INVESTIGATION ON THE ACCURACY OF THE CURRENT PRACTICES IN ANALYSIS OF RAILWAY TRACK CONCRETE SLEEPERS

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Abstract: *In this paper, the main factors in the analysis of the railway concrete sleepers are investigated and new recommendations are made in order to improve the accuracy of the current practices in analysis of the railway track system. First, a comprehensive literature survey is conducted, then, FEM models for a railway track system are developed and used to discuss and evaluate the assumptions commonly used in the analysis of the railway track system. The analysis factors investigated include stress distribution under a concrete sleeper, rail-seat load, and dynamic coefficient factor. Finally, recommendations and needs for continuation of the research are presented.*

Keywords: *Sleeper, Railway track, Dynamic factor, Current practices.*

1. INTRODUCTION

Extensive increases in axle loads, speed and traffic volumes in rail transport systems as well as the introduction of new design criteria such as the dynamic behavior of rolling stocks, passengers riding comfort, and track life cycle costs have caused the subject of mechanistic analysis and design of railway track structure to arise. Also complementary decision support systems require more precise analytical and mechanistic approaches for railway track system [1], [2]. This subject had been realized in the road pavements (both flexible and rigid pavements) long ago, so that, the implementation of comprehensive numerical researches and field studies (such as major AASHTO tests) resulted in the standard mechanistic-empirical method for road pavement design approach, introduced in AASHTO 2002 [3]. Track system comprises many components among which the roles of sleepers are noticeable. The function of the sleepers are to transfer the vertical, lateral and longitudinal rail seat loads to the ballast and foundation, and to maintain the track gauge and alignment by providing a reliable support for the rail fasteners. The vertical loads subject the sleeper to a bending moment which is dependent upon the condition of the ballast underneath the sleeper. The performance of a sleeper to withstand lateral and longitudinal loading is dependent upon the sleeper's size, shape, surface geometry, weight and spacing.

Before the sleeper can be analyzed in terms of its capacity to withstand the bending stresses caused by vertical rail seat loads, the sleeper support condition and its effect upon the contact pressure distribution must be qualified [4]. The contact pressure distribution between the sleeper and the ballast is mainly dependant upon the degree of voiding in the ballast under the sleeper. This voiding is caused by traffic loading and is due to the gradual change in the structure of the ballast and the subgrade. Considering the important functions of the sleepers in the railway track system and the necessity of developing a more precise analysis approach, this research is aimed at the investigation of the current practices and the development of a more justifiable sleeper analysis method.

2. REVIEW OF THE LITERATURE

In the current practices, analysis of sleepers comprises four steps [5]. They are: considering a dynamic coefficient, calculating real seat loads, assuming a stress distribution pattern under the sleepers, and applying static equilibriums to a structural model of sleepers. These are discussed in this section.

2.1. Stress Distribution Pattern under Sleepers

The exact contact pressure distribution between the sleeper and the ballast and its variation with time will be of importance in the structural design of sleepers. It is practically impossible to predict the exact distribution for a sleeper in the in-track condition [6]. In order to calculate the sleeper bending stresses a uniform contact pressure distribution between the sleeper and ballast is assumed to occur in practice; thereby enabling a visual interpretation of how the vertical force exerted by the rail on the sleeper is transmitted to the ballast. Various hypothetical contact pressure distributions between the sleeper and the ballast are presented in Table 1.

Principally bearing pressure distribution under railway sleepers depend on factors such as compaction and density of ballast aggregates under the sleeper, tamping quality, and even the geometrical conditions of the railway line. Evidently the aforementioned conditions will change in accordance with loading cycles, and ballast and sub-ballast deterioration.

When track is freshly tamped the contact area between the sleeper and the ballast occurs below each rail seat. After the tracks have been in service the contact pressure distribution between the sleeper and the ballast tends towards a uniform pressure distribution. This condition is associated with a gap between the sleeper and the ballast surface below the rail seat. The condition of center binding of concrete sleepers tends to develop when maintenance is neglected. Hence it can readily be seen that contact pressure distribution between the sleeper and ballast is a time dependent, i.e. cumulative traffic tonnage, variable. Before the contact pressure between the sleeper and the ballast can be calculated the following factors must be quantified:

Table 1. Hypothetical distribution of sleeper bearing pressure (Current practices).

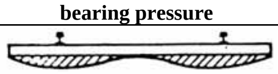
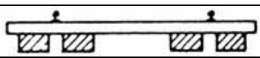
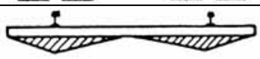
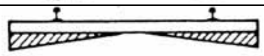
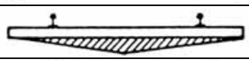
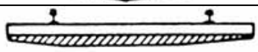
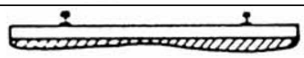
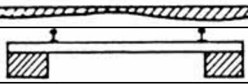
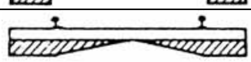
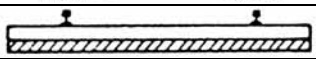
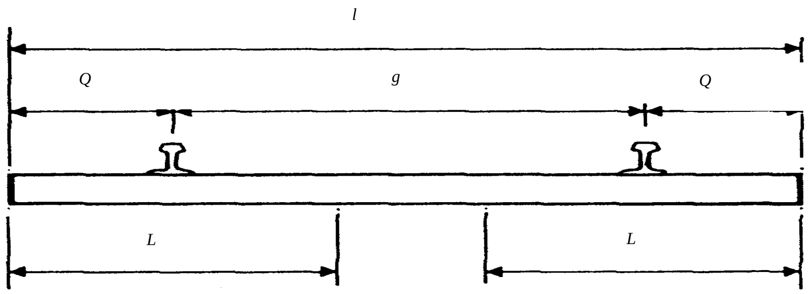
Item No.	Distribution of bearing pressure	Developers	Remarks
1		ORE[16],Talbot[7]	Laboratory test
2		ORE[6],Talbot[8],Battelle[9],Clarke[10]	Tamped either side of rail
3		ORE[19],Talbot[8]	Principal bearing on rails
4		ORE[19],Talbot [8]	Maximum intensity at ends
5		Talbot[8]	Maximum intensity in middle
6		Talbot[7]	Center bound
7		Talbot[7]	Flexure of sleeper produces variations form
8		ORE[19],Talbot[8],kerr[11],Schramm[12]	Well tamped sides
9		ORE[19],Talbot[8]	Stabilized rail seat and sides
10		AREA[13],Raymond[14],Talbot[8]	Uniform pressure

Table 2. Effective Length of sleeper support at the rail seat.



Suggestion by:	Effective Length of sleeper support at the rail seat
AREA[13]	Distance from the end of the sleeper to the point inside of the edge of the rail base over which tamping operations extend
Clarke[10]	$L=(l-g)\left(1-\frac{(l-g)}{125t^{0.75}}\right)$ in which l, g, and t are total sleeper length (mm), distance between the center-line of rail seats (mm), and sleeper thickness (mm), respectively.
Schramm[12]	$L=\frac{l-g}{2}$
Simplified Clarke[10]	$L=l/3$

- The effective sleeper support area beneath the rail seat, in other words, the length of stress distribution under the sleeper, and
- The maximum rail seat load occurring at the sleeper.

Some of the main suggestions on the calculation of the effective length of stress distribution under the sleeper are presented in Table 2. The maximum rail seat load is discussed in Section 2.2.

2.2. Rail-seat Load

The exact magnitude of the load applied to each rail seat depends upon several parameters including: the rail weight, the sleeper spacing, the track modulus per rail, the amount of play between the rail and sleeper, and the amount of play between the sleeper and ballast. The influences of the last three factors vary in accordance with the standard of the track maintenance, and their effect is to distribute the applied sleeper loading to sleepers with adequate support. Various methods have been developed to calculate the magnitude of the rail seat load and of these; the methods outlined in this paper are the most frequently used.

The maximum rail seat load can be determined theoretically by a long beam on a continuous elastic foundation model, and this is the approach suggested by Talbot (1918-1934) and by Clarke [8, 10]. Using this model the maximum rail seat load (kN) can in general be determined by:

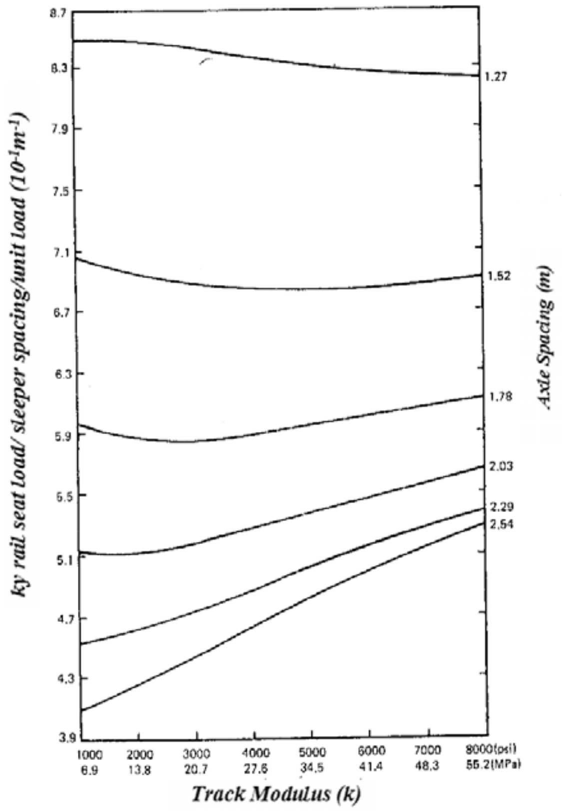
$$q_r = S \times K \times Y_m \times F_1 \qquad (1)$$

In which, S is the sleeper spacing (center to center of sleepers in meters), K is the track modulus (MPa) per rail as considered in the Winkler foundation, Y_m is the maximum rail deflection caused by the interaction of a number of axle loads about a given reference position (mm), and F_1 is the Factor of safety to account for variations in the track support caused by variations in the standard of the track maintenance (Clarke [10] adopts a value of F_1 equal to 1).

O'Rourke [15] has shown theoretically that under unit train condition, where adjacent wheel loads can be assumed to be the same, the product ky_m/unit load is, for a given rail section, nearly constant for any value of track modulus. It was found that this product was mainly dependent upon the axle spacing of the vehicle, (smaller axle spacing having a more significant effect, as expected, refer to Figure 1). A formula was developed to determine the rail seat load q_r (kN), which simplifies equation 1 to:

$$q_r = 0.56 \times S \times F_1 \times P \quad (2)$$

in which, S is the sleeper spacing (m), P is the design wheel load (kN), and F_1 is the factor to account for variations in the track support caused by variations in the standard of the track maintenance. The coefficient 0.56 represents the average value of the product ky_m/unit load (Fig. 1), for the smallest axle spacing of cars. These axle spacing is being approximately 1.8m (for axles in the same bogie), and 2.3 m (for axles between adjacent cars).



*Note: Rail Moment of Inertia I=37.5*10⁻⁶ m⁻⁴*

Fig. 1. Influence of the modulus of rail support (ky) for various axle spacing and assumed track modulus-(Current Practices) [15].

Other design methods in this respect include the AREA method, the ORE method and the method in which the applied wheel load on the rail is considered as being distributed between three adjoining sleepers. A comparison of these methods used in the calculation of the maximum rail seat load is presented in Table 3. It is interesting to note that the value of the factor of safety F_1 used by AREA for concrete sleepers is approximately 1.33 to 1.50 whereas the ORE recommended value of C_1 is 1.35. The determined value of C_1 is based upon experimental data and would seem to be more justifiable for use than the AREA assumed value [16], [17].

Table 3. Comparison of the formulae used for the calculation of the maximum rail seat load.

Methods	Maximum Rail-Seat load (kN)
3 Adjacent Sleepers Method [9]	q_r=0.5p
Australian Formula, ARS [15]	q_r= 0.43p
AREA method (Pre-stressed concrete sleepers at 760 mm centers) [13]	q_r=0.6p
ORE method (BR type F pre-stressed concrete sleepers at 760 mm centers) [16]	q_r=0.65p
Where P=design wheel load (kN), and the sleeper spacing adopted is 760 (mm) for the comparison.	

2.3. Dynamic Coefficient Factor

In the current practices, the wheel loads are considered to be static, taking into account a dynamic coefficient factor. Researchers all over the world have recommended several formulas and values for the calculation of the dynamic coefficient. A summary of the main formulas recommended so far are presented in Table 4. In the table, V is the velocity of train in km/h, D is the diameter of the wheel in mm, K is the modulus of the rail support system in MPa, g is the gauge width in mm, α' and β' relate to mean value of the impact factor and γ' to the standard deviation of the impact factor, P_u unsprung weight at one wheel (kN), D_j track stiffness at the joints (kN/mm), $(\alpha_1+\alpha_2)$ the total rail joint dip angle (radian).

Table 4. Recommended relationship for dynamic coefficient factors.

Standard	Relation
AREA[17]	$\Phi = 1 + 5.21\frac{V}{D}$
Eisenmann [18]	$\Phi = 1 + \delta\eta\ t$
ORE [16]	$\Phi = 1 + \alpha' + \beta' + \gamma'$
DB [20]	$\phi = 1 + \frac{V^2}{30000}$, $\phi = 1 + \frac{4.5V^2}{10^5} - \frac{105V^3}{10^7}$
BR [21]	$\Phi = \frac{8.784(\alpha_1 + \alpha_2)V}{P_s} \left[\frac{D_j P_u}{g}\right]^{1/2}$
India [22]	$\phi = 1 + \frac{V}{58.14k^{0.5}}$
South Africa[23]	$\phi = 1 + 4.92\frac{V}{D}$
CA [24]	$\phi = 1 + \frac{19.65V}{DK^{1/2}}$
WMMTA [24]	$\phi = (1 + 3086 * 10^{-5}V^2)^{0.67}$
SADEGHI [25]	$\phi = 1.098 + 8 \times 10^{-4}V + 10^{-6}V^2$

3. DISCUSSION ON ACCURACY OF CURRENT PRACTICES

As stated above, several formulas and recommendations have been developed for dynamic coefficient, rail-seat load, and stress distribution pattern under the sleepers. In order to compare the above recommendations and formulas, and to investigate the accuracy of the current practices, two theoretical models of railway track system are developed. The results obtained form the analyses of the models are used to evaluate the current sleeper analysis method.

3.1. Modeling Approaches

Capabilities of ANSYS program is used for the development of railway track models. First, a model of the track system is developed considering the cross-section of the system and, then, a second model is created based on longitudinal section of the track system. The first model consists of a sleeper and its support system. The second model includes the rail, sleepers and the support system. As experimentally proved by Selig, Walter, Esveld, and Sadeghi ([26], [27], [28]), sleepers stay in the linear limit in the range of current axle loading (0 to 25 tons), therefore, the linear method is used for the analyses of the sleepers. Also, for the modeling purpose, a well-compacted and continuous ballast layer is assumed under the concrete sleeper (i.e., a good maintenance condition is considered.).

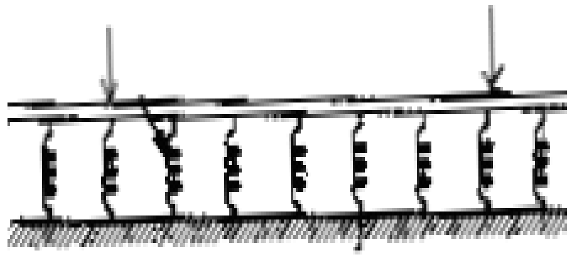


Fig. 2. Cross section modeling of ballast and concrete sleeper.

3.1.1. Modeling of the cross section of the railway track system (CSM)

To model the cross section of the track system, a concrete sleeper is considered in three dimensions and the ballast is modeled as series of springs representing a well-compacted and continuous ballast layer under the sleeper. Spring elements are contrived in 5 centimeters intervals. Wheel loads are applied at two point loads each in a distance of 55 centimeters from sleeper ends. The mechanical characteristics of spring elements are considered as follows:

K: Spring Stiffness Value (8 MN/m)

C: Spring Damping Coefficient (15 kNs/m)

Fig. 2 indicates the schematic diagram of the model. Fig. 3 and Table 5 illustrate its geometrical and mechanical characteristics.

3.1.2. Modeling of the Longitudinal section of the track system (LSM)

A model is developed to represent the longitudinal section of the railway track system. This model comprises elastic base plates with damping property, 60 rigid sleepers, and an infinite elastic damped layer under the sleepers. In Figure 4, a schematic view of the model is presented. Mechanical input parameters of the model are presented in Table 6.

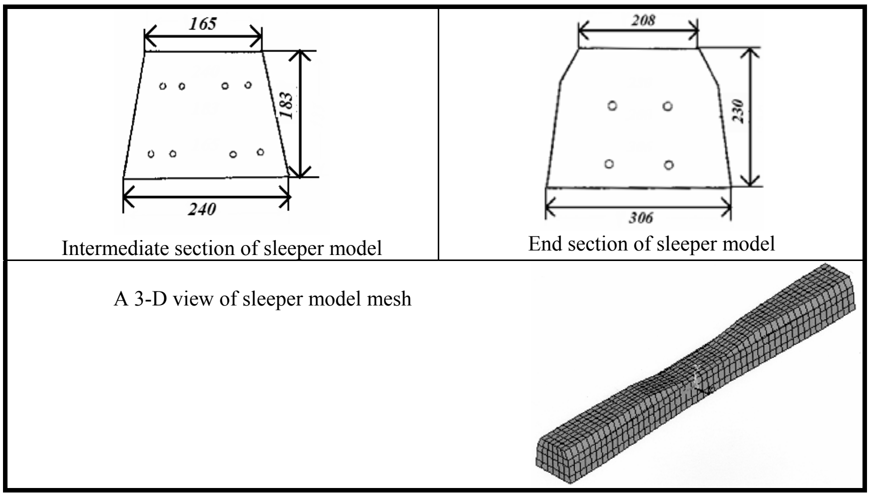


Fig. 3. Geometrical characteristics of the model.

Table 5. Mechanical characteristics of cross section model of track.

Item number	Item	Value
1	Sleeper length	2.6 meters
2	Average Sleeper Width	30 Centimeters
3	Sleeper Height	End Section: 22 Centimeters Intermediate Section: 18.3 Centimeters
4	Concrete Density	2320 Kg/m^3
5	Young Modulus	30 Gpa
6	Poisson Ratio	0.15
7	Pre-stressing bars cross section (8 F7 Bars)	310 mm^2

Table 6. Mechanical characteristics of longitudinal model.

Item Number	Mechanical Characteristic	Abbreviation	Value
1	Rail cross section area	A	$63.3 * 10^{-4}$ m^2
2	Rail moment of inertia	I_{zz}	$2346*10^{-8}$ m^4
3	Rail height	H	0.152 m
4	Rail pad stiffness	K_1	$3032*10^{-6}$ N/m
5	Rail pad damping coefficient	C_1	29000 Ns/m
6	Ballast layer stiffness	K_2	$8000*10^{-3}$N/m
7	Ballast layer damping coefficient	C_2	15000 Ns/m
8	Half of sleeper mass	M	50 Kg
9	Rail Young modulus	E	$200*10^{+9}$Pa
10	Rail density	r	7800 Kg/m^2
11	Poison ratio	n	0.3
12	Train Speed	V	200 Km/h
13	Wheel load	F	10 Ton
14	Number of sleepers	N	60
15	Load reaction time	T	0.01 S

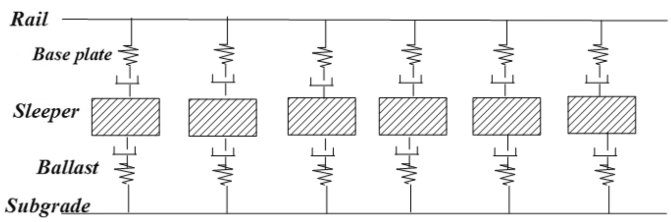


Fig. 4. Schematic view of longitudinal section track structure model.

3.2. Analysis Results

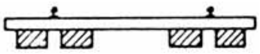
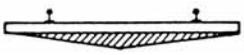
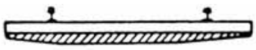
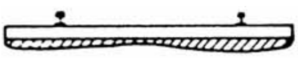
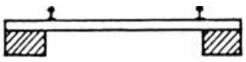
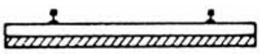
As discussed above, the main factors in the current sleeper analysis approach are stress distribution pattern under sleepers, rail- seat load, and dynamic coefficient factor. In order to improve the accuracy of the current practices in analysis of sleeper, the consideration of the above three factors are investigated. The models developed here are analyzed for this investigation. The research methodology and the results are as follows.

3.2.1. Stress distribution pattern under sleepers

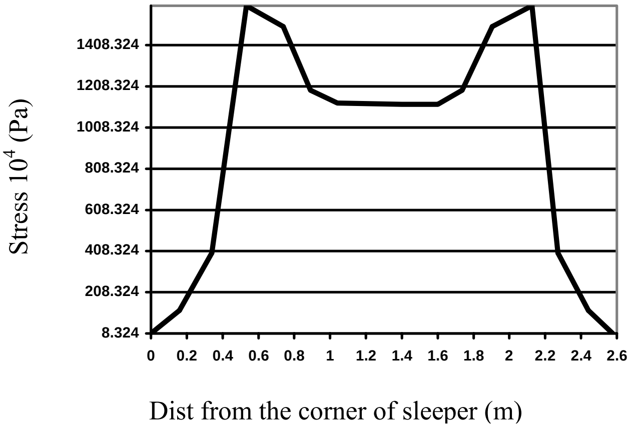
In order to investigate the stress distribution pattern under sleepers, CSM was analyzed with the consideration of the proposed loading patterns under the sleeper. From this analysis, the deflection and stress results are obtained. CSM was again analyzed under static and transient loads with consideration of springs and dashpots to represent the sleeper support system. The results of these two kinds of analyses are compared to evaluate the proposed stress distribution patterns. The details are as follows.

For the first analysis, the loading patterns proposed by others are considered to represent the ballast pressure under the sleeper. Therefore, springs in CSM are replaced by those loading pattern presented in Table 1, and 10 ton loads are applied in the rail seat positions on the sleeper. With this composition, the sleeper was analyzed to obtained stresses and nodal deflections. The results, including two principal stresses, Von-Misses Stresses, and maximum sleeper deflections, are presented in Table 7. Diagram of the stresses and the deflections for selected loading patterns (pattern numbers 3, 4, and 7 in Table 7) are presented in Figs. 5 to 10.

Table 7. Maximum deflection and other stress outputs resulted from sleeper model Analysis.

Proposed loading parents	Pattern Number	Beneath the Sleeper			On top fiber of sleeper		
		Δ_y (mm)	σ_1 (MPa)	σ_{von} (MPa)	σ_y (MPa)	σ_1 (MPa)	σ_{von} (MPa)
	1	0.207 x=0	8.32 x=0.55	8.35 x=0.55	3.24 x=0.55		
	2	۰/۱۰۹ x=0	8.85 x=0.55	8.6 x=0.55	9.7 x=0.55		
	3	0.212 x=0	8.51 x=0.55	8.54 x=0.55	9.74 x=0.55		
	4	0.491 x=0	17.7 x>0.55	1.75 x=0.55	9.53 x=0.55		
	5	0.311 x=1.3			9.84 x=0.55	18.6 x=1.3	20.7 x=1.3
	6	0.263 x=1.3			9.82 x=0.55	15.4 x=1.3	17.1 x=1.3
	7	0.138 x=0	8.61 x=0.55	8.61 x=0.55	9.82 x=0.55		
	8	0.242 x=0	10.4 x=0.55	10.4 x=0.55	9.67 x=0.55		
	9	0.218 x=0	10.5 x=0.55	10.5 x=0.55	9.67 x=0.55		
	10	0.102 x=1.3	7.07 x=0.55	7.01 x=0.55	3.38 x=0.55		

X is the distance from one end of the sleeper in meter



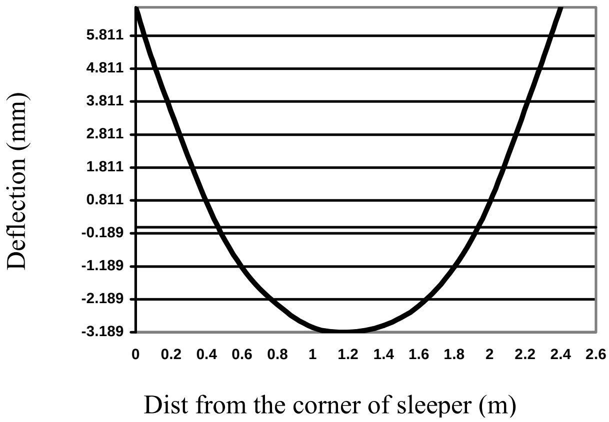


Fig. 5. Stresses in sleeper for stress distribution pattern No. 8.

Fig. 6. Displacement in sleeper for stress distribution Pattern No. 8.

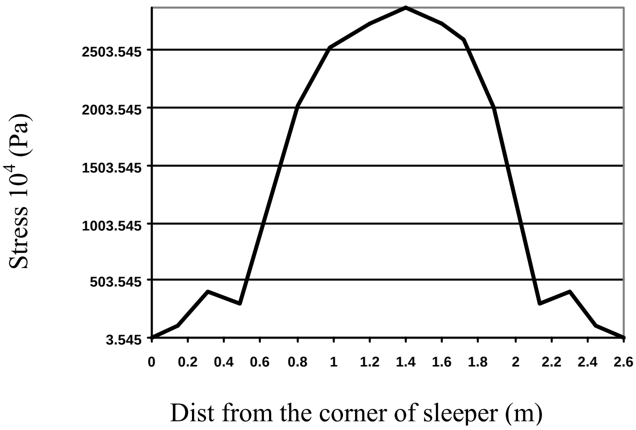


Fig. 7. Stresses in sleeper for stress distribution pattern No. 6.

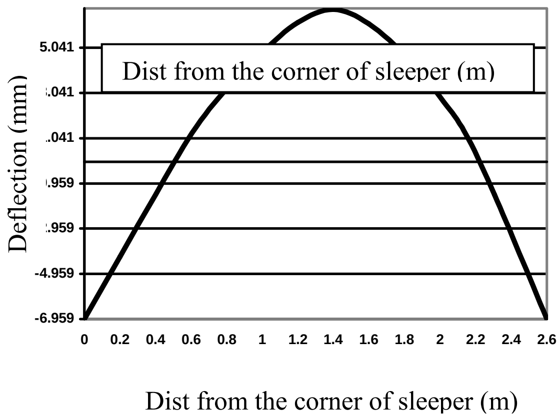


Fig. 8. Displacement in sleeper for stress distribution pattern No. 6.

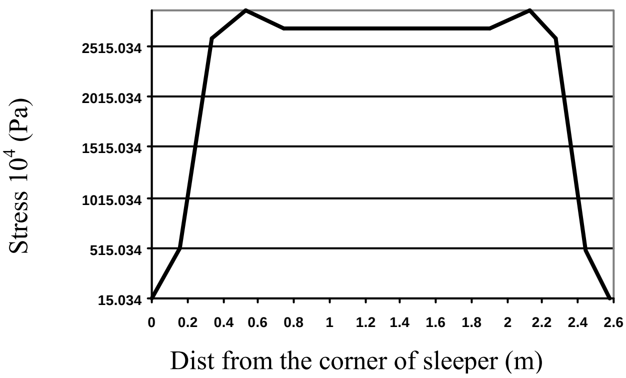


Fig. 9. Stresses in sleeper for stress distribution pattern No. 4.

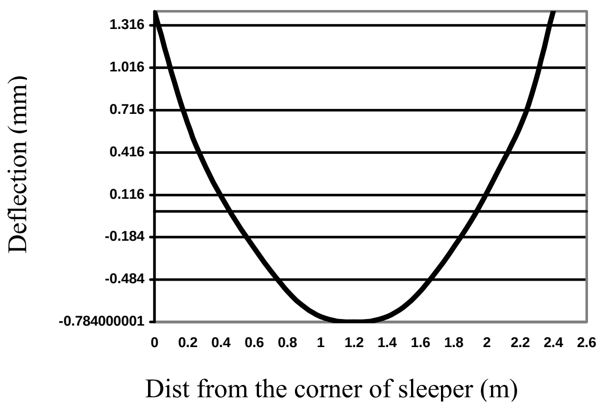


Fig. 10. Displacement in sleeper for stress distribution pattern No. 4.

Second, the first part of the model is analyzed under two static wheel loads of 10 tons. The deflection results in a vector form are presented in Figure 11. Maximum deflection value of about 0.367 (mm) can be observed under the rail seat and minimum (close to null value) is in the intermediate section. The results confirm that the total nodal reaction exactly corresponds to 20 tones (sum of two assumed wheel loads).

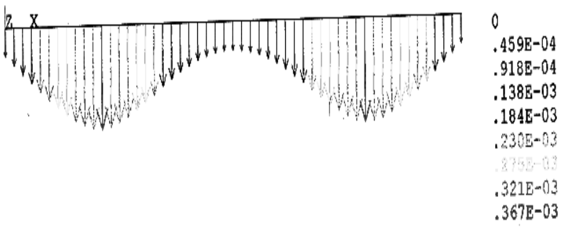


Fig. 11. Vector sleeper deflection obtained static analysis.

The vector deflection pattern is of interest. As indicated in Figure 11, the deflection shape of the sleeper is a combination of two parabolas. Since the deflection is proportional to the spring load under the sleeper and, in turn, is proportional to the pressure under the sleeper, it can be deduced that the stress distribution under the sleeper are more close to the stress distribution pattern proposed by ORE and Talbot [16],[7]. To verify this conclusion, dynamic analysis of the model is conducted. More over, it is tried to investigate the variation in stress distribution pattern if some track parameters such as speed, sleeper type and track stiffness are changed. These are discussed below.

For dynamic analysis, geometrical and mechanical characteristic of CSM is similar to the static load case. In this case instead of considering a static load, a transient load is considered. The load is assumed to be periodic (i.e. equal distance between the train axles). Based on the Arbabi's suggestion [29] the diagram of the wheel load against the time for a 10 tons load is considered as shown in Fig. 12. The train speed is assumed to be 30 kilometers per hour. Sleepers are placed in 60 centimeters intervals in longitudinal direction.

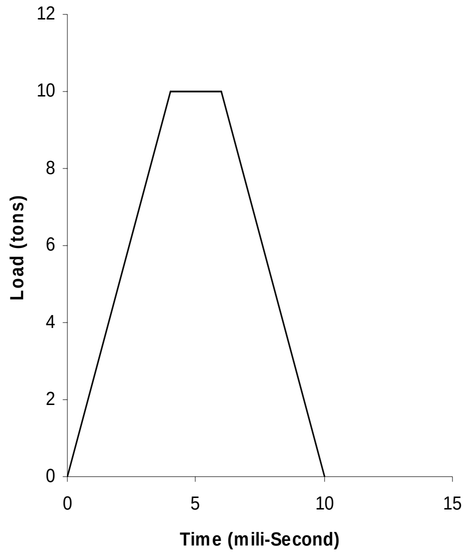


Fig. 12. Incremental loading curve versus time.

Vector displacement pattern in y direction is presented in the following figure. The maximum deflection of 0.386 (mm) can be observed under the rail-seat and the minimum value is close to zero. Based on the results presented in the figures, both deflection patterns obtained from static and dynamic analysis indicate the same pattern. Minimum and maximum deflection positions are the same in both cases.

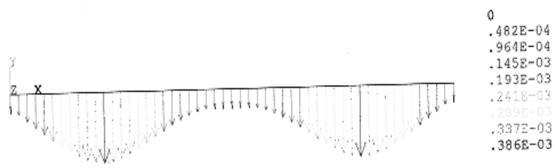


Fig. 13. Deflection factor of dynamic load case (Train speed=30 Km/h).

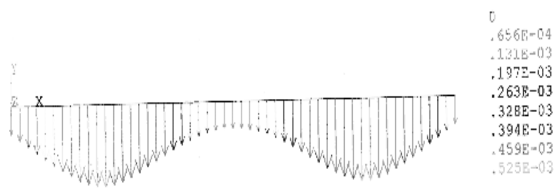


Fig. 14. Nodal vector deflection of sleeper in speed of 300 Km/h.

The track model is analyzed in different conditions by changing the values of influencing parameters such as speed, sleeper type and track stiffness. All cases showed a similar pressure distribution pattern. In other words, the results obtained indicate that the deflection pattern (and correspondingly stress distribution pattern) is the same as previous cases and only the magnitudes of the vectors are changed. As an example, the deflection vector of the sleeper for the train speed of 300 Km/h is shown in Figure 14.

3.2.2. Rail-seat load (q_r)

Considering a good track maintenance condition, there are two main parameters which influence the ratio of rail-seat-load/wheel-load. These two parameters are: the train speed, and the sleeper spacing [30]. In order to investigate the percentage of the wheel load transferred to the sleepers, the second model (LSM) was analyzed. The same as the previous analysis, the load is considered to be periodic and the Arbabi's suggestion [29] for the wheel load is taken into account. The model was analyzed for different train speeds and different sleeper spacing. The results obtained are presented in Table 8 providing us with the maximum rail-seat load for different train speed up to 360 (Km/h). The maximum value is 29.786 kN which corresponds to 29.8% of static wheel load.

The results indicate that the rail-seat load has an increasing pattern for the low values of the train speed; it remains almost constant up to about 180 Km/h train speed and then increases as the train velocity increases. Almost 9 sleepers contribute to supporting the rail under one wheel load. Based on the least squired errors, the relationship between the rail-seat load and the train speed is obtained as follows.

$$q_r = -9e(-7)v^4 + 7e(-4)v^3 - 1.46e(-1)v^2 + 12.437v + 27512 \quad (3)$$

In which q_r is the rail-seat load in Newton and v is the train speed in km/h.

The results for the real-east load versus the sleeper spacing for a ten tons wheel load is presented in Figure 9. As indicated in the figure, the relationship between rail-seat load and the sleeper spacing is linear. The expression representing this relationship is as follows. (q_r is the rail-seat load in Newton and S is the sleeper spacing in meter).

Table 8. Maximum rail-seat load versus train speed.

V (Km/h)	0	40	60	100	150	200	250	360
q_r (N)	27512	27860	27868	27881	27928	28298	28670	29786

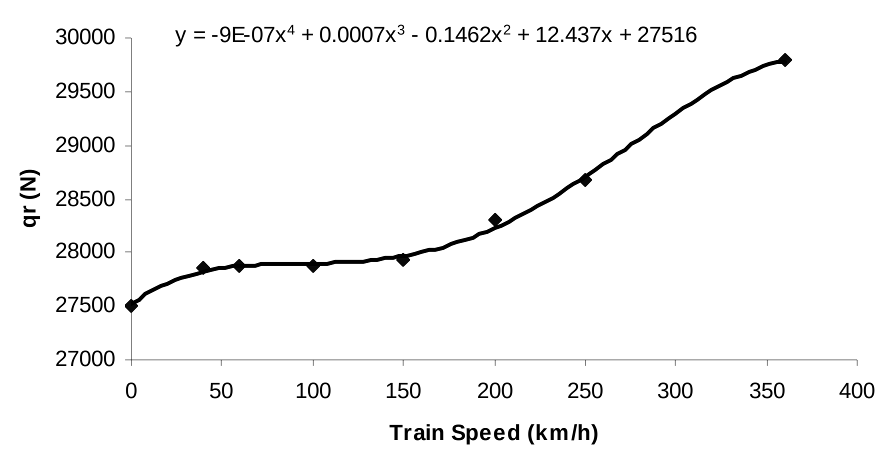
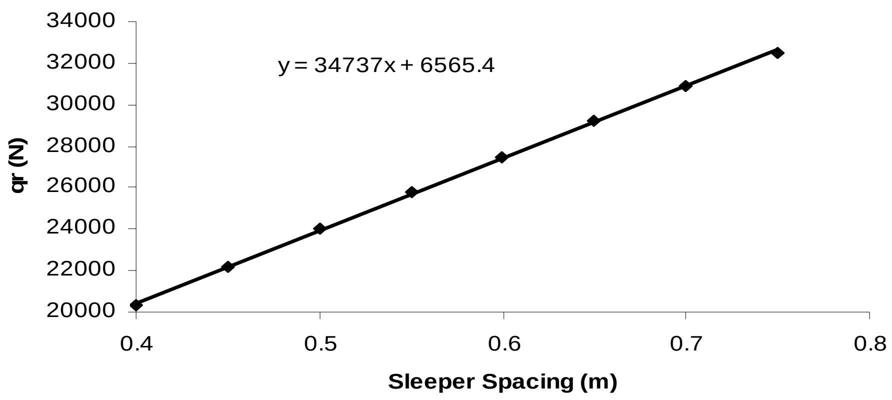


Table 9. Maximum rail-seat load versus sleeper spacing.

S (m)	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75
q_r (N)	20321	22181	23996	25769	27502	29197	30859	32488



S is the sleeper spacing

$$q_r = 34734\,S + 6565 \qquad (4)$$

Combining equations 2 and 3, the real-seat load can be expressed as a function of wheel load. The obtained relationship between the real-seat load and the wheel load is presented below.

$$q_r = f \times [\; -9e(-12)v^4 + 7e(-9)v^3 - 1.46e(-6)v^2 + 12.437e(-5)v + 0.27512 \;](1.27S + 0.23)P \qquad (5)$$

In which q_r is the rail-seat load in tons, v is the velocity of the train in km/h, P is the wheel load in tons, S is the sleeper spacing in meters, and f is the factor of safety representing the track maintenance condition. First term of the equation is very small in value comparing to the rest, therefore, omitting the first term and considering f to be 1.35 as suggested by ORE [6] (for concrete sleepers), the equation would have the following form.

$$q_r = 1.35 \times [\; 7e(-9)v^3 - 1.46e(-6)v^2 + 12.437e(-5)v + 0.27512 \;](1.27S + 0.23)P \qquad (6)$$

This expression seems to be more closed to the proposed values by ASR [15]. Considering sleeper spacing to be 760 mm and the speed of the rain to be 160 km/h the value of rail-seat load is equal to 44% of the wheel load (P). Referring to Table 3, this value is almost equal to 43% proposed by ARS (Australian Standards).

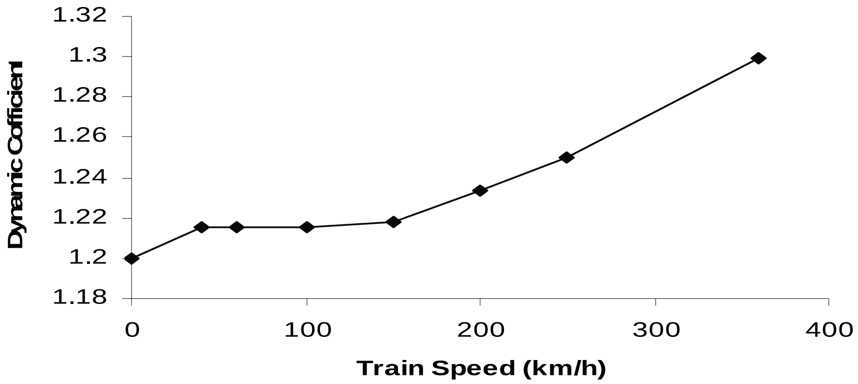
3.2.3. Dynamic coefficient factor (D.C.F)

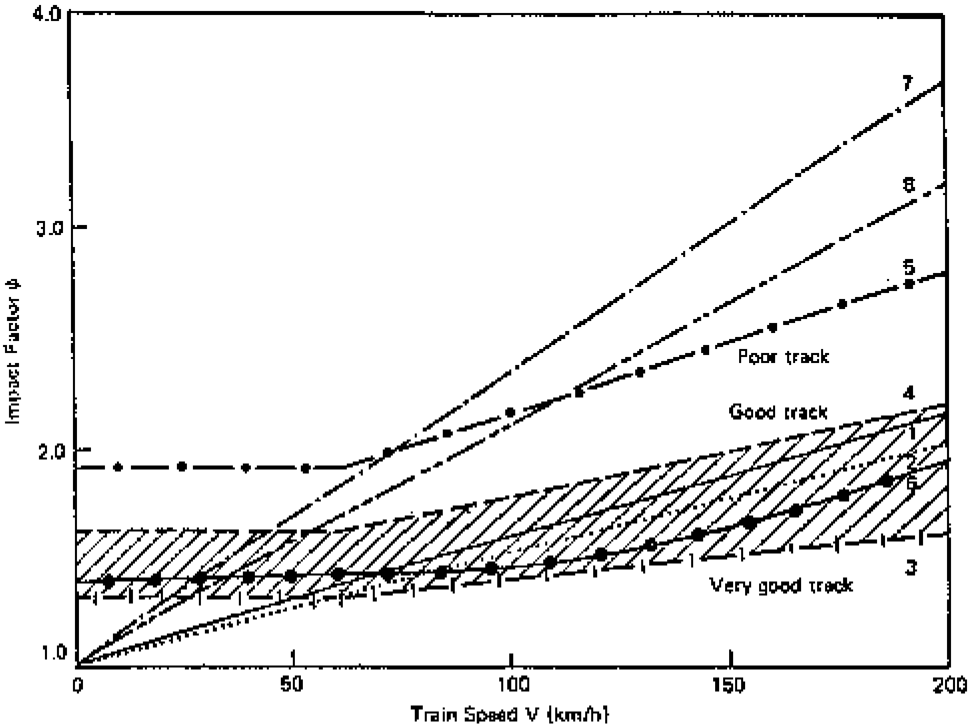
As discussed in Section 2.2, several formulas and values are suggested for the dynamic coefficient, noticing that each suggestion has been made based on a certain criteria. D.C.F. should be obtained based on the purpose of analysis. Therefore, when analyzing sleepers, the rail load seat must be considered for the calculation of D.C.F.

As it can be seen from the analysis results presented in section 3.3.2, the maximum rail seat load obtained from the static analysis is 27.502 kN. The rail seat load increases as the velocity of the train increases. For a certain speed of a train, if we divide the rail seat loads obtained from dynamic analysis by those obtained form static analysis, we can reach to an estimation of D.C.F. ORE suggested the addition of 1.2 to D.C.F in order to consider the track maintenance condition (track degradation factor) [19]. Using the results presented in the previous section and including the ORE's suggestion, D.C.F. as a function of velocity is obtained and presented in Table 10.

Table 10. Dynamic coefficient factor versus train velocity.

V (Km/h)	0	40	60	100	150	200	250	360
D.C.F.	1.2	1.2156	1.2156	1.2156	1.218	1.2336	1.2504	1.2996





No.	Formula	Remarks
1	AREA [17]	Wheel Diameter=900mm
2	AREA [17]	Wheel Diameter=1000mm
3	Eisenmann [18]	Very good track UCL=99.9%
4	Eisenmann [18]	Good track UCL=99.9%
5	Eisenmann[18]	Poor track UCL=99.9%
6	ORE [19]	Coefficient for track conditions=1.2
7	B.R. [21]	Class 55 Diesel Electric, P_2=86.5 kN, P_0=65 t
8	B.R.[21]	Keszrel Diesel Electric, P_2=112.7 kN, P_v=2.12 t

Fig. 15. Dynamic coefficient factors from various resources.

The mostly used values for the dynamic coefficient factor in the current practices are presented in Figure 15. Comparison of the D.C.F developed here and those presented in Figure 15 indicates that the ORE's recommendation is much closed to what obtained here.

4. CONCLUSIONS AND RECOMMENDATIONS

In this paper, the main parameters in the analysis of railway track concrete sleepers are investigated and new recommendations are made in order to improve the accuracy of the current practices in the analysis of the railway track system. The factors investigated here are: stress distribution under a concrete sleeper, rail-seat load, and dynamic coefficient factor. The following results have been reached in this research:

- The results of this research indicate that, for the analysis of sleepers, the ORE's suggestion is confirmed to be most true for the determination of stress distribution under the railway sleepers. In other words, the best assumption for pressure distribution under the railway sleepers is the combination of two parabolas.
- Results obtained from this research indicate that the most suitable expression for rail-seat load for the analysis of the sleepers is in the following form. This expression confirms the proposed values by Australian Standard (ARS).

$$q_r = 1.35 \times [\ 7e(-9)v^3 - 1.46e(-6)v^2 + 12.437e(-5)v + 0.27512\ ](1.27S + 0.23)P$$

- Since this research was aimed at analyses of sleepers, the rail seat load was considered as the main criteria for the calculation of D.C.F. Using the results presented in this paper and including the factor of safety proposed by ORE, D.C.F. as a function of velocity is obtained (shown below). The results indicate that the ORE's recommendation is much closed to what obtained here.

$$f = -3.6e(-11)v^4 + 3.6e(-8)v^3 - 6e(-6)v^2 + 6e(-4)v + 1.2$$

The research results presented in this paper indicate that the expressions and the values proposed by ORE (European Standards) for the stress distribution pattern under a concrete sleeper and the dynamic coefficient factor seem to be more justifiable for the use when analyzing sleepers. While the expression recommended by ARS (Australian Standards) for the rail-seat loads is confirmed to be more suitable.
Validation of all mechanistic relationships and their calibrations with local technical and operation conditions are other subjects which should be dealt with correspondingly. For future work and researches one should realize the lack of field and laboratory tests results in railway field for model calibration and performing the analysis under transient loading conditions. Research work on the topic (with concentration on field investigations) is in progress.

ACKNOWLEDGMENT

The financial support of the Railway Research Center, Ministry of Road and Transportation of Iran is most appreciated. The facilities of the Iran University of Science and Technology are used for which the author is thankful.

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