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INVESTIGATION OF THE INTERNAL FORCES OF THE FIRST TRACK CONSTRUCTED WITH Y-SHAPE STEEL SLEEPERS UNDER OPERATION IN HUNGARY
SUMMARY OF RESULTS OF RESEARCH

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Abstract

The Hungarian State Railways (MÁV Rt.) plans to reconstruct the tracks with short rails and rail joints in its trunk line network by continuously welded rails, that is possible by applying, among other technical solutions, the Y-shape steel sleepers. The first track with Y-shape steel sleepers was constructed in Hungary in November 2003, in the Szabadbattyán – Tapolca railway line at the stop of Badacsony. As a consequence of the application of the Y-shape steel sleepers, a continuously welded rail track has been constructed in a curve with a radius of R=300 m, where previously there had to be rail gaps and rail joints with the concrete sleepers. On behalf of the Hungarian State Railways (MÁV Rt.), the Budapest University of Technology and Economics, Department of Highway and Railway Engineering carried out research series on the track with Y-shape steel sleepers under operation. The series of track measurements had the following aims:

1. to assess the technical parameters of the track with Y-shape steel sleepers,
2. to compare the technical parameters of the Y-shape steel sleepered track with those of a track with concrete sleepers,
3. to determine how these parameters change with time.

The track measurements included three series:

1. determining the displacements of the sleepers and the rails under dynamic load of a locomotive,
2. measuring the lateral displacement of the track in a curve, perpendicular to its centre line due to the change of temperature between the variation summer and winter,
3. assessing the graph of the track examination coach.

In this paper, the first two subjects will be discussed. The third theme of the research will be investigated in another paper.

In Chapter 2, the Y-shape steel sleepers and the tracks constructed with them are described technically in general. The first track section constructed with Y-shape steel sleepers in Hungary is introduced in Chapter 3. Chapter 4 discusses the measurements and their results carried out on the track with Y-shape steel sleepers in Hungary. An evaluation of the results and of the track is given in Chapter 5.

Keywords: Y-shape steel sleeper, continuously welded rail track, ballasted track, railway track.

1. Introduction

The Hungarian State Railways (MÁV Rt.) plans to reconstruct the tracks currently with short rails and rail joints in its trunk line network by continuously welded rails, that is possible by applying, among other solutions, the Y-shape steel sleepers.

The Thyssen-Krupp Gft, who manufactures and sales the Y-shape steel sleepers, charged the Budapest University of Technology and Economics, Department of Highway and Railway Engineering to carry out a homologation process so the Y-shape steel sleepers can be constructed in the Hungarian railway track network. Based on the documentations of the sleepers, computations, results of international research, international experiences and observations of operational tracks, the Department of Highway and Railway Engineering has determined that the Y-shape steel sleepers meet all the specifications of the construction, maintenance and operation of the Hungarian track network, and the Y-shape steel sleepers can be constructed therein.

Before the construction of the Y-shape sleepers in large numbers, the Hungarian State Railways decided to make a research track section in the main line of Szabadbattyán – Tapolca, at the stop of Badacsony, in order to investigate the technical parameters of the continuously welded rail track with ballast bed under Hungarian operational circumstances.

2. Technical Description of the Y-Shape Steel Sleepers [1, 2]

2.1. General Description of the Y-shape Steel Sleepers

The general shape of the Y-shape steel sleepers is illustrated in *Fig.1.* Their most important features are:

- the sleeper is made of two major beams and two minor beams,
- within one rail fastening, the major and the minor beams are parallel to each other,
- the major and the minor beams have the cross section of IB 100 S-1,
- the major beams are manufactured by bending the section of IB 100 S-1,
- the major and the minor beams are connected by L section beams welded on their bottom surfaces and by rectangular sectional steels welded on the top surfaces,
- different sleeper spacing can be obtained by bending the major beams to a different degree, and therefore the width of the sleeper can be altered,
- various special structures can be fastened on or welded to the sleeper, such as cogwheel-bar.

The major and the minor beams have the cross-section of IB 100 S-1, that is 140 mm wide, 95 high, the thickness of the web is 6 mm and the average thickness of the flange is 7.5 mm.

The sleepers that can be constructed into normal gauge railway tracks, are manufactured with two lengths. The structural length is understood at the top surface of the sleeper. The 2000 mm long sleepers have the length of 2000 mm on the top surface and 2300 mm on the bottom surface, they are signed as ‘sleepers with normal length’. The 2200 mm long sleepers have the length of 2200 mm on the top surface and 2500 mm on the bottom surface, they are signed as ‘long sleepers’.

The systems of the Y-shape steel sleepers are marked according to the distances between the centre points of the rail supports. The most common systems are the ‘*230 – 550 – 230*’, the ‘*230 – 600 – 230*’ and the ‘*230 – 650 – 230*’ mm systems. The 230 – 550 – 230 system is manufactured with the length of 2200 mm, the 230 – 600 – 230 and the 230 – 650 – 230 systems have the length of 2000 mm.

Any type of rail can be fastened on the sleepers and the rail fastening can have any type of rail cant.

It is possible to join a track section with Y-shape steel sleepers and a section with cross sleepers by laying transition sleepers. Left and right transition sleepers are distinguished, the left ones are marked as ‘Üli’ (Übergang links), the right ones as ‘Üre’ (Übergang rechts), and the Y-sleepers that can be laid in normal open tracks have the mark of ‘No’ (normal).

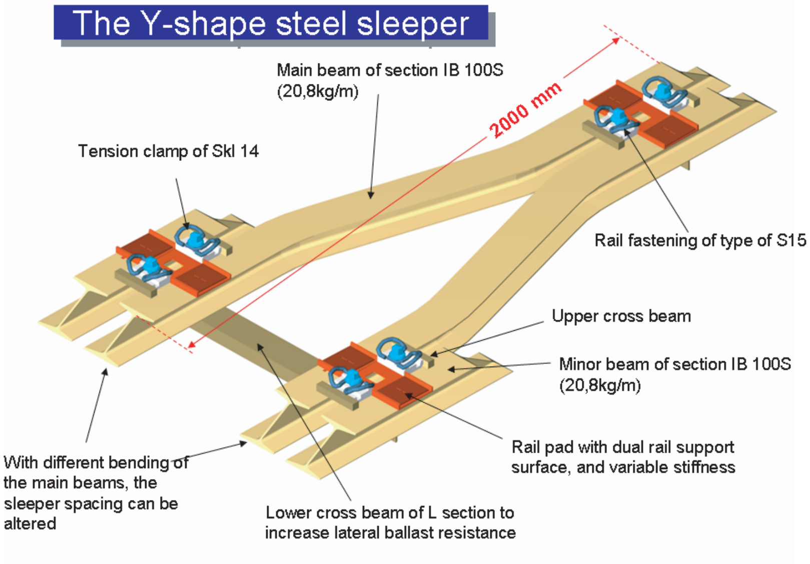

Fig. 1. General structural forming of the Y-shape steel sleepers

The rail fastening of type S15 supports the rail at two railpads, whose centre points are 230 mm away from each other. The rail is fastened by a tension clamp of Skl14 that is tensioned by a screw driven into a plastic insert. Gauge is kept by plastic inserts supported laterally by the upper cross beams. The rail cant is secured by the rail pad.

2.2. Structure and Geometry of the Y-shape Steel Sleepers Constructed in the Szabadbattyán – Tapolca Railway Line

Y-shape steel sleepers of system of 230 – 650 – 230 mm were constructed in the railway line of Szabadbattyán – Tapolca. The rail system is MÁV 48, the cant is 1:20. The distance between the centre points of the rail supports is 230 – 650 – 230 mm, and the distance between the centre lines of the main and minor beams is 190 – 690 – 190 mm. The sleeper is 1210 mm wide. The length of the minor sleeper is 500 mm on the top surface and 800 mm on the bottom surface. Assembled with the rail fastening, the normal sleeper weighs 142 kg, the transition sleeper weighs 139 kg.

The transition sleeper has distances of 230 – 210 – 230 mm between the centre points of the rail supports and 190 – 250 – 190 mm between the centre lines of the main and minor beams. They are 770 mm wide. The structural length and the cross-sectional area is the same as for the normal Y-shape steel sleepers.

2.3. Technical Description of the Ballasted Track with Y-shape Steel Sleepers of System of 230 – 650 – 230

2.3.1. Arrangement of the Sleepers

The arrangement of the sleepers of system 230 – 650 – 230 including the transition sleepers in the track is illustrated in *Fig. 2*. The distance between the centre line of the normal sleepers is $(650 + 230) \cdot 1.5 = 1320$ mm.

The specific number of sleepers per kilometres is 758 pc/km. The distance between the screws of the rail fastenings is 880 mm.

2.4. Determining the Lateral Displacement of the Y-shape Steel Sleepered Track with Continuously Welded Rail in a Curve due to the Change of Temperature

One of the aims of the research-series of Y-shape steel sleepered track is to determine the magnitude of the lateral shift of the Y-shape steel sleepered track, perpendicular to its centre line, due to the internal tension or compression forces resulting from the change of temperature due to the annual variation summer and winter. It is also an aim to investigate if this lateral displacement through the years can be considered to be elastic or residual.

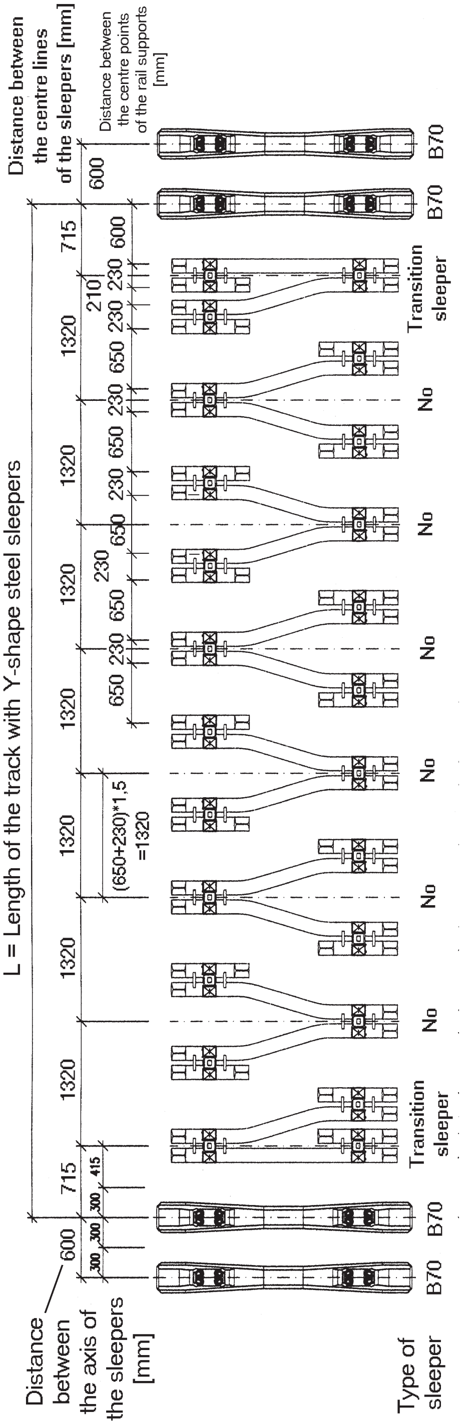

Fig. 2. Arrangement of the sleepers of system of 230 - 650 - 230 mm

2.4.1. *Form of the Ballast Bed*

A possible cross-section of the ballast bed is indicated in *Fig. 3*. The sleepers are 2000 mm long on the top surface. The width of the ballast shoulder on both sides is 300 mm. The minimum thickness of the ballast is 300 mm measured under the bottom surface of the sleepers. The sleepers are 95 mm high, of which the minimum total thickness of the ballast is 395 mm. The ballast is 2600 mm wide on the top surface and 4020 mm wide on the formation level.

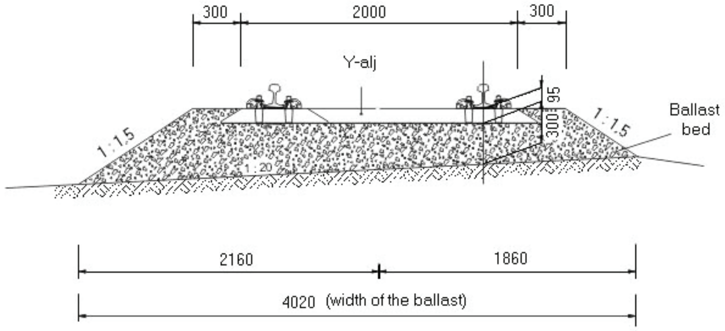

Fig. 3. A typical cross-section of the track with Y-shape steel sleepers

2.5. *The most Important Advantages of the Tracks with Y-shape Steel Sleepers against the Tracks with Cross-Sleepers*

Advantages of the tracks with Y-shape steel sleepers:

- the track with Y-shape steel sleepers can not buckle, it dilatates elastically perpendicular to the centre line of the track with changing temperature,
- higher lateral ballast resistance than that of concrete sleepers,
- the sleeper bears the bending and torsion internal forces,
- low construction height, the height of the cross-section of the sleeper is 95 mm,
- less ballast thickness,
- less ballast width,
- narrower formation,
- less number of rail fastenings,
- low mass to transport at construction,
- high resistance to corrosion,
- the material can be welded well,
- easy realigning of track.

3. Technical Description of the Track Constructed with Y-shape Steel Sleepers in the Szabadbattyán – Tapolca Railway Line [1, 2]

The Y-shape steel sleepers of system of 230 – 650 – 230 were constructed, in the Szabadbattyán – Tapolca railway line, not far from the stop of Badacsony, in the curve between chainages of 1039+31 – 1043+39. The radius of the curve is $R = 300$ m, the length of the pure circular curve is 286 m. The transition curves between the straight track section and the circular curve are 68 m long at both ends of the curve. The track is superelevated at 93 mm. The maximum permissible speed in this curve is 60 km/h.

Altogether 300 normal Y-shape steel sleepers and two transition sleepers were constructed in the track. The track and its surroundings are illustrated in *Fig. 4*.

Fig. 4. The track with Y-shape steel sleepers and its surroundings at chainage of 1041 + 40

4. Methods of the Investigationof the Technical Parameters of the Track with Y-shape Steel Sleepers

On behalf of the Hungarian State Railways, the Department of the Highway and Railway Engineering of the Budapest University of Technology and Economics carried out track measurements in order to investigate the technical parameters of the track with Y-shape steel sleepers. The series of track measurements had the following aims: [2]

- to assess the technical parameters of the track with Y-shape steel sleepers,
- to compare the technical parameters of the Y-shape steel sleepered track with those of a track with concrete sleepers,

- to determine how these parameters change with time.

The track measurements included the three following methods of research [2]:

- determining the displacements of the sleepers and the rails under dynamic load of a locomotive,
- measuring the lateral displacement of the track, perpendicular to its centre line, due to the change of temperature between the variation summer and winter,
- assessing the graph of the track examination coach.

Two series of measurements were carried out, in November 2003 and in May – July 2004.

In order to compare the technical parameters of the Y-shape steel sleepered track with those of a track with concrete sleepers, simultaneuosly comparative measurements were carried out on another track with short rails and rail joints in a curve with a radius of 300 m, on the same railway line between the stations of Révfülöp and Badacsonytomaj. This track section was built with concrete sleepers of type LI. This type of sleeper has a length of 2420 mm, a width of 295 mm on the bottom surface, a maximum thickness of 225 mm, and it weighs 303 kg. The rail type is MÁV48, the rail is not continuously welded and therefore has rail joints. The sleeper spacing is 0.6 m. The radius of this track sections is $R = 300$ m, and the maximum permissible speed in this section is $V = 60$ km/h [2].

4.1. Determining the Displacements of the Sleepers and the Rails under Dynamic Load of a Locomotive

For the measurements, a four-axle diesel locomotive of type M41 was applied, whose static axle load is 175 kN. Under its passing, the following displacements were measured on the track with the Y-shape steel sleepers and also on the track with concrete sleepers of type LI [2]:

- the absolute vertical displacement of the sleepers at the outer side of the outer rail, and at the outer side of the inner rail, in case Y-shape steel sleeper on its three ends, measured against a concrete fix-block established near the track,
- the absolute horizontal displacement of the sleepers measured against a concrete fix-block established near the track,
- the relative vertical displacement of the two sides of the rail base measured against the sleeper,
- the relative horizontal displacement of the rail head, measured against the sleeper.

The locomotive passed over the measured sections at two different speeds: at $V = 5$ km/h and $V = 60$ km/h, at each speed and at each section at least six times. An example of a recorded curve of the vertical displacement of an end of a Y-shape steel sleeper is illustrated in *Fig. 5*, due to a locomotive speed of 60 km/h [2].

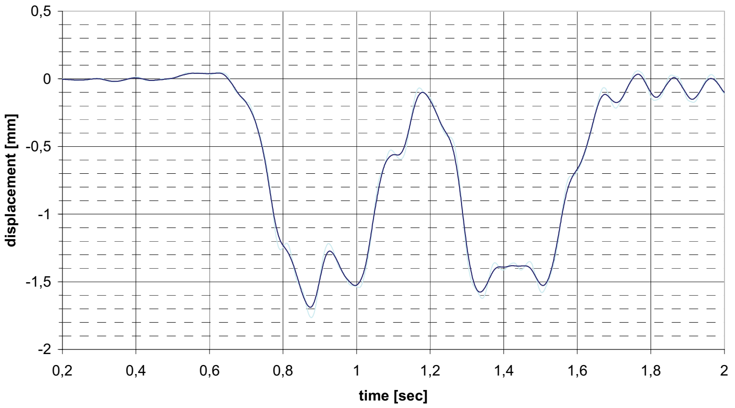

Fig. 5. The absolute vertical displacement of an end of a Y-shape steel sleeper, speed of the locomotive: 60 km/h

The averaged results of the measured values of the displacements detailed above are contained in *Table 1* for the tracks with Y-shape steel sleepers and with concrete sleepers of type LI, for locomotive speeds of V = 5 km/h and 60 km/h, for the time periods of measurements.

The averaged values of the results of the measured displacements of the sleepers and the rail are illustrated graphically on *Figs. 6* and *7* for the tracks with Y-shape steel sleepers and with concrete sleepers of type LI, for speeds of $V = 5$ and $V = 60$ km/h.

Four measurements were carried out at the following times:

Time of measurement of the position of track after its construction:	8 December 2003,
Three further measurements:	20 February 2004, 16 April 2004, 23 July 2004.

Table 1. The average values of the displacements of the sleepers and the rail of the tracks with Y-shape steel sleepers and with concrete sleepers of type LI

Type of sleeper in track	Speed [km/h]	Year	Vertical displacement of sleeper at outer rail [mm]	Vertical displacement of sleeper at inner rail [mm]	Horizontal displacement of sleeper [mm]	Vertical displacement of rail base against sleeper [mm]	Horizontal displacement of rail head against sleeper [mm]
Y-shape steel sleepers	5	2003	1.633	2.031	0.228	0.432	0.532
		2004	1.543	1.991	0.242	0.192	0.602
	60	2003	1.756	2.120	0.282	0.320	0.451
		2004	1.593	1.996	0.282	0.175	0.660
Concrete sleepers of type LI	5	2003	0.867	1.014	0.535	0.627	0.269
		2004	0.767	0.927	0.509	0.605	0.409
	60	2003	0.950	1.110	0.405	0.458	0.226
		2004	0.861	1.046	0.411	0.459	0.411

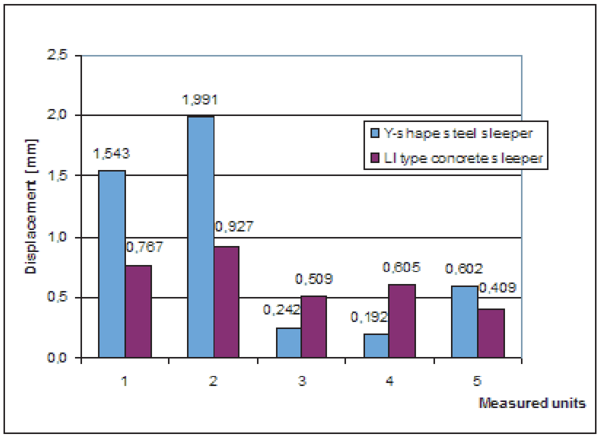

Fig. 6. Averaged results of the measured displacements in case of track with Y-shape steel sleepers and with concrete sleepers of type LI, in case of speed V = 5 km/h

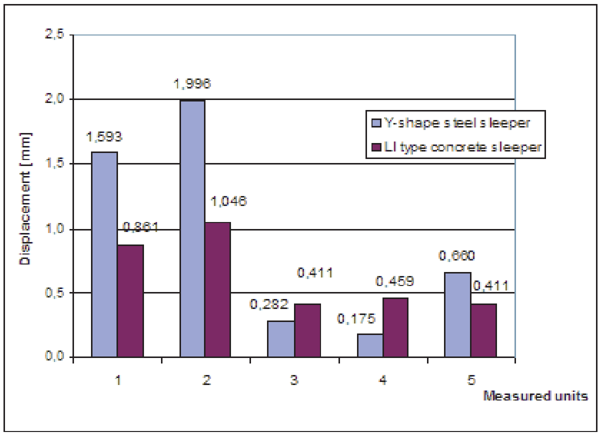

Fig. 7. Averaged results of the measured displacements in case of track with Y-shape steel sleepers and with concrete sleepers of type LI, in case of speed V = 60 km/h

Measured units:
1. average value of the absolute vertical displacement of the sleepers at the outer side of the outer rail,
2. average value of the absolute vertical displacement of the sleepers at the outer side of the inner rail,
3. average value of the absolute horizontal displacement of the sleepers,
4. average value of the relative vertical displacement of the two side of the rail base measured against the sleeper,
5. average value of the relative horizontal displacement of the rail head, measured against the sleeper.

The position of the relevant points of the track was determined by using surveying theodolite, against concrete fix-blocks installed near the track. A hole with a depth of 1 mm and a diameter of 1 mm was punched into the midpoint of the upper surface of the upper cross beam, at the inner side of the outer rail. The positions of these points were determined by using theodolite.

The positions of such points were measured at every $8th$ rail fastenings. The distance between two rail fastenings is 0.88 m, of which the distance between two measured points is 7.04 m. The subsequent measured points lie alternating either on the open or on the closed end of the sleeper. Together with the transition sleeper, the positions of altogether 59 Y-shape steel sleepers were determined. The surveying is illustrated in *Fig. 8*.

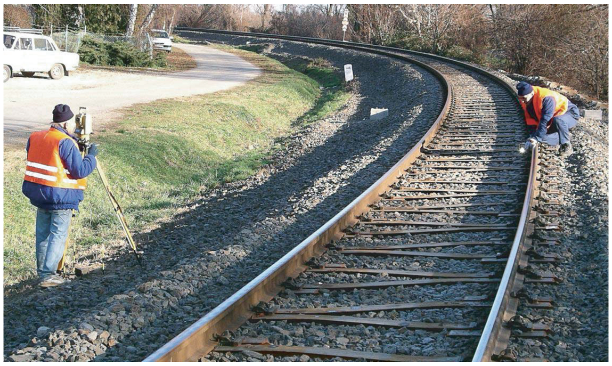

Fig. 8. Carrying out the measurement of the position of the points on the sleepers

The straight track sections constructed with concrete sleepers, joining the transition curves were also involved in the measurements over a length of 40 – 50 m, in order to determine the horizontal lateral displacement of these sections due to the annual variation of the temperature between summer and winter. The rail is of type MÁV48 and continuously welded, the sleepers are of type L, and the sleeper spacing is 0.6 m. Every $12th$ sleeper was involved, therefore the measured points are 7.2 m away from each other.

The results of the measurements of December 2003, April 2004 and July 2004 are illustrated in *Fig. 9* in the way that 'x' axis of the coordinate-system indicates the position of the track in the circular curve at the measurement carried out in February 2004, and the displacement of the individual point of the sleepers, perpendicular to the centre line of the track is indicated on the 'y' axis at the three other periods of measurements. The basic measurement to which the results of the other measurements are compared is chosen to be February 2004, because of two reasons. One of them is that the coldest period was this one, and the other is that the track could not consolidate after its construction until the first measurement that was in December 2003. The average lateral displacement of the sleepers in the circular curve (points 17 – 58), perpendicular to the centre line of the track, compared to the position of the track in February 2004, the rail temperature and the weather in the period prior to the time of measurement are contained in *Table 2*.

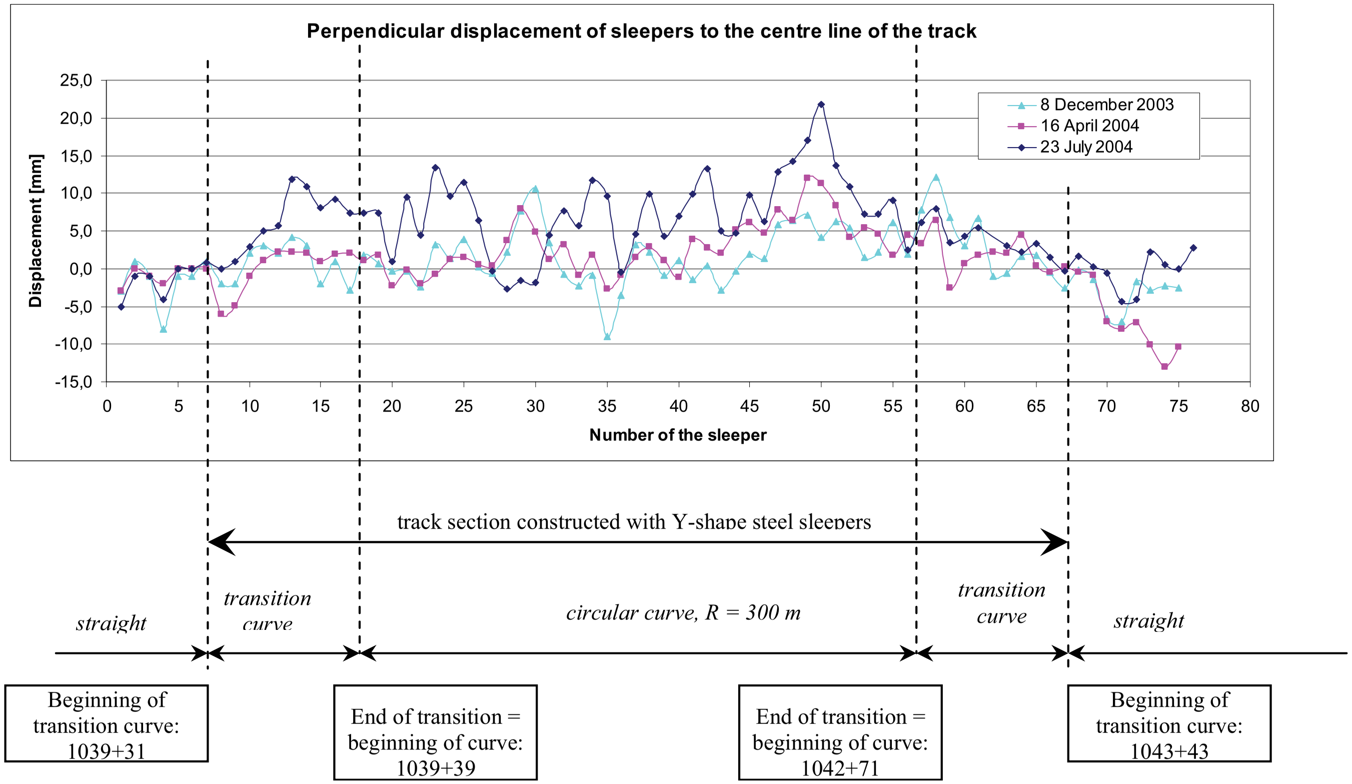

Fig. 9. The lateral displacement of the measured points of the sleepers, perpendicular to the centreline of the track at the time of December 2003, April 2004 and July 2004 compared to the measured position in February 2004

Table 2. Average lateral displacement of the sleepers in the circular curve (points 17 – 58), perpendicular to the centre line of the track, compared to the position of the track in February 2004, the rail temperature and the weather in the period prior to the time of measurement

Time of measurement	Average lateral shift of the track [mm]	Rail temperature [°C]	Weather in the period previous to the measurement
8 December 2003	2.0	−4 – −2	Mild, temperature above 0°C in the daytime, and below 0°C at nights
20 February 2004	—	−5 – −2	Permanently very cold −10 – −15°C at nights
16 April 2004	3.0	30 – 32	Sunny, warm
23 July 2004	7.5	50 – 52	Permanently sunny and hot, above 30°C in the daytime

4.2. Assessment of the Graph of the Track Examination Coach

The assessment of the graph of the track examination coach and its results will be discussed in another paper at a later time.

5. Assessment of the Results of the Measurements

5.1. Displacement of the Sleepers and the Rails

Of the results of the vertical and horizontal displacement of the sleepers and the rails of the Y-shape steel sleepered track with continuously welded rail and the track with rail joints and concrete sleepers of type LI, under the movement of locomotive, the followings can be determined:

The *vertical displacement* of the Y-shape steel sleepers varies within the range of 1.3 – 2.4 mm that can be considered to be normal under an axle load of 175 kN. The vertical displacement of the concrete sleepers of type LI is within the range of 0.6 – 1.2 mm. The vertical displacement of the Y-shape steel sleepers is approximately 1.5 – 2 times greater than that of the track with concrete sleepers of type LI. It is due to two facts, one of them is that the sleeper spacing of Y-shape steel sleepers is 0.88 m and that for the concrete sleepered track is 0.6 m. The other fact is that the thickness of the ballast under the concrete sleepered track is between 0.8 – 1.0 m, that is 2 – 3 times thicker than under the track with Y-shape steel sleepers that results in the track with concrete sleepers being much stiffer. However, the stiffness of the substructure also greatly influences the vertical displacement of the sleepers, but there are no such measurements regarding these sites.

The *horizontal lateral* displacement of the Y-shape steel sleepers was found to be within the range of 0.1 – 0.4 mm, and that for the concrete sleepers of LI is within the range of 0.3 – 0.7 mm, under the same load. The ballast shoulder of the track with LI sleepers is much more compacted than that of the track with Y-shape sleepers. In spite of this fact, the Y-shape steel sleepers move less in the horizontal lateral direction under the same load than the concrete sleepers of type LI. *The track with Y-shape steel sleepers is much more stable horizontal laterally than the concrete sleepered track.*

The results of the vertical and horizontal displacements of the sleepers and the rail do not change to a great extent between the time of measurements of November 2003 and May 2004.

5.2. Lateral Displacement of the Y-shape Steel Sleepered Track due to the Change of Temperature

Of the results of the displacements of position of the sleepers (points 17 – 58), perpendicular to the centre line of the track, in the circular curve, in the four time periods, the following conclusions can be drawn:

Due to the permanently cold weather in January and February, by the time of the measurements in February 2004, the track within the circular curve shifted on average 2 mm towards the centre point of the curve, since the time of measurement in December 2003, although the temperature of the rail was almost the same at the two measurements. Of these results, the conclusion can be drawn, that *the weather of the time period prior to the time of measurement has an influence on the lateral movements of the track, and that the lateral movements due to change of temperature are slow deformation.*

By the time of the measurements in April, the track moved on average 3 mm away from the centre point of the circular curve, compared to its position at time of measurement in February, due to a difference in rail temperature of 35°C.

Due to the permanently hot weather prior to the measurement, *the track moved on average 7,5 mm perpendicular to its centreline* by the measurement in July 2004, *due to a change in rail temperature of 55°C*, since the time of measurement in February 2004. The movement of the majority of the sleepers, perpendicular to the centreline of the track, varies within the range of 4 to 10 mm.

On basis of the results, it can be concluded that the track with continuously welded rails and Y-shape steel sleepers moves radially, perpendicular to the centre line of the track, due to the change of temperature. To determine that whether the property of this effect of such lateral movements is elastic or residual with the change of temperature will be the object of further research and measurements. It is not possible to draw conclusions on such problem from the results gained from the change of one cold – hot weather (February – July).

6. Conclusion

Based on the results of the research of the vertical and horizontal displacement of the sleepers and the rails under the movement of a locomotive, and the lateral displacement of the Y-shape steel sleepered track due to the change of temperature, it can be concluded that the track constructed with Y-shape steel sleepers performs well and satisfies the specifications of railway operations and maintenance. It is possible to construct a continuously welded rail track with the Y-shape steel sleepers in curves with low radius, where rail gaps and rail joints have to be constructed if the track is supported by concrete sleepers. With further research more detailed and more accurate results and parameters could be obtained.

References

[1] LIEGNER, N.: The Application of the Y-shape Steel Sleepers in Hungary, *Mélyépítő Türkörkńep Magazin*, April 2004, Budapest.

[2] LIEGNER, N. – KAZINCZY, L.: Research Report on the Investigation of the Ballasted, Continuously Welded Rail Track with Y-shape Steel Sleepers and the Track with Rail Gaps, Rail Joints and concrete sleepers under operation, Department of Highway and Railway Engineering, Budapest University of Technology and Economics, Budapest, 2004.