \beta \cdot F_y \cdot \frac{m}{d} - \frac{1}{2} \cdot \beta \cdot F_z$$

This force is pull on:
- fastening without baseplate $\rightarrow$ by one-side rail spikes,
- fastening with baseplate $\rightarrow$ by both sides fastening elements.
Horizontal force equilibrium equation:

\[ \beta \cdot F_y = f \cdot \beta \cdot F_z + F'_y \]

\[ F'_y = \beta \cdot F_y - f \cdot \beta \cdot F_z \]

where

• „f”: coefficient of friction between the sleeper and the rail foot (0.3).
The longitudinal fastener strength is the ability of the fastener system to provide longitudinal restraint to the rail and prevent rail movement or creepage under all loading conditions. Longitudinal loading can evolve due to train action, such as train braking and acceleration, specifically the variation in temperature, both rail and ambient.
The force on rail is originated from dilatation and rail wandering/creeping ($F_x$). This force wants to move the rail above sleeper and baseplate. Friction between rail foot and sleeper, as well as between rail foot and baseplate occurs against displacement force, friction depends on the clamping force unto fastening. So the clamping force unto fastening is correct, if the sleeper moves inside ballast and not the rail foot slides in baseplate.
Legends in the figure have the following meanings:

"F_{e1}" : the friction of ballast in bottom and lateral endplate of the sleeper,

"F_{e2}" : the pressure of the ballast in forehead of sleeper.
The maximal ballast resistance in one sleeper: $F_{e2} \approx 15$ kN.

• Force in one fastening: $= 7.5$ kN.
\[
\frac{F_{e2}}{2} = f \cdot F_{sz} \rightarrow F_{sz} = \frac{F_{e2}}{2 \cdot f}
\]

where

- "\( F_{sz} \)" : the maximal anchor force.

The maximal anchor force depending on friction between the rail foot and baseplate or rail pad:
- if \( f=0.3 \) → \( F=25 \) kN,
- if \( f=0.65 \) → \( F=11.5 \) kN,
- if \( f=0.11 \) → \( F=68.2 \) kN.
The pressure from rail foot to sleeper:

$$\sigma_s = \frac{\beta \cdot F_z}{d \cdot s}$$
The rigid frame of the track
The lateral direction forces are transferred from rail to fastenings, and to sleepers. Majority of these lateral direction forces are balancing by railway track, because the track behaves horizontal frame structure against these forces (girths: rails, columns: sleepers). This frame structure works appropriate, if there is no swivel in the girth-column junction, therefore the structure is rigid frame. The rigid frame in railway track means that the anchor force unto the fastenings is explicate to anti-rotation moment. If the rail-sleeper junctions are changed, it changes the rails perpendicular positions, then the track is deformed. This lateral direction deforming can be seen in the next figure.
railway track without geometry failures  

railway track with geometry failures (deformed track)
REFERENCES


• KAZINCZY, L. (2004). Vasúti pályák (Railways), BMEEOUVAT22 manual for students of a Budapest University of Technology and Economics Faculty of Civil Engineering. HEFOP/2004/3.3.1/0001.01.
REFERENCES


• ir. J. van ‘t Zand and ing. J. Moraal: STATIC AND DYNAMIC TESTS ON RAIL FASTENING SYSTEMS, Delft University of Technology DELFT

REFERENCES

DR. SZABOLCS FISCHER – BALÁZS ELLER – ZOLTÁN KADA – ATtilA NÉMETH:

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