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Time Consumption Modeling of Planning Vertical Profile of High-Speed Railways

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A B S T R A C T

A short survey on modern track maintenance methods is given, concentrating on the developments in recent years. The ongoing refinement of the machinery should be shown as the influence of IT-solutions. On top the economic view to the track infrastructure is briefly demonstrated. Further developments in track hardware solutions must respect the obtained high level of track work mechanization. However, with respect to presentation time some other ongoing developments unfortunately are not discussed. Prominent amongst those are: the advent of high grade rail steels like heat-treated perlitic steels, the experiments with bainitic steels and, the introduction of hydraulically driven turnouts with special high-speed-prone rail geometry or the latest machine sets for general subgrade rehabilitation.

1. Introduction

In the last half of the century, the world has enjoyed rapid development of high-speed railway. The high-speed railway are resulted from the specialized developments of high-speed railway and expanded out of passenger traffic system [1].

High-speed railway is a type of passenger rail transportation that operates significantly faster than the normal speed of rail traffic [2] and plays a more and more important role in our daily life. According to the specific definition of the European Union, High-speed railway refers to the transformed railway tracks whose operating speed can be above 200 km/h and the new specialized railway tracks whose speed can be above 250 km/h [2]. As the social and economic benefits is one of the features of high-speed railways beside many features like high-speed, large passing capacity, high efficiency and less pollution, so many studies on efficient energy management have been carried out in metro and rail transit systems [3]-[5]. The reduction of energy consumption is also seen as one of the key objectives for the development of sustainable mobility by use of high-speed train. The completion of a high-speed train project will lead to a huge increase in electricity consumption in spite of the comparatively lower mean energy consumption per passenger kilometre [6]. However, a high-speed train project requires a very heavy investment for a country, mainly due to the cost of civil works. Therefore, the high investment must be balanced by a shorter trip time and lower energy consumption. In this context, More than 40 years ago, a simplified method of calculation of energy and time consumption and operating expenses was derived by Wang Di [7] in form of mathematic models and graphs. The calculation work was done in cooperation with engineers of the Third Design Institute of Railway Ministry and was proved satisfactory in practical designs. The theoretical idea and the main procedure are still useful today. Referring to large amount of design data, the profiles between passing sidings or intermediate stops may be classified into six types of imitation, Figure 1.

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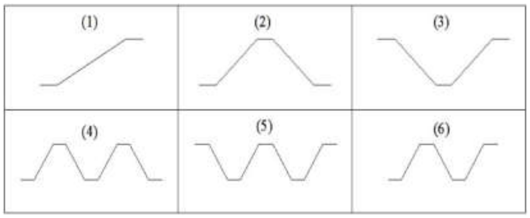

Figure 1. Imitating Types of Railway Profile

2. Theoretical Study

2.1. Gradient Value

The maximum gradient (i_{max}) is calculated by using the Equation (1) [8]:

$$i_{max} = (3600P_k - \omega_o g\, V_{max})/g\, V_{max}\ (\%) \quad (1)$$

where, P_k is the required power per ton (KW/t), V_{max} is the maximum speed of train (Km/h), g is the gravity acceleration (g = 10 m/s2), ω_o is the basic resistance of the maximum speed of running train (N/KN), and for calculating this resistance for CRH3 (EMU), this research uses the Equation (2) [8]:

$$\omega_o = 0.66 + 0.00245V + 0.000132V^2 \quad (2)$$

2.2. Time consumption

Time consumption of train running between station A and station B is calculated by using the Equation (3)[8]:

$$T_{A/B} = \sum(t_i.L_i) + t_s + t_p(min) \quad (3)$$

Where t_s, t_p are the extra time consumption of starting and parking of a train. In general, for electric traction and Diesel traction: t_s = *1~ 3 min*, t_p= *1~ 2 min.*

Li is the length of slope (km), t_i is the time consumption per kilometer on a gradient section (min/km), for ascending, t_i= *60 / Vi*, *Vi* is the balancing speed and can be obtained from the unit force graph. But the braking system of high speed train is using computer-controlled comprehensive braking mode. It does not contain the concept of train converted braking ratio and brake lining converted friction coefficient which is in general train brake calculation. Also it does not need to consider the train basic resistance and gradient resistance. Therefore, the effective braking distance can be directly calculated by a given deceleration [9].

When the train is getting off a slope, t_i is calculated from the Equation (4):

$$S = V_{max}t \quad (4)$$

where *S* is the horizontal distance of the gradient section (m), *V* is the maximum speed (Km/h). But when the train is getting off a slope and there is a station at the end of the gradient section, the running time is calculated according to Equation (5) for uniformly variable motion:

$$S = V.t + 0.5at^2 \quad (5)$$

where *S* is the braking distance (m), *V* is the speed (Km/h) and *a* is the deceleration (m/s^2).

3. Conventions

It is assumed that the distance between two following stations is (L = 30 Km) and this distance will divide for each gradient section as shown later in each profile.

The additional time for starting and parking of the train is considered to be 3min: $t_s + t_p$=3min.

This study chooses the China Railway High-speed (CRH) Electrical Multiple Unit (EMU) type-3 and Figure 2 shows its unit force curve.

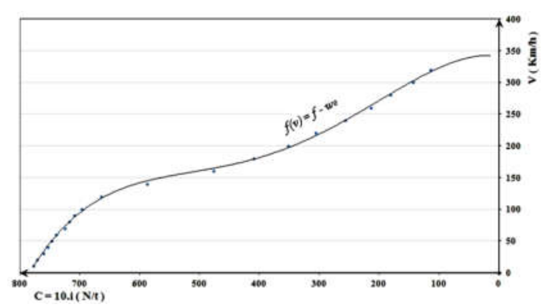

Figure 2. Unit force curve of the CRH3 (EMU)

From main technical parameters of CRH3 (EMU), it is found that the values of P_k and Vmax which belong to CRH3 are;

P_k= 21.05 KW/t , V_{max} = 350 Km/h.

By changing the speed of CRH3 (EMU), this research acquires different values of gradient as shown in Table 1.

Table 1. Values of gradient for each speed of CH3 (EMU)

V(Km/h)	350	300	250	200
ω_o(N/kN)	17.687	13.275	9.523	6.43
i (%)	3.96	11.98	20.79	31.46

4. Calculation Process

The relationship between time consumption and gradient is obtained by applying the previous theoretical study of changing the value of maximum gradient and then calculating the time for each profile as follows:

4.1. Vertical Profile No.1

Figure 3 shows the vertical profile between the two stations A and B with the distance changing in each gradient. Table 2 shows the values of time consumption for each value of the maximum gradient.

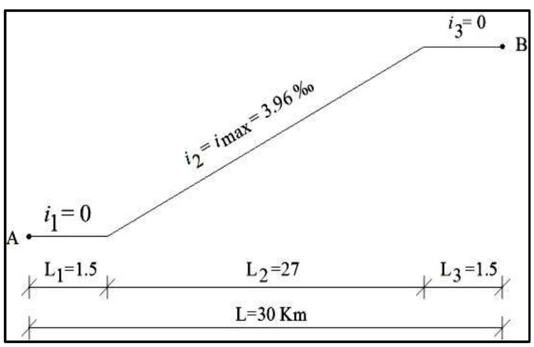

Figure 3. Vertical profile No.1

Table 2. Time consumption for profile No.1

Gradient i (‰)	3.96	11.98	20.79	31.46
Time t (min)	8.28	8.68	9.58	11.06

Figure 4 shows the relationship between time consumption and the maximum gradient for profile No.1.

4.2. Vertical Profile No.2

Figure 5 shows the vertical profile between stations A and B with the distance changing in each gradient. Table 3 shows the values of time consumption for each value of the maximum gradient.

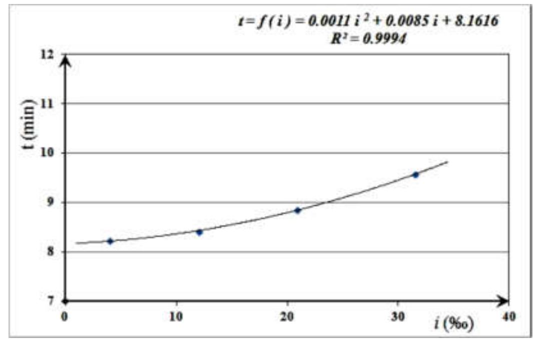

Figure 4. The curve t = f (i) of profile No.1

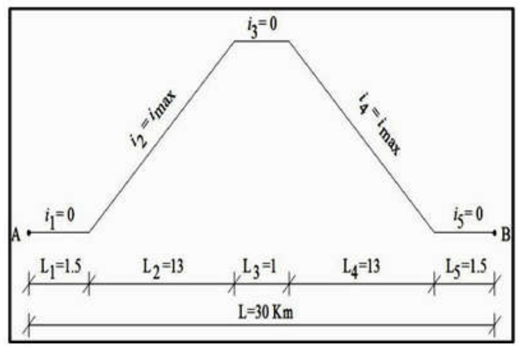

Figure 5. Vertical profile No.2

Table 3. Time consumption for profile No.2

Gradient *i* (‰)	3.96	11.98	20.79	31.46
Time t (min)	8.22	8.41	8.85	9.56

Figure 6 shows the relationship between running time and the maximum gradient for profile No.2.

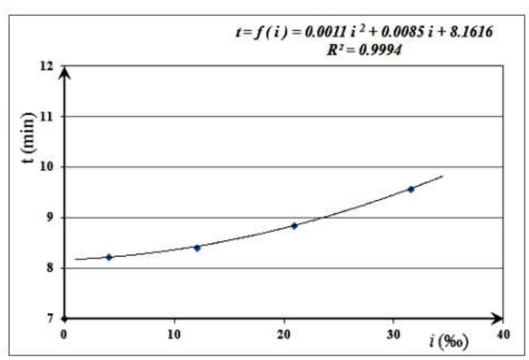

Figure 6. The curve t = f (i) of profile No.2

4.3. Vertical Profile No.3

Figure 7 shows the vertical profile between two stations A and B with the distance changing in each gradient. Table 4 shows the values of time consumption for each value of the maximum gradient. Figure 8 shows the relationship between running time and the maximum gradient for profile No.3.

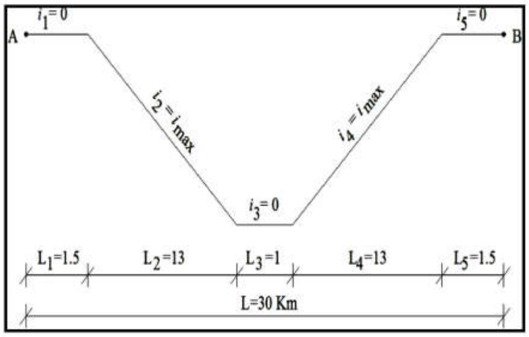

Figure 7. Vertical profile No.3

Table 4. Time consumption for profile No.3

Gradient i (‰)	3.96	11.98	20.79	31.46
Time t (min)	8.22	8.41	8.85	9.56

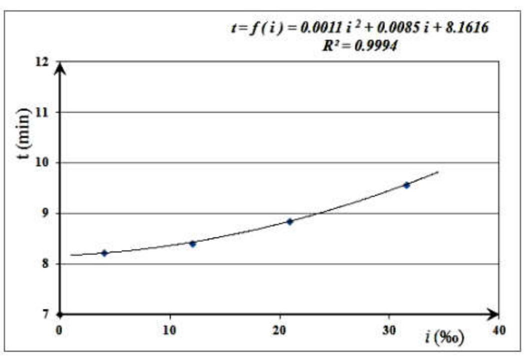

Figure 8. The curve t = f (i) of profile No.3

4.4. Vertical Profile No.4

Figure 9 shows the vertical profile between two stations A and B with the distance changing in each gradient. Table 5 shows the values of time consumption for each value of the maximum gradient.

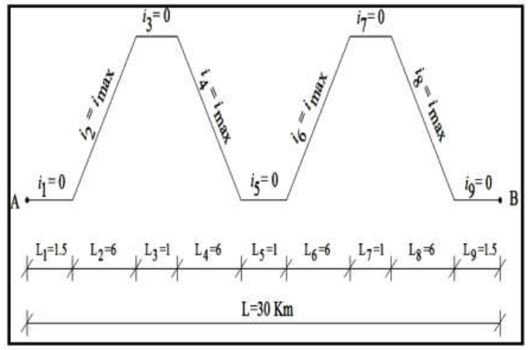

Figure 9. Vertical profile No.4

Table 5. Time consumption for profile No.4

Gradient *i* (‰)	3.96	11.98	20.79	31.46
Time t (min)	8.23	8.41	8.80	9.46

Figure 10 shows the relationship between running time and the maximum gradient for profile No.4.

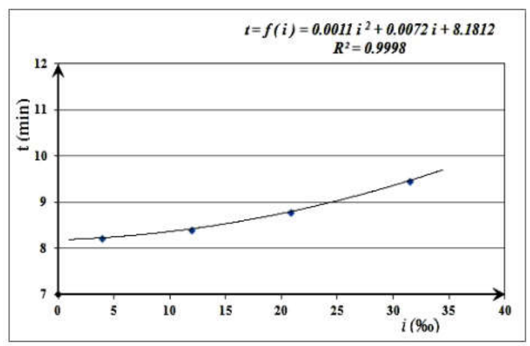

Figure 10. The curve t = f (i) of profile No.4

4.5. Vertical Profile No.5

Figure 11 shows the vertical profile between two stations A and B with the distance changing in each gradient. Table 6 shows the values of time consumption for each value of the maximum gradient.

Table 6. Time consumption for profile No.5

Gradient i(‰)	3.96	11.98	20.79	31.46
Time t min	8.23	8.41	8.80	9.46

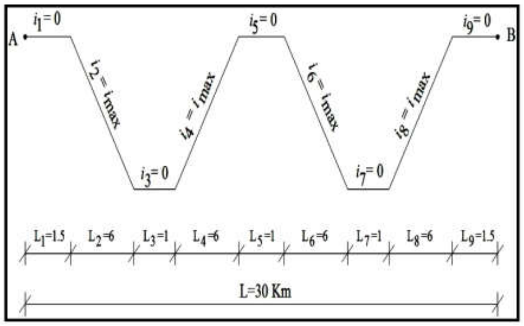

Figure 11. Vertical profile No.5

Figure 12 shows the relationship between running time and the maximum gradient for profile No.5.

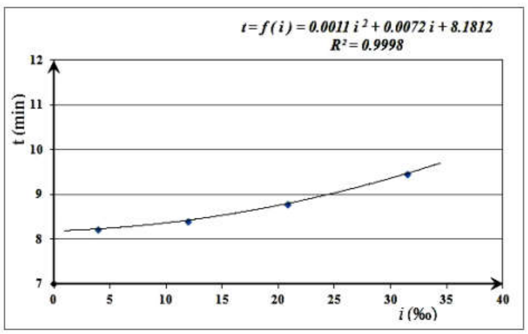

Figure 12. The curve t = f (i) of profile No.5

4.6. Vertical Profile No.6

Figure 13 shows the vertical profile between two stations A and B with the distance changing in each gradient. Table 7 shows the values of time consumption for each value of the maximum gradient.

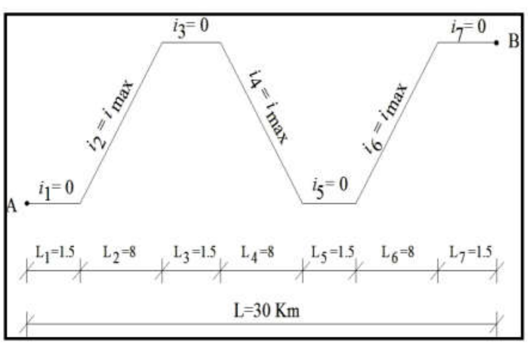

Figure 13. Vertical profile No.6

Figure 14 shows the relationship between running time and the maximum gradient for profile No.6.

Table 7. Time consumption for profile No.6

Gradient i(‰)	3.96	11.98	20.79	31.46
Time t min	8.24	8.48	9.01	9.89

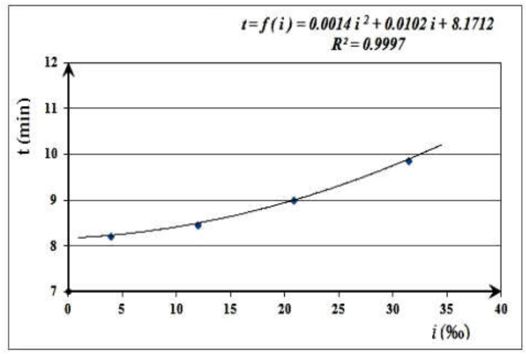

Figure 14. The curve t = f (i) of profile No.6

5. Results and Discussions

By summarizing the previous results, Table 8 shows the values of time consumption with changing the value of the maximum gradient for each profile. Also, Table 9 shows time consumption model for each profile. A set of vertical profiles as shown in this study were assumed in the past years. This series of patterns was drafted from a number of exiting railways for imitation of practical projected lines. Till now, no objectionable case has been discovered. However, it could not be regarded as the only way of imitation. For other countries and even for certain cases in China, different set of typical profile is not excluded. In the planning of a projected line, an overall inspection of the general route on the contour map is always necessary. If the designer pays attention to the towns, villages and industrial and mining points, a preliminary scheme of arrangement of the station and train stops may be sketched. Of course, the real railway profile is possible to be the same as the six typical patterns which have been mentioned at the introduction of this paper. But the comparison of many times with the sections of existing railway lines, the imitation method shows high degree of similarity.

Table 8. Time consumption values for the six profiles

Gradient i		3.96	11.98	20.79	31.46
Time consumption t(min)	Profile No.1	8.28	8.68	9.58	11.06
	Profile No.2	8.22	8.41	8.85	9.56
	Profile No.3	8.22	8.41	8.85	9.56
	Profile No.4	8.23	8.41	8.80	9.46
	Profile No.5	8.23	8.41	8.80	9.46
	Profile No.6	8.24	8.48	9.01	9.89

Table 9. The function of time consumption for the six profiles

Time Consumption Function t (min)	Profile No.1	$T= f(i) = 0.0024i^2 +0.0172i +8.1628$
	Profile No.2	$T= f(i) = 0.0011i^2 +0.0085i +8.1616$
	Profile No.3	
	Profile No.4	$T= f(i) = 0.0011i^2 +0.0072i +8.1812$
	Profile No.5	
	Profile No.6	$T= f(i) = 0.0014i^2 +0.0102i +8.1712$

6. Conclusions

Studying the time consumption is very important issue for planning the vertical profile of high-speed railway lines. This research has studied the relationship between time consumption and the maximum gradient for six standard vertical profiles. Based on the theoretical analysis result, the following conclusions are drawn:

Time consumption model is a quadratic function for all profiles. The R-squared values for all models are more than 99%.

The results show that the time consumption is similar for the profiles which have symmetrical sketch with a horizontal axis, whereas unsymmetrical sketch of different profiles have different values of time consumption.

Table 8 presented that both profiles No.2 and No.3 have equal value of time consumptions. Consequently, they have the same model of time consumption. Moreover, the profile No.4 and No. 5 approve the same result.

The time consumption increases with the increasing of gradient value for each profile.

The percentage of increasing of time consumption between the first and the last value of gradient for each profile is: 33.6% for profile No.1, 16.3% for profiles No.2 and No.3, 14.9% for profiles No.4 and No.5 and it is 20% for profile No.6.

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