Transactions on the Built Environment vol 33, © 1998 WIT Press, www.witpress.com, ISSN 1743-3509

Use of continuous welded rail track in sharp curves, high gradients and turnouts

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Abstract

Characteristics of track situation and loading for urban, suburban and regional rail transport are pointed out. Short description of the advantage of the continuous welded rail track is presented. The elastic-plastic model of the continuous welded rail track structure with the effect of the vertical load on longitudinal resistance is applied. Train braking/traction forces as well as homogeneous and non-homogeneous thermal loading are considered. Applications of the model for analysis of the continuous welded rail track behaviour in sharp curves, high gradients and turnouts are presented. Calculations are carried out for track and load parameters typical for the urban, suburban and regional rail transport. The possibilities of application of the model for determination of rules of the use of the continuous welded rail track in urban and regional rail transport conditions have been discussed.

1 Introduction

Continuous welded rail (CWR) track is introduced to replace bolted joints which are weak structural links and costly to maintain. The increased usage of CWR track needs significant research for understanding and controlling failure caused by thermal and other service loads. Two of the major failure modes are[12]:

- track buckling,
- rail breaks.

Rules of the use of the CWR track are determined by several railroad administrations as well as by international organisations (e.g. by Union

Internationale des Chemins de Fer, based on European Rail Research Institute investigations). Urban and regional rail transport companies partly use railroad rules, partly use original conceptions. For example: on Polish State Railways the use of CWR track is permissible on curves with minimum radius of curvature 600 m, and on Krakow Tramway Network the CWR track is under service on curves with radius less than 200 m. These tracks are designed as separate tramway lines.

It is clear that in urban, suburban and regional passenger transport systems only light trains are applied. It is also clear that railway track buckling frequently occurs on unloaded track (comp. e.g. [12]). It follows that use of CWR track in urban and regional conditions needs special rules. These rules must be formulated on theoretical and experimental investigations, partly by application the railroad experiences.

Urban, suburban and regional passenger transport may be characterised as follows:

1. Track situation:
   a) high gradients (even to 50-60 ‰),
   b) many turnouts, level crossing and cross-over of the tracks),
   c) many sharp curves (in streets radius of curvature even 20-30 m),
   d) tracks in streets or separate;
2. Loading:
   a) static axle load in order 50-75 kN,
   b) train speed in order 50-100 km/h,
   c) high frequency of train passages,
   d) existing of many zones of train braking/accelerating,
   e) existing of zones of non-homogeneous thermal loading (partially sun and shade).

These conditions should be taken into account in the track structure design process and during service.

The aim of the paper is presentation of theoretical base for use of CWR track in urban, suburban and regional rail transport conditions. The paper presents selected problems which were investigated at the Krakow University of Technology for European Rail Research Institute D-202 Committee (1993-1997 y.) as well as for Krakow City Transport Ltd. (1985-1995 y.).

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2 Theoretical and empirical research on CWR track - short description of the state of the art

Samavedam[12] presents existing theoretical approaches, experimental works as well as safety concept to use of CWR track. Van[13] studies the problem of positional stability of CWR track on straight lines and curved track. Albrecht et al.[1] and Esveld[6] present physical and technical problems connected with the application of the CWR track in railroad conditions. Eisenmann[5] and Ignjatic[7] describe empirical and theoretical investigations on CWR behaviour on sharp curves. Papers of Czyczula & Tomana[4] and Kaess[8] give the examples of investigations of longitudinal forces and displacements of welded turnouts and adjacent zones. Problem of high traction/braking forces also in combination with non-homogeneous thermal loading were studied by Rhodes[10] and Czyczula[3]. Bösl[2] was analysed longitudinal track movements under cyclic non-homogeneous thermal loading. Novakovich[9] and Sato et al.[11] present special effects: rheological and dynamic properties of ballast in the longitudinal direction.

In this paper three models of CWR track will be considered:

- the model of straight line track for analysis of traction/braking forces in combination with high gradients and non-homogeneous thermal loading as the development and modification of the model, presented in the paper of Czyczula[3];
- the model of sharp curves which partly is generalisation and partly simplification of the model presented in the papers[1,7,12,13];
- the model of turnout and group of turnouts as the generalisation of the approach, presented by Czyczula & Tomana[4].

Due to restriction of the size of the paper, only physical models and examples of calculations will be presented (mathematical models are relatively complicated).

3 Application of CWR track on the straight lines - analysis in longitudinal and vertical directions

The basic analysis concerns the following model of the track:

- rails - elastic prismatic beams with the longitudinal stiffness EA (E - rail steel Young modulus, A - cross section area of both rails - Fig. 1);

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- rail foundation (fasteners, sleepers and ballast) – perfectly elastic - plastic longitudinal resistance with including the effect of vertical loading[13].

The basic model of the loading may be characterised as follows:

- uniform loading in vertical q [kN/m] and longitudinal t [kN/m] directions (Fig. 1);
- non-uniform rail temperature increase ΔT(x) – the linear change of the temperature over the length of 2λ (Fig. 2);
- additional longitudinal force due to gradient of the line.

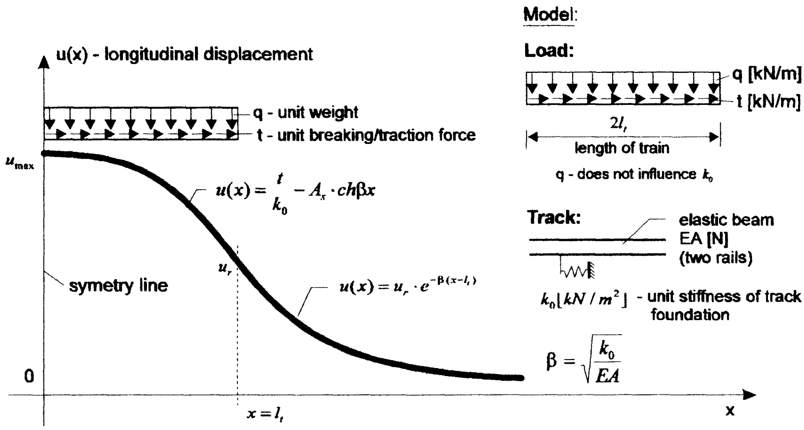

Figure 1: Model of track and its mechanical load.

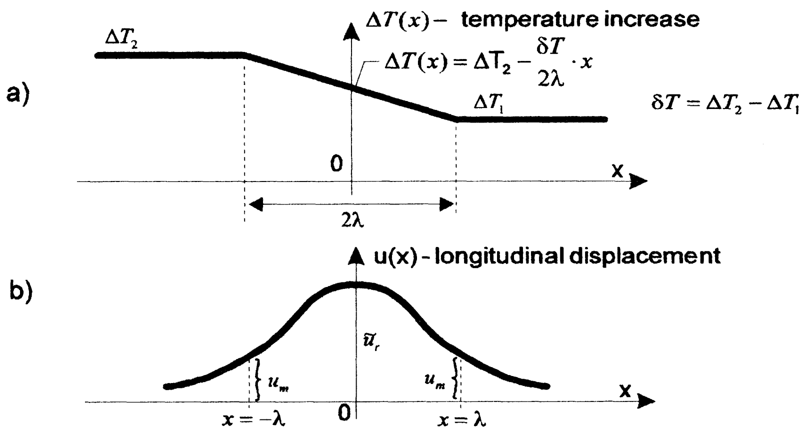

Figure 2: Model of thermal load: a) distribution of the temperature increase, b) distribution of longitudinal displacements.

Original Krakow University of Technology software gives the possibility of determination of elastic - plastic track response for any foundation characteristics and any thermal and mechanical loads, also for separate axle load and non-linear changes of the rail temperature along the track.

From the practical point of view the assumption of bilinear (perfectly elastic - plastic) track foundation behaviour, the linear temperature change along the track and limitation of track response to the elastic zone is justified. In this case track destressing process is eliminated. Introducing the degree of track creep prevention as:

$$d_{cp} = u_{max}/u_{lim} \tag{1}$$

where:

- u_{max} - maximum longitudinal rail displacements follows from the traction/braking, gradients and non-homogeneous thermal loading;
- u_{lim} - limit longitudinal displacement for elastic response,

we obtain the practical measure which determines the possibility of the track longitudinal creep. If $d_{cp} < 1$ then track creep does not occurs and longitudinal forces in CWR track follows only from cyclic temperature variations. Practically assumed safety level should be introduced and u_{max} must be multiplied by assumed coefficient - this problem will be not considered.

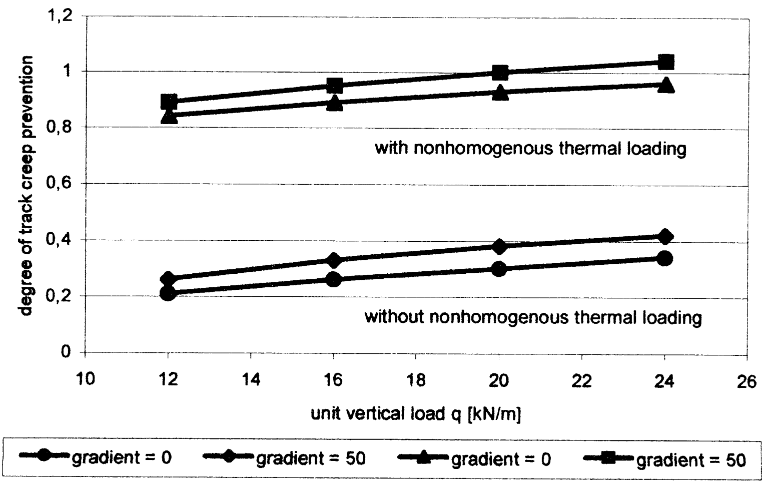

Figure 3: Influence of unit train weight on the degree of track creep prevention.

Fig. 3 shows the example of analysis – influence of the train vertical unit loading on the degree of track creep prevention for various gradients of the line and non-homogeneous thermal load. All calculations were carried out for the length of train of 40 m, for the intensity of braking $\mu = 0{,}2$ ($\mu = t/q$; t - braking force, q - vertical load, see Fig. 1) and for the following track parameters:

- rails - S-49 (cross section area of single rail - 6296 mm^2);
- longitudinal resistance : stiffness $k_o = 5000$ kN/m^2, limit resistance r_b = 8 kN/m, friction coefficient of foundation - 0,5.

As can be seen non-uniform thermal loading, assumed as a change of the temperature increase of 20^0C along the length of 60 m, is the basic factor which - for light trains - influences the possibility of track creep.

4 Application of CWR track in sharp curves

Consider the model of the track in which:

- equivalent elastic beam consist of two rails with the lateral stiffness EI (E - rail steel Young modulus, moment of inertia of two rails in horizontal plane);
- fasteners are modelled by elastic springs with constant torsional stiffness θ;
- ballast is modelled as perfectly elastic - plastic constrain with the parameters: k_l - lateral stiffness [kN/m^2], r_l - limit ballast lateral resistance [kN/m].

Only the thermal uniform rail temperature increase will be analysed. Also track mechanical and geometrical imperfections are considered. Because only small displacements will be analysed therefore effect of longitudinal movements may be neglected (comp. papers of Samavedam[12] and Van[13]). Train loads induce lateral forces but - at the same time - increase lateral resistance[12,13]; this effects will be neglected.

Consider the following example:

- track situation: circular curve with the angle 90 deg, radius of curvature R = 50-200 m and transition curves of the length of 50 m for both sides of the arc;
- loading: only thermal with $\Delta T = 40^0$C;
- track structure: rails: S-49, torsional fasteners stiffness $\theta = 1500$ kNm/rad per m track, ballast lateral stiffness $k_l = 4000$ kN/m^2, limit resistance $r_l = 16$ kN/m;
- imperfections - mechanical; in central zone of the curve: 25 % decrease of lateral stiffness over the length of 7.8 m.

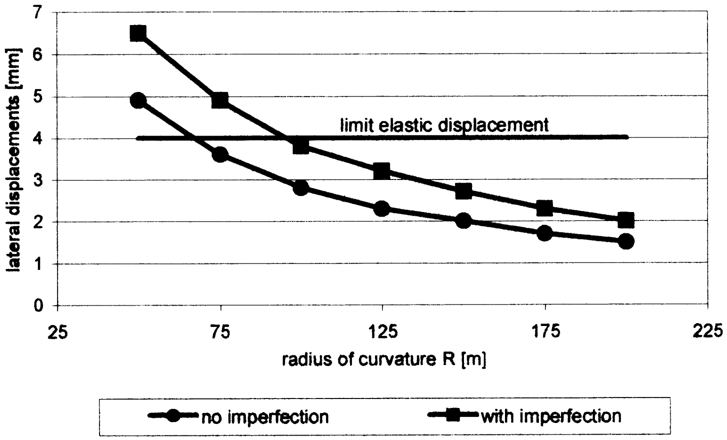

Figure 4: Influence of the radius of the curvature on the lateral curve response.

Figure 4 shows the influence of the radius of the curvature on maximum lateral displacements with and without of mechanical imperfections. For calculations the original Krakow University of Technology software was used. In considered range of calculations if the radius of curvature is less than about 100 m then the curve response is restricted to the elastic zone.

5 Welded turnouts and group of turnouts

Consider two dimensional model of turnout and adjacent zones (stress plane without vertical direction), described by the following elements:

- rails and sleepers - elastic bodies with real dimensions and real material properties;
- fasteners and ballast - equivalent bodies giving real elastic- plastic behaviour in longitudinal and lateral directions (for fasteners equivalent elements are modelled also the torsional stiffness).

Only the uniform rail thermal load for the following track situations are analysed:

- track diversion,
- track diversion with connection of two parallel tracks
- single crossover
- double crossover

Ideal turnouts is considered with perfect circular arc and any radius of curvature and assumed angle of turnout. For calculations the original

Krakow University of Technology software was used in the combination with ALGOR - FEM system.

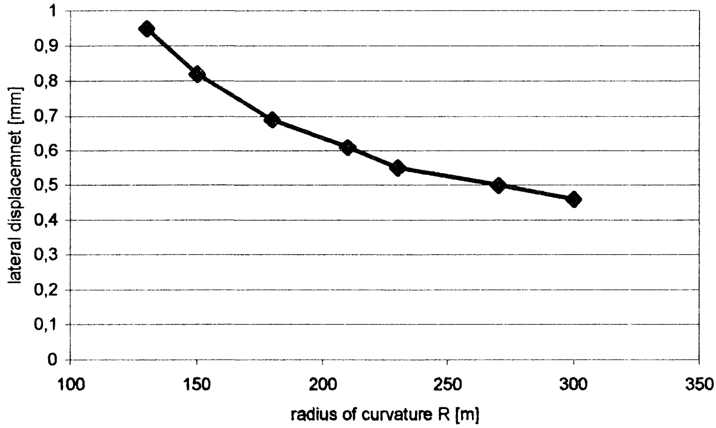

Figure 5: Influence of the radius of the turnouts on maximum lateral displacements.

Figure 5 shows the influence of the radius of the turnouts on maximum lateral displacements for single crossover situation. The tangent of the angle of the turnout changes in the interval 1:6 – 1:9. All calculations were carried out for the following parameters:

- rails - S-49;
- sleepers - wooden, with the cross section area 0,25 x 0,17 m and basic length of 2,5 m;
- fasteners - equivalent torsional stiffness θ = 1500 kNm/rad per m track;
- ballast - equivalent lateral stiffness - k_l = 4000 kN/m^2; equivalent limit lateral resistance r_l = 12 kN/m (limit elastic displacement – 3 mm);
- thermal loading - $\Delta T = 40^0C$;
- track spacing - 4,0 m.

In all analysed cases the lateral response of the system of turnouts is restricted to the elastic zone.

6 Summary and conclusions

The paper presents physical models for analysis of CWR track behaviour, especially in high gradients, sharp curves and turnout conditions. Uniform and non-uniform thermal loading are considered as well as train braking/traction forces. Application of the perfectly elastic-plastic rail foundation model gives the possibility to introduce the simple creep prevention concept - limitation of track response to the elastic zone for the assumed prevention level (creep prevention coefficient). This approach gives the possibility to design of the track structure, the track situations and the service loading without significant longitudinal creep and lateral residual displacements.

Presented examples of calculations show the possibility to use of CWR track in the urban, suburban and regional rail transport. It means that track maintenance costs will be significantly reduced with preservation of the traffic safety. The proposed theoretical model and software may be applied for determination of rules of the use of CWR track in the urban, suburban and regional passenger rail transport.

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