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Prestressed Concrete Ties for Elevated Rail Transit Structures

Tirants en béton précontraint pour voies ferrées suspendues

Vorgespannte Betonschwellen für Hochbahn-Tragsysteme

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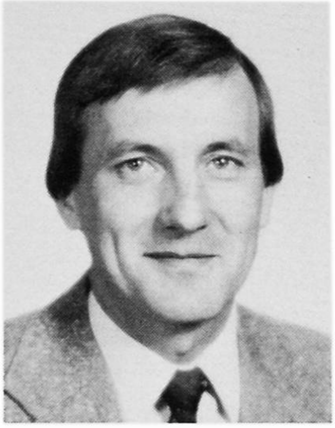

Ivan Campbell, born 1940, received his engineering degrees from the Queen's University of Belfast, N. Ireland. For the past fifteen years he has been involved in research into prestressed concrete transportation structures.

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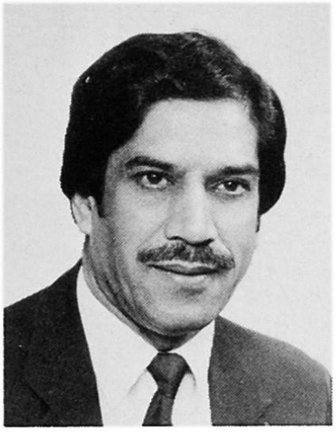

Saeed Mirza, a graduate of the University of Karachi, Pakistan obtained his M.Eng. and Ph.D. degrees at McGill University, Montreal, Canada. He has been active in research into the behaviour of structural concrete elements and subsystems using physical and computer (finite element) models over the past twenty years.

SUMMARY
A study of the distribution of wheel loads among the ties in an open deck railway bridge containing precast prestressed concrete ties is described. Analytical modelling of the system indicated that only three parameters have a significant influence on load distribution. Full scale load tests confirmed the findings of the analytical model. An open deck system may find application in elevated guideways for transit vehicles.

RESUME
Une étude sur la distribution des charges d'essieux sur les tirants d'un pont de chemin de fer à tablier suspendu est présentée. L'étude analytique a montré que seuls trois paramètres ont une importance significative, résultat confirmé par les essais. Ce genre d'ouvrage peut être utilisé pour des voies de chemin de fer suburbaines surélevées.

ZUSAMMENFASSUNG
Eine Studie über die Verteilung der Radlasten auf die direkt auf den Stahllängsträgern aufliegenden vorgespannten Betonschwellen einer offenen Bahnbrücke wird präsentiert. Die analytische Modellierung des Systems zeigte, dass nur drei Parameter einen bedeutenden Einfluss auf die Lastverteilung haben. Belastungsversuche bestätigen die theoretischen Ergebnisse. Offene Fahrbahnsysteme können ihre Anwendung in Hochbahn-Tragstrukturen finden.

1. INTRODUCTION

Open decks are widely used for bridges on the railway systems in Canada. Such a bridge comprises rails supported on ties spanning between two main longitudinal girders. Unlike a conventional railroad bridge where the ties are supported by ballast, the ties transfer the wheel loads directly from the rails to the main longitudinal supporting girders and thus are referred to as bridge ties. This structural system is economical in that the dead weight of ballast is eliminated.

A deck with timber ties is susceptible to fire, which not only causes damage to the timber ties but also to other components of the bridge superstructure, resulting in major traffic disruptions and hazards to life and property, as well as in costly maintenance. Consequently, the Canadian Railways (Canadian National and Canadian Pacific) are considering replacing the timber ties with precast prestressed concrete ties.

An open deck bridge system with concrete ties is shown in Fig.1. The arrangement is similar to the one with timber ties, except that elastomeric pads are incorporated between the rails and the ties (rail-tie pad), and between the ties and the supporting girders (tie-girder pad). These pads are required since a concrete tie is much stiffer than a timber tie and a larger impact would result from wheel loads if the pads were not incorporated.

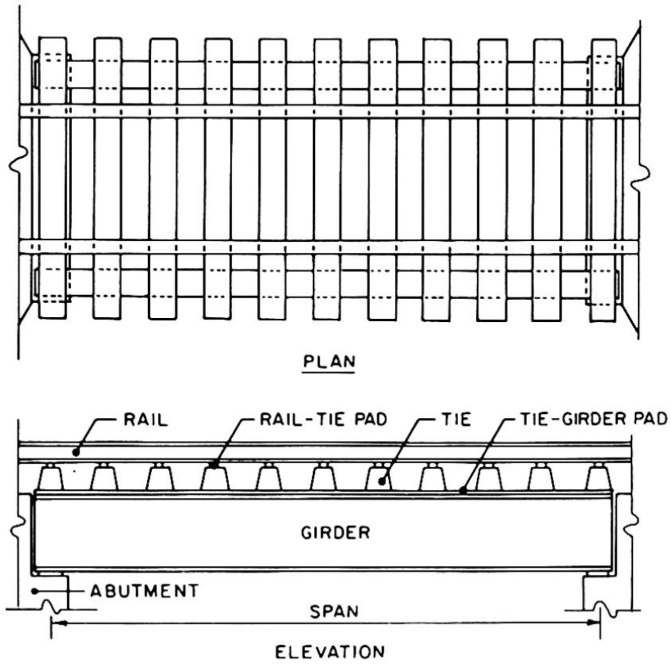

Fig.1. Open deck railway bridge with concrete ties

A recent research program on precast prestressed concrete bridge ties, has been carried out jointly by McGill University, Montreal, Canada [1] and Queen's University, Kingston, Canada [2]. This program studied the distribution of wheel loads to the ties in an open deck system with precast prestressed concrete ties, as well as the strength of the ties under static and repeated loadings. The distribution of wheel loads among the ties was studied by both analytical models and full scale laboratory testing and is described in this paper.

The analytical work on wheel load distribution showed that the distribution of a wheel load among the ties is affected mainly by the stiffness of the tie-girder pads, the type of rail and the spacing of the ties. It was also found that, for a particular type of rail and stiffness of tie-girder pad, the percentage of wheel load taken by a tie increased linearly with tie spacing. The validity of the analytical model was confirmed by the full scale load testing. The load tests also showed that improper seating of the ties on the tie-girder pads, as a result of differential elevation at the rail seat of the ties prior to installation of the rail, influenced the distribution of wheel loads significantly. Assuming proper seating of the ties, the maximum load taken by a tie is about one-third of the wheel load when soft tie-girder pads are used. However, the load level in a tie can rise to around 60 percent of the wheel load when the ties are improperly seated. Based on this research program, recommendations with regard to suitable design criteria for a precast prestressed concrete bridge tie were made. These recommendations are being evaluated by the Canadian Railways in a field appraisal program.

Although this system has been developed for conventional railway track, it is felt that a similar system could be utilized on elevated guideways for rapid transit vehicles, particularly in non-urban environments where aesthetics and noise level are not critical. The findings of this study would be applicable to such a system.

2. THEORETICAL STUDY OF LOAD DISTRIBUTION

The distribution of a wheel load to the ties depends on the properties of the various components of the system (see Fig.1), namely:

(a) location of the wheel load with respect to the ties;
(b) stiffness of rail-tie pads;
(c) differential elevation of the ties;
(d) stiffness of the supporting girders;
(e) type of tie;
(f) spacing of supporting girders;
(g) stiffness of tie-girder pads;
(h) type of rail;
(i) spacing of ties.

The relative effects of these variables were established from a parametric study using an analytical model of the system.

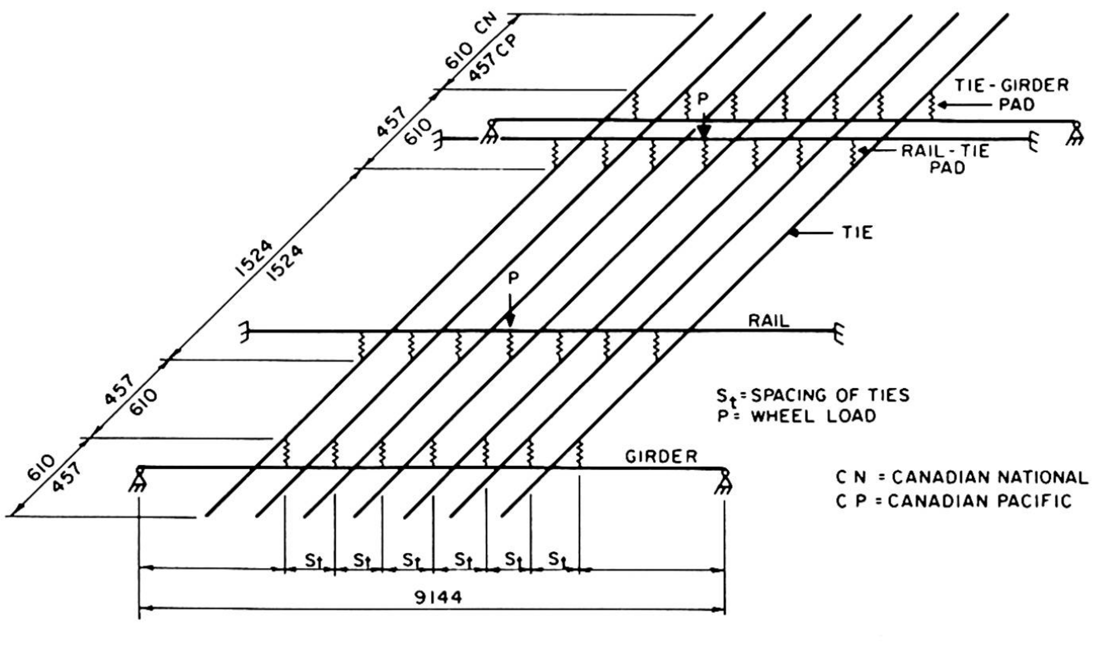

Fig.2. Idealized bridge system

An idealization of a typical system is shown in Fig.2. It was assumed that the main supporting steel girders were simply supported over a representative span of 9.1 m. The length of the rails was taken as the same as the bridge span and both ends of each rail were assumed to be fixed to simulate continuity of the rail. Both the rail-tie pads and the tie-girder pads were modelled as linear elastic springs. The computer program SAP IV [3] was used for the analysis. The rails and bridge girders were simulated by beam elements, while the pads were simulated by truss elements, whose properties were chosen to give the required stiffnesses. As shown in Fig.2, a wheel load was applied simultaneously to each rail.

Table 1 Variation of Parameters of the System

Parameter	Unit	Value			
Stiffness of rail-tie pad	kN/mm	315	Rigid	–	–
Stiffness of girder (EI)	$MN.m^2$	416	830	1664	–
Type of tie	-	CN`A´	CN`B´	CP	–
Spacing of girders	m	2.44	2.74	–	–
Stiffness of tie-girder pad (K)	kN/mm	25	50	99	180
Type of rail	kg/m	49.6	57.0	65.5	–
Spacing of ties (S_t)	mm	406	457	508	559

Initially models containing three, five, seven and eleven ties were studied. In each case the wheel loads were positioned over the central tie since this represents the most critical condition of loading in the central tie. It was concluded that the model with seven ties was adequate, since the load distributions among the ties for the seven and the eleven tie arrangements were similar. Further, with the eleven tie system, the outermost ties were subjected to uplift. Also, it was found that the load distribution was the same whether the rail-tie pad was assumed to be rigid or to have its actual stiffness of 315 kN/mm. Consequently, a model incorporating seven ties and rigid rail-tie pads was used throughout the study. The variations considered for the parameters of the system are shown in Table 1. The rationale used in establishing these values and details of the type of tie are given in References 1 and 2.

Figure 3 shows the distribution of the wheel loads among the seven ties for three different girder stiffnesses where girder stiffness has been defined as the product of the modulus of elasticity (E) and second moment of area (I). The load, expressed as a percentage of a wheel load, refers to the load which each rail exerts on the tie. The values of the other parameters of the system are indicated in Fig.3. It is seen that the maximum load occurs in the central tie (tie number

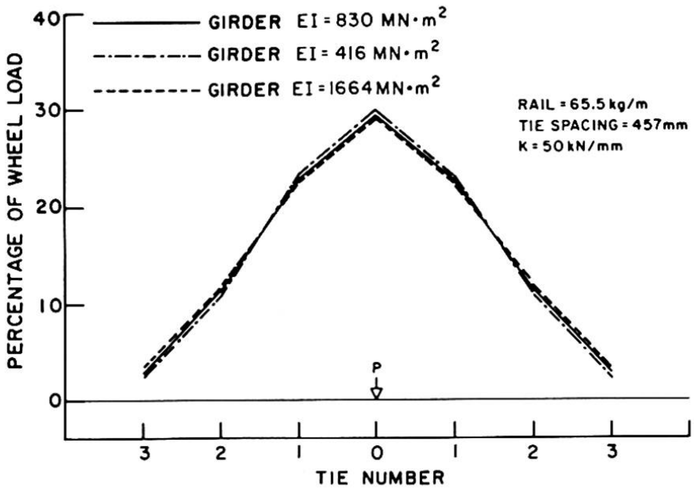

Fig.3. Effect of girder stiffness on load distribution

'0'), which is located underneath the wheels, and that the distribution among the ties is similar for the three different girder stiffnesses. It may be concluded that the stiffness of the supporting girders is not a significant parameter as far as load distribution is concerned. A similar conclusion was reached regarding the effect of the type of tie and the spacing of the girders.

Figure 4 shows the distribution of wheel load among the ties for a particular system in which the stiffness (K) of the tie-girder pads varies as shown. It is seen that the distribution of load is influenced by variations in the tie-girder pad stiffness. The load taken by the tie under the wheel increases with pad stiffness. It may be concluded that the stiffness of the tie-girder pad is a significant parameter for load distribution. A similar conclusion was reached regarding the type of rail and the spacing of the ties. Thus only these three parameters influence load distribution significantly.

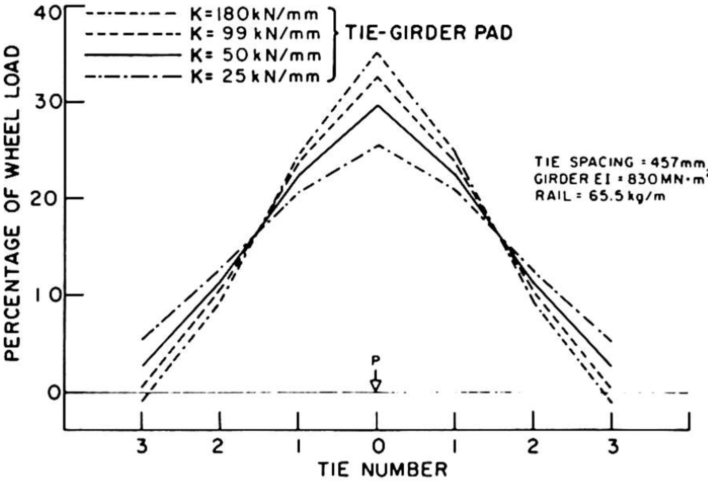

Fig.4. Effect of tie-girder pad stiffness on load distribution

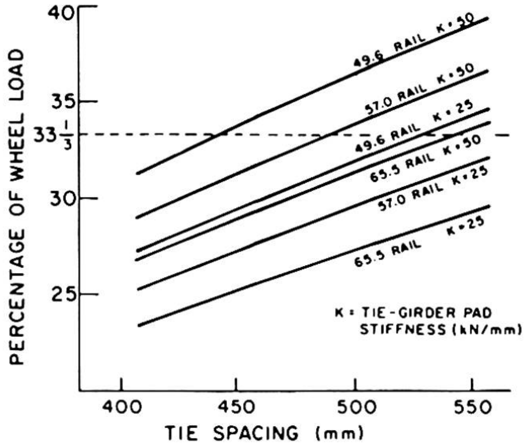

Fig.5. Variation of tie loading with tie spacing, rail type and tie girder pad stiffness

Figure 5 shows the variation of load in the tie under the wheel loads with tie spacing for different types of rail and tie-girder pad stiffnesses. The load increases with tie spacing approximately linearly in each case. Consequently, an equation having the following form may be used in estimating the maximum wheel load in a concrete bridge tie:

$$D = A + BS_t \qquad (1)$$

where D is the percentage of wheel load on the bridge tie and S_t is the tie spacing (mm), while A and B are constants given in Table 2.

Table 2 Constants A, B for Equation 1

Type of rail (kg/m) \ Pad stiffness (K) (kN/mm)		25	50
49.6	A	8	10
	B	0.048	0.053
57.0	A	7.5	9
	B	0.044	0.050
65.5	A	7	8
	B	0.041	0.047

It can be seen from Fig.5, that the commonly used design assumption [4] where the maximum load taken by a tie is equal to one-third the wheel load is reasonable, provided relatively soft tie-girder pads are incorporated in the system.

The analytical model assumes that all the ties are properly seated on the tie-girder pads. During the laboratory load testing it became apparent that improper seating could occur due to variation in elevation at the rail seats of adjacent ties and subsequent lifting of ties from the tie-girder pads when the rail was installed. This variation in elevation results from variation in the thickness and from differential camber of the ties. The effects on load distribution of improper seating of the ties was investigated using the analytical model by assuming gaps to exist between the ties and the girders at various locations. Figure 6 shows the influence of a gap between the girder and one end of the tie under the wheel loads. The distribution for the system without gaps is shown for comparison. It is seen that, in the central tie, the load at rail A, which is the rail adjacent to the end of the tie where the gap exists, is an uplift (tension in the rail fastener), while the load at the other rail (rail B) is higher than that when no gap exists.

Overall, it was found that the presence of gaps in the system resulted in loads in some of the ties being higher than those in the equivalent system without gaps. In a system with a single gap, the highest percentage of wheel load (41%) was found to occur in the central tie when the gap existed in the adjacent tie. From the study of a system with two gaps, a maximum load of 57% of a wheel load was found in the central tie when a gap existed at one end of both the ties adjacent to the central tie.

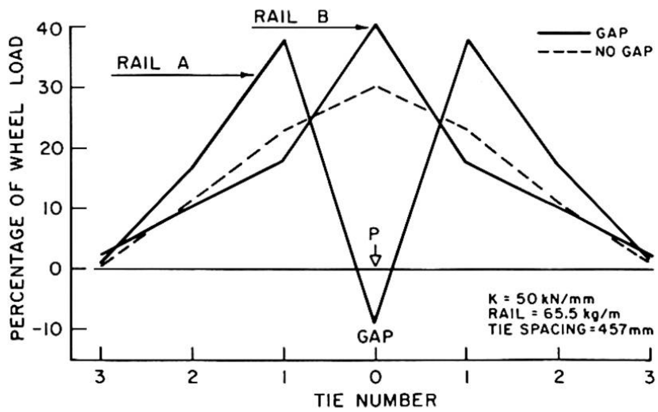

Fig.6. Effect on load distribution of a gap at the central tie

When the differential elevation effect is considered, the design assumption that the maximum load taken by a tie is equal to one-third of the wheel load is not acceptable. Consequently, the influence of potential differential elevation of the ties in an actual system should be assessed during the field appraisal program.

3. LOAD DISTRIBUTION TESTS

The set-up used for full scale laboratory testing of the open deck bridge system is shown in Fig.7. Nine ties were supported on two longitudinal girders. Simulated wheel loads were applied by means of a loading beam to the rails, which were attached to the ties using Pandrol fasteners. Load was applied to the loading beam by jacks reacting against another beam to which were attached tie rods anchored to the substructure. To ensure proper seating of the ties, subsequent to fastening the rail, shims were inserted between the ties and the tie-girder pads.

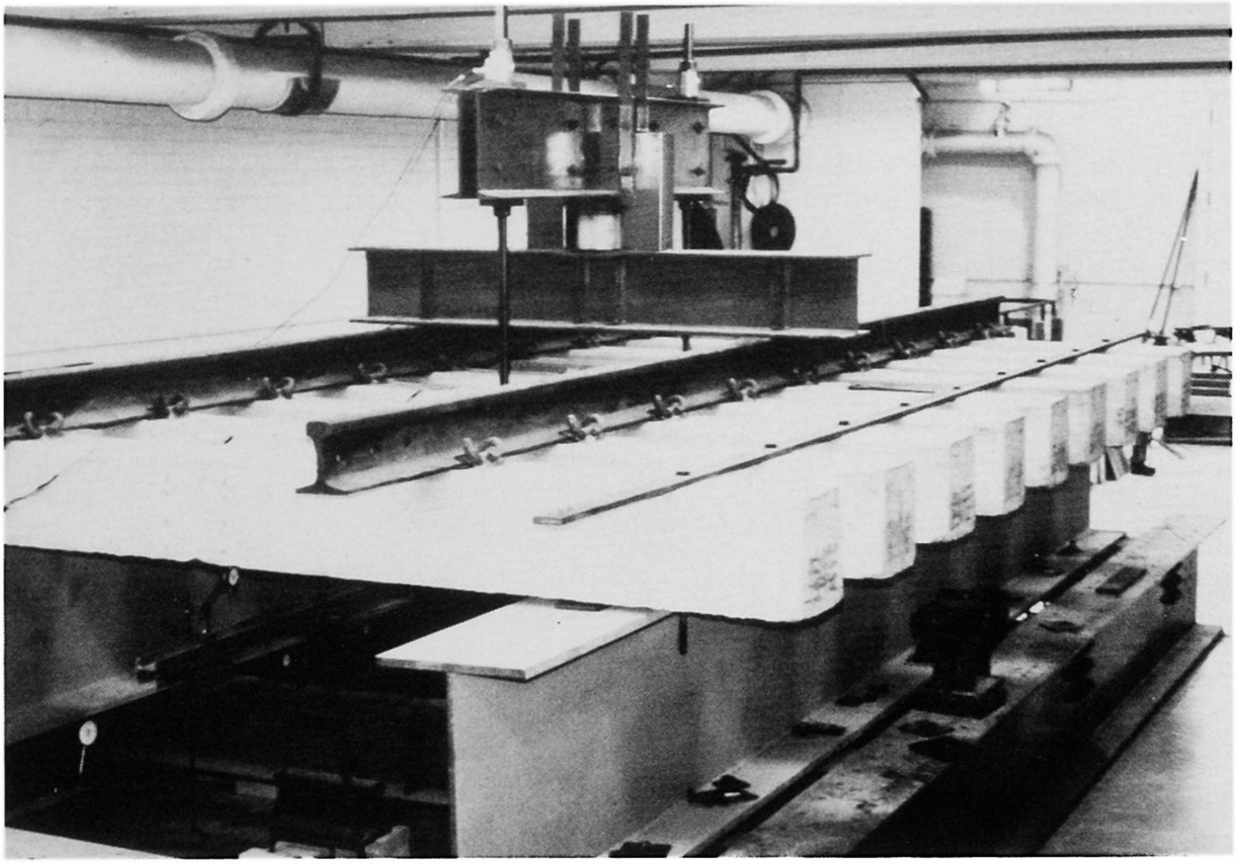

Fig.7. View of load distribution test

The load distribution among the ties was determined by measuring the flexural deformation of each of the nine ties by means of dial gauges. Each tie was calibrated prior to the load distribution tests by subjecting it to known simulated wheel loads and obtaining a load-deflection response curve.

The three significant parameters identified in the analytical study were varied in the load distribution tests. Results from a typical test are shown in Fig.8. Generally good agreement was obtained between the test data and the analytical predictions, thereby establishing the validity of the analytical model.

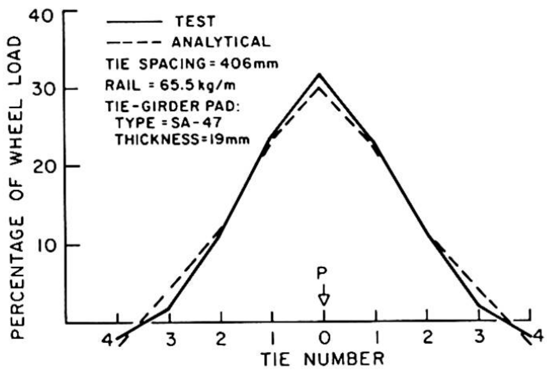

Fig.8. Comparison of test data with analytical prediction

Additional load distribution tests were conducted using the improper seating of the ties as obtained immediately after assembly of the various components. It was observed that, when the tie directly underneath the wheel loads was not seated properly, it did not carry the maximum load. Instead, the maximum load was carried by an adjacent tie. These tests showed an increase up to 60 percent in the maximum tie load in a system where all the ties were not properly seated. Further, these tests indicated a load distribution similar to that predicted by the analytical model in which gaps were considered to exist between the ties and the tie-girder pads at the relevant locations. The significant variation in load distribution suggests a strong need for a rigorous dimensional control and proper seating of all ties in an actual open deck bridge system.

4. FUTURE DEVELOPMENTS

Field testing of concrete ties in an open deck bridge system is currently being undertaken by the Canadian Railways. Load distribution, as well as the improper seating problem, are being studied in two bridges located on mainline track. Impact loads experienced by the ties are also being measured in order to establish realistic design loads for concrete bridge ties.

This open deck bridge system may be applicable to elevated guideways for rapid transit vehicles, where compatibility problems arise between the guideway beams and direct fixation continuous welded rail as a result of temperature variation. Use of ties on the girders effectively isolates the rail from the supporting structure and thus differential movement could be accommodated. This application requires further study.

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