**Zeitschrift:** IABSE proceedings = Mémoires AIPC = IVBH Abhandlungen

**Band:** 11 (1987)

**Heft:** P-117: Modeling of highway traffic loads in Switzerland

**Artikel:** Modeling of highway traffic loads in Switzerland

**Autor:** Bez, Rolf / Cantieni, Reto / Jacquemoud, Joseph

**DOI:** https://doi.org/10.5169/seals-40377

# Modeling of Highway Traffic Loads in Switzerland

## Modélisation des charges du trafic routier suisse

## Modellbildung für die Strassenverkehrslasten der Schweiz

**Rolf BEZ**
Civil Engineer
Swiss Fed. Inst. of Technology
Lausanne, Switzerland

Rolf Bez, born 1957, received his civil engineering degree from the Swiss Federal Institute of Technology in Lausanne (EPFL). Since 1980, he has been a research engineer at the Institute for Steel Structures (ICOM) of EPFL, working mainly in the domain of bridge loading.

**Reto CANTIENI**
Civil Engineer
Fed. Lab. Mat. Testing and Res.
Dübendorf, Switzerland

Reto Cantieni, born 1945, received his civil engineering degree from the Swiss Federal Institute of Technology in Zurich (ETHZ). After being employed for three years in a design firm, he joined the Institute of Structural Engineering at the ETH Zurich as an assistant. Since 1974 he has worked at EMPA, involved mainly in structural dynamics problems.

**Joseph JACQUEMOUD**
Dr.-Eng.
Bridge and Road Office
Sion, Switzerland

Joseph Jacquemoud, born 1950, received his civil engineering degree and his doctorate from the Swiss Federal Institute of Technology in Lausanne (EPFL). He then joined the Institute for Steel Structures at RWTH Aachen (Fed. Rep. of Germany), where he worked for two years. Since 1982, he has been chief bridge engineer for the Canton of Valais (Switzerland).

**SUMMARY**

A new concept of loading, which clearly distinguishes between load carrying capacity and serviceability limit states, was adopted for the revision of the Swiss loading code. This paper illustrates the methods used by the new approach of modeling traffic loads. Safety concepts, characteristics of highway traffic in Switzerland, critical loading situations and the serviceability objectives are outlined. Finally, numerical values are proposed for static and dynamic loads.

**RÉSUMÉ**

Un nouveau concept de charge, faisant clairement la distinction entre les vérifications de la capacité portante et de l'aptitude au service, a été adopté pour la révision de la norme de charge suisse. Cet article montre quelle démarche a été suivie au niveau de la modélisation du trafic routier suisse. Il aborde successivement le concept de sécurité, les caractéristiques du trafic routier, les situations de danger et les objectifs d'utilisation. Des valeurs numériques pour les coefficients dynamiques et pour les modèles de charges utilisés sont ensuite proposées.

**ZUSAMMENFASSUNG**

Ein neues Konzept für die Festlegung von Lasten, das klar zwischen den Nachweisen der Trag- und der Gebrauchsfähigkeit unterscheidet, wurde im Rahmen der Revision der schweizerischen Belastungen angenommen. Der vorliegende Artikel beschreibt die Grundlagen, die zur Entwicklung der Lastmodelle für den Strassenverkehr benutzt worden sind. Dazu werden das Sicherheitskonzept, die Gegebenheiten des Strassenverkehrs, die Gefährdungsbilder und die Nutzungsziele umrissen. Schliesslich werden Zahlenwerte für den dynamischen Beiwert sowie für die Lastmodelle für Trag- und Gebrauchsfähigkeitsnachweis vorgeschlagen.

## 1. INTRODUCTION

In 1980 a new committee under the chairmanship of Prof. Hirt was formed to revise the Swiss loading code SIA 160 [1]. This committee started its work with the goal to define more clearly the limit states of load carrying capacity and serviceability. Various subgroups were created to describe load models and the corresponding numerical values as for example for dead load, variable loads, snow and wind loads, earthquake and extraordinary loadings. The authors of this paper are members of the subgroup "variable loads".

The backround for modeling of highway traffic loads according to the concept of the new code is presented here. The article is limited to a discussion of the load carrying capacity and serviceability limit states. The fatigue limit state is not treated, as it requires a slightly different statistical evaluation of the traffic and must consider the fatigue strength caracteristics of the building material.

Load modeling was undertaken in a manner such that it would be completely independent of the static system, geometry, span length of the structure as well as the materials with which the structure is constructed. The different factors used in evaluating traffic load characteristics were defined in order to accommodate the evolution of traffic loading. All factors concerned with the structure itself are given in codes dealing with the individual materials of construction. It is for this reason that the provisions outlined in this article provide only for the calculation of traffic load magnitudes. Calculations of individual member loads for different structural systems using these provisions have been performed but are not discussed here.

## 2. SAFETY CONCEPTS

The concept of safety adopted by the proposed code revision [2] is described in detail in reference [3]. In this chapter, fundamental safety concepts are summarized considering ultimate strength and serviceability criteria.

### 2.1 Ultimate strength calculations

For ultimate strength calculations, two types of live loads are applied to the structure in combination with dead loads. These two types of live loads are termed predominant and accompanying. The combinations consist of one predominant live load and normally one accompanying live load. Each combination is checked for all members in the structure. The predominant load is the live load which represents the main hazard to the safety of the structure; other live loads are termed accompanying. This distinction is made as it allows different levels of safety to be defined for each type of load. Safety may be estimated by a given confidence level based on the statistical distribution of the load.

Sufficient strength of a member in a structure is assured when the following equation is satisfied :

$$\frac{R}{\gamma_R} > S_d \tag{1}$$

R : resistance of the member calculated according to the code for the material used,

$\gamma_R$ : resistance factor defined in the code for the material used,

$S_d$ : design load where the maximum value is determined by considering all appropriate loading cases.

The design load $S_d$ is further defined as follows :

$$S_d = S(Q_d, G_d, Q_a) \tag{2}$$

$Q_d$ : predominant load,

$G_d$ : dead load,

$Q_a$ : accompanying load.

When traffic loads are considered to be the predominant load $Q_d$, this value is established using the Swiss Recommendation SIA 260 [4], which was used as the reference document defining the safety concept. The design value $Q_d$ is defined as follows :

$$Q_d = \gamma_s Q^* \tag{3}$$

$\gamma_s$ : factor applied to $Q^*$. This factor is not a load factor : it considers the possible effects of other accompanying loads not accounted for explicitly by $Q_a$. The value $\gamma_s$ is normally taken to be 1.1.

The characteristic value $Q^*$ is defined by the following equation :

$$Q^* = m_Q + \beta\, \delta_Q\, s_Q \tag{4}$$

$m_Q$ : mean value of the load Q,

$\beta$ : safety index,

$\delta_Q$ : linear factor,

$s_Q$ : standard deviation of the distribution of the load Q.

With the values of $\beta$ and $\delta_Q$ fixed for the purpose of the development of the code at 4.0 and 0.8 respectively [4], equation (4) may be reduced to the following :

$$Q^* = m_Q + 3.2\, s_Q \tag{5}$$

This equation may be used when the statistical distribution of the loading is normal. If the load Q is better described by an other distribution, the value $Q^*$ must then be determined in a manner appropriate to the distribution, such that the probability of failure remains the same.

Note that when traffic loads are considered to be the accompanying live load, $Q_a$ is established using the approximate mean value of $m_Q$.

### 2.2 Serviceability criteria

In order to guarantee that a structure is safe and to ensure the comfort of its users during short term loading, the value $S_{ser,short}$ is defined in the following manner :

$$S_{ser,short} = S(G_m, Q_{ser,short}) \tag{6}$$

$G_m$ : mean value of the dead load,

$G_{ser,short}$ : short term load used to verify the structure according to a given serviceability limit state.

The design values of $Q_{ser,short}$ are determined in a manner which best corresponds to the real live loading. Long term live loading $Q_{ser,long}$ such as snow load and long term loads in a building, rarely exist on a highway bridge. Thus, only the short term live load is needed. Additional criteria for long term loading in buildings or for the cracking of concrete bridges have been developped. They do not involve traffic loading and therfore are not discussed here.

## 3. CHARACTERISTICS OF HIGHWAY TRAFFIC

The traffic loads prescribed by the new code are not always directly measurable since they are extreme cases involving one or more vehicles. Field measurements were performed and provided the statistical basis for estimating appropriate code values.

Most field measurements were taken during a survey in 1975 and 1976, undertaken by the Swiss Federal Highway Administration (OFR), the Swiss Federal Laboratories for Materials Testing and Research (EMPA) and by the Institute of Steel Construction (ICOM) of the Swiss Federal Institute of Technology in Lausanne. Measurements were obtained for four different major highways in Switzerland. A total of 2340 trucks were identified, stopped and recorded without police intercepting overloaded vehicles such as not to bias the statistics [5] [6] [7]. Variables studied included truck type, axle loadings and axle spacings. In addition, the volume census of traffic on each route was taken [8]. All these results formed the basis of the further studies.

The principle findings are the following :

- the number of vehicles (trucks and cars) varies between 2500 and 7500 per day and per direction depending upon the survey location,
- the percentage of trucks in the total traffic volume varies between 8 % and 25 % depending upon the survey location,
- truck weights frequently exceed the legal gross weight limits up to 20 % (280 kN being the maximum gross weight limit for any type of commercial vehicle in Switzerland),
- the most severe truck, that is to say, with the greatest total load to length ratio, has three axles and a legal gross weight limit of 250 kN,
- the minimum axle spacings for three axle trucks were 3 and 1.3 meters.

It should be mentioned that the front and the back overhangs were not checked. These were conservatively taken to be 1.5 meters. The ratio of trucks to total traffic for each lane of multiple lane highways, as well as the caracteristics of cars, were taken from a study carried out in Germany [9]. Table 1 gives an example of truck distribution per lane.

Table 1 - Average percentage of trucks in each lane for highways with 2 or 3 lanes [9].

| NUMBER OF LANES IN EACH DIRECTION | PERCENTAGE OF TRUCKS IN LANE | | |
|---|---|---|---|
| | 1st lane | 2nd lane | 3rd lane |
| 2 | 34 % | 4 % | — |
| 3 | 47 % | 8 % | 1 % |

Continued measurements would be recommendable to monitor changes in traffic composition and density.

## 4. CRITICAL LOAD SITUATIONS

When designing a highway bridge, it is necessary to check all possible load patterns which may determine individual member dimensions. This means that all possible critical load situations which may reasonably be expected during the design life of the structure should be considered. Each situation, analyzed by use of equation (2), consists of predominant and accompanying loads as well as dead load, as described in Chapter 1.

The following situations were investigated for predominant and accompanying loads :

1. Predominant Loads :
   - an isolated crossing by a single overloaded truck,
   - a number of moving trucks passing each other,
   - a simultaneous crossing by two or three heavily loaded three axle trucks,
   - a stationary lane load consisting of different types of trucks, such as may be present during a traffic jam,
   - a moving lane load consisting of different trucks,
   - a stationary load consisting of a mixture of trucks and cars as may be present over the whole roadway during a traffic jam.
2. Accompanying Loads :
   - an isolated crossing by a single truck,
   - a stationary load consisting of a mixture of trucks and cars as may be present over the whole roadway during a traffic jam,
   - a moving lane load consisting of a mixture of trucks and cars.

Equation (1) must be satisfied for all possible situations. Therefore, it is important to examine all possible critical load situations during the life of the structure. The load models presented in Chapter 5 were developed with this purpose in mind.

## 5. SERVICEABILITY OBJECTIVES

In order to verify the behavior of a structure according to a particular service state, the loads for that service state must correspond to the serviceability objectives. These include durability, comfort of the user, esthetics and suitability of the structure for the use envisioned. These objectives are met by checking concrete cracking, vibrations, deformations and the properties of the materials used.

Finally, to satisfy the different criteria necessary for highway traffic the following situations need to be checked :

- an isolated crossing by a single truck,
- a stationary load consisting of a mixture of trucks and cars over the whole roadway as may be present during a traffic jam,
- a moving lane load consisting of a mixture of trucks and cars.

## 6. TRAFFIC MODELING

To represent the different load situations identified in the preceding chapters, the following three load models are used :

- Load model 1 represents the concentrated effect of an isolated truck located anywhere on the roadway or the sidewalk [2]. The truck is idealized as shown in Figure 1 and its geometry corresponds to that of the three axle truck, which constitutes the most severe load. The load is considered to be moving; the design loads for each axle (determined in Chapter 8) are thus multiplied by a dynamic coefficient $\phi_1$, defined in Chapter 7.
- Load model 2 represents a lane load consisting of slowly moving trucks (loading is determined using a stationary lane load, see Chapter 8). The lane load is taken to be 2.5 meters wide which corresponds to the truck's width and is placed at the most critical location in the roadway. This load is multiplied by a dynamic coefficient $\phi_2$, defined in Chapter 7.
- Load model 3 represents a stationary lane load consisting of a mixture of trucks and cars. No dynamic coefficient is applied to these loads. Applied loads are assumed to be uniform over the entire width of the roadway with the exception of the lane in which load models 1 and 2 are applied.

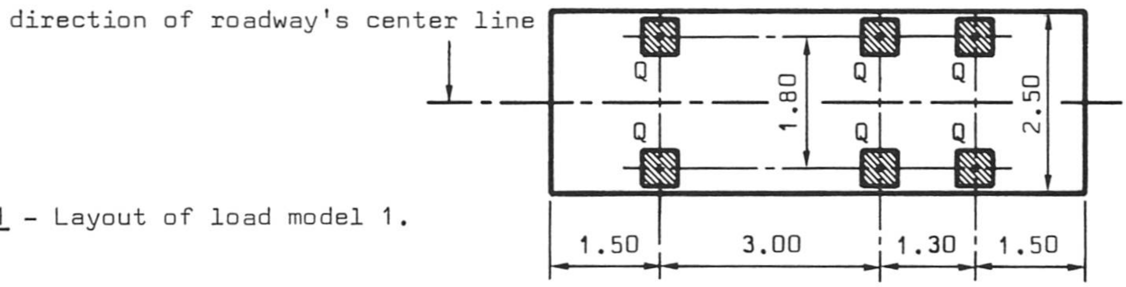



Fig. 1 - Layout of load model 1.

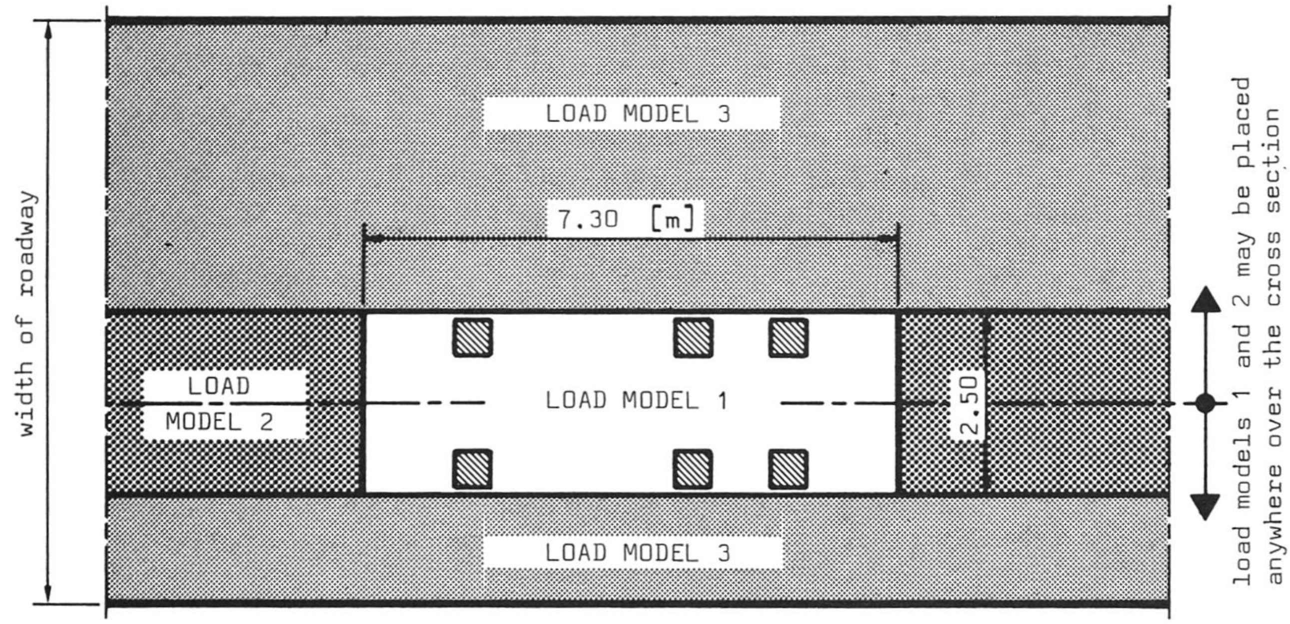



Fig. 2 - Loading case to consider for the ultimate strength criteria check when highway traffic is considered as the predominant load.

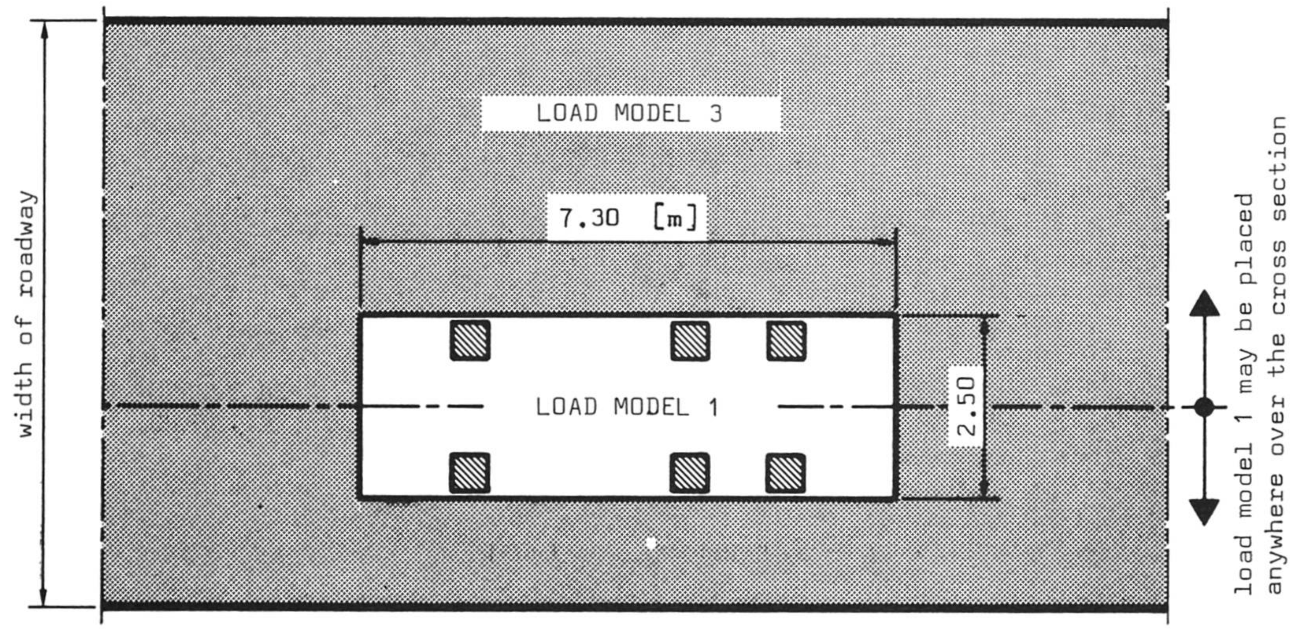



Fig. 3 - Loading case to consider for the serviceability criteria check related to highway traffic.

If the traffic is considered to be the predominant load for the ultimate strength criteria check, a combination of load models 1, 2 and 3 must be used, as shown in Figure 2 [2]. The load case shown in Figure 2 thus represents an extreme condition where an overloaded truck is placed in a line of moving trucks while a stationary mixture of trucks and cars (load model 3) is distributed over the rest of the roadway.

If, however, the traffic is considered to be an accompanying load, only load model 3 should be used. This may for example be the case when checking a member subject to a predominant wind load.

To check the serviceability criteria for the structure, load models 1 and 3 must be considered, as shown in Figure 3 [2].

All load models are meant to be used with both long and short span bridges.

## 7. DYNAMIC LOAD COEFFICIENTS

According to a generally accepted simplification, dynamic loads are taken into account using coefficients which are applied to the static loads. The proposed revisions to the Swiss loading code [2] use two dynamic coefficients, $\phi_1$ and $\phi_2$, which are applied to load models 1 and 2, respectively. The values of these dynamic coefficients are given in Figure 4 [2]. They were determined on the basis of the following two studies :

- tests on over 200 highway bridges since 1958 [10],
- dynamic tests on the Deibüel bridge in 1978 [11].

Reference [10], reports measurements made on the main members of bridges during the passage of a truck having a gross weight of 160 kN. Investigation of the results of these tests showed that the dynamic coefficient mainly depends on the fundamental frequency of the structure, the speed of the vehicle and the surface characteristics of the roadway.

The tests on the Deibüel bridge [11] enabled a more detailed analysis of the effects of vehicle type and road surface condition to be carried out. Based on a statistical analysis of Swiss heavy commercial vehicles [5], twelve different trucks (representing eight vehicles types) with a gross weight between 161 kN and 403 kN have been chosen for these tests. In addition to isolated vehicle crossing, several measurements were made for simultaneous crossing by two and four trucks. The effect of improving the initially very bad road surface was also investigated with some of the test trucks. In addition, a study of the transverse behavior of the bridges tested was undertaken. The results of the tests conducted on the Deibüel bridge are summarized as follows :

1. Longitudinal behavior of the main load carrying members :
   - Individual trucks with more than two axles produced larger dynamic coefficients than individual trucks with only two axles. It is for this reason that the dymanic coefficient $\phi_1$, presented in Figure 4, is slightly higher than the values given in [10] for two axle trucks.
   - Tractor-trailers and tractor-semitrailers produce smaller dynamic coefficients than individual two axle trucks.
   - Two or four trucks passing at the same time produce dynamic coefficients smaller than half of those observed during the passage of one truck with more than two axles. This is reflected in Figure 4 as the dynamic coefficient $\phi_2$ is 50 % of $\phi_1$.
2. Transverse behavior :

   Two load cases have been studied, trucks passing near the centerline of the bridge and trucks passing at the outside edge. Dynamic increments for the transverse elements did not exceed the values determined for the main members.

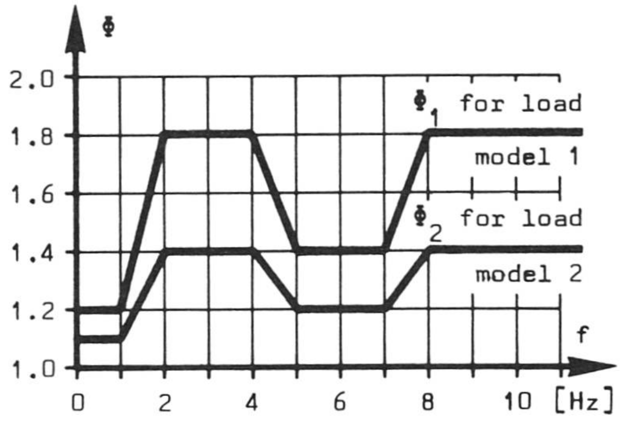



Fig. 4 - Dynamic coefficients for highway traffic loads as a function of the fundamental frequency of the element examined.

3. Road surface characteristics :
   An improvement in the road surface quality does not always guarantee a reduction of the dynamic coefficient. In some isolated cases, a small increase may be noted for trucks with two axles. The corresponding values however never exceeded the maximum values for three axle trucks. As a result, the dynamic coefficients shown in Figure 4 may be used as an upper bound value. An increase in the dynamic coefficient for trucks with more than two axles was never observed.

In Figure 4, the relation between the dynamic coefficient $\phi$ and the fundamental frequency f indicates two zones where the dynamic coefficient is maximized. These two zones are for frequencies 2 to 4 Hz, and above 8 Hz. These zones correspond to the natural frequencies of the trucks themselves, or more specifically those associated with the axles and the body. Often the bridges exhibit very little damping [10]. Their dynamic behavior is thus strongly influenced by the similarity of the natural frequencies associated with the bridge and the vehicles which use the structure. Calculation of these variables requires extensive expert analysis [12]. The transverse fundamental frequency of bridges is often difficult to estimate due to changes in the supporting conditions. However, practical experience suggests that these values are higher than 8 Hz. As a result, the maximum dynamic coefficient, shown in Figure 4, should then be used.

With respect to truck speed, the values used in the code are the maximum dynamic values recorded. Truck speed is therefore eliminated from the analysis. This is valid for usual road surface conditions.

The quality of road surfaces in Switzerland is dealt with by codes SNV 640520a [13] and SNV 640521a [14]. Measurement methods for road surface geometry and allowable surface roughnesses are defined. These codes and the dynamic coefficients measured for the Deibüel bridge showed good correspondance. Measurements were taken while the road surface was in poor condition, just within the limits defined in [14]. This illustrates that the dynamic coefficients shown in Figure 4 are valid if the quality of the road surface does not exceed these limits. If they are significantly exceeded, it is possible that the dynamic amplifications may become larger than those predicted by the code. To represent such cases, dynamic coefficients were measured when trucks passed over a 45-50 mm thick plank placed on the roadway. The results of these measurements are also given in [10] and [11].

## 8. CALCULATION OF DESIGN VALUES

In the preceding chapters, the data basis for highway traffic and the critical load situations have been presented. In this chapter, the procedure and methods used to calculate design load values are discussed. General concepts are emphasized rather than detailed calculations. A summary of the design values is given in Table 2 [2]. This table represents the final result of an intensive investigation undertaken by a working group of SIA 160 [15].

Design cases where loads are treated as predominant (sect. 8.1), accompanying (sect. 8.2), and service loads (sect. 8.3), are treated separately.

Table 2 - Design values for the different highway load models.

| | | ULTIMATE STRENGTH CRITERIA | | | SERVICEABILITY CRITERIA | |
|---|---|---|---|---|---|---|
| | | predominant load $Q_d$ | | accompanying load $Q_a$ | short term load $Q_{ser,short}$ | |
| | | q [kN/m²] | Q [kN] | q [kN/m²] | q [kN/m²] | Q [kN] |
| Load model 1 | | | 90 | — | | 50 |
| Load model 2 | | 7.5 | | — | — | |
| Load model 3 - width of roadway in meters | ≤ 9 | 5.0 | | 2.0 | 2.0 | |
| | > 9 and ≤ 13 | 4.5 | | 2.0 | 2.0 | |
| | > 13 | 3.5 | | 2.0 | 2.0 | |

## 8.1 Predominant Loads

When designing for predominant traffic loads, load models 1, 2 and 3 must be used in combination (see Chapter 6, Figure 2). Design loads for these three models are determined using the definitions given in Chapter 2. The design method for each load model is given separately in the following subsections.

### 8.1.1 Load model 1

The load survey performed in Switzerland [6] indicates that an equal distribution of the total weight of the three axle truck over each axle may be assumed. Therefore, axle loads for load model 1 (Figure 1) were determined on the basis of a histogram of 6611 individual axle weight measurements during traffic investigations in 1975-1976. This histogram is shown in Figure 5 [6]. The analysis yielded the following results :

- mean load : $m_x$ = 48.0 kN,
- standard deviation : $s_x$ = 23.7 kN,
- maximal observed value : $X_{max}$ = 155 kN.

If equation (5) is applied (assuming that the axle weight distribution is normal) a characteristic value X* = 124 kN is obtained. This value is smaller than the maximum observed value of 155 kN. This illustrates that the axle weight distribution is not normal, but may be better described as a gamma distribution, as shown in Figure 5. The characteristic value of a gamma distribution yields X* = 161 kN.

Using the characteristic value of X* = 161 kN, equation (3) gives a design value $X_d$ of 180 kN per axle, or **90 kN per wheel (Table 2).**

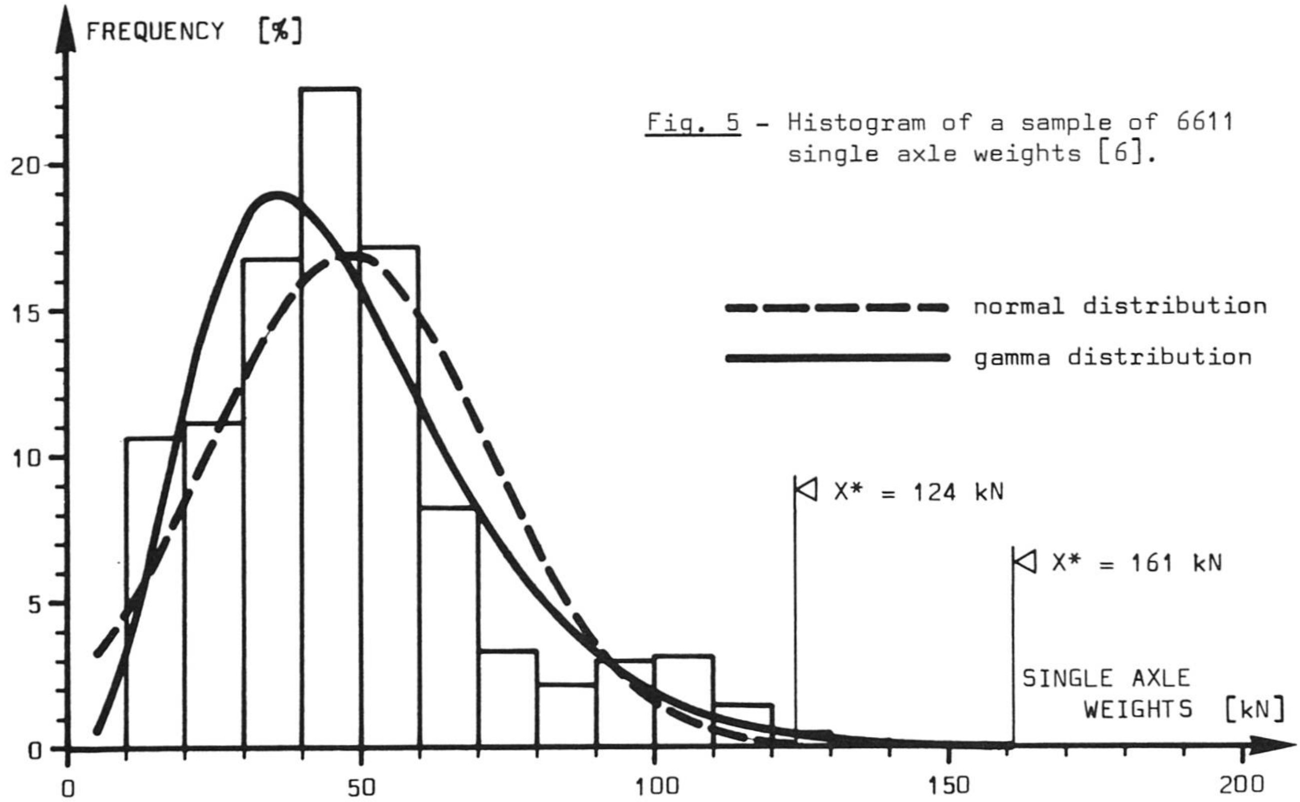



Fig. 5 - Histogram of a sample of 6611 single axle weights [6].

### 8.1.2 Load Model 2

The design value for this load model was established using a computer based simulation including sequence of arrival and truck spacing modelling. Using the axle loads and axle spacings from [5] [6], it is possible to reconstruct lines of trucks in order to model conditions such as traffic jams. Therefore, lane loads are simulated using measured values for a series of n trucks (n = 1,2, 3,...), with respect to the order in which they were observed during the survey. For each series, the total weight of the n trucks is divided by the total length of the line to compute the mean value of load per unit length. Two cases are considered :

1. A stationary line of trucks (the dynamic coefficient considered to be zero). The spacing between the trucks is assumed to be 0.5 meters, a very severe case.

2. A moving line of trucks (the dynamic coefficient $\phi_2$ is accounted for and calculated as defined in Chapter 6). Based upon field measurements the spacing between vehicles is taken to be 2.5 meters. This spacing is valid for truck speeds of up to 20 km/h.

It was found that the traffic between Basel and Zürich was the most severe and thus, it served as the basis for the simulation.

The results of this study are shown in Figure 6 for the case of a stationary line of trucks with a spacing of 0.5 m. The figure illustrates that the mean value is fairly independent of the length of the n trucks used to construct the file. In contrast, the scatter of the values decreases with the length of the line. This scatter becomes nearly independent of the number of trucks for line lengths greater than 100 m. Therefore, the characteristic value for load model 2 is assumed independent of the number of trucks for lengths greater than 100 m. Increases in lane loadings for values less than 100 m are covered as the super-

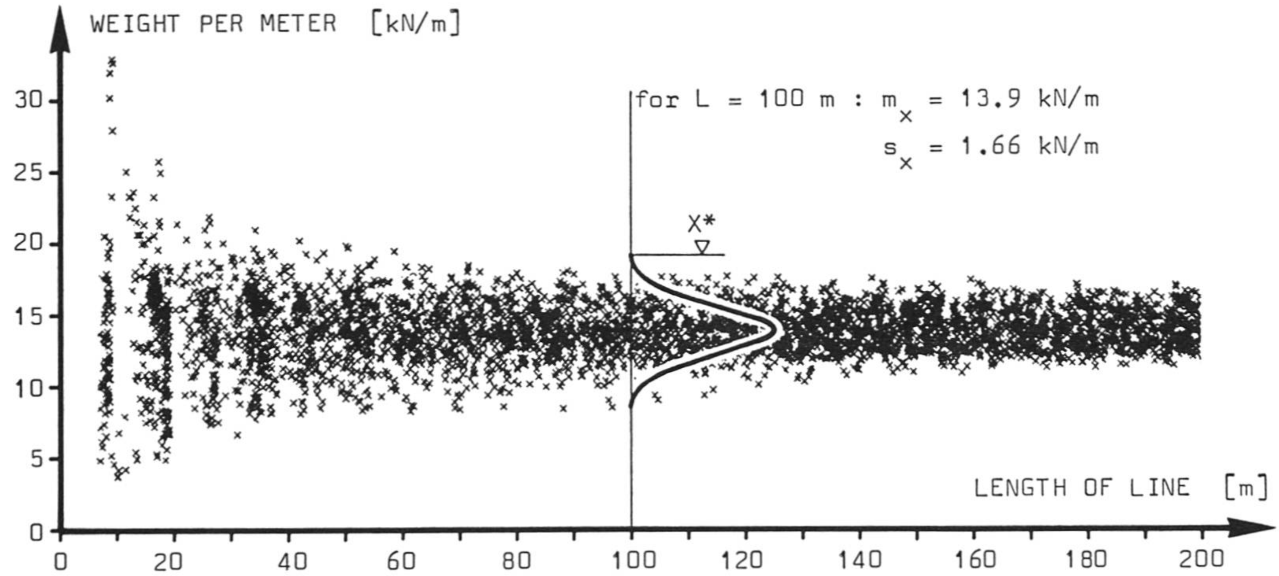



Fig. 6 - Variation of the weight per meter of truck lane loads with 0.5 m between vehicles as a function of the length of the line of n trucks used to construct the lane load.

position of load models 1 and 2 prevails in this range. The statistical analysis is shown in Table 3 for both stationary and moving lane loads.

It should be noted that for this load model the assumption that the weight distribution is normal is valid, in contrast to the load distribution of model 1.

Characteristic values were calculated using equation (5) and give the following results :

- for the stationary lane load : X* = 19.2 kN/m,
- for the moving lane load : X* = 17.7 kN/m.

If the dynamic coefficient $\phi_2$ (varying between 1.1 and 1.4, as described in Chapter 6) is taken into account, we obtain a value of $\phi_2 \cdot X^*$ between 19.5 and 24.8 kN/m. These values are larger than the value of 19.2 kN/m calculated for the stationary lane load without dynamic coefficient. This confirms the assumption that load case 2 should be considered as a moving lane load.

Table 3 - Statistical analysis of lane loads consisting of lengths of n trucks longer than 100 m.

| | | STATIONARY LANE LOAD | MOVING LANE LOAD |
|---|---|---|---|
| Spacing between trucks | e | 0.5 m | 2.5 m |
| Mean | $m_x$ | 13.9 kN/m | 12.4 kN/m |
| Standard deviation | $s_x$ | 1.66 kN/m | 1.65 kN/m |
| Maximum observed value | $X_{max}$ | 17.5 kN/m | 15.9 kN/m |
| Characteristic value | X* | 19.2 kN/m | 17.7 kN/m |
| | | 7.7 $kN/m^2$ | 7.1 $kN/m^2$ |
| Design value | $X_d$ | — | 7.5 $kN/m^2$ |

The characteristic value X* determined in this way corresponds to an uniformly distributed load of 7.1 kN/$m^2$ over a width of 2.5 m (corresponding to a standard overall truck width). Finally, equation (3) gives a design value $X_d$ of **7.5 kN/$m^2$** (Table 2).

### 8.1.3 Load Model 3

Design values for load model 3 were calculated using a simplified probabilistic method [15]. The details of the method are not presented here; only the important steps are summarized.

1st Step : The mean value for a stationary lane load consisting of a mixture of trucks and cars is established using the following values :

- a mean truck occurrence in different traffic lanes according to Table 1 for 2 and 3 lanes; for 4 lanes, the fourth lane is considered to be free of trucks.
- a mean truck length of 11.9 meters [6],
- a mean car length of 4.5 meters [9],
- a constant vehicle spacing of 0.5 meter,
- the measured weight per meter of truck traffic between Basel and Zürich [6][9]

In this manner, mean lane loads of 6.7, 6.33 and 5.5 kN/m, for 2, 3 and 4 lanes, respectively, were obtained.

2nd Step : To determine the characteristic value for lane loads, it is necessary to determine a lane load corresponding to a level other than the mean. This was obtained with the 95 % fractile for combined truck and car loads using the binomial law. The percentage of trucks is defined such that it will be exceeded less than 5 % of the time. In addition, the 95 % fractile for the weight of trucks between Basel and Zürich [6] and for cars [9] is used.

Using these values, stationary lane loads can be calculated as a function of their length. For a lane load of 100 m, this value is 11.4, 10.0 and 8.53 kN/m for 2, 3 and 4 lanes, respectively.

3rd Step : With the mean and the 95 % fractile values defined, it is now possible to evaluate the characteristic values of the lane loads using the assumption that their distribution is normal. These characteristic values were calculated to be 15.9, 13.6 and 11.4 kN/m for 2, 3 and 4 lanes, respectively, and assuming a stationary lane load of 100 m in length.

4th Step : The characteristic value X* of load model 3 is established in accordance with the number of lanes by calculating a value of uniform load which, when placed in combination with load model 2, results in the same characteristic value as step 3. In Figure 7, the variation of X* (expressed in kN/$m^2$ for a standard lane width of 3.0 m) as a function of the length of a series of n stationary vehicles is shown, for 2, 3 and 4 lanes. The characteristic values of the load were chosen so as to be independant of their length, as was the case with load model 2. The values are those corresponding to a 100 m line length. This is justified, as in the previous case, by the simultaneous presence of a concentrated load, determined in load model 1. A comparison of the results with deterministic situations of 2 to 4 lane loads confirms this assumption. Finally, a logarithmic regression of the curves obtained using the binomial law was performed (Figure 7). This yields characteristic values X*, for load model 3, of 4.8, 4.11 and 3.29 kN/$m^2$ corresponding to 2, 3 and 4 lanes, respectively.

5th Step : The concept of a specific number of traffic lane loads is changed to that of a load distributed over the entire roadway, with limit widths of 9 and 13 m corresponding to 2 and 3 lanes respectively. For 4 lane bridges, the roadway is considered to be greater than 13 m wide.

Using these boundary conditions and equation (3), design values $X_d$ for load model 3 were fixed at **5.0, 4.5 and 3.5 kN/$m^2$**, for roadway widths of $<$ 9, $<$ 13 and greater than 13 m, respectively (Table 2).

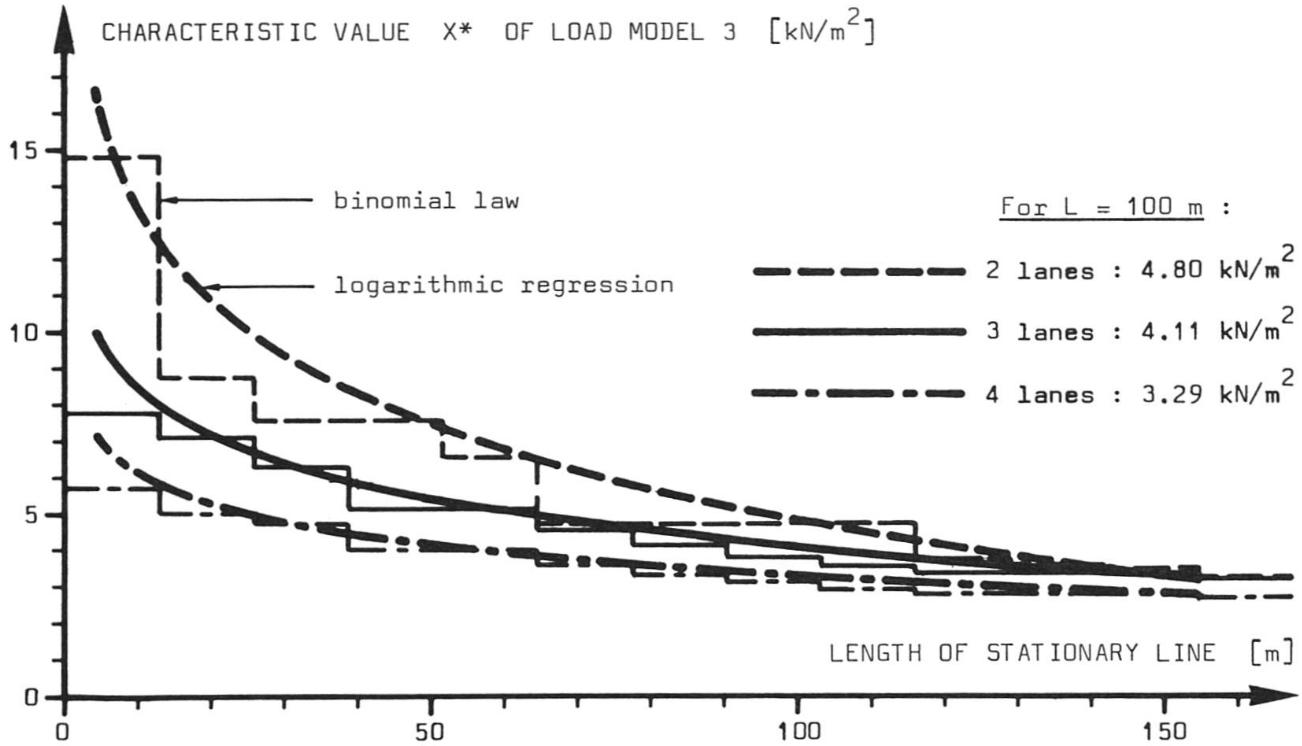



Fig. 7 - Variation of characteristic value X* for load model 3 as a function of the length of the line of n vehicles used to construct the lane load.

### 8.2 Accompanying loads

The accompanying load is composed only of load model 3 (Chapter 3). Design values are calculated using the mean load of a mixture of stationary trucks and cars. This situation is frequently encountered in urban areas and is found to be more severe than moving traffic.

Using the mean percentage of trucks [8], the mean length and mean weight per meter of the trucks [6] and of the cars [9] enabled the weight per meter to be estimated at 5.34 kN/m. If this value is transformed into a load applied over one lane width of 3 m, we obtain 1.8 kN/m$^2$. This yields a value $Q_a$ of **2.0 kN/m$^2$** which is independent of the width of the roadway (Table 2).

### 8.3 Serviceability loads

The check of serviceability criteria insures both the good functioning of the bridge as well as the comfort of the user. Load cases should thus represent mean values encountered during normal usage. It is for this purpose that load models 1 and 3 are employed (Figure 3).

Load model 3 is calculated in the same manner as when it is used for an accompanying load. It represents a mixture of stationary trucks and cars, and the design value of **2.0 kN/m$^2$** corresponds to a mean value (Table 2).

The design value of load model 1 was established to correspond to the weight of three axle trucks since these trucks show an increasing frequency on Swiss highways. These trucks have a maximum legal weight of 250 kN. Gross weights of up to 20 % more than the legal limit are frequently observed. As a result, a design value of 300 kN for the total weight is used in load model 3. This weight corresponds to an axle load of 100 kN or **50 kN per wheel** (Table 2).

## 9. CONCLUSIONS

This paper presented the design principles and the numerical values upon which the proposed revisions to the Swiss loading code SIA 160 [2] are based. To further define the concepts presented in this article, the following remarks may be of interest :

1. An increase in maximum gross truck weight from 280 kN to 380 kN would harmonize load limits between Switzerland and its neighboring countries. Such a change in legal limits would occur without changing the maximum legal axle load. Therefore, it is possible to predict that foreseeable evolutions in Swiss highway traffic will have little effect on the values presented here.
2. Comparisons with the loading code currently in use [1] have been undertaken. These comparisons showed that for various structural bridge systems and for individual structural elements, the proposed changes provide more uniform safety levels.
3. Since the revisions described in this paper were first proposed, some modifications and simplifications have been suggested, the most important of which are :
   - The predominant and accompanying loads shall be defined not as design loads but as the product of a nominal value $Q_n$ and a load factor $\gamma$ and $\psi$ respectively.
   - For load model 1, only two axles with a spacing of 1.3 m shall be retained, and load model 2 shall be applied over the entire lane length not leaving an open space in the area occupied by load model 1, as shown in Figure 8.

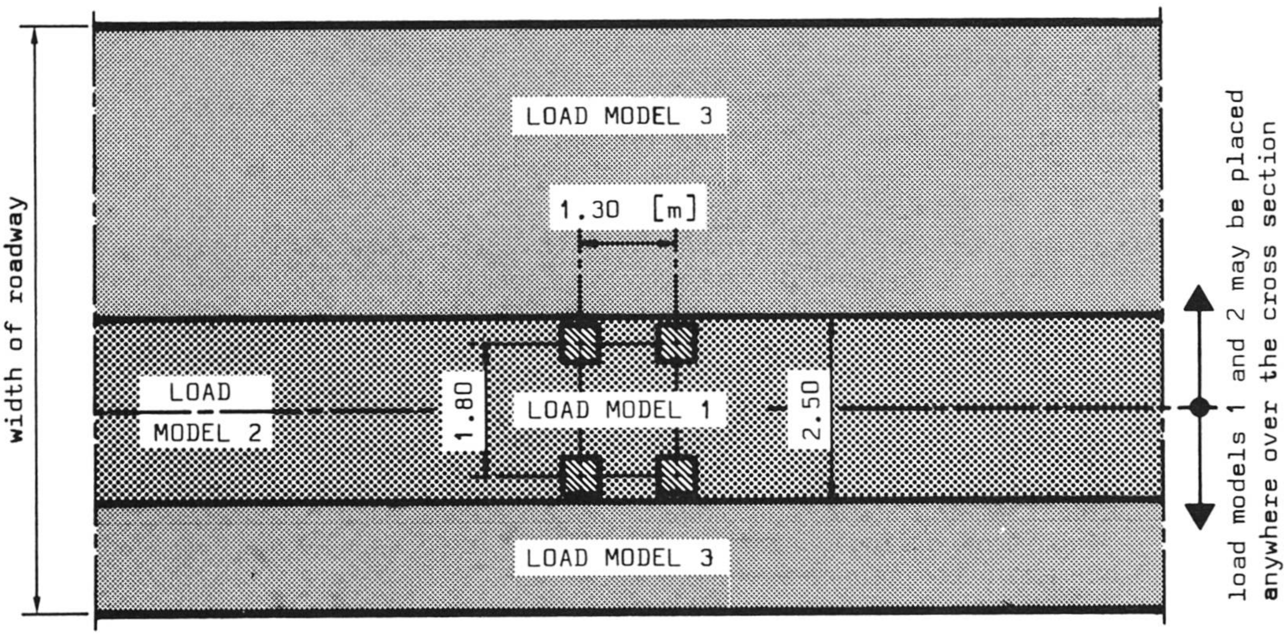
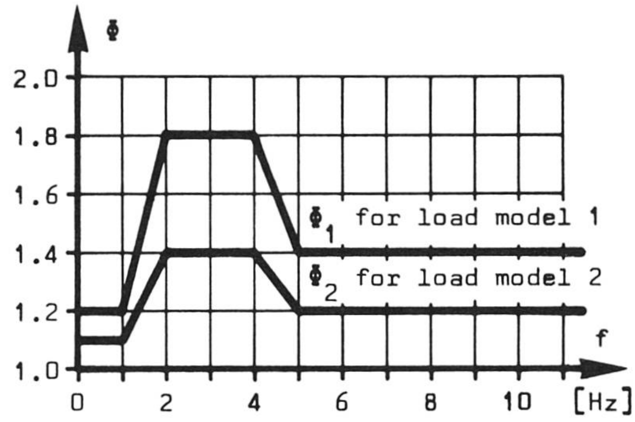



Fig. 8 - Loading case to consider for the ultimate strength criteria check when highway traffic is considered as the predominant load.

   - The dynamic coefficients for longitudinal and transverse elements shall be defined separately. For transverse elements the maximum values $\phi_1$ and $\phi_2$ shall be considered, whereas Figure 9 will be applied for longitudinal elements.

Fig. 9 - Dynamic coefficients to be applied for longitudinal elements.




The design values will be reevaluated to account for these revisions. The Swiss loading code is expected to reflect this design concept in the next edition to be published sometime in spring 1987.

Acknowledgments

This article is a modified version of the original french text "Modélisation du trafic routier suisse" published November 7, 1985 in the journal "Ingénieurs et architectes suisses", vol. 111, no 23, in Lausanne (Switzerland).

The authors would like to thank the staff of the SIA, of EMPA and ICOM for their assistance during this work, both technical and financial and for assistance during the preparation and the translation of the text.

References

[1] NORME SIA 160. Norme concernant les charges, la mise en service et la surveillance des constructions. Zurich, SIA, 1970.

[2] PROJET DE NORME SIA 160. Actions sur les structures. Zurich, SIA, 1985.

[3] HIRT M. A. Konzept des Normentwurfs SIA 160. Schweizer Ingenieur und Architekt, Zürich, vol. 103, no 11, 1985, pp. 206-209.

[4] INSTRUCTION SIA 260. Sécurité et comportement en service des structures porteuses. Zurich, SIA, 1980.

[5] CANTIENI R. Statistische Untersuchung des Schwerverkehrs in der Schweiz. Dübendorf, EMPA F + E Nr. 10502, 1978.

[6] JACQUEMOUD J., BEZ R. Dépouillement statistique du trafic routier suisse. Lausanne, EPFL, ICOM, rapport interne, 1980.

[7] JACQUEMOUD J. Analyse du comportement à la fatigue des ponts-routes. Lausanne, EPFL, thèse no 389, 1980.

[8] OFFICE FEDERAL DES ROUTES: Statistische Erhebung von Achslasten des Schwerverkehrs. Trafics Etoy, Mumpf, Gossau et Cresciano. Berne, OFR, 1975 + 1976.

[9] JACQUEMOUD J. Untersuchung zur Reduzierung der Verkehrslasten für das Bauvorhaben Rodenkirchen-Rheinbrücke Aachen, Rhein.-Westf. Technische Hochschule, Lehrstuhl für Stahlbau, 1982.

[10] CANTIENI R. Dynamic Load Tests on Highway Bridges in Switzerland - 60 Years Experience of EMPA. Dübendorf, EMPA Report No. 211, 1983.

[11] CANTIENI R. Dynamische Belastungsversuche an der Bergspurbrücke Deibüel. Dübendorf, EMPA (publication in preparation).

[12] BILLING J.R. Estimation of the Natural Frequencies of Continuous Multi-Span Bridges. Ontario Ministry of Transportation and Communications, Report RR 219, 1979.

[13] NORME SNV 640520a. Planéité, contrôle de la géométrie. Zurich, Association suisse de normalisation, 1977.

[14] NORME SNV 640521a. Planéité, exigences. Zurich, Association suisse de normalisation, 1977.

[15] BEZ R. GT 3/SIA 160 - Traffic Loads. Lausanne, EPFL, ICOM, internal report, 1985.