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ELASTIC BEHAVIOUR OF CONTINUOUSLY EMBEDDED RAIL SYSTEMS

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Abstract

Due to the rapid development of railway technologies new solutions spread widely. A fast development can be noticed in the field of fastening systems. This study expounds a new fastening type, the continuously embedded rail system. Its laboratory testing was carried out in the Railway Structural Laboratory of the Budapest University of Technology and Economics.

Keywords: permanent way, elastic fastening system.

1. Introduction

Probably one of the most spectacular developments that permanent ways went through since the beginning of the railways can be seen in the improvement of fastening systems. This development became more rapid in the last decades, especially in the last few years. It can be explained by the increasing demands of railway transport due to the competitive situation between transport means. The demands railways have to satisfy are the reduction of travel time, punctuality and comfort. These improvements are realised in practice by high-speed tracks and generally by continuously increasing speed. But these demands of railway traffic increase the severity of requirements a permanent way has to meet.

One of the most important aspects transportations are judged by is protection of the environment. Basically it can be stated that railway is an environment friendly means of transport. In spite of this fact the damaging influences that are mostly noise- and vibration nuisance have to be decreased. These considerations also justify the development of special solutions of permanent way elements.

The above detailed demands are especially valid in urban areas where the aesthetic appearance is very important, as well. An aesthetically built track that fits into the local conditions can even give a special face to a town.

All the requirements mentioned above revive the need of development of new fastening systems that basically differ from the traditional types.

2. Requirements of Fastening Systems

The most important function of fastening systems is to provide strong and flexible connection between rail and its supporting structure that can be sleeper or slab. In addition to this main function fastenings have to meet other requirements that are in some cases contradictory.

Functions that fastening systems have to fulfil:

A.) *Rail stability aspects*

- To have sufficient resistance against the vertical and lateral wheel-forces transferred by rail and thus provide gauge.
- To be able to accept the longitudinal loads and thus avoid rail creep and ensure the utilization of ballast resistance in case of continuously welded tracks.
- To allow sufficient frame rigidity by having large rotation resistance and thus avoid buckling of track.
- To behave elastically against the vertical and horizontal forces thus the damages caused by dynamic forces can be reduced.

B.) *Construction and maintenance aspects*

- To be suitable to be built in any section of the track – in straight and curved, on bridges and in tunnels, in open tracks, in station tracks and in turnouts.
- To ensure the electric isolation of rails.
- Its construction and maintenance to be simple, fast and mechanized. Individual parts of the fastening should be simply and fast replaceable, as well as the rails and sleepers.
- Not to cause too large wear, damage on the rail and the sleeper due to traffic.

C.) *Economical aspects:*

- To contain only few parts.
- Its price should correspond to its quality and lifespan.
- To need little maintenance.

Because of the newly appearing demands detailed in the introduction these requirements have to be completed. The new functions of fastening systems:

- To fasten the rail elastically in the horizontal plane, so not only vertically but laterally and longitudinally, as well. This elasticity could be designed in advance.
- To be able to use in slab tracks.
- To calm down the noise and vibration generated by the vehicle.
- With reduced need of maintenance its lifespan should increase.
- To be aesthetic.
- Plastic elements of the fastening should be recyclable.

3. Categorisation of Fastening Systems

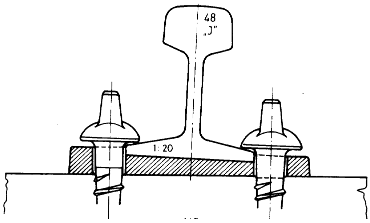
Fixing of the rail down to the supporting system can be basically solved with

- direct or
- indirect (separated)

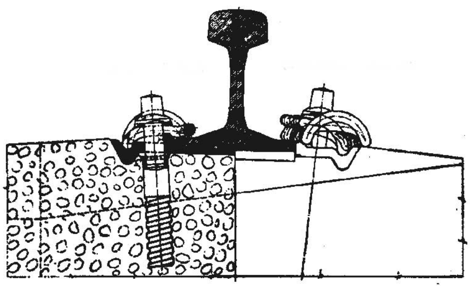
fastenings. Both types can be

- rigid or
- elastic,

depending on the elements used in the system. Direct fastenings can be seen in *Fig. 1*, while indirect fastenings in *Fig. 2*.



a) Direct, Rigid fastening with Coach Screw on Wooden sleeper



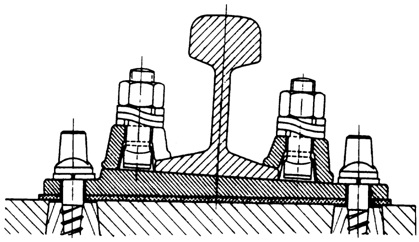
b) Flexible Fastening System, type w14 with Skl Clamp on Concrete sleeper

Fig. 1. Direct Fastenings

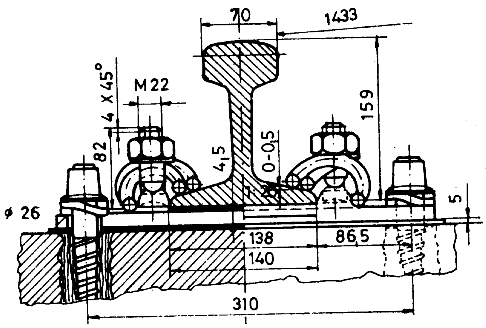
Due to new plastic industrial technologies a new fastening category was formed that can satisfy the increasing demands. These fastenings are the elastic embedded rail systems that can be categorized as follows:

A.) The rail is continuously embedded without using any clamping, anchoring element. The embedding can be created:

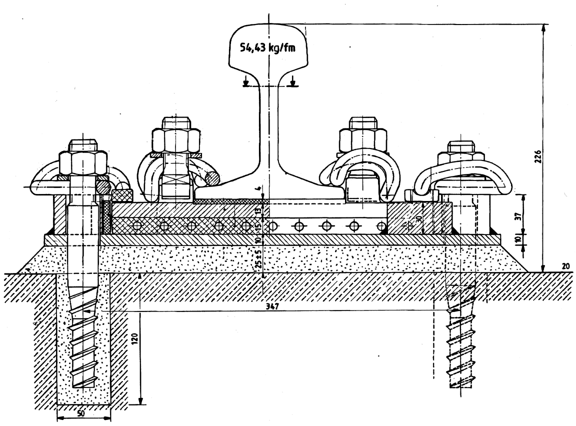
- by pouring in-situ,
- by pre-fabricated rubber elements or
- in manufacture by pre-coating.



a.) GEO Rigid Fastening System on Concrete Sleeper



b.) GEO Flexible System with Skl 3 Clamp on Concrete Sleeper



c.) Flexible Fastening System with Skl 12 and Skl ET Clamps on Concrete Slab

Fig. 2. Indirect Fastenings

B.) The rail is discontinuously embedded without using any clamping, anchoring element.

C.) The rail is fixed down traditionally with a flexible fastening system and the rail is embedded afterwards. The embedding can be executed:

- by pre-fabricated rubber or plastic elements or
- by pouring in-situ.

4. Continuously Embedded Rail Systems, the Rail Poured Out In-Situ

4.1. Introduction of the Fastening System

The fixing of the rail in these systems basically differs from the traditional fastening systems, as steel anchoring elements are not used at all. In case of the continuously embedded rail systems the rail is laid in a longitudinal recess created in the base structure and poured out with elastic embedding material. This fastening system can be used only in ballastless tracks.

The general cross-sectional arrangement of the fastening system can be seen in *Fig. 3*. Its most important elements are:

1. longitudinal recess created in the base structure,
2. elastic embedding material,
3. elastic base strip,
4. space filling elements.

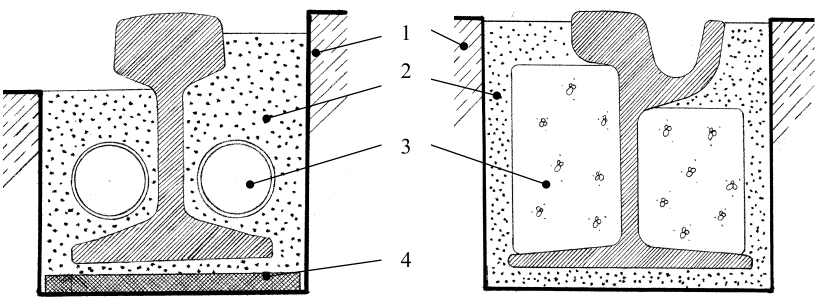


Fig. 3. Continuously Embedded Rail Systems

The material of the *recess* can be reinforced concrete or steel, depending on the track structure.

Fixing down of rail is realized by the contact of the *embedding material* with the rail and the recess surface. Widespread systems basically vary in the composition of this material, in most of the cases it is a two-component elastomer occasionally with added cork. These self-spreading materials are usually adsorbing after 2 hours and obtain their total strength within 10–20 hours.

For obtaining greater vertical elasticity a rubber or cork *base strip* is placed under the rail.

For reducing the amount of the embedding material space filling elements are placed on both sides of the rail that can be PVC pipe or cement-based brick in the fish-plate pass.

4.2. Features of the Fastening System

The most important features of the system:

- The track becomes laterally elastic that ensures the permanence of the gauge.
- Good solution for slab tracks.
- Structural heights of tunnels and bridges can be reduced.
- Due to elastic bedding the radiated noise and vibration of track can be radically damped.
- Track maintenance need is low.
- Aesthetic appearance.

4.3. Mechanical Testing of Continuously Embedded Fastening Systems

4.3.1. Introduction of the Testing

Several types of similarly created continuously embedded rail systems were tested in the Railway Structural Laboratory of the Budapest University of Technology and Economics in the last years. As direct flexible fastenings were also tested during this period, it was possible to compare these.

The aim of the testing is to determine the behaviour of the system against vertical, horizontal lateral and longitudinal forces. For this reason the specimens were vertically and diagonally loaded with static load and the displacements were registered. Dynamic tests were also carried out in these directions in the 1 . . . 9 Hz frequency interval. Usually fatigue tests were also done with 3 . . . 5 millions of repetition number, thus the effect of repeated load on the structure could be analysed as well. Finally longitudinal displacement tests were carried out.

The specimens were usually 1 m long for comparability and because of the available amount of material and laboratory circumstances. Three different types of embedding material were used. The cross-sectional arrangements of the specimens were different in the rail (UIC 54, UIC 60, Ri52), in the space filling elements (PVC pipe or brick) and in the base strip. Specimens without base strip were also tested. The dimensions of the recess were also different basically depending on the rail type, but the thickness of the embedding material between the rail and recess surface was kept to be minimum 20 mm.

4.3.2. Vertical Bedding Coefficient

The vertical elasticity of the superstructure is very important to be able to stand the dynamic loads caused by the everyday traffic. The characteristics of this elasticity can be expressed by the bedding coefficient C [N/mm^3] that describes the relationship between pressure p [N/mm^2] acting on the bedding and deflection of the rail y [mm].

$$p = C \cdot y. \tag{1}$$

Empirical determination of the bedding coefficient can be executed by measuring the vertical deflection under the loaded area. Then C can be calculated by the following formula:

$$C = \frac{Z}{4sy}\sqrt[3]{\frac{Z}{EIy}}. \tag{2}$$

The symbols are:

Z – load [kN],
s – the width of support (rail flange) [mm],
E – elastic (Young) modulus of the rail [N/mm^2],
I – inertial moment of the rail [mm^4].

As the flexibility of the rail is considered in this method it can be used only in case of at least as long a specimen as the wavelength of the deflection A [mm]. The displacement wavelength can be calculated with the help of the theoretical calculation of the stresses in a longitudinally supported superstructure by Zimmermann:

$$A = 2 \cdot \frac{3}{4}\pi \cdot L = \frac{3}{2}\pi \cdot \sqrt[4]{\frac{4E \cdot I}{C \cdot s}}. \tag{3}$$

In the above formula: L – length of rigidity [m].

The wavelength cannot be calculated without knowing the definite value of the bedding coefficient but with assuming an initial data, the minimal length of the specimen can be calculated. Assuming $C = 0.2$ N/mm^3 that is less than expected $A = 4.35$ m. As there were only 1 m long specimens tested in our laboratory another method was needed for determining the bedding factor.

The other method of the empirical determination of the bedding coefficient after measuring y is using the

$$C = \frac{Z}{y \cdot s \cdot l} \tag{4}$$

formula, where l [m] is the length of the rail in the specimen.

This formula can be used correctly only in case of rigid deflection of the rail, in other words if the vertical displacement of the rail is the same in each cross-section of the specimen.

For examining the question if the results measured on a short specimen are correct, 12.5 m and 2.5 m specimens were tested in a foreign research laboratory. The bedding coefficient of the long specimen was calculated according to (2), while that of the short one according to (4) and the result was equal. It means that measuring on short specimen can provide correct result for the bedding coefficient.

As mentioned above, the condition of using formula (4) is the rigid deflection of the rail. For this reason the vertical displacements were always checked in three points, in the middle and the two ends of the specimens. Though the results were usually not the same in these points, the difference was negligibly small.

The final results of the measurements on different types of continuously embedded rail systems loaded with static force resulted $C = 0.22 \ldots 0.48$ N/mm^3. The tests proved that the value depends basically on the properties of the embedding material and the existence of the base strip. According to the result it can be stated that structures the bedding coefficient of which is near the lower value are better from the point of view of track elasticity. It is especially important in case of transition zones where ballasted and slab tracks are meeting and the elasticity changes suddenly, as the bedding coefficient of ballasted tracks is only about $C = 0.1 \ldots 0.15$ N/mm^3.

The values of the coefficient determined from dynamic tests were in each case higher than the above, $C = 0.26 \ldots 1.20$ N/mm^3. According to the results it can be established that the value of the dynamic bedding coefficient of more rigid systems (C is high) grows much more than those of more elastic ones.

Similar measurements repeated after the fatigue test proved that the value of the coefficient grows by approximately 10–30%.

4.3.3. Lateral Elasticity

One of the most important roles of fastenings is to avoid the overturning and the lateral sliding of rail or to keep these movements in low limits and thus ensure constant gauge for a long time. In case of traditional fastenings it is ensured by heavily tensioned clamping elements that hold down the rail.

In case of continuous embedding the lateral displacement of the rail depends on the elasticity of the embedding material. There is no unique solution for calculating a lateral bedding coefficient as the thickness of the materials is inconstant within a cross-section and the overturning of the rail causes unknown reaction forces. For this reason the aim of the testing was to measure the lateral displacements.

Beside recording the lateral displacements due to different static and dynamic loads, they were also continuously recorded during the fatigue test. The most important practical result of the fatigue test is the change of the lateral displacement during the repeated load. It helps predict the lifespan of the track gauge. The lateral displacements of continuously embedded systems can be seen in *Fig.4* in comparison with direct and indirect traditional fastening systems, as function of repetition number.

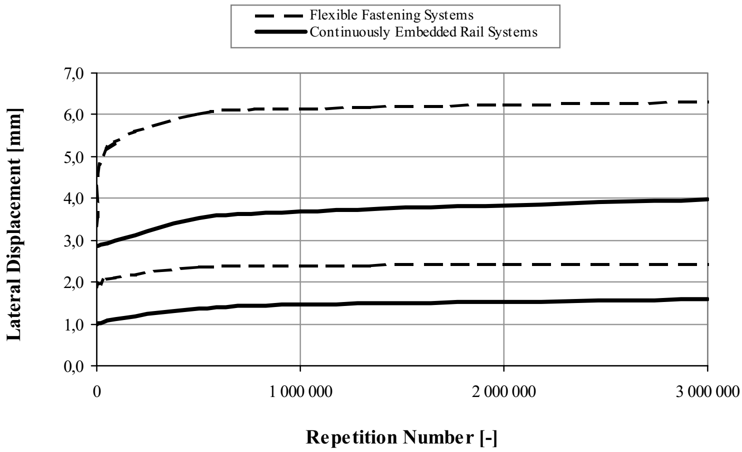


Fig. 4. Lateral Displacement of Rail During Fatigue Test in Case of Different Flexible Fastening Types and Embedded Rail Systems

The solid curves in the diagram present the extreme behaviour of continuously embedded systems, while the dashed lines show the traditional flexible fastenings that were tested in our laboratory.

The bottom dashed line was measured on direct, flexible fastening (type *Fig. 1*b) while the upper dashed line on indirect, separated flexible type (see *Fig.2*c). The fatigue tests were always performed on a single pair of fastenings according to scissor scheme, never on longer track field.

The thick boundary curves were chosen as the minimum and the maximum values measured on different embedded fastening systems and converted to 0.6 m long specimen. According to the results it can be stated that the lateral displacement of the structure depends first of all on the elasticity of the bedding material. In case of specimens with brick space filling the displacements were always less than those with PVC pipe which can be explained by the smaller amount of material beside the rail.

As the curves represent the displacements of 0.6 m long structures for the same test loads they can be compared with each other. But here it must be remarked that the real displacement in the track will be less because of the load distribution effect of the adjacent fastenings or the continuous embedding.

The comparison of the values generally proves that continuously embedded fastening systems suffer less lateral displacement as an effect of repeated load than flexible spring fastenings. It is also an experimental observation that these materials have delayed elasticity, which means that after load removal the residual deformation was always less than 1.5 mm.

4.3.4. Longitudinal Bedding Factor

An important part of the laboratory testing is to measure the resistance of the structure against longitudinal (dilatation) forces. This can be carried out by longitudinal displacement test.

Completing these tests it can be established that the bedding material behaves like a spring. It means that tensile force is generated in the material during the dilatation movement that is proportional to the displacement. The elasticity that represents the longitudinal behaviour of this system can be expressed by the spring constant d_l [N/mm]:

$$d_l = \frac{F}{\Delta l}. \qquad (5)$$

In the above formula

F – longitudinal force [kN],
Δl – displacement [mm].

As the value of d_l depends on the length l [m] of the test specimen it is more practical to calculate with its specific value. This specific value is the longitudinal bedding factor
ρ [kN/mm/m] that can be calculated as:

$$\rho = F/\Delta l/l = \frac{d_l}{l}. \qquad (6)$$

This expresses the force that results 1 mm longitudinal displacement on a 1 m long specimen.

Completing the tests and calculating ρ the results are between 11.9 . . . 44.4 [kN/mm/m]. The force-displacement diagrams belonging to these extreme values with solid lines can be seen in *Fig.* 5 converted to 0.6 m length. This figure also contains the behaviour of a traditional, good quality flexible fastening against longitudinal forces illustrated by the dashed line.

It must be remarked that the goodness of a system cannot be seen directly from the value of ρ or the slope of the curve, but it has to be proved by theoretical calculation that was worked out in the Railway Engineering Department many years ago. This calculation determines the minimum value of the elastic rail end movement the system should have due to the real dilatation forces.

According to the formerly mentioned results generally it can be stated that those systems are better which have smaller slope in the force-displacement curve, in other words which have greater displacement for the same force.

It was also proved that systems with PVC pipe space filling have small value of longitudinal bedding factor, as the contact area of the bedding material and the rail is much bigger than in case of bricks. It is also proved that systems in which the bedding material is more elastic can suffer bigger longitudinal movement without destruction and its residual deformation will also be smaller.

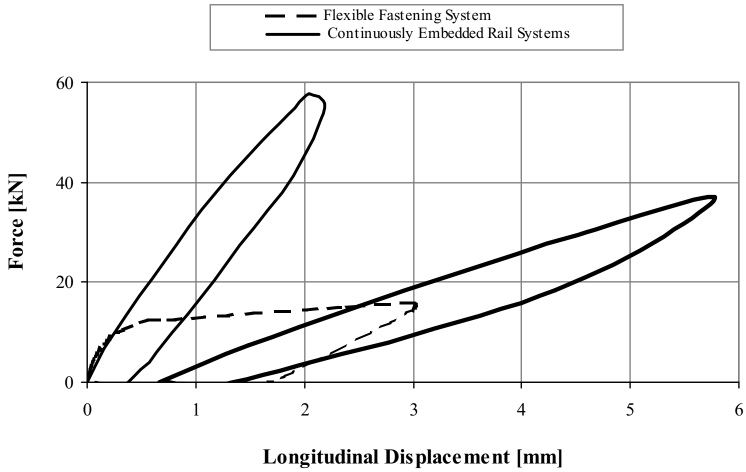


Fig. 5. Longitudinal Displacement of Rail in Case of Different Embedded Rail Systems and a Flexible Fastening Type

It can also be stated that continuously bedded rail systems can bear much more longitudinal force without destruction and have smaller residual deformation than the traditional, flexible fastenings.

5. Summary

The steadily growing demands of transport clearly show the way of the improvement that railway track structures have to move forward. These demands urge the technological companies to develop new methods, like the continuously embedded rail systems as fastening types that are already world-wide known and used.

A newly developed fastening system not only must have new properties like damping of noise and vibration but must perform at least as well as an existing system does. In this case the laboratory test carried out in the Railway Structural Laboratory of Budapest University of Technology and Economics proved that the continuously embedded rail systems not only have several new advantages but can bear the traffic loads better and for longer than formerly used types.

References

[1] VÁSÁRHELYI, B., *Railway Track Superstructure*, Közlekedési Kiadó, 1953.
[2] NEMESDY, E., *Railway Track Superstructure,* Tankönyvkiadó, 1966.
[3] MEGYERI, J., *Railway Engineering*, Műegyetemi Kiadó, 1997.

[4] HORVÁTH, A., *Arrangement and Design of Rail Fastening Systems*, Műszaki Könyvkiadó, 1984.
[5] SZAMOS, A., *Materials and Structures of Railway Track Superstructure*, KÖZDOK, 1991.
[6] ESVELD, C., *Modern Railway Track*, MRT Production, West-Germany, 1989.
[7] HORÁTH, F. (ed.), *Construction and Maintenance of Railway Track I.–II.*, MÁV Vezérigazgatóság, 1999.
[8] KORMOS, GY., Longitudinal Behaviour of Rail Embedded in Elastic Material, *Közlekedéstudományi Szemle*, 2001, (under publication).
[9] KAZINCZY, L. – KORMOS, GY. – LUDVIGH, E., Study about the Adaptation of Edilon Fastening System on the Bridges of the Newly Designed Railway Line between Zalalövő-Bajánsenye, 1999.
[10] *Theoretical and Laboratory Examination for the Certificate of Competency of the Edilon Rail Fastening System*, – Final Report, TUB, Department of Railway Engineering, 1996.
[11] *Approval Test about the Possible Adaptation of Edilon Rail Fastening System in 160 km/h Speed Tracks*, TUB, Department of Railway Engineering, 1999.
[12] *Approval Test about the ORTEC Powerflex Embedded Rail Fastening System with Rail-type Ri52*, BUTE, Department of Highway and Railway Engineering, 2001.
[13] *Approval Test about the ORTEC Powerflex Embedded Rail Fastening System with Rail-type UIC54*, BUTE, Department of Highway and Railway Engineering, 2001.
[14] *Research Study about the Approval Tests of Rail Fastening System W14 of Vossloh Rail Systems Ltd.*, BUTE, Department of Highway and Railway Engineering, 1999.
[15] *Research Study of the Approval Tests about the Modernisation of Rail Fastening System of the Northern-Southern Budapest Underground Line Recommended by Vossloh Rail Systems Ltd.*, BUTE, Department of Highway and Railway Engineering, 2000.