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Load Distribution Characteristics for a Bridge Model at Ultimate Limit State

Caractéristiques de distribution de charge pour un modèle de pont soumis à un état-limite ultime

Lastverteilungscharakteristik unter Traglast für ein Brückenmodell

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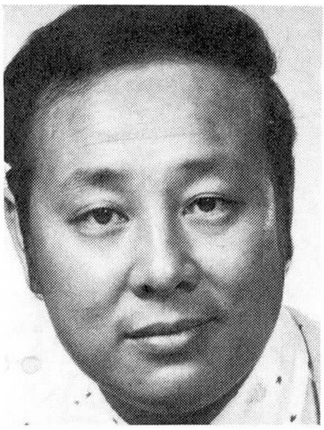

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SUMMARY
This paper is concerned with the overload behavior of a composite continuous slab-on-girder bridge model consisting of four steel girders supporting a cast-in-place reinforced concrete deck. A non-linear finite element program was used to study the load distribution characteristics, and to develop the load distribution factors for the ultimate limite state which include load redistribution, non-linear behaviour and other effects.

RÉSUMÉ
Cet exposé traite du comportement sous surcharge d'un pont-dalle mixte. Le modèle comprend quatre poutres en acier supportant une dalle coulée sur place. Un logiciel d'éléments finis non linéaires a permis d'étudier les caractéristiques de distribution de charge et de développer les facteurs de distribution de charge pour l'état-limite ultime incluant la redistribution des charges, le comportement non linéaire et d'autres effets encore.

ZUSAMMENFASSUNG
Diese Veröffentlichung befasst sich mit dem Verhalten einer durchlaufenden Verbundträgerbrücke unter Überbelastung. Das Modell besteht aus vier Stahlträgern mit einer Stahlbetonplatte. Mit Hilfe eines nichtlinearen Finite Elemente Programms wurde die Lastverteilungscharakteristik untersucht und die Lastverteilungsfaktoren bestimmt, die Momentenumlagerung, nichtlineares Verhalten und andere Effekte einschliessen.

1 INTRODUCTION

For more than thirty years now, composite slab-on-girder bridges have been one of the most popular bridge types in the short to medium span range. A large number of these bridges were built in Ontario and the rest of North America with rapid expansion of the infrastructure over this period. In that time span, legal load limits have increased significantly, to the point where in some cases they are greater than the loads for which these bridges were originally designed. Although the generally satisfactory performance of these structures indicates that they have sufficient capacity to support the service loads, current analytical methods used in bridge design often indicate that the safety levels against failure are less than the minimum acceptable standards required by the code.

In the field of bridge design, current practice is to use elastic methods of analysis to determine the distribution of load effects, while the capacities are set equal to the ultimate resistances of the various components which imply inelastic behavior. In addition, the capacity of the structure is normally limited to that load at which the first section reaches its capacity based on elastic methods of analysis. A reserve of capacity between first yield and complete collapse usually exists. In a highly redundant structure such as a multi-girder, continuous composite slab-on-girder bridge, the magnitude of such a reserve capacity could be significant. If post-elastic methods were available to determine the magnitude of this strength reserve, the ultimate capacities of many of these old structures would no longer be in question. Significant savings could also be achieved in the design of new structures by exploiting some of this post-elastic strength reserves. As a result, a more uniform level of safety prior to collapse could be achieved for different structures leading to better overall economy.

In order to study this problem thoroughly we have used a large scale bridge model rather than a prototype structure, because experimental results from a controlled laboratory enviroment is more reliable than that from a field condition. However, in this paper only analytical results of the load distribution characteristics for this slab-on-girder bridge model will be presented. Load distribution factor D as defined in reference [1] will be used as the measure to quentify the load distribution characteristics.

The behaviour of the bridge model and load distribution factors reported in this paper were based on simulated Ontario Highway Bridge Design Code (OHBDC) truck loading [2]. A non-linear finite element program package was used to study the load distribution characteristics, and to develop the load distribution factors for the ultimate limit state which include load redistribution, non-linear behaviour and other effects .

2 ANALYTICAL PROCEDURE

A finite element program package, ADINA [3] was used to analyse the bridge model. Both elastic and non-elastic behaviour of the steel girders of the bridge were taken into consideration in the finite element idealization. The element type used throughout the model is an isoparametric shell element with nine nodes. Only material nonlinearity was considered in the analysis. In the plastic regions the Von Mises yield criterion of isotropic strain hardening material and associated flow rule were used. Since the line of the simulated truck wheel loads are always applied on the deck either directly above or near the girders, it is therefore reasonable to model the concrete deck by linear elastic shell elements, and the steel girders by three-dimensional elasto-plastic shell elements. Also, because the steel diaphragms are mainly transfering shear forces between steel girders, they can be conveniently idealized as three-dimensional beams using elastic shell elements.

3 GEOMETRY AND MATERIAL PROPERTIES OF THE BRIDGE MODEL

The bridge model geometry is shown in Figure (1), while the material properties are summerised in Table (1) .

3.1 Load System

The loading system consists of OHBDC truck load scaled down to fit the model and positioned such that to produce the following maximum force effects :

1. The maximum positive longitudinal moment at the middle span.
2. The maximum positive longitudinal moment at the end span .

3.2 Scaled OHBDC Load

The load scale factor was calculated so that the bending stresses produced in the prototype by the actual loads would be equal to the bending stresses produced in the model due to the scaled load. The load scale factor was found to be 0.094 ($\frac{1}{10.63}$). The OHBDC truck load is shown in Figure (1). This loading was simplified by combining the two 140 kN loads into one 280 kN load. This simplified loading was then moved longitudinally (from left to right) along the prototype bridge until the position of maximum moment was found (positive moment governs). The applied loads were then reduced by the load scale factor (0.094), and the spacings of the loads were reduced by the geometric scale factor (0.354) to get the model scale truck load . The scale truck load was further simplified. The 5.64 kN load was eliminated to create only three lines of load. The magnitude of these three loads were increased by (7.18%) in order to produce the same maximum moment with three loads as was produced by the original four loads, see Figure (1).

4 RESULTS AND DISSCUSION

Due to the restriction on the lenght of paper, only part of the results are presented in this paper. The parameters and load cases investigated in this paper are summarized in Table (2). Details of other analytical results can be found in reference [4].

Some typical results of bending moment and load distribution factors are given in Table (3). It can be seen, that distribution factors are nearly constant under low magnitude of load (elastic stage). This value is a function of the elastic stiffnesses of the slab and the girder as well as the load configuration. The distribution factors start to decrease when first yield occurs at an interior girder. This trend continues until the section becomes fully plastic. Then, any further increasing external load will distribute to exterior girders until a sufficient number of plastic hinges have developed to form a collapse mechanism.

Also, in Figure (2), the moment ratio for each girder at the three stages (elastic, elasto-plastic, and ultimate) is plotted, where the moment ratio is given by the total live load moment in each girder divided by the total live load moment across the section. For those cases where the three lanes were loaded (PTC, PTS-3L), the bulk of the load is carried by the interior girders in an elastic distribution (i.e. elastic stage). At stage two (elasto-plastic), the transverse distribution of the moments begins to improve, reaching the uniform distribution at ultimate .

For load case, PTS-2L, in elastic stage, the most of the moments were carried by the girders G2, G3, and G4, with a larger proportion resisted by the girders G3 and G4. In the post-elastic stage, the transverse distribution improves among the two most heavily loaded girders (G3 and G4). The girders G1 and G2 also resist an increased proportion of the moment.

For load case, PTS-1L, the load is initially carried by the interior girders in the elastic stage . However, as the load increases to cause yielding of the interior girders, the distribution of the moments begin to change. At the elasto-plastic and ultimate stages, the transverse distribution of the moments begin to improve .

The longitudinal distribution of the bending moment, ψ, is also given in Table (3), which shows small amount of longitudinal redistribution achieved for the PTC analysis: 0.2% to 15.2% at stage two (elasto-plastic), and up to 19.4% at ultimate.

Some results were presented graphically in Figure (2) to study the effect of number of loaded lanes. For the three lane bridge analysed, two conclusions can be made regarding the effect of number of loaded lanes. Firstly, one or two lane loaded cases would not govern the design of the bridge at ULS regardless of whether capacity is based on elastic strength calculation or plastic collapse mechanism. Secondly, three lane loaded case generally will govern the design of the bridge at ULS and it is possible to achieve a collapse mechanism. This would be contingent upon sufficient capacity in the slab to allow complete transverse redistribution. However, in one or two lane loaded cases, the formation of a collapse mechanism is highly improbable because significant decrease in stiffness and rapidly increase in deflection were predicted before any substantial transverse redistribution could be achieved .

5 CONCLUSIONS

1. The distribution factors varied significantly from elastic stages to ultimate stages. The transverse distribution factors started with a constant value in the elastic stage. After yielding occurred, a greater percentage of load was redistributed laterally to the exterior girders and at the same time the load was redistributed

longitudinally to the supports.

2. Load distribution characteristics dramatically improved when the number of loaded lanes increased, for example, between the elastic and ultimate stages the load distribution factor, D, for the interior girders increased by approximatly 9% in the three lane loaded case, this percentage increased up to 28% and 26% respectively for one or two lane loaded cases.
3. The governing load case for design purposes is generally a symmetrical one in which all lanes are loaded. One or two lane loaded case would not govern the design of a three lane bridge at ULS regardless of whether capacity is based on elastic strength calculations or plastic collapse mechanism.

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Table 1: Design details of the bridge model and material properties

Bridge span length	=	16.186 m.
Bridge width	=	3.220 m
Spacing of beams	=	900 mm.
Size of beams	=	$W15 \times 10$
Slab thickness	=	62 mm.
Number of beams	=	4
Yield stress of beams	=	300 MPa
Modulus of elasticity of steel	=	200×10^3 MPa
Modulus of elasticity of concrete	=	43.6×10^3 MPa
Poisson's ratio for the steel	=	0.30
Poisson's ratio for the concrete	=	0.15
Shear connectors used	=	$C38 \times 2.5$

Table 2: Summary of the parameters and load cases investigated

$\underline{PTC}$
1- Maximum positive moment in the continuous span bridge.
2- Transverse hinges included in the analysis.
3- Longitudinal hinges included in the analysis.
$\underline{PTS-3L}$
1- Maximum positive moment in the end span after the formation of first internal hinge.
2- Transverse hinges included in the analysis.
3- Three lanes loaded.
$\underline{PTS-2L}$
1- Maximum positive moment in the end span after the formation of first internal hinge.
2- Transverse hinges included in the analysis .
3- Two lanes loaded .
$\underline{PTS-1L}$
1- Maximum positive moment in the end span after the formation of first internal hinge .
2- Transverse hinges included in the analysis.
3- One lane loaded .

Table 3: Moments and Load Distribution Factors

Load factor PTC	Moment (kN.m)		D (m)		ψ (m)
	Exterior	Interior	Exterior	Interior	
1.0	29.18	35.32	0.6630	0.5479	–
2.0	58.37	70.63	0.6630	0.5479	–
3.82*	111.52	134.92	0.6630	0.5479	1.
4.0	116.73	140.84	0.6620	0.5486	0.9981
4.6	134.57	160.66	0.6581	0.5513	0.9948
5.2	153.63	178.90	0.6493	0.5576	0.9912
5.8	173.93	192.17	0.6315	0.5715	0.9783
6.4	184.58	190.73	0.6100	0.5903	0.9089
7.0	192.12	190.80	0.5979	0.6020	0.8479
7.44**	195.60	191.47	0.5937	0.6065	0.8064

Load Factor PTS-3L	Moment (kN.m)		D (m)	
	Exterior	Interior	Exterior	Interior
1.0	33.18	40.21	0.6636	0.5476
3.0	99.53	120.62	0.6636	0.5476
3.8*	127.11	152.65	0.6603	0.5498
4.0	133.92	160.08	0.6586	0.5510
4.4	150.76	176.84	0.6519	0.5557
4.8	166.61	188.01	0.6385	0.5658
5.0	175.75	190.52	0.6252	0.5767
5.4	189.55	204.58	0.6238	0.5780
5.8	193.98	192.89	0.5983	0.6017
5.93**	189.33	190.58	0.6019	0.5980

Load Factor PTS-2L	Moment (kN.m)		D (m)	
	Exterior	Interior	Exterior	Interior
1.0	34.74	35.36	0.6300	0.6190
2.0	69.49	70.71	0.6299	0.6190
4.0*	139.08	141.41	0.6296	0.6192
6.0	208.28	201.10	0.6294	0.6518
7.0	220.33	212.86	0.6651	0.6885
8.0	215.43	209.76	0.7164	0.7358
10.0	240.68	240.24	0.7687	0.7701
11.0	259.30	260.93	0.7815	0.7767
11.18**	265.81	264.86	0.7811	0.7810

Load Factor PTS-1L	Moment (kN.m)		D (m)	
	Exterior	Interior	Exterior	Interior
1.0	7.32	16.45	2.922	1.301
2.0	14.65	32.90	2.922	1.301
8.0	58.59	131.62	2.922	1.301
8.2*	60.06	134.69	2.918	1.301
12.0	91.04	189.88	2.777	1.331
14.0	121.56	205.64	2.422	1.432
16.0	142.67	198.44	2.152	1.547
18.0	168.87	211.24	2.026	1.619
20.0	181.67	215.19	1.966	1.660
20.42**	185.08	217.65	1.958	1.665

ψ : Longitudinal distribution factor
* first yielding started at the interior girder
** both exterior and interior girders yielded

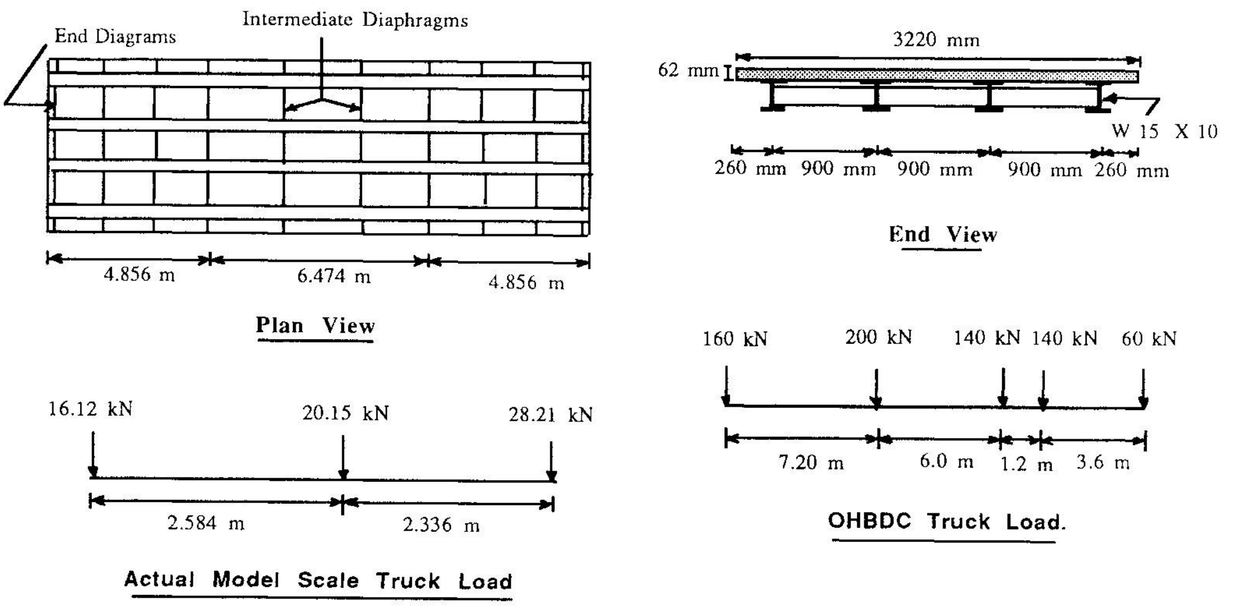

Figure 1. Details of Bridge Model and Loading.

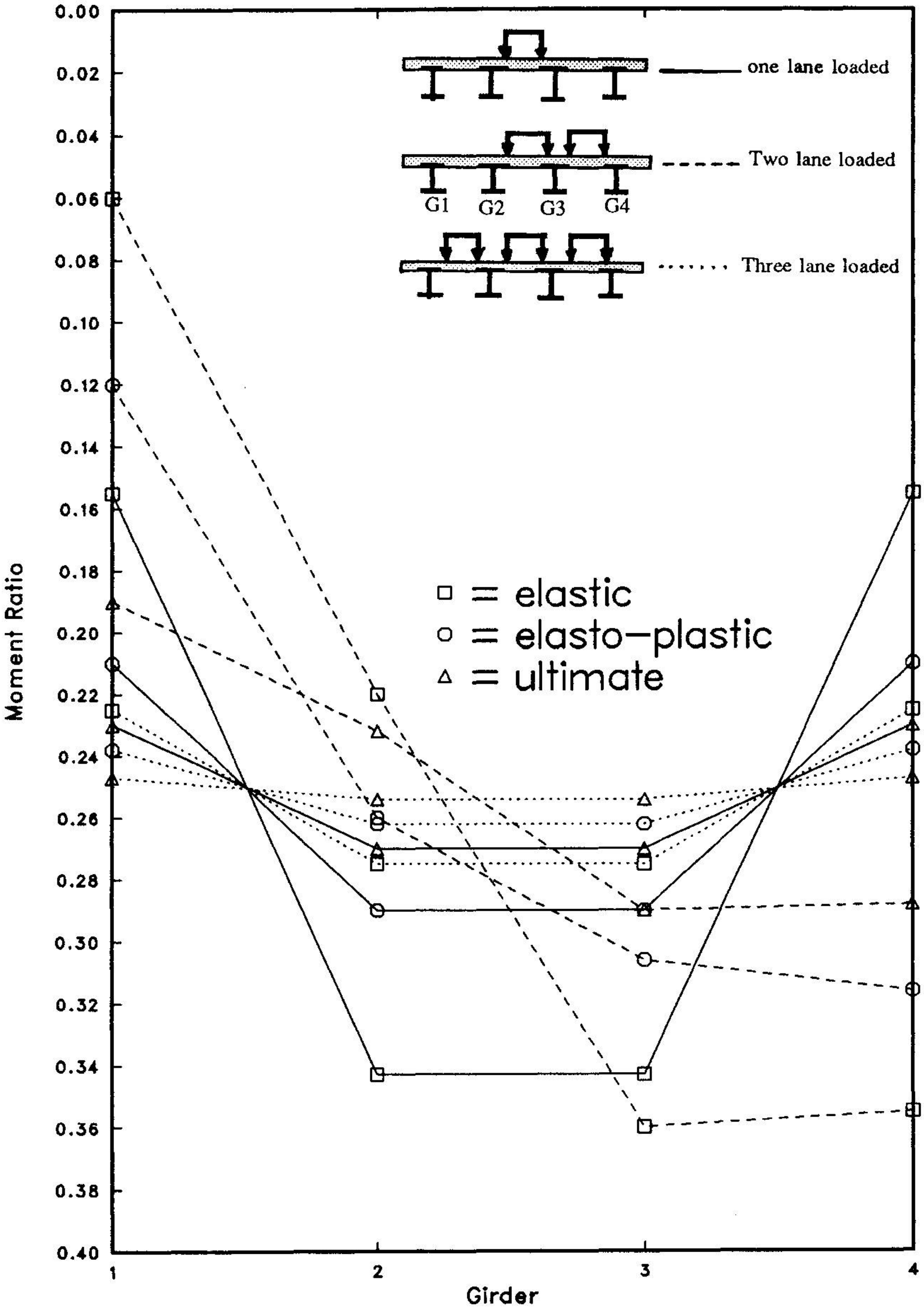

Figure 2. Transverse Moment Distribution .