A Study on the development of vehicular loding for design of highway bridges in Saudi Arabia.

Saleem Parvez

Civil Engineering

May 1997

Abstract

The current MOC 600 kN truck loading for design of bridges in Saudi Arabia was adopted arbitrarily following the configuration of AASHTO HS20 truck loading, ensuing a transition from earlier lighter truck load models. However, it was not developed on a rational basis from data analysis of the local traffic.

The primary objective of this work is to develop a load model for design of short span bridges and to examine the adequacy of the current MOC 600 kN truck loading under the context of the prevailing truck loadings. A rigorous load survey of the heavy trucks is carried out to obtain informative data on truck configurations and axle loads. Based on the survey data a proposed bridge loading formula is adopted using the concept of 'equivalent base length', and from this formula a 650kN Model truck load is developed for design of short span bridges. A modified uniformly distributed lane load is also presented as a substitute for the design load. The adequacy of the current MOC 600 kN model is compared with the proposed 650 kN Truck Model by rigorous analysis of slab and girder-slab type bridge decks, simple and two span continuous, having different geometric configurations. An overweight truck of 790 kN found in the truck survey is also included in the comparative study to give an insight into the extent of the possible over stressing of members and draw attention to the need of development of appropriate load factors for Load Resistance Factor Design (LRFD).

A Study on the Development of Vehicular Loading for Design of Highway Bridges in Saudi Arabia

by

Saleem Parvez

A Thesis Presented to the

FACULTY OF THE COLLEGE OF GRADUATE STUDIES

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DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

CIVIL ENGINEERING

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A STUDY ON THE DEVELOPMENT OF VEHICULAR LOADING FOR DESIGN OF HIGHWAY BRIDGES IN SAUDI ARABIA

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Date: 2/6/97

بسم الله الرحمن الرحيم

In the name of *Allah*, the most beneficent, the most merciful.

Dedication

This work is dedicated to my
beloved mother
and to the
everlasting memories of my father.

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Praise and thanks be to Almighty Allah (SWT) for His limitless help and bestowing me with the health. patience and determination to complete this work: and peace and prayers be upon his Prophet Muhammad (SAW).

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

FULL NAME OF STUDENT : **Saleem Parvez**

TITLE OF STUDY : **A Study on the Development of Vehicular Loading for Design of Highway Bridges in Saudi Arabia.**

MAJOR FIELD : **Civil Engineering (Structures)**

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MASTER OF SCIENCE DEGREE

KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS

Dhahran, Saudi Arabia

May 1997.

خلاصة الرسالة

اسم الطالب الكامل : سليم بارفيز

عنـوان الرسالــة : دراسة في تطوير حمل المركبات عند تصميم جسور الطرق في المملكة العربية السعودية

التخصـــص : الهندسة المدنية

تاريخ الشهـــادة : مايو ١٩٩٧م

إن لائحة وزارة المواصلات الخاصة بأحمال الشاحنات (MOC 600 KN) والمعمول بها حالياً لتصميم الجسور في المملكة العربية السعودية مستمده من قانون الهيئة الأمريكية للنقل (AASHTO HS 2O) وهي بذلك لاتأخذ في الحسبان الظروف المحلية.

إن الهدف الرئيسي من هذه الدراسة هو تطوير نموذج أحمال لتصميم الجسور القصيرة واختبار مدى ملائمة القانون الحالي للأحمال الحالية . فقد تم جمع معلومات مستفيضة عن أحجام الشاحنات الثقيلة وأحمالها . وبناءً على هذه المعلومات طورت معادلة مبنية على مبدأ « الطول القاعدي المتكافيء » ومن هذه المعادلة أُستنبط نموذج أحمال ذو الـ ٦٥٠ كيلو نيوتن الحالي لتصميم الجسور القصيرة وقد أجريت مقارنة بين نموذج الـ ٦٠٠ كيلو نيوتن ونموذج الـ ٦٥٠ كيلو نيوتن المقترح من خلال دراسة تحليلية مستفيضة على الجسور ذوات الباع والباعين . وقد شملت تلك المقارنة الحمل ٧٩٠ كيلو نيوتن لاستكشاف امكانية حدوث اجهادات عالية في أجزاء الجسور والارشاد إلى تلافيها عن طريق تطوير عوامل الأمان أثناء عملية التصميم.

درجة الماجستير في العلوم

جامعة الملك فهد للبترول والمعادن

الظهران ، المملكة العربية السعودية

مايو ١٩٩٧

CHAPTER 1

1. INTRODUCTION

1.1 BACKGROUND

Bridge design is an important field of structural design. A bridge is normally designed for the following loads and forces when they exist :- dead load, live load, impact or dynamic effect of the live load, wind loads, and other forces such as longitudinal forces, centrifugal forces, thermal forces, earth pressure etc (1).

The most significant load considered in the design of a bridge is the live load from the vehicles. It is the weight of the vehicles on the bridge accompanied by other loads such as impact or dynamic effect of a moving truck, braking force, centrifugal force, etc. Live load is a time-varying load with a short duration depending on the traffic volume. The existence of a variety of vehicles with different lengths, widths, weights and different number of axles and their spacing, makes the traffic load a

complex load pattern. A reliable model load has to be derived from the complex load pattern for use as "design load" in bridges. This model load, a hypothetical prescription of actual load, is assumed to yield design that would be safe and yet not excessively estimated to yield design that would lead to an uneconomical design.

Most of the countries like England, France, America and Germany have developed their own hypothetical vehicular load for design of bridges. The models specify the axle loads, spacing and the gross weight for design. The first load model was developed in United States of America, put forth as the AASHO standard (American Association of State Highway Officials) for design of bridges. This standard has been used in many countries, such as Canada and Saudi Arabia.

In the Province of Ontario, Canada, a rigorous attempt was made in the late seventies to develop a bridge design code, specifying the vehicular load that is a truer representative of the actual load (2). The modeling of the truck load followed an extensive survey of the existing vehicles and their characteristics.

A large number of highways and bridges were designed and built during the early phase of the rapid development of the infrastructure in Saudi Arabia. Prior to 1973 bridges were designed using the AASHO H20 truck model (1). This design load seemed to underestimate the actual loads, which resulted in upgrading the design load to AASHTO HS20 + 10% (4). The AASHTO HS20 truck and lane loads are shown in Figs.1.1 and 1.2. This load was replaced by MOC 400 kN design truck as it proved to be inadequate to represent the heavy truck traffic. This design load remained in force till 1981 (4).

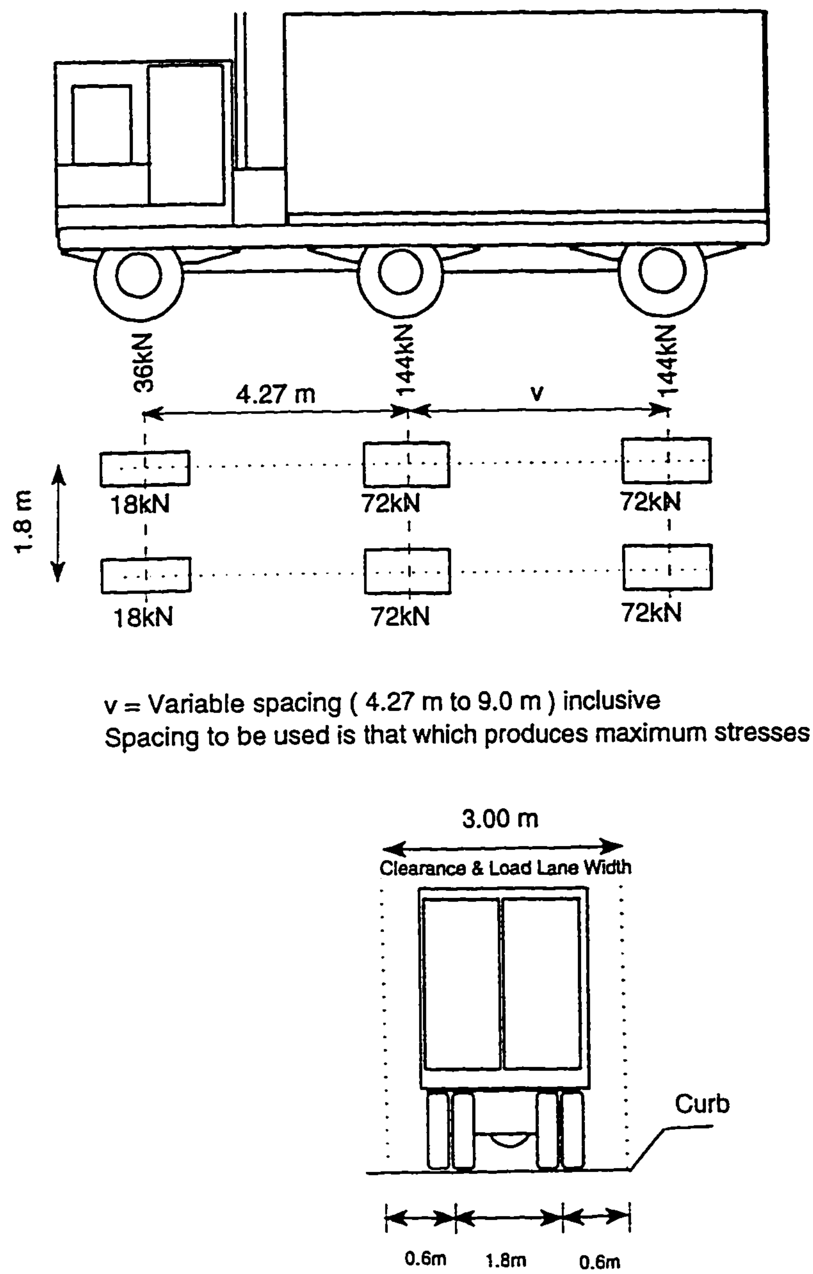
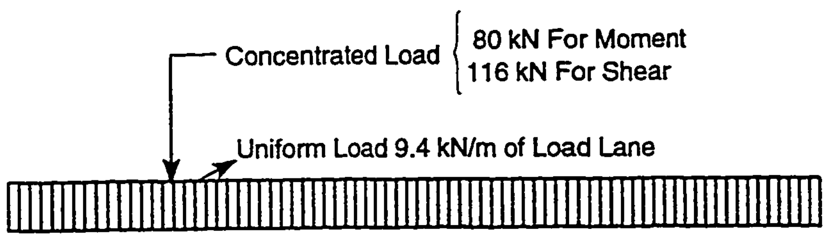


Fig. 1.1 AASHTO HS20 (MS 18) Truck Loads



HS20 -44 (MS18) Loading

Fig. 1.2 AASHTO Lane Loads

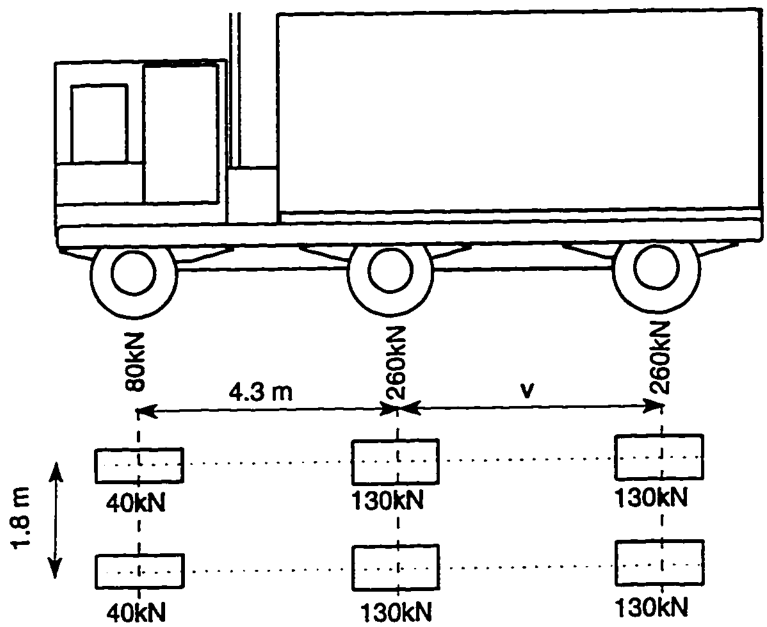
Periodic checks revealed that several slab type and slab-on- girder type bridge decks, suffered damages from extensive cracking due to the high intensity of loading. The design loads were further increased arbitrarily in 1981 to the current level of MOC 600 kN Truck and Lane load model (4) as shown in Figs.1.3 and 1.4.

By the end of 1995, the total length of main roads in the Kingdom reached to 36,281 km and the agricultural roads to 95,811 km, bringing the total road length to 132,092 km (5). Additional 50,000 km of roads and a number of bridges are to be built over the next 15 years at an estimated cost of SR. 44 billion (5). It is obvious that the current design load was not developed based on a mathematical modeling but arbitrarily increased to account for the heavy truck loads. Whether the adopted load is safer or not needs to be checked and this has led to the funding of a research project AR-15-64 sponsored by King Abdul Aziz City for Science and Technology (44) and currently under progress in the Department of Civil Engineering at KFUPM.

1.2 TASKS

The general objectives of this study is to develop a vehicular live load model for design of bridges based on the data collected through traffic survey in Saudi Arabia. The specific objectives of this research are:

1. To collect large amount of traffic data for heavy vehicles from the existing sources which include MOC's data bank and the way-side weighing stations to



v = Variable spacing (4.3 m to 9.0 m) inclusive
Spacing to be used is that which produces maximum stresses

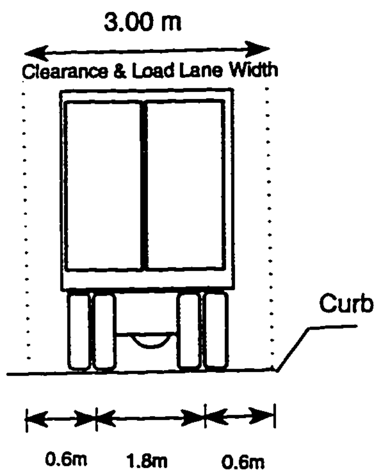
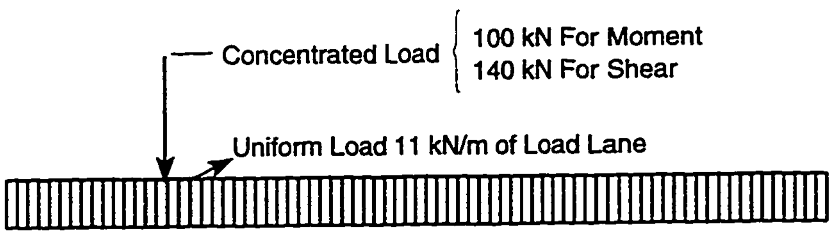


Fig. 1.3 MOC 600 kN Truck Loads



Lane Loading
(Lane Load Width = 3.0 m)

Fig. 1.4 MOC Lane Loads

provide information on axle loads and axle spacing. These data will be collected from a number of strategic corridors in all the provinces of the Kingdom where flow of heavy trucks are known to be significant, providing a broad spectrum and coverage of traffic loads across this vast land.

2. To develop the characteristic dimensions of a design load, using the concept of 'equivalent base length'.
3. To compare the adequacy of the proposed vehicular loading and the current MOC 600 kN truck load by comparing the results of maximum design forces with those obtained from heaviest truck loads selected from the load survey having statistically meaningful frequencies which cannot be ignored for a safe design. Comparison will be made on slab type and slab on girder type bridge decks of different span lengths, both simple and continuous.
4. To propose a new recommended design load if the current MOC truck loading appears to be either deficient to reflect adequate safety for short span bridges or overly conservative.

CHAPTER 2

2. LITERATURE REVIEW

2.1 GENERAL

Highway bridges are designed with a set of prescribed loads, usually in the form of truck loadings and distributed lane loads, to cater to the worst possible effects of vehicular loadings on bridges. The prescribed design loads are hypothetical representation of actual loads which is highly irregular and complex with a variety of variables, and are intended to produce safe design. Codes and specifications for various countries, such as USA (3) and U.K. (6) specify these loadings for design. Different countries have adopted different loadings revealing a divergent load pattern (7). However, not only little published work is available regarding the technical background of these model loads, but also the available information is too sketchy to build a sound theoretical basis.

Generally, two types of loads are prescribed for bridge design: (a) truck load and (b) lane load consisting mainly of distributed load of uniform intensity. The former caters to the worst possible truck loading and the latter represents an arbitrary length of traffic loadings consisting of different vehicle types. Whereas the design of short span bridges is normally controlled by the truck load, its use may not influence the design of main girders in long span bridges where a lane load of some intensity and of arbitrary length may prove to be more critical. This is because a short length may be filled with heaviest trucks but a long length will not. Furthermore, as the length of traffic increases, the maximum expected load per unit length decreases, thus the intensity of uniformly distributed lane loading will decrease with longer spans.

In the absence of a generally agreed-upon boundaries between short, medium and long span bridges, the criteria proposed in Ref. 8 can be used to identify the limits. Bridges with spans up to 20 m can be defined as being short span, those with spans between 20 and 125 m as medium span bridges and bridges spanning more than125 m can be called as long span bridges.

2.2 LIVE LOAD FOR LONG SPAN BRIDGES

Although this does not explicitly belong to the current study, a brief coverage is included here to highlight the distinction between the loadings applicable to the design of long and short span bridges.

The study of live loads for design of long span bridges has drawn considerable attention in view of the fact that such loading, usually uniformly distributed, must be established with a greater degree of reliability and appropriateness. References 9 to 14 can be cited as representative samples of work on the traffic loads for long span bridges. Findings of these works indicate that a uniformly distributed loading is the best representation of loading for design of main girder or longitudinal members in long span bridges. The loaded length can be of any length, continuous or discontinuous, which would produce the worst effect. Furthermore, as the length of the load increases, a reduction in the intensity is applicable. The credible load occurring on a short span bridge is the heaviest truck or trucks that can travel on the bridge deck, but this is not the case for a long span bridge because this structure will not be entirely covered by the heaviest possible vehicles. This claim was tested in Vancouver, British Columbia, Canada (14).

2.3 LIVE LOAD FOR SHORT SPAN BRIDGES

Research work devoted to the development of appropriate truck loads for short span bridges is markedly scanty compared to long span bridges. This observation can be well explained by the fact that the truck load which controls the design of short span bridges must be modeled after the existing or anticipated truck loads, but for the

design of long span bridges identification of a single truck is not a critical requirement in general.

The live load constitutes of many parameters including truck weight, axle loads, axle configuration, span length, position of the vehicle on the bridge (transverse and longitudinal), number of vehicles on the bridge (multiple presence) and projected future growth (15). This creates difficulty in the development of design truck loads.

The structural design of roads and bridges is based upon the traffic which the structure is expected to carry during its life. An appropriate load model should be developed based on the actual traffic loading conditions and the projected loading. Robinson (16) stressed the need to consider local vehicle characteristics in selecting geometric design standards and Rolt (17) focuses on axle loads for commercial vehicles in developing countries. Inaccurate estimates may lead to premature failure, excessive maintenance, or over design of the structure (18).

A design load model essentially should meet the following requirements: (1) it should be realistic in prediction of worst load effects on structures, (2) it should be simple to use, and (3) it should produce safe results for different span lengths and geometric configuration of bridges without being overly conservative.

2.3.1 AASHTO LOAD MODEL

The highway bridge loadings prescribed by AASHTO (3) which are used widely in USA and in some other countries consist of truck loads and lane loads (Figs. 1.1 and 1.2) and were developed in 1944. No change has been made to these, although it is widely recognized that these loadings should now be reviewed in the context of actual traffic pattern (19-20), as vehicles are not full of say AASHTO HS20 trucks but of vehicles with a myriad of shapes, sizes and weights. Some states, for example Louisiana and California have proposed revised loads for design taking into account current load patterns.

A committee report on loads and forces (19) confirmed a decade ago the need of the development of appropriate loading taking into account significant population of actual trucks through a survey. It has also been pointed out that AASHTO design loads are not in close correspondence with the actual traffic and may underestimate the worst effects from operating trucks moving on the roads (21).

2.3.2 ONTARIO LOAD MODEL

The most significant work in the development of appropriate truck loads which has received global attention was conducted by the Ministry of Transportation and Communication, Ontario, Canada to produce the Ontario Highway Bridge Design Code (OHBDC) (22). The Ontario load model for bridge with spans under 125 m

(23) is based on extensive surveys of highway traffic and modeling of the loads (25-28). A major study was performed in 1975 and covered about 10,000 heavy vehicles (28).

The modeling work began with the perception that the actual loading of the different truck configurations must be replaced by a mathematically treatable continuous function (23). Survey of truck loads included heavily loaded trucks and a data base was formed (25). Davenport and Harman (26) studied the structural effects (shears, moments, deflections, axial forces, etc.) caused by highway traffic at the University of Western Ontario, supported by the Ministry of Communication, Ontario. As the traffic loading is a random process, the largest live load effects that occur can be predicted only in a statistical manner. Also, from the results of a vehicle weight survey, Csagoly and Knobel (27) confirmed that the distribution of heavy vehicles is indeed nearly normal.

The OHBDC truck loading was modeled by using the concept of 'equivalent base length' which is defined as 'an imaginary finite length on which the total weight of a given sequential set of concentrated loads is uniformly distributed such that this uniformly distributed load would cause force effects in a supporting structure not deviating unreasonably from those caused by the sequence itself' (22, 24, 29). The equivalent base length (B_m) concept was first outlined with an axiomatic approach to justify its application and then more formal proof of the validity of the concept was presented (29). Another work which was primarily aimed to appraise the use of

Ontario's concept of equivalent base length in modeling truck loads was conducted by O'Connor (30) on a project funded by Australian Road Research Board.

2.3.3 RELIABILITY BASED MODELING

A major development for structural codes in recent years has been the introduction of structural reliability concepts to assist code writers to formulate safety checking models and derive appropriate safety factors. These reliability models recognize the uncertainties in modeling extreme load events and in analytical methods, and the uncertainties associated with the variability in material and system strength capacity. The goal is to establish a reliability or safety index which incorporates the actual safety margins and the uncertainties or randomness in the strength, load and analysis procedures. Recent code changes, such as the OHBDC (22), demonstrated the formal reliability methods that can be used to calibrate safety factors based on uncertainty levels for all components in the design and evaluation process.

Nowak (31, 32, 33) provided statistical models which were useful in the development of load and resistance factors for 1991 edition of OHBDC (22). Nowak's load models were developed on the basis of the 1975 Ontario surveys which covered about 10,000 selected trucks. The maximum 50-year live load was determined by exponential extrapolation of the extreme values obtained in the survey.

For each truck, bending moments and shear forces were calculated for a wide range of simple spans. The resulting cumulative distribution functions of moments and shears were plotted on normal probability scale. Moments and shears were then determined by extrapolation of the distributions for various time periods. On the basis of this analysis, it was recommended that the tandem axle load in the OHBDC (34) be increased from 140 kN to 160 kN for spans less than 40 m.

2.3.4 AASHTO's Load Resistance Factor Design

The Load Resistance Factor Design (LRFD) specifications of AASHTO (35) introduces a new regulation of live loads. The live load model, consisting of either a truck or a tandem coincident with a uniformly distributed lane load, was developed as a notional representation of shear and moment produced by a group of vehicles routinely permitted on highways by various states under the 'grandfather' exclusions to weight limitation. These results were based on a study conducted by the Transportation Research Board (TRB) (36) and the load model is called notional because it is not intended to represent any particular truck. The effects of an axle sequence and the lane load are superimposed in order to obtain extreme values. This is a significant departure from the standard AASHTO approach for working stress or load factor design where either the truck or the lane load with an additional concentrated load is used for extreme cases. Ref. 37 provides information on the

largest and smallest truck configuration observed in truck load survey and proposes new live load model for design of bridges.

2.4 MODEL LOAD IN SAUDI ARABIA

Most of the earlier bridges were designed with a prescribed design load of AASHTO HS20-44 + 10% (4). Soon this was replaced by the Ministry of Communications (MOC), Riyadh to 400 kN vehicle, as HS20 loading plus 10% soon proved to be far inadequate to represent the heavy truck loadings. The 400 kN vehicle was geometrically similar to that of HS20. Even the upgraded MOC 400 kN vehicle failed to serve as an adequate model for design. Uncontrolled, unabated movement of heavy vehicles over the bridges produced distressing level of cracking of the deck slabs and girders and, in many cases, produced local failures of the deck slab in the form of potholes (38, 39). Ref. 40 provides a picture of the truck types and the axle loads prevailing at that time.

In recognition of the need to upgrade further the design load and to enforce truck weight limits, MOC sharply increased the loading in 1985 to the currently used MOC 600 kN vehicle and lane loads as shown in Figs. 1.3 and 1.4. It also introduced legal load limits for various types of trucks to eliminate or minimize damages to bridges and roadways. This truck loading is also similar to AASHTO HS20 (MS18) truck configuration with the exception of heavier axle loads.

Limited field surveys conducted in mid-80's indicated that large proportions (almost 90%) of all the trucks exceeded the legal load limits (40). The national project (38) sponsored by the MOC and funded by the King Abdulaziz City for Science and Technology (KACST) documented damages suffered by several bridges, the causes of which were attributed to heavy truck loadings.

The existence of a considerable number of heavy trucks was also confirmed by a truck load survey conducted in a project jointly sponsored by King Abdulaziz City for Science and Technology and MOC (41). The results of this study revealed that the heavy trucks constituted about 25% of the total traffic on major highways, about 25% of individual truck axles had loads in excess of 8 metric tons and about 20% of individual axles were in violation of load limits set by MOC.

In 1985 MOC introduced wayside weighing stations to control the overweight problem and penalties were imposed in 1986. The effect of this enforcement of legal weights sharply reduced the number of accidents caused by trucks and also the amount of overweight above the legal limits was considerably reduced (42). The effect of truck weight enforcement was recently reviewed by Al-Abdul Wahhab (43) who asserts that more rigorous enforcement is necessary to curb violation.

A survey of the limited literature available on the development of appropriate truck loads reveals very little information on the published work which can be cited and used as references. This is presumable due to the fact that for such a complex task engineering prudence, conservatism and arbitrariness took precedence over rationality.

The conclusion made out of the above discussion is that the current MOC 600 kN truck loading for design of highway bridges in Saudi Arabia was adopted after the AASHTO HS20 (MS18) truck as the best possible response at a time when highway structures were facing a devastating consequence of heavy truck loads. However, the current three-axle design vehicle does not represent the truck types that are widely prevalent. Further, the truck configurations seen in Saudi Arabia are not similar to those in the USA and their design load modelled after AASHTO may not be relevant.

This study was therefore conducted to verify the adequacy of the current MOC loading in the light of extensive data collection of truck weights and to propose an alternative loading which would be more appropriate for the design of short span highway bridges.

CHAPTER 3

3. METHODOLOGY FOR THE DEVELOPMENT OF LOAD MODEL

3.1 APPROACH TO THE PROBLEM

The random loadings of vehicles consisting of different weights and axle spacings cannot be uniquely represented by a single truck load to produce identical effects on a bridge structure. In view of the fact that the procedure followed by the Ministry of Transportation and Communication, Ontario, Canada (29) in developing the highway bridge loading is highly meritorious, it is proposed that this approach be pursued for the development of design loadings for the Kingdom in the absence of any other well documented methodology. The basic approach behind Ontario's approach is the concept of Equivalent Base Length (EBL) which allows, within an acceptable range of error, a conversion of a group of point loads (e.g. a typical truck) into an equivalent uniform load length 'B_m .' Since maximum bending moment is

often the critical force for design. B_m can be formulated to produce near identical moment in a simple and continuous beam within an acceptable degree of accuracy.

3.2 EQUIVALENT BASE LENGTH TECHNIQUE

Historically, the axiom of EBL was postulated by assuming the possibility of distributing the gross weight of the vehicle uniformly over a finite length such that the distributed load would cause force effects not deviating unreasonably from those caused by the vehicle itself. To achieve such equivalence, two conditions must be satisfied:

1. $W = w \cdot B_m$;

where W = total truck weight, w = equivalent uniformly distributed load and B_m = equivalent base length.

2. The absolute sum of moments of the concentrated forces and the absolute sum of moments of the uniformly distributed load about any point in space be equal in magnitude.

For a point (A) (Fig.3.1) located at a distance "y" from the center of gravity of the vehicle, the following moment equation may be obtained:

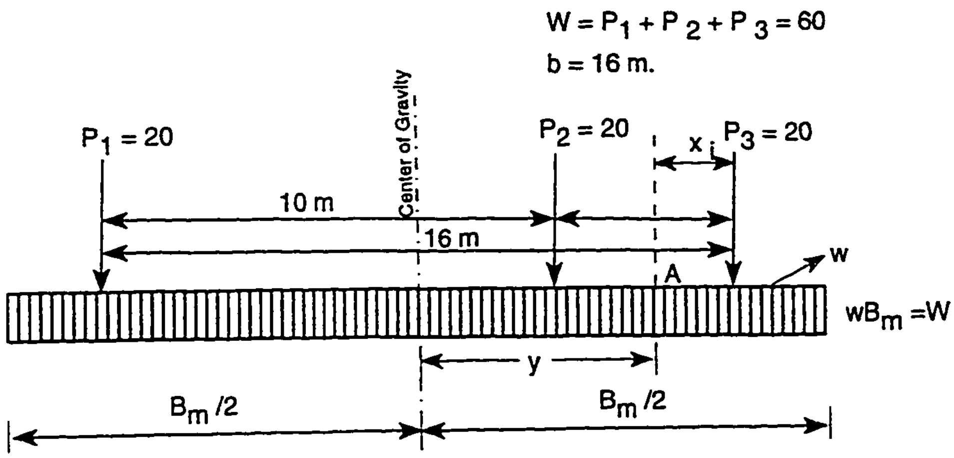


Fig. 3.1 Equivalent Base Length

$$\Sigma \mid P_i x_i \mid = \frac{w}{2}[(\frac{B_m}{2}+y)^2+(\frac{B_m}{2}-y)^2] \tag{3.1}$$

Hence:

$$B_m = \frac{2}{W}\{ \Sigma \mid P_i x_i \mid + \sqrt{(\Sigma \mid P_i x_i \mid^2 - y^2 w^2}\} \tag{3.2}$$

Generally, the point of interest is located at the centre of the gravity of the vehicle, for which the calculation of B_m becomes straightforward.

Substituting y = 0 in Equation 3.2

$$B_m = \frac{4}{W} \Sigma \mid P_i x_i \mid \tag{3.3}$$

For a general expression of B_m, the moment equivalency was established using the simply supported beam only.

As proposed in Ref. 29, B_m for a given set of concentrated loads (Fig.3.1) is calculated using the following formula derived with reference to simply supported beams:

$$B_m = \frac{4\Sigma \mid P_i x_i \mid}{W} - \frac{2}{L}\left(\frac{\Sigma P_i x_i}{W}\right)^2 \tag{3.4}$$

where:

L = span length;

x_i = distance of axle load P_i from axle load P_m, which is closest to the centre of gravity of the vehicle;

W = total truck load = $w \cdot B_m$;

It has been found that 2/L in the second term can be safely replaced by $\frac{2(N-1)}{bN}$ to make EBL independent of the bridge span length, where N = number of axles of the vehicle and b = base length of the vehicle (29).

The final equation is based on this substitution so that

$$B_m = \frac{4\Sigma\,|\,P_i x_i\,|}{W} - \frac{2(N-1)}{bN}\left(\frac{\Sigma P_i x_i}{W}\right)^2 \qquad (3.5)$$

3.3 LOAD MODEL POSTULATION

One of the major advantages of EBL is that it can be applied not only to the vehicle as a whole but also to any subconfiguration thereof (Appendix - A.1). Using a computer program the calculation of B_m for all possible sequential axle load configurations of truck loads can be easily performed. A plot of all data points for W and the corresponding B_m can be obtained, considering all survey results. Such a global plot of survey data would look something like the one shown in Fig.3.2 (24). This plot can then serve as the basis of developing an equation for B_m which would

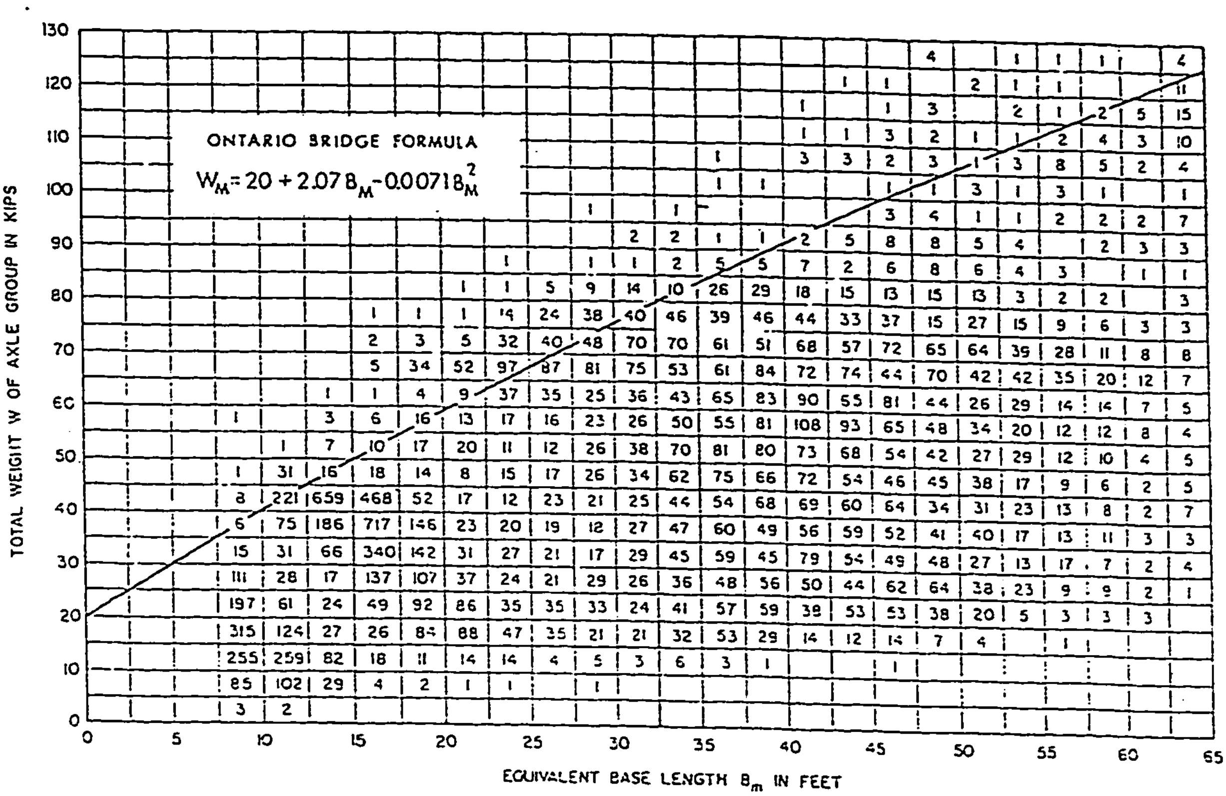


Fig. 3.2 Plot of W_m Vs. B_m

cover all load configurations (i.e.) actual B_m for a given truck load configuration will fall below the proposed B_m envelope.

Once the B_m equation is developed, the next step would be to develop a truck configuration by choosing axle loads and axle spacings in a manner which would closely fit into the B_m enevlope.

Limited load surveys conducted in the past (38, 41) have revealed the existence of a variety of heavy trucks in Saudi Arabia, ranging from a two-axle type to a longer, articulated six-axle vehicle. Concept of base length seems to be applicable if a large number of data on different truck types are taken into account.

CHAPTER 4

4. COLLECTION AND ANALYSIS OF VEHICLE DATA

4.1 GENERAL

Collection of a large volume of truck load data is an essential prerequisite to the development of the model. Clearly then, the data collection must be achieved in a broader scale covering all heavy truck corridors and passages throughout the Kingdom.

The data used in this study has been collected from two sources: (1) from the MOC's data bank and (2) additional load surveys at several chosen locations. The first source provided voluminous data as all data from weighing stations are stored in MOC's Riyadh headquarters. Currently, there are 28 weighing stations operating in the Kingdom. The locations of these stations are shown in Fig. 4.1. The data are

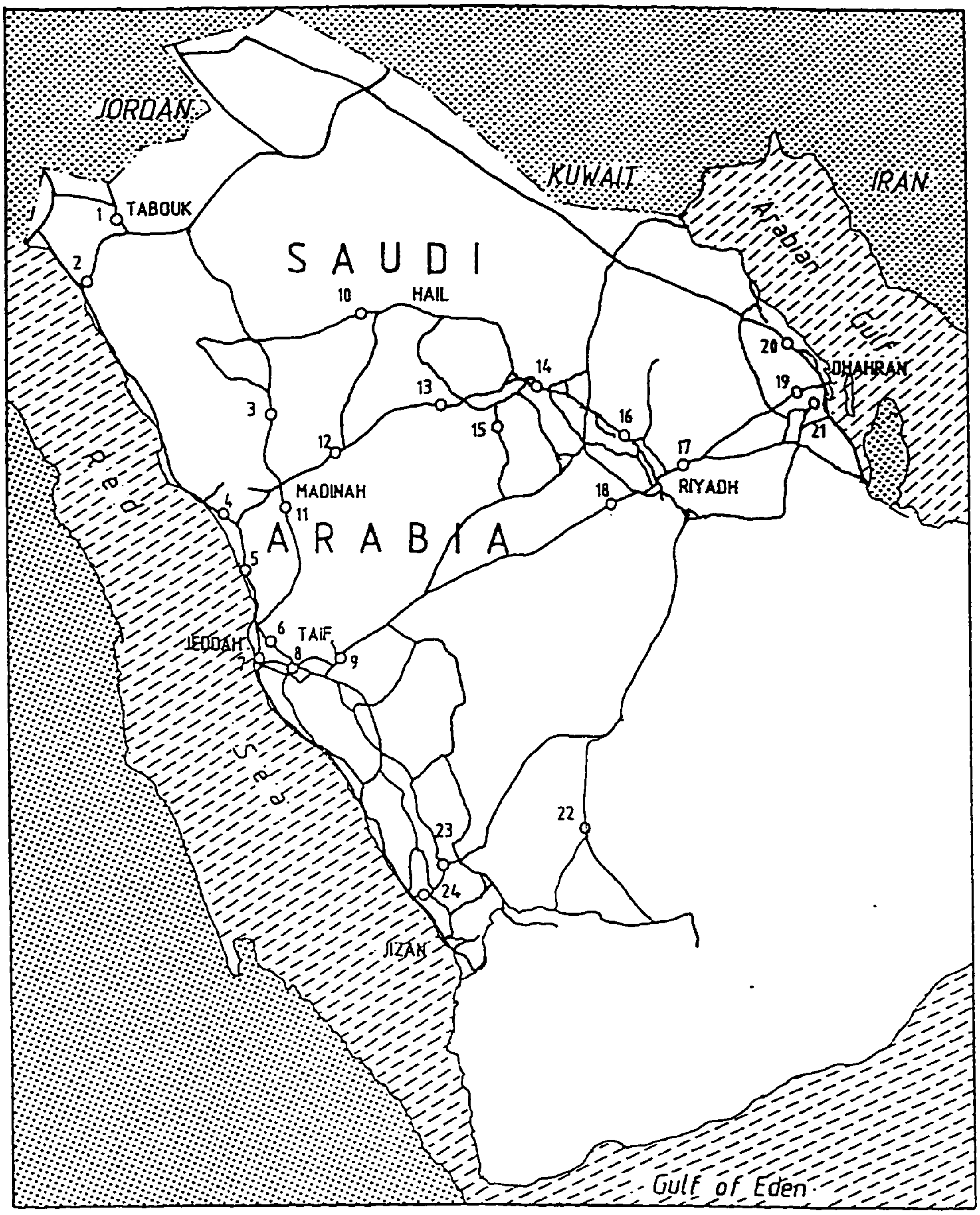


Fig. 4.1 Location of Weighing Stations in Saudi Arabia.

stored in computer diskettes to provide information on truck weights, axle weights and the overweights above the legal limits. Apart from these weights, the stored data provide information on the location of weighing station, vehicle plate number, time and the imposed fine for overweight.

Data were retrieved from the MOC's data bank for the last four years namely, 1413H, 1414H, 1415H, and 1416H . The data were available in the ASCII formats and this was reformatted to a readable form using a program written in Mathematica 2.2. These data from various stations were stored in separate datafiles.

In addition to the data from MOC's data bank, sample measurements of axle loads and axle spacings have been carried out at different locations in the Kingdom to verify the accuracy of the weigh stations and enforcement of weigh regulation practice. As the data from the weighing stations do not include axle spacings, measurements were taken for axle spacings both center to center and along the length, for different types of trucks.

4.2 TRUCK CLASSIFICATION ACCORDING TO MOC - RIYADH.

For the purpose of enforcement of weight control for trucks, MOC has classified trucks into 8 basic types, as shown in Fig.4.2 and explained in Table 4.1. The legal weights of these trucks are also shown in Fig.4.2. As three of these trucks have identical maximum legal weight of 40 T, for the purpose of recording truck

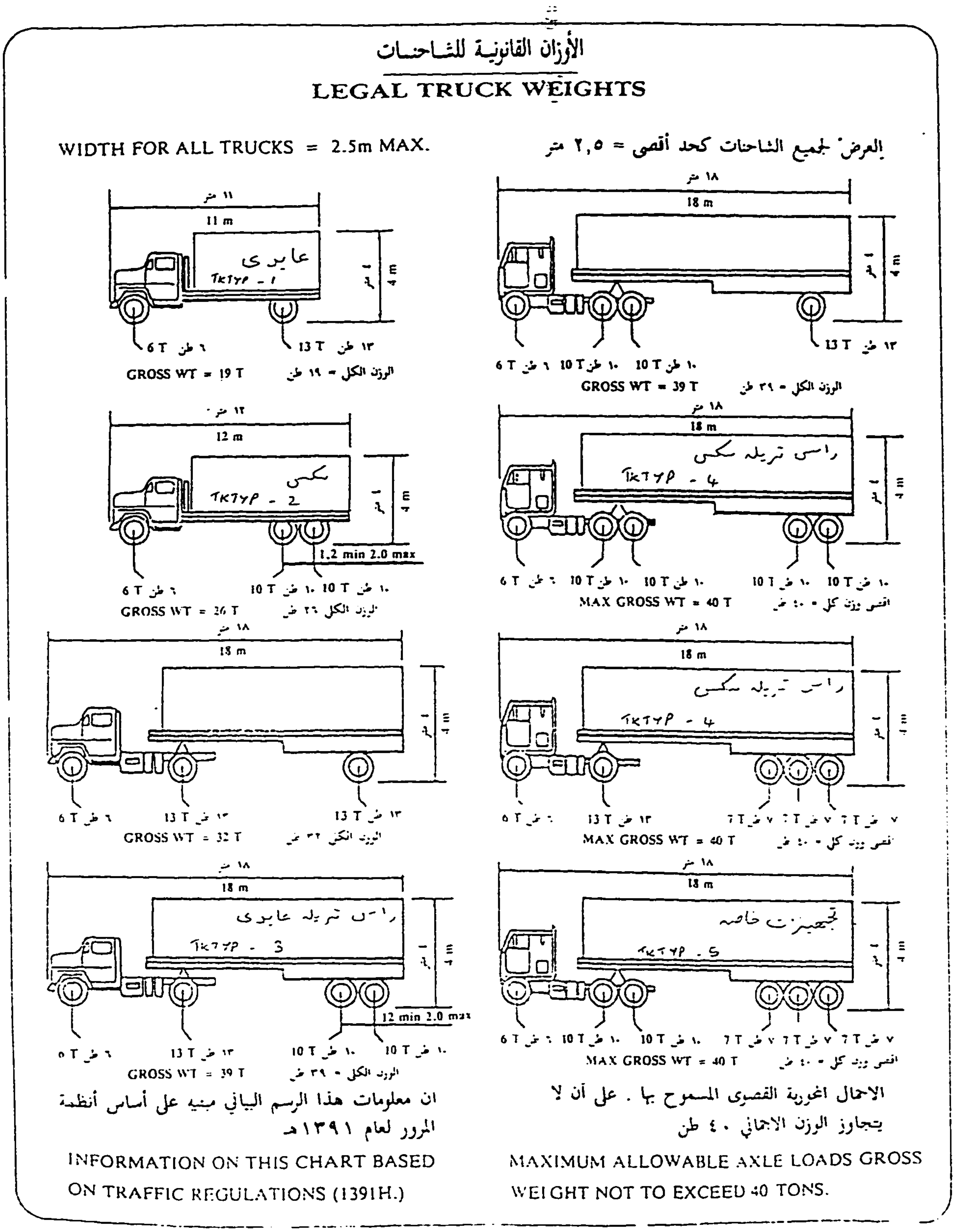


Fig. 4.2 Legal Truck Weight Limits in Saudi Arabia.

TABLE 4.1 : MOC Truck Classification and Legal Weights

MOC Classification	Truck Types at Weighing Stations	Configuration	Number of Axles	Legal Weight
Class 1	Type 1	Rigid	2	19T
Class 2	Type 2	Rigid	3	26T
Class 3	Type 3	Trailer type	3	32T
Class 4	Type 4	Trailer type	4	39T
Class 5	Type 4	Trailer type	4	39T
Class 6	Type 5	Long Trailer type	5	40T
Class 7	Type 5	Long Trailer type	5	40T
Class 8	Type 5	Long Trailer type	6	40T
Unclassified	Type 0	Special	> 6	40T

weights at a weighing station, trucks are classified into 5 types, type 1 to type 5, based on axle configurations, as shown in Fig. 4.3. At a truck weighing station, the truck weight data are automatically recorded along with the truck type codes. Additionally, the weighing stations assign a truck classification code of 0 (zero), if the truck classification is unknown or cannot be related to a known type.

4.3 DATA COLLECTION FROM MOC

4.3.1 MOC's Data

The truck load data collected at the weighing stations are sent on a monthly basis to MOC's headquarters in Riyadh for storage. The data are stored on 3½ in. computer diskettes in the ASCII format. Through MOC's cooperation, the stored data were retrieved and then reformatted for analysis.

Although there are 28 weighing stations in the Kingdom, only 19 stations which are equipped with computerized data storage facilities supply the truck weight data regularly to MOC. The list of these 19 stations from which data were obtained is given in Table 4.2 breaking down the stations into four provinces. The truck data for the Southern Province was not available from MOC's data bank. Each station has an area code and station code number for identification.

المملكة العربية السعودية

ادارة مرور المنطقة الشر

ادارة العامة للطرق والنقل
بالمنطقة الشرقية

أخي السائق ...

لا تنشغل بغير الطريق من أجل سلامتك وسلامة الشا
حافظ على الوزن المقرر نظاماً .

— جدول مخالفات زيادة الوزن —

Type V اجمالي الحمولة والسيارة ٤٠ طن	Type IV اجمالي الحمولة والسيارة ٣٩ طن	Type III اجمالي الحمولة والسيارة ٣٣ طن	Type II اجمالي الحمولة والسيارة ٢٦ طن	Type I اجمالي الحمولة والسيارة ١٩ طن	[illegible]
–	–	–	–	٣٠٠	[illegible]
–	–	–	–	٦٠٠	[illegible]
–	–	–	–	٩٠٠	[illegible]
–	–	–	–	١٢٠٠	[illegible]
–	–	–	٣٠٠	١٥٠٠	[illegible]
–	–	–	٣٠٠	١٨٠٠	[illegible]
–	–	–	٦٠٠	١٨٠٠	[illegible]
–	–	–	٦٠٠	٢١٠٠	[illegible]
–	–	٣٠٠	٩٠٠	٢٤٠٠	[illegible]
–	–	٣٠٠	٩٠٠	٢٧٠٠	[illegible]
–	–	٦٠٠	١٢٠٠	٣٠٠٠	[illegible]
–	–	٩٠٠	١٥٠٠	٣٣٠٠	[illegible]
–	٣٠٠	٩٠٠	١٥٠٠	٣٦٠٠	[illegible]
٣٠٠	٣٠٠	١٢٠٠	١٨٠٠	٣٦٠٠	[illegible]
٣٠٠	٣٠٠	١٢٠٠	١٨٠٠	٣٩٠٠	[illegible]
٣٠٠	٦٠٠	١٥٠٠	٢١٠٠	٤٢٠٠	[illegible]
٦٠٠	٦٠٠	١٥٠٠	٢١٠٠	٤٢٠٠	[illegible]
٦٠٠	٦٠٠	١٥٠٠	٢١٠٠	٤٥٠٠	[illegible]

Fig. 4.3 MOC Classification of Trucks Used at a Weighing Station.

TABLE 4.2 : List of Weighing Stations Supplying the Data

Province	Corridor Location	Area Code	Station Code
Eastern	Dammam-Riyadh	3	1
	Dammam-Abu Hadriyah	3	2
Central	Riyadh-Dammam	1	1
	Riyadh-Taif	1	2
	Riyadh-Qasim	1	3
	Taif-Riyadh	6	1
	Qasim-Madina	13	1
	Ras Dukhna-Bajadiah	13	2
	Qasim-Riyadh	13	3
	Sulayl-Najran	18	1
Northern	Tabuk-Halat Ammar	7	1
	Hail-Alula	20	1
Western	Jeddah-Rabigh	2	1
	Jeddah-Asfan	2	2
	Jeddah-Makkah (Old)	2	3
	Madina-Makkah	4	1
	Madina-Qasim	4	2
	Yanbu-Madina	9	1
	Khayber-Madina	25	1

4.3.2 Information from MOC's Data

Among all the information in the data file, the most useful information was the total truck weight, axle weights, truck-type codes and truck class codes. These information was selected from the data file. The MOC data file does not give any information regarding the truck axle spacings which are essential for calculation of equivalent base length (EBL) for axle combinations.

4.4 ANALYSIS OF DATA OBTAINED FROM MOC

4.4.1 Yearwise Analysis

The total number of trucks recorded from different weighing stations for the four years, namely 1413H, 1414H, 1415H and 1416H was 1,161,951. The information about the class and loads for the above trucks was obtained from the filtered data files using a program written in Mathematica 2.2 (Appendix B.1). The year wise recorded truck data are presented in Table 4.3. The breakdown of the trucks into different MOC classes is shown in Table 4.4 and in Fig. 4.4.

The data in Table 4.4 and in Fig.4.4 show that approximately 80% of all trucks falls into class 4 and 5 with 4 axles (whose legal weight limit is 39 tons). The

TABLE 4.3 Year wise breakdown of data from MOC.

Year	Number of Trucks
1413 H	213,033
1414 H	239,164
1415 H	307,767
1416 H	401,987
Total	1,161,951

TABLE 4.4: Year wise breakdown of Trucks into MOC Classes

Truck Classification		Year 1413 H		Year 1414 H		Year 1415 H		Year 1416 H	
MOC Class	Number of Axles	Number of Trucks	Percentage of Total	Number of Trucks	Percentage of Total	Number of Trucks	Percentage of Total	Number of Trucks	Percentage of Trucks
1	2	22,267	10.45	16,528	6.91	19,359	6.29	28,469	7.08
2	3	8,554	4.02	7,658	3.2	8,502	2.76	12,263	3.05
3	3	402	0.19	126	0.05	249	0.08	482	0.12
4 & 5	4	155,793	73.13	192,406	80.45	253,178	82.26	326,226	81.15
6 & 7	5	24,968	11.72	21,324	8.92	25,079	8.15	31,860	7.93
8	6	922	0.43	953	0.4	1,165	0.38	1,889	0.47
Other	7	93	0.04	75	0.03	149	0.05	626	0.16
Other	8	34	0.02	94	0.04	86	0.03	172	0.04
Total		213,033	100%	239,164	100%	307,767	100%	401,987	100%

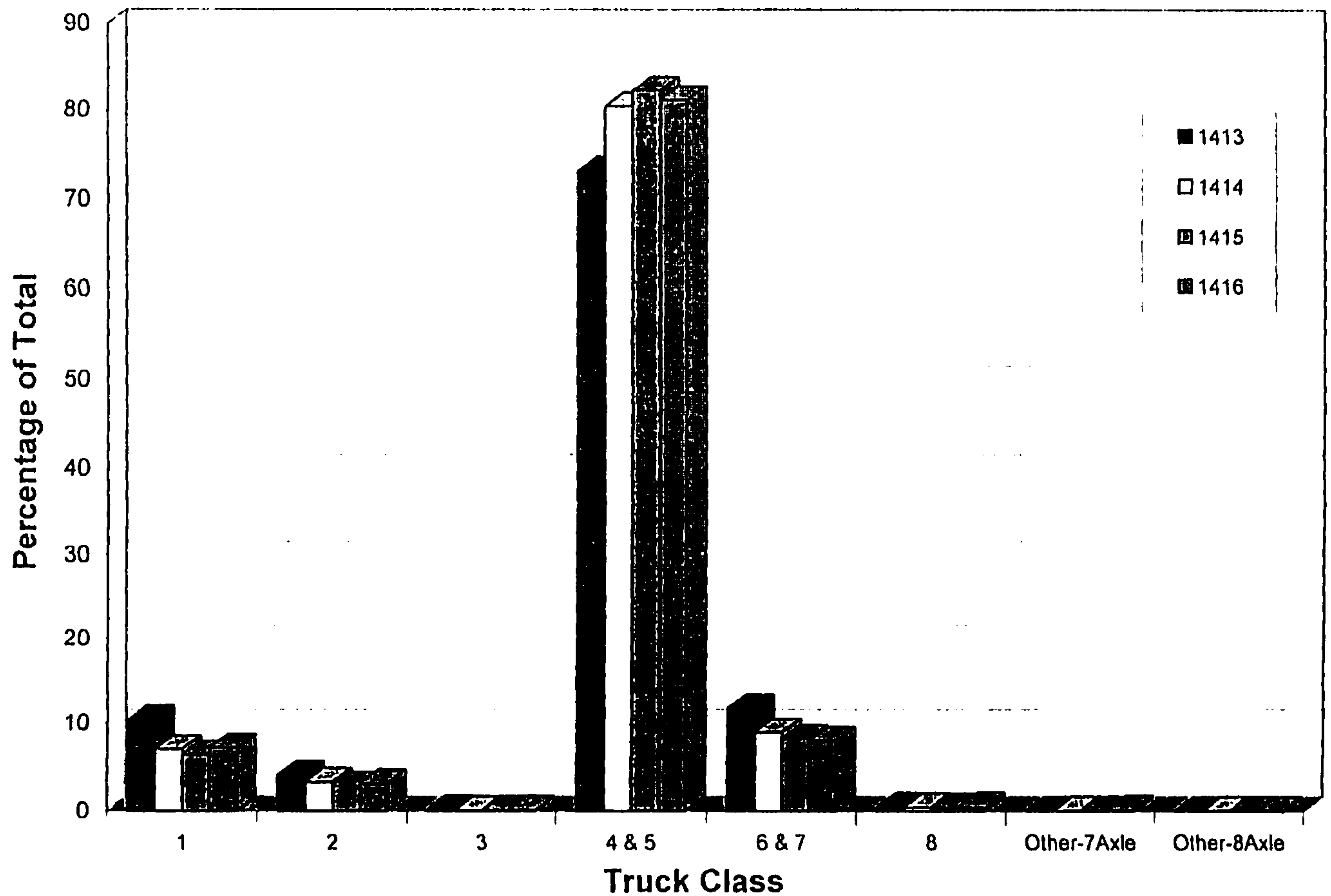


Fig. 4.4 Year wise distribution of Trucks into MOC Class

next highest population belongs to class 6 and 7 with 5 axles (whose legal weight limit is 40 tons), representing about nearly 10% of the total. Special trucks with 7 and 8 axles (other types) were also recorded, although their number was small. The most important observation made in this statistics, is that, the Class 3 type of truck which is the basis of the MOC Load Model (Fig.1.3) is very scarce. These type of trucks constituted only 0.1% of the samples.

Table 4.5 and Fig. 4.5 shows the proportions of overweight trucks in each MOC class for each of the four years considered in the study. The results show that almost 40-50% of the Class 4 and 5 trucks exceeded the allowable loads. The phenomenon of overloading exists among all classes of trucks. About 40% of the trucks are found to be overloaded among all the cases, exception being Class 3 trucks. In the Class 3 category, only 2-3 % of the truck population was found to exceed the allowable load limit.

As the overweight number was not very meaningful by itself, it was necessary to quantify the amount of overweights. For this purpose, Tables 4.6 through 4.9 were prepared to give the breakdown of Overweight Trucks into varying range of excess loading for the years 1413H, 1414H, 1415H and 1416H, respectively. Most of the trucks were found to exceed the allowable load limit by only 10-15%. This beneficial effect was attributed to the current weight regulations imposed by MOC by instituting wayside weighing stations. The weighing stations permit the truckers to carry only 10% more than the allowable weight for the carrier. Truck drivers are fined for weights exceeding this limit. The percentage of overloaded trucks decreased

TABLE 4.5 : **Overweight Trucks in Each MOC Class.**

MOC Class	No. of Axles	Year 1413 H. % of Overweight Trucks	Year 1414 H. % of Overweight Trucks	Year 1415 H. % of Overweight Trucks	Year 1416 H. % of Overweight Trucks
1	2	32.4	23.60	24.91	24.83
2	3	41.1	33.34	39.56	35.29
3	3	2.00	3.17	1.20	1.24
4 and 5	4	51.97	49.06	53.10	39.87
6 and 7	5	43.51	40.03	46.77	35.50
8	6	41.43	40.40	40.60	19.27
Other	7	59.14	37.33	44.30	6.55
Other	8	26.47	40.43	18.60	29.07

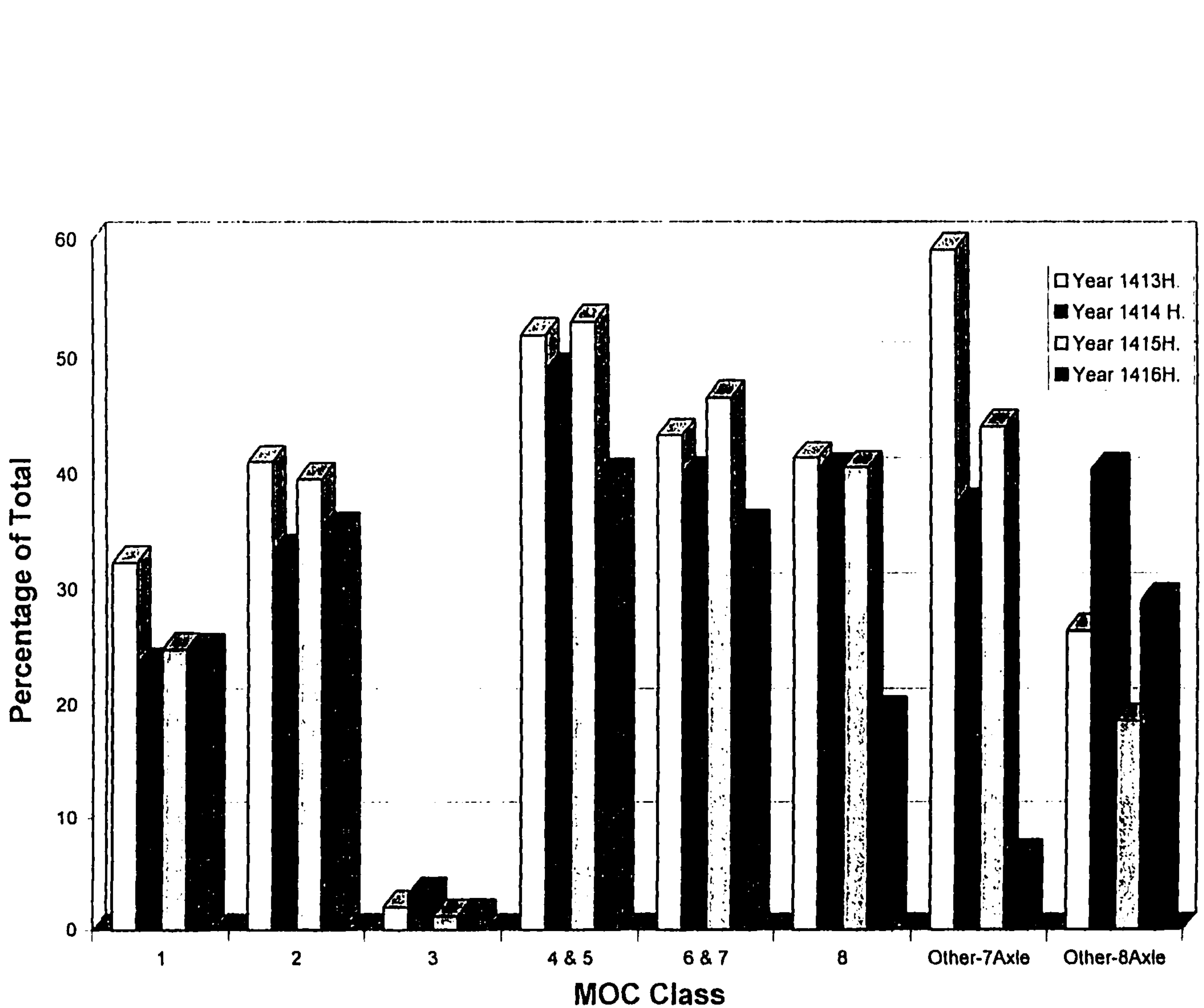


Fig. 4.5 Overweight Trucks in Each MOC Class

TABLE 4.6 : **Breakdown of Overweight Trucks in 1413H**

MOC Class	No. of Axles	No. of Overweight Trucks	Range of Overweights in Percentage									
			≤ 5	> 5 to ≤ 10	> 10 to ≤ 15	> 15 to ≤ 20	> 20 to ≤ 25	> 25 to ≤ 30	> 30 to ≤ 50	> 50 to ≤ 80	> 80 to ≤ 100	> 100
1	2	7,221	27.59	32.28	31.92	5.04	1.70	0.67	0.69	0.11	0	0
2	3	3,514	26.27	33.18	31.39	4.84	2.11	1.37	0.75	0.09	0	0
3	3	8	37.50	37.50	12.50	0	12.50	0	0	0	0	0
4 and 5	4	80,962	32.66	45.62	20.04	1.03	0.25	0.13	0.20	0.06	0.01	0
6 and 7	5	10,863	34.73	43.16	17.96	2.03	0.46	0.39	0.55	0.61	0.09	0.02
8	6	382	36.65	25.13	8.38	2.62	4.97	2.36	8.90	10.47	0	0.52
Other	7	55	12.73	7.27	14.56	7.27	5.45	16.36	16.36	20.00	0	0
Other	8	9	11.11	11.11	0	11.11	0	0	22.22	0	11.11	33.34

TABLE 4.7 : Breakdown of Overweight Trucks in 1414H

MOC Class	No. of Axles	No. of Overweight Trucks	Range of Overweights in Percentage									
			≤ 5	> 5 to ≤ 10	> 10 to ≤ 15	> 15 to ≤ 20	> 20 to ≤ 25	> 25 to ≤ 30	> 30 to ≤ 50	> 50 to ≤ 80	> 80 to ≤ 100	> 100
1	2	3,901	37.61	35.02	22.38	3.08	0.59	0.44	0.74	0.15	0	0
2	3	2,553	28.48	38.46	26.64	3.37	1.18	0.74	0.86	0.35	0	0
3	3	4	50.00	25.00	25.00	0	0	0	0	0	0	0
4 and 5	4	94,393	38.89	42.95	17.09	0.7	0.14	0.05	0.11	0.07	0.00	0
6 and 7	5	8,535	40.69	40.89	14.21	2.65	0.66	0.27	0.34	0.21	0.06	0.02
8	6	385	23.64	34.81	21.04	3.9	1.56	2.08	5.97	6.23	0.52	0
Other	7	28	17.86	28.57	0	7.14	7.14	0	17.86	17.86	3.57	0.26
Other	8	38	42.11	31.58	21.05	0	0	2.63	2.63	0	0	0

Table 4.8 : Breakdown of Overweight Trucks in 1415H

MOC Class	No. of Axles	No. of Overweight Trucks	Range of Overweights in Percentage									
			≤ 5	> 5 to ≤ 10	> 10 to ≤ 15	> 15 to ≤ 20	> 20 to ≤ 25	> 25 to ≤ 30	> 30 to ≤ 50	> 50 to ≤ 80	> 80 to ≤ 100	> 100
1	2	4,823	35.68	32.35	26.50	4.30	0.73	0.10	0.25	0.06	0	0
2	3	3,363	27.71	31.58	35.50	2.35	0.77	0.71	0.98	0.39	0	0
3	3	3	100.00	0	0	0	0	0	0	0	0	0
4 and 5	4	134,445	36.88	44.03	18.20	0.59	0.13	0.06	0.04	0.02	0.00	0
6 and 7	5	11,729	38.33	45.46	13.90	1.30	0.37	0.24	0.20	0.13	0.06	0.03
8	6	473	30.02	31.50	17.50	4.44	1.90	2.54	6.13	5.07	0.85	0
Other	7	66	31.82	25.76	13.60	6.06	6.06	0	9.10	4.54	1.51	1.52
Other	8	16	18.75	56.25	18.80	6.25	0	0	0	0	0	0

TABLE 4.9 : Breakdown of Overweight Trucks in 1416H

MOC Class	No. of Axles	No. of Overweight Trucks	Range of Overweights in Percentage									
			≤ 5	> 5 to ≤ 10	> 10 to ≤ 15	> 15 to ≤ 20	> 20 to ≤ 25	> 25 to ≤ 30	> 30 to ≤ 50	> 50 to ≤ 80	> 80 to ≤ 100	> 100
1	2	7,070	35.13	36.35	24.10	3.48	0.49	0.30	0.17	0	0	0
2	3	4,328	34.40	36.78	23.60	2.96	0.65	0.76	0.28	0.44	0.07	0.02
3	3	6	50.00	16.67	0	0	16.67	0	16.67	0	0	0
4 and 5	4	130,068	44.13	41.43	13.40	0.73	0.15	0.05	0.08	0.04	0.01	0.00
6 and 7	5	11,311	47.27	39.08	11.70	0.88	0.23	0.06	0.22	0.26	0.21	0.12
8	6	364	32.97	35.99	14.60	3.57	2.20	3.57	4.40	2.47	0.27	0
Other	7	41	26.83	36.59	14.60	0	2.44	4.88	0	7.32	7.32	0
Other	8	50	46.00	38.00	14.00	0	0	0	2.00	0	0	0

with an increase in the load range. This shows the success of the truck weight control regulations. Figs. 4.6 through 4.13 present the data graphically.

Tables 4.10 through 4.13 compare Legal Weight, Maximum Weight and Average weight for each class of vehicle for the years 1413H, 1414H, 1415H and 1416H. respectively. These data indicate that under the prevailing weigh control regulations too, the phenomenon of overloading still exists and may be one of the cause for the bad condition of roads and bridges in the Kingdom. Figures 4.14 through 4.17 indicate the same graphically.

4.4.2 Province wise analysis

Data analysis for each province, namely East, West, North, and Central was also carried out as part of the KACST project AR-15-64. Only the statistics pertaining to the percentage of Overweight trucks in each of the provinces is presented here. The other details of the provincial data analysis can be found in Refs. 44 and 45. Tables 4.14 through 4.17 detail the percentage of Overweight vehicles in each province for 1413 H, 1414 H, 1415 H, and 1416 H, respectively. Figures 4.18 through 4.21 portray this data graphically.

The province wise study also indicated that the 4-axle trucks (MOC class 4 and 5) dominated the truck population, consisting over 70% to 80% of the volume in all the provinces. Although the number of trucks counted for the North Province was

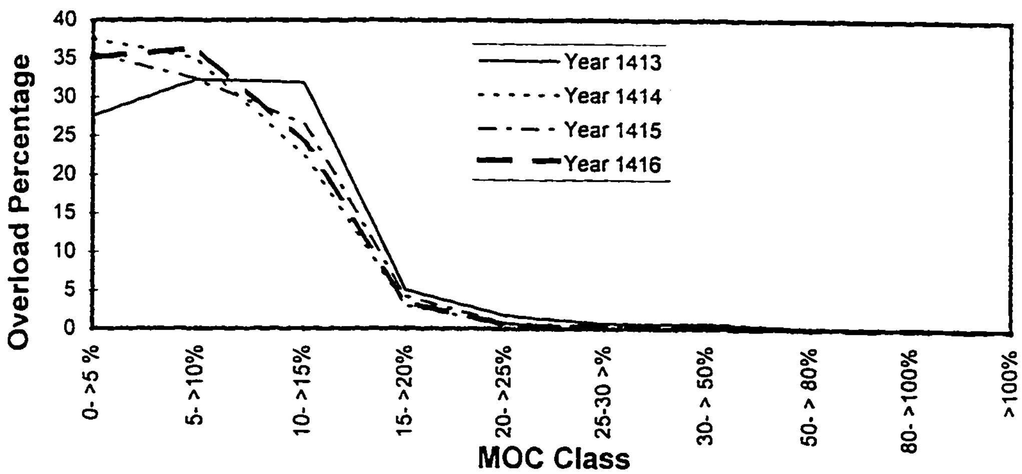


Fig 4.6. Overload Variation- MOC Class 1.

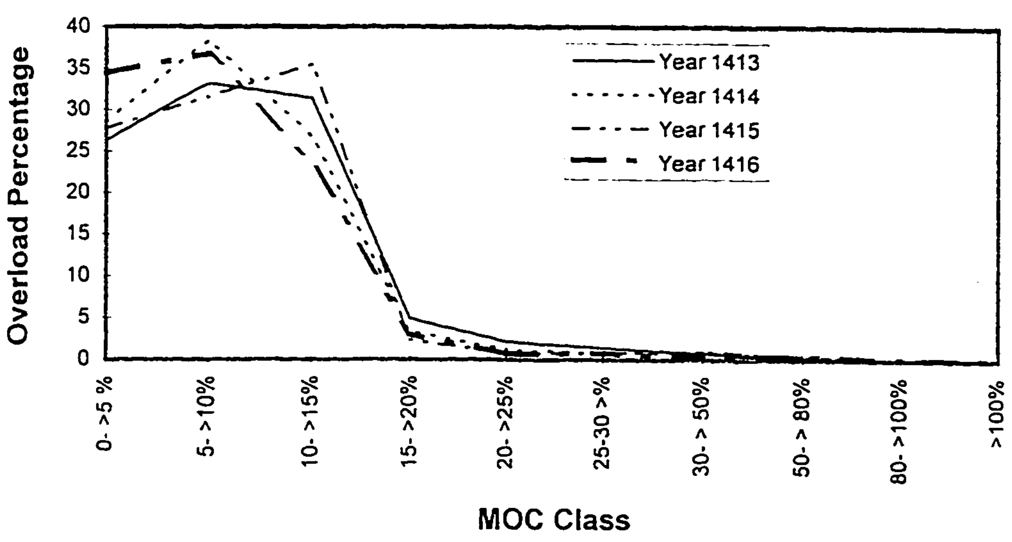


Fig 4.7. Overload Variation - MOC Class 2.

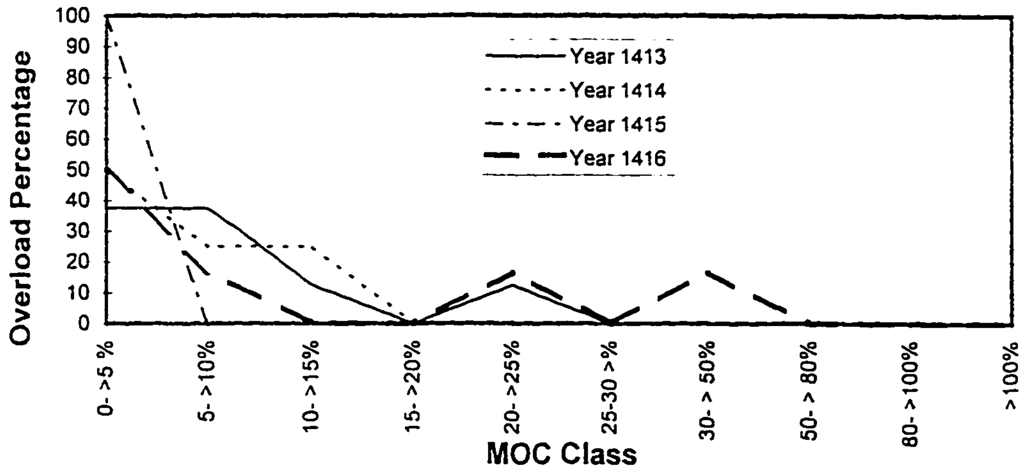


Fig 4.8. Overload Variation- MOC Class 3.

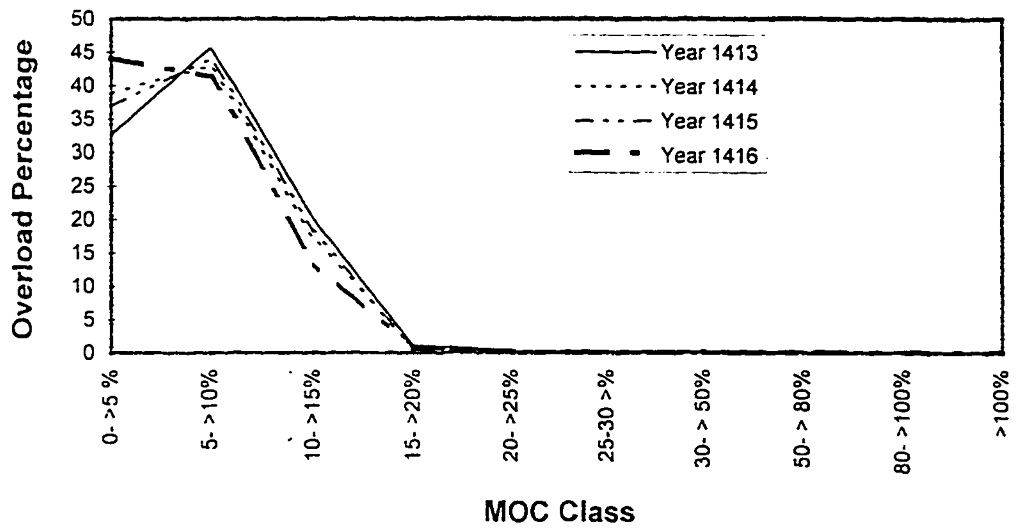


Fig 4.9. Overload Variation - MOC Class 4 & 5.

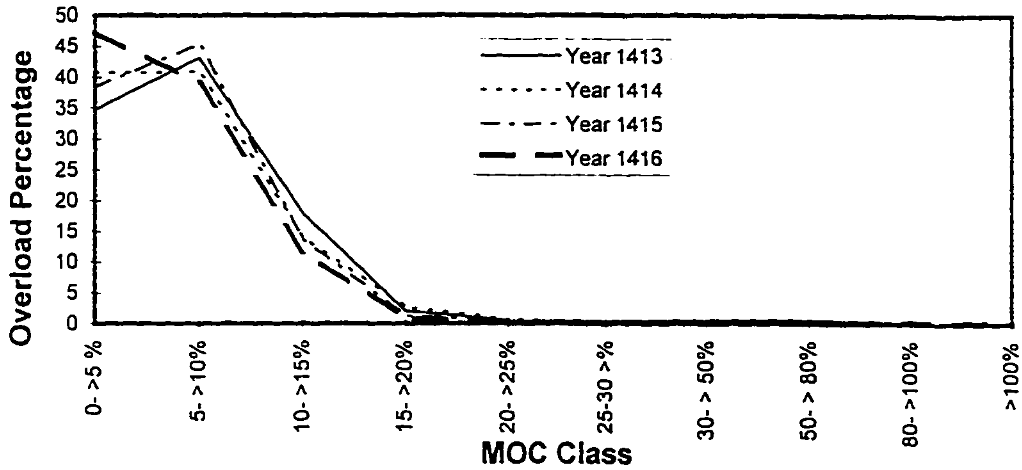


Fig 4.10. Overload Variation- MOC Class 6 & 7.

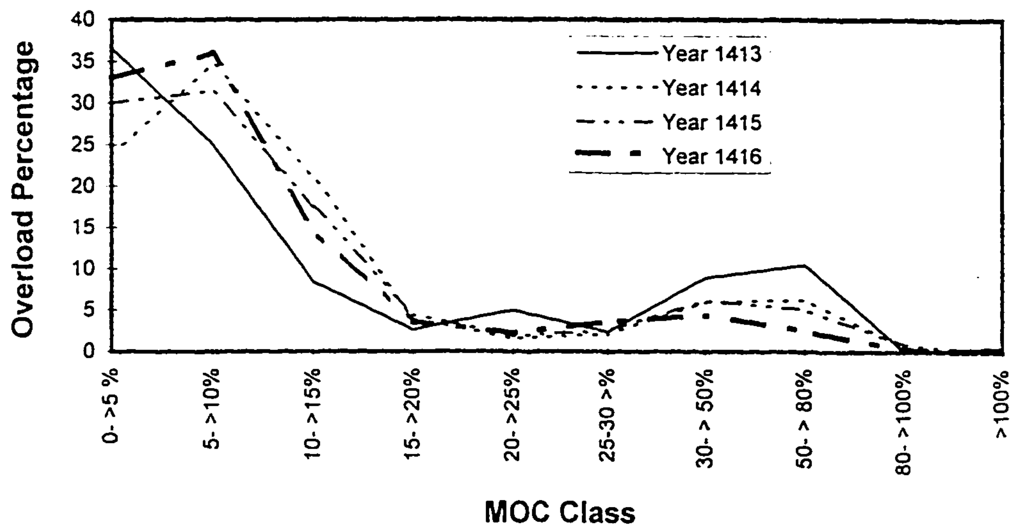


Fig 4.11. Overload Variation - MOC Class 8.

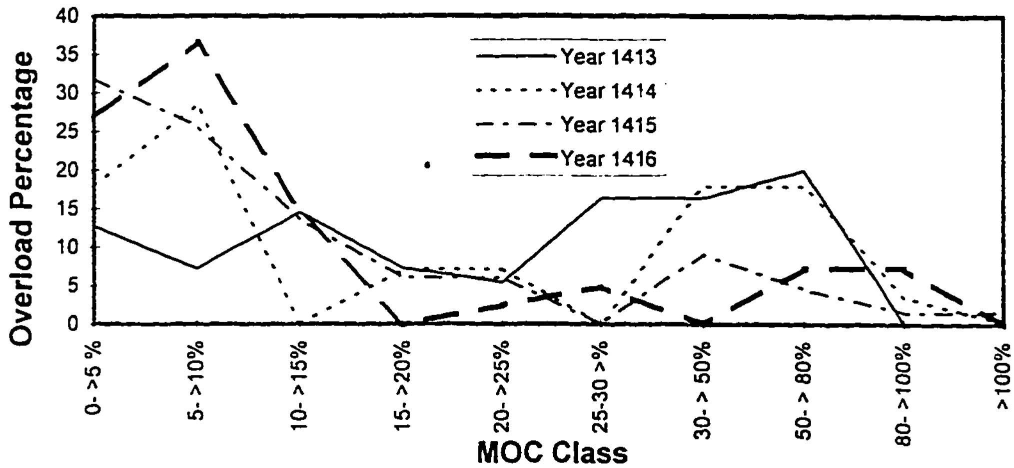


Fig 4.12. Overload Variation- MOC Class Other - 7 Axel.

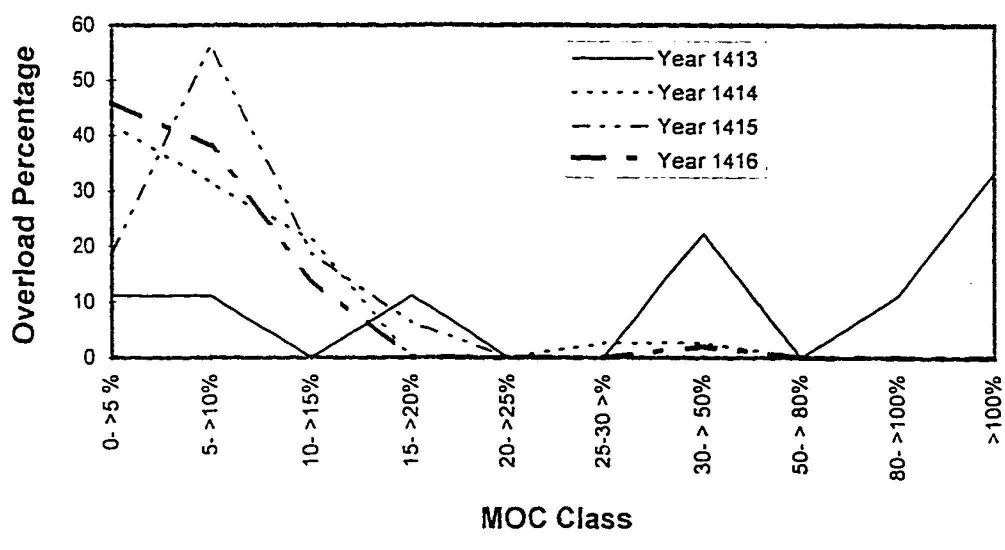


Fig 4.13. Overload Variation - MOC Class Other- 8 Axel.

TABLE 4.10 : Comparison of Legal Weight, Maximum Weight and Average Weight for Each Class: 1413H

MOC Class	No. of Axles	Legal Weight (tons)	Maximum Weight (tons)	Maximum Overweight by Percentage	Average Weight (tons)
1	2	19.0	30.70	61.58	16.50
2	3	26.0	45.12	73.54	23.25
3	3	32.0	39.40	23.12	16.70
4 & 5	4	39.0	76.04	94.97	37.10
6 & 7	5	40.0	99.19	148.0	36.80
8	6	40.0	81.25	103.1	37.00
Other	7	40.0	66.19	65.48	44.60
Other	8	40.0	89.61	124.0	34.20

TABLE 4.11 : **Comparison of Legal Weight, Maximum Weight and Average Weight for Each Class: 1414H**

MOC Class	No. of Axles	Legal Weight (tons)	Maximum Weight (tons)	Maximum Overweight by Percentage	Average Weight (tons)
1	2	19.0	31.32	64.84	15.50
2	3	26.0	44.31	70.42	22.25
3	3	32.0	36.70	14.69	17.65
4 & 5	4	39.0	79.22	103.10	35.80
6 & 7	5	40.0	85.38	113.40	35.45
8	6	40.0	84.95	112.40	35.58
Other	7	40.0	77.82	94.55	37.60
Other	8	40.0	58.72	46.80	37.00

TABLE 4.12 : Comparison of Legal Weight, Maximum Weight and Average Weight for Each Class: 1415H

MOC Class	No. of Axles	Legal Weight (tons)	Maximum Weight (tons)	Maximum Overweight by Percentage	Average Weight (tons)
1	2	19.0	29.84	57.05	16.30
2	3	26.0	46.72	79.69	23.95
3	3	32.0	33.20	3.75	17.55
4 & 5	4	39.0	73.27	87.87	37.08
6 & 7	5	40.0	80.98	102.45	36.30
8	6	40.0	88.96	122.24	36.55
Other	7	40.0	87.40	118.50	40.20
Other	8	40.0	45.87	14.68	34.10

TABLE 4.13 : Comparison of Legal Weight, Maximum Weight and Average Weight for Each Class: 1416H

MOC Class	No. of Axles	Legal Weight (tons)	Maximum Weight (tons)	Maximum Overweight by Percentage	Average Weight (tons)
1	2	19.0	26.00	36.84	15.30
2	3	26.0	52.22	100.85	21.90
3	3	32.0	42.00	31.25	19.30
4 & 5	4	39.0	79.18	103.03	35.50
6 & 7	5	40.0	86.32	115.80	36.30
8	6	40.0	78.00	95.00	34.55
Other	7	40.0	75.74	89.35	35.20
Other	8	40.0	54.72	36.80	31.00

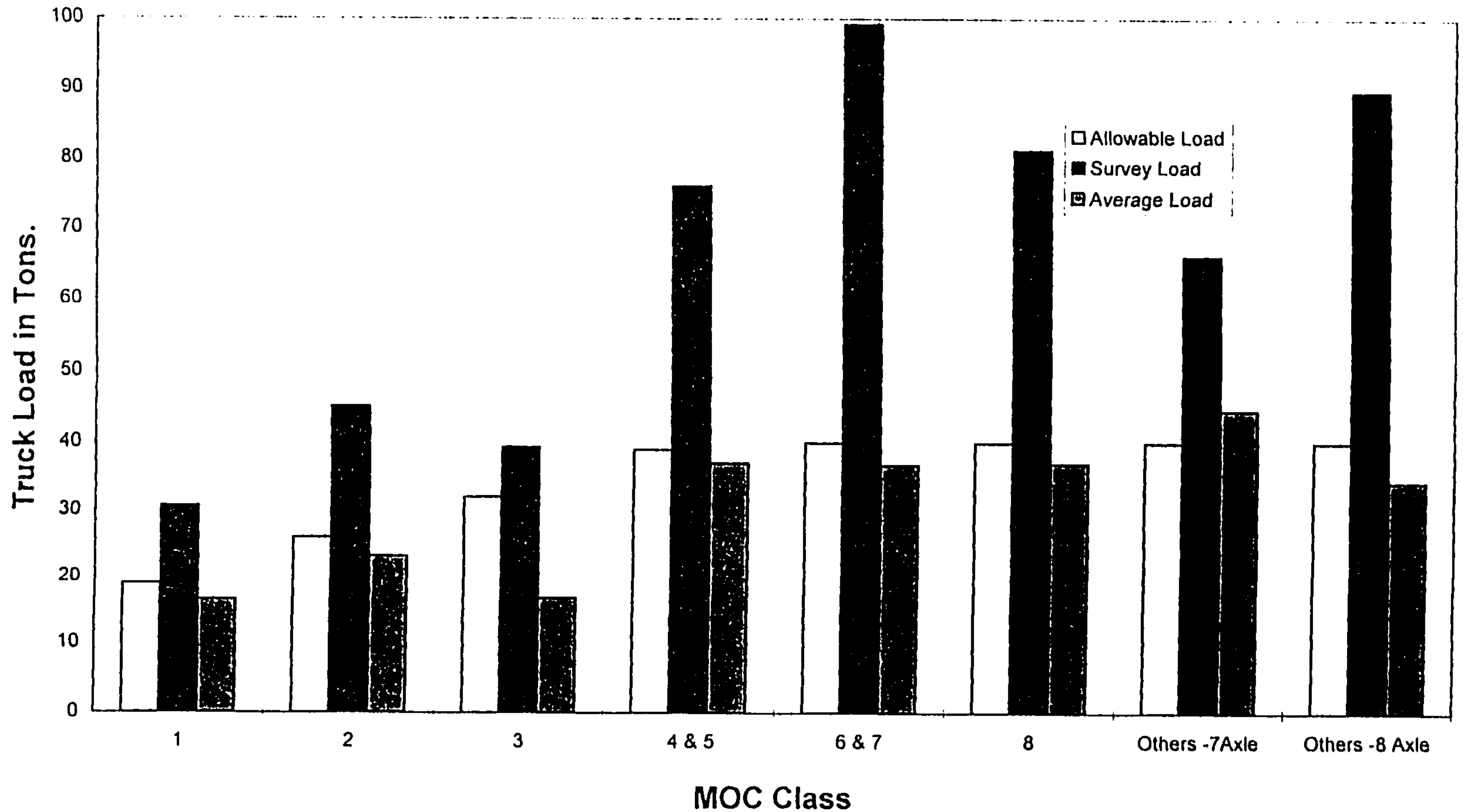


Fig. 4.14 Comparison of Legal Weight, Maximum Weight and Average Weight of Trucks : Year 1413 H

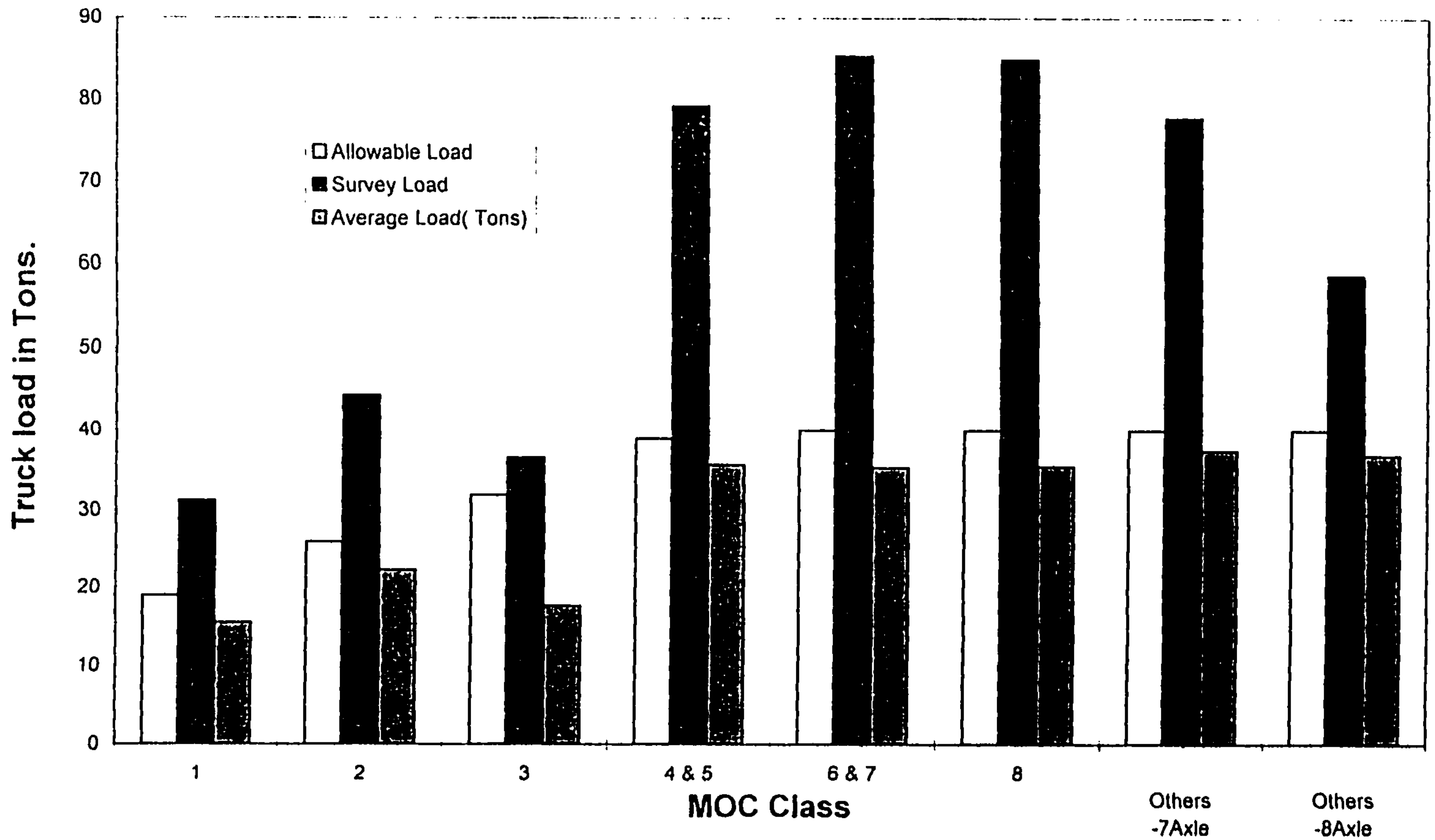


Fig.4.15 Comparison of Legal Weight, Maximum Weight and Average Weight of Trucks : Year 1414 H.

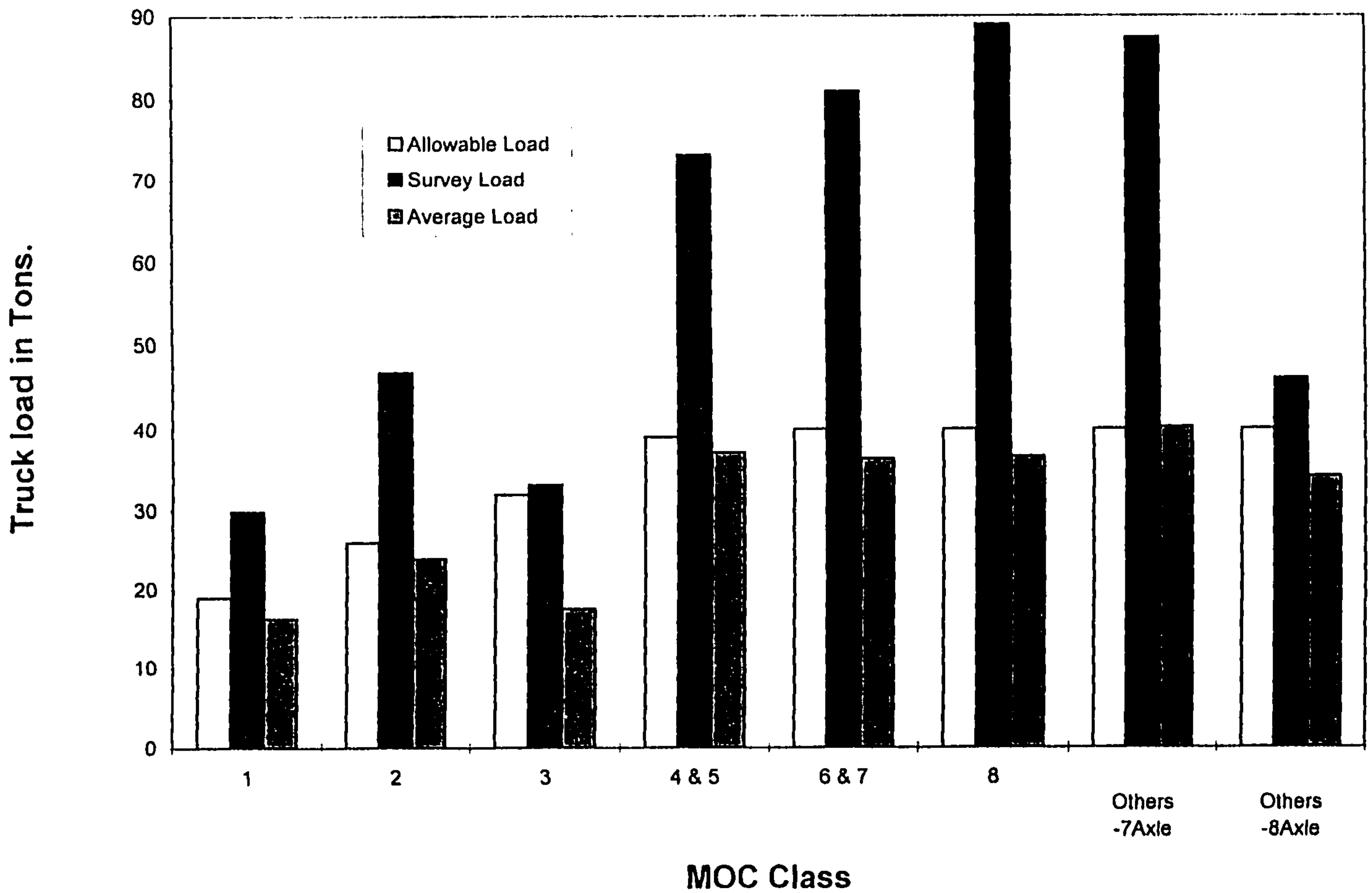


Fig.4.16 Comparison of Legal Weight, Maximum Weight and Average Weight of Trucks : Year 1415 H.

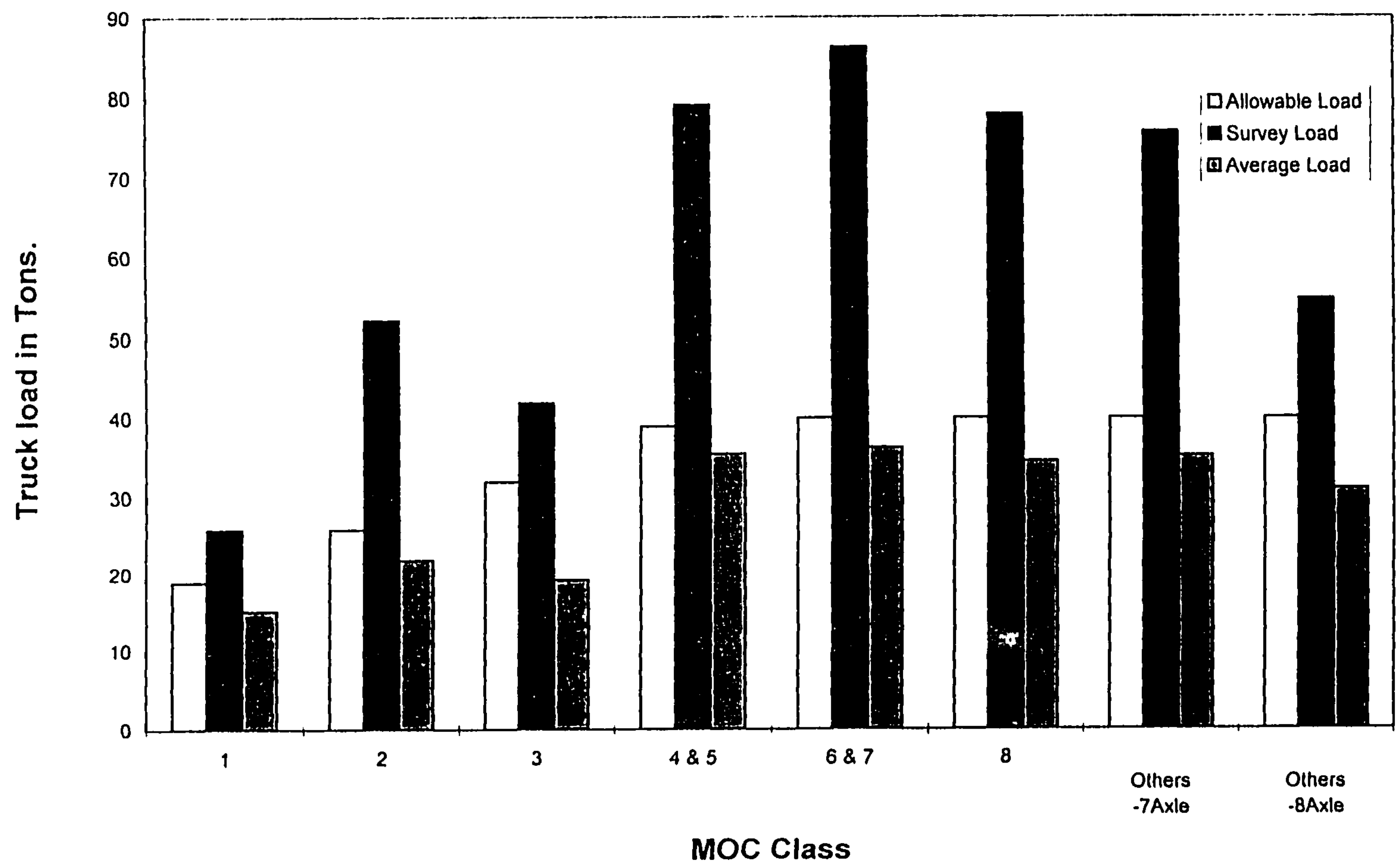


Fig.4.17 Comparison of Legal Weight, Maximum Weight and Average Weight of Trucks : Year 1416 H.

TABLE 4.14 : Percentage of Overweight Trucks in the Eastern Province

MOC Class	Year 1413 H	Year 1414 H	Year 1415 H	Year 1416 H
1	33.90	25.46	26.90	8.08
2	50.52	32.08	52.15	19.01
3	0.52	0.00	4.55	6.00
4 and 5	53.83	63.21	62.76	27.55
6 and 7	43.07	54.85	60.32	40.33
8	48.60	62.32	55.10	12.93
Other - 7 Axle	62.07	37.93	46.88	2.86
Other - 8 Axle	6.67	66.67	11.11	28.00

TABLE 4.15 : Percentage of Overweight Trucks in the Western Province

MOC Class	Year 1413 H	Year 1414 H	Year 1415 H	Year 1416 H
1	22.10	22.65	16.57	31.07
2	24.32	23.23	27.78	38.28
3	1.01	1.72	0.00	0.48
4 and 5	37.96	44.20	48.29	43.89
6 and 7	34.52	34.77	29.87	23.58
8	30.86	31.54	30.57	26.28
Other - 7 Axle	40.00	0.00	30.26	33.33
Other - 8 Axle	33.33	66.67	23.08	0.00

TABLE 4.16 : Percentage of Overweight Trucks in the Northern Province

MOC Class	Year 1413 H	Year 1414 H	Year 1415 H	Year 1416 H
1	68.43	27.05	46.11	26.08
2	55.61	24.11	51.55	41.09
3	50.00	0.00	0.00	0.00
4 and 5	60.88	49.71	57.81	36.64
6 and 7	51.90	44.95	45.43	49.91
8	15.00	22.45	31.08	33.01
Other - 7 Axle	0.00	0.00	0.00	0.00
Other - 8 Axle	100.00	0.00	0.00	0.00

TABLE 4.17 : Percentage of Overweight Trucks in the Central Province

MOC Class	Year 1413 H	Year 1414 H	Year 1415 H	Year 1416 H
1	31.30	23.14	20.75	25.56
2	46.04	41.24	35.89	39.16
3	4.67	5.66	0.00	1.35
4 and 5	58.89	42.01	44.98	46.73
6 and 7	47.77	29.74	43.73	36.16
8	40.58	26.62	39.93	32.91
Other - 7 Axle	65.91	45.45	66.67	46.15
Other - 8 Axle	66.67	38.64	17.24	46.67

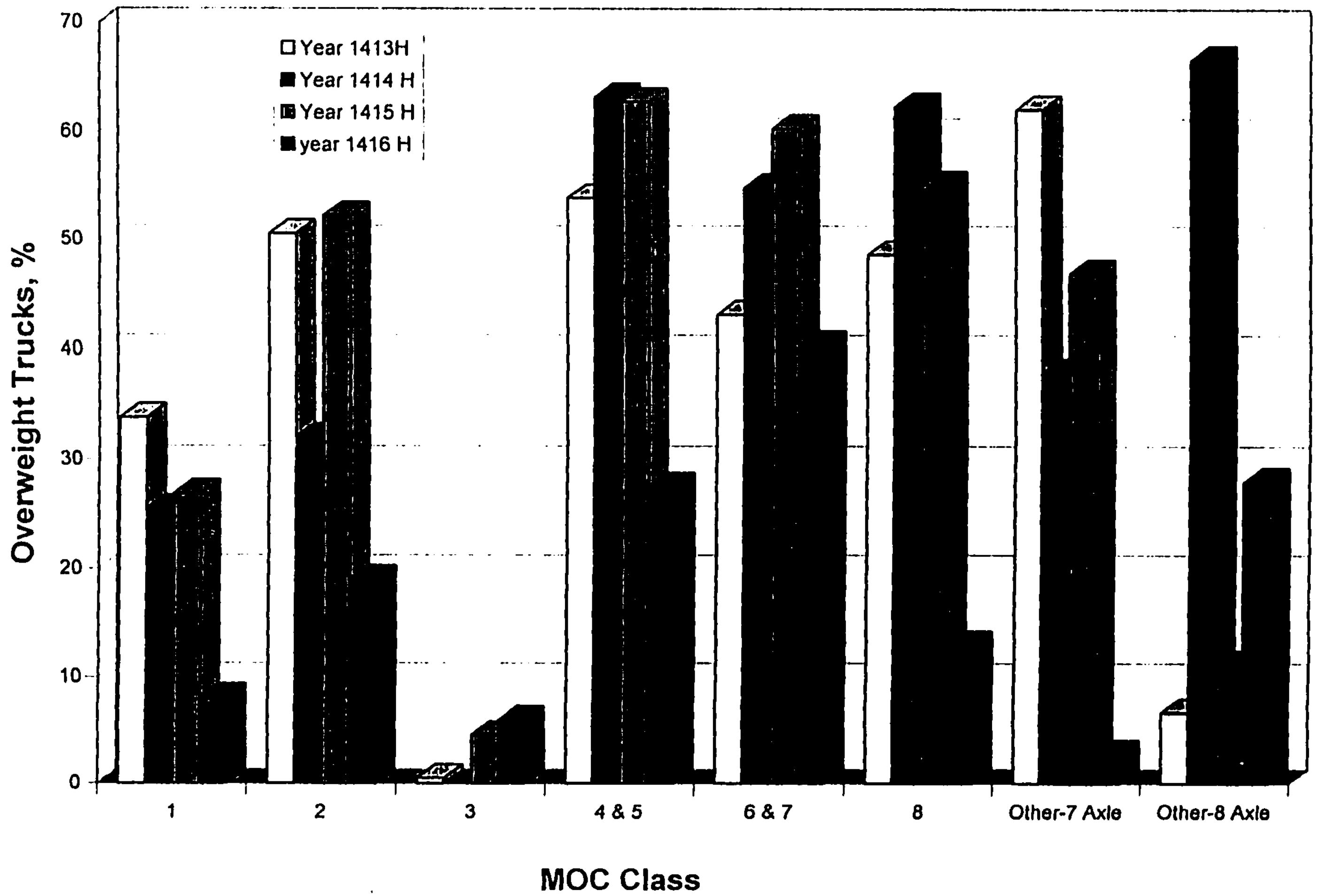


Fig.4.18 Overweight Trucks in the Eastern Province

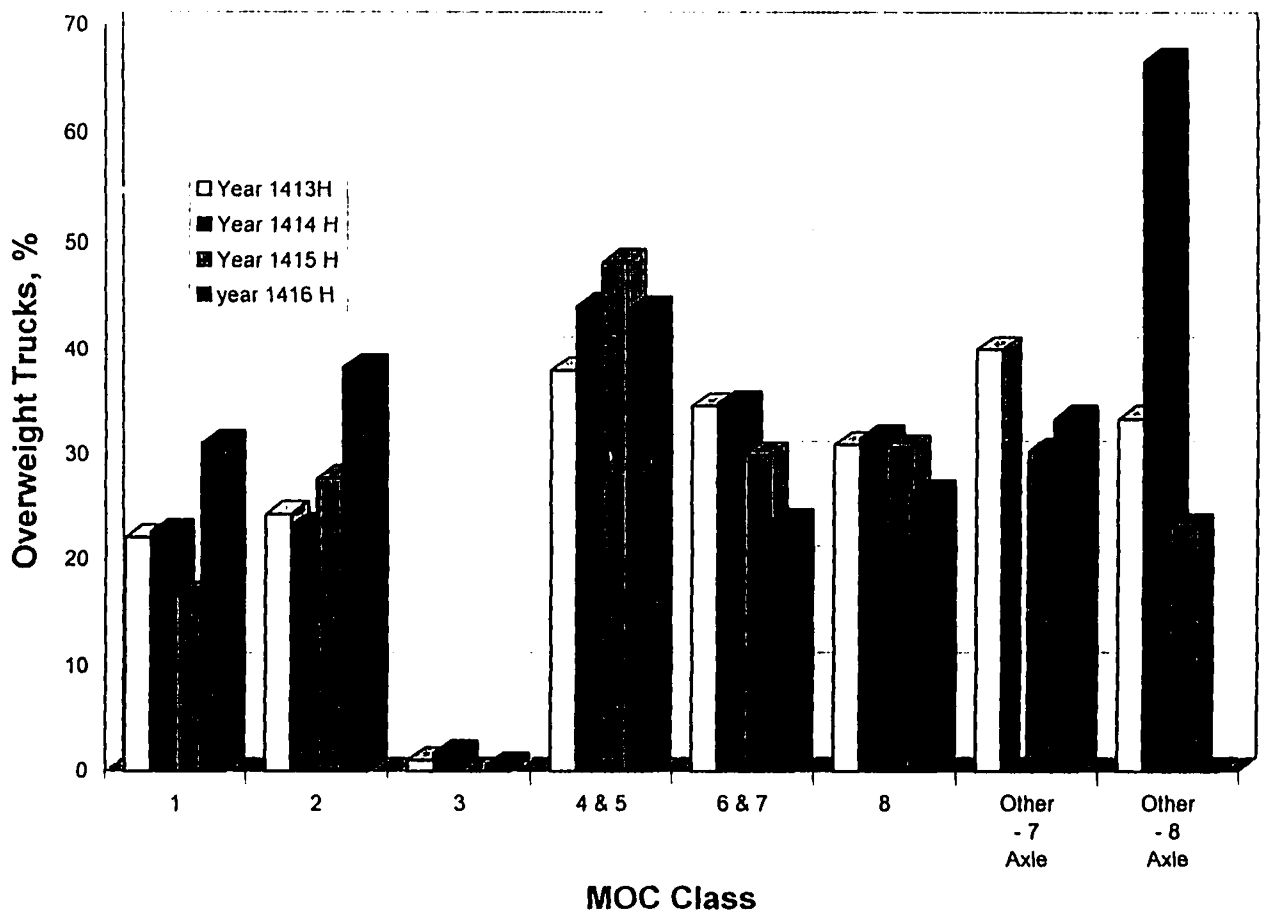


Fig.4.19 Overweight Trucks in the Western Province

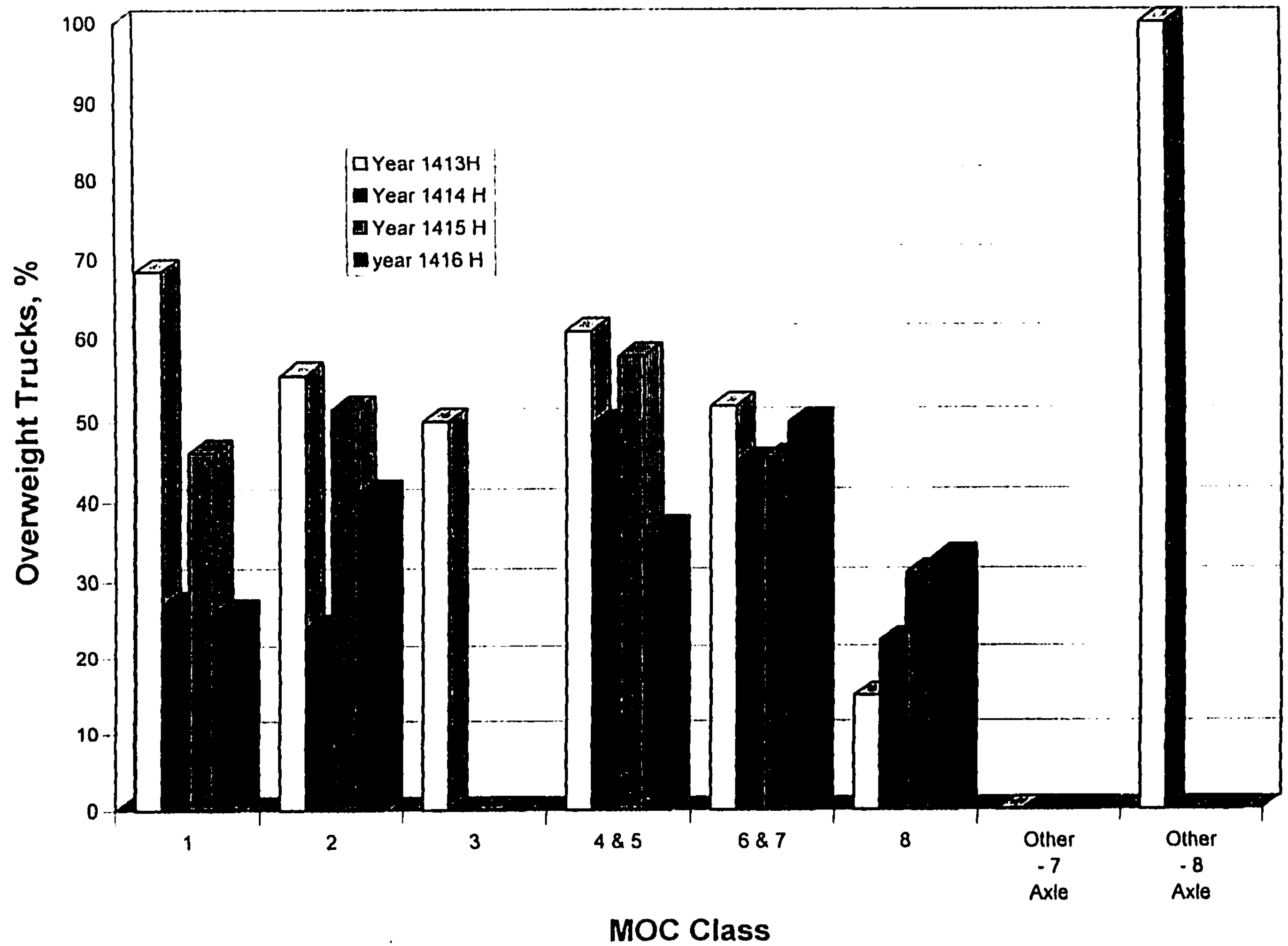


Fig.4.20 Overweight Trucks in the Northern Province

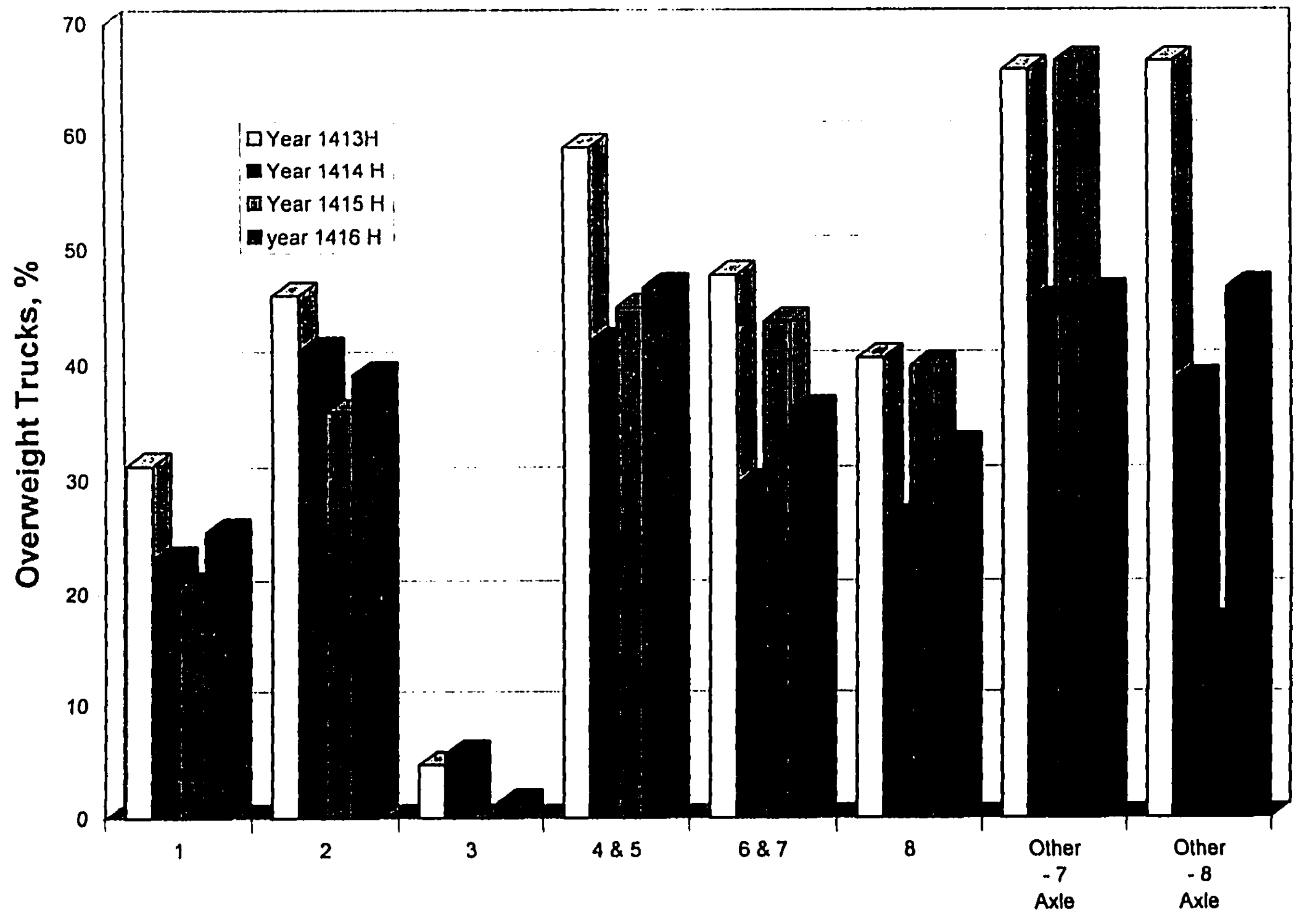


Fig.4.21 Overweight Trucks in the Central Province

considerably less than in the other provinces, however it leads the other provinces in the number of overweight trucks in most of the classes. The results for the Eastern Province indicated a sharp decrease in the percentage of overweight trucks in the year 1416H when compared with the preceding years. There is no plausible explanation to this as overweight phenomenon depends perhaps on several influencing parameters.

The overweight phenomenon in the Western Province which was mostly steady in the years 1413H, 1414H and 1415H showed a marked increase in the MOC class 1 and 2. A marginal decrease in the overweight trucks was noted in other classes. The analysis of the Central Province indicated a marginal growth of overweight trucks in the MOC classes 1, 2, 4 and 5 over the preceding years. A steady decrease in the overweight truck population was noted in other classes in the year 1416H. Results indicate that although overloading persists in every province, the percentage of overloaded trucks along the years has been consistently decreasing. This may be the result of rigorous truck load monitoring and weight enforcement by the authorities concerned. The other reasons may be that the truckers may be avoiding the truck weighing stations by using detours and minor roads. The bad condition of bridges and roads does not really prove that the overloading phenomenon has really diminished in the Kingdom. To verify the overloading phenomenon and check for the loop holes if any, in the weight monitoring system, surveys at several stations, both at weigh scale side and non-weigh scale side of the freeways were conducted by KFUPM (44 and 45).

4.5 TRUCK SURVEY CONDUCTED BY THE KFUPM TEAM

4.5.1 Need for the sample load survey

As the secondary source of truck data, sample load surveys were conducted by the team under Project AR 15-64, at two weighing stations in each of the different provinces with the primary objective to determine the axle spacings of the various trucks, an information which is vitally needed in this work. The measured axle spacings serve as a guide in allocating a fair value of the axle spacings for the truck data collected from the load survey.

4.5.2 Layout of way-side weighing stations

Layout of all way-side weighing stations is basically the same. A station is located adjacent to the highway and the trucks are directed by posted signs ahead of the station to take the designated route leading to the weighing station for weighing. It is required by traffic regulation that all trucks carrying goods must be weighed at the station.

4.5.3 Survey Procedure

The weights of trucks was measured by a computerized weighing scale manufactured by Intercomp in U.S.A., Model No. PT300, Portable Wheel Load Weigher having a gross weight of 16.8 kg. The recommended operating temperature for this equipment is –28° to 65°C. The accuracy of the measured weights is ±1%. The scale is activated simply by turning on the 'ON' key.

At a weighing station, the pair of weighing scales is placed about 2.4 m centres. For a smooth ascending and descending of the wheels, the sloping ramps are provided on each side of the scale, forming a gradual transition for the height difference between the roadway and the weighing scale. The pair of scales, known as master scale and slave scale, is connected to a laptop computer using proper port connections. The scales send continuous output to the computer which records the data in a file.

To record the truck weights, the drivers were asked to drive the truck slowly, placing one axle at a time on the weighing scale to avoid impact from sudden stoppage. With the axle on the scales motionless, the static reading was recorded directly as the axle load. Once a reading is taken, the driver moves the truck to position the next axle on the scale.

The axle spacings were measured manually by using a hand-held, distance measuring rolling wheel which measures the distance as the wheel is rolled from one

axle to the other. The entire procedure of recording loads and spacing of axles for a truck takes about two minutes.

As the axle spacings have to be recorded manually, a special form (sample copy shown in Appendix A.2) was designed using MOC's truck classification and was used in the sample load surveys.

4.5.4 Survey on the Non-scale side of Freeway.

While the survey was relatively easier to conduct at the weighing station where all trucks are required to pass through the station, the survey on the opposite side of the highway was extremely difficult as the trucks have to be halted by flagging and then slowly directed to the roadside where the weighing scale was installed to take the measurements. As the task involved stopping and diverting trucks on a busy highway, the permission of conducting such a survey from the concerned authority was necessary. The local police extended their full cooperation to the survey team in completing their work. Without their active cooperation, the time-taking survey work could not have been completed.

4.5.5 Locations

Sample truck load surveys were conducted by the team in three provinces: (a) West (b) Central and (c) East.

4.5.5.1 Survey in theWestern Province

In the Western Province, the following three weighing stations were selected:

(i)	Jeddah-Makkah (Old)	:	Station-Code 2-3
(ii)	Jeddah-Asfan	:	Station-Code 2-2
(iii)	Jeddah-Makkah (New)	:	Station-Code - N/A

The data were measured and recorded at the first two weighing stations, identified as 2-3 and 2-2, and the data for the Jeddah-Makkah (New) were recorded continuously by the weighing station itself following the team's instruction. In total, 3152 trucks were weighed and measured in this survey out of which 475 trucks exceeded the legal weight limits. Table 4.18 provides the statistics of the survey work.

TABLE 4.18 : **Sample Survey of Trucks in the Western Province**

MOC Class	No. of Axles	No. of Trucks Surveyed	No. of Overweight Trucks	Percentage of Overweight Trucks	Maximum Weight (tons)
1	2	311	44	14.14	25.48
2	3	140	20	14.28	31.87
3	3	2	0	0.0	26.70
4 and 5	4	2516	375	14.90	50.05
6 and 7	5	114	23	20.18	56.50
8	6	44	4	0.91	109.16
Others	7	28	9	32.14	54.28

TABLE 4.19 : **Sample Survey of Trucks in the Central Province**

MOC Class	No. of Axles	No. of Trucks Surveyed	No. of Overweight Trucks	Percentage of Overweight Trucks	Maximum Weight (tons)
1	2	32	8	25.00	20.17
2	3	14	3	21.43	28.52
3	3	–	–	–	–
4 and 5	4	430	115	26.74	47.03
6 and 7	5	29	8	27.59	43.33
8	6	–	–	–	–
Others	7	3	1	33.33	52.05

4.5.5.2 Survey in the Central Province

In the Central Province, the load survey was conducted for three days at the two weighing stations:

(i)	Riyadh-Taif	:	Station-Code 1-2
(ii)	Riyadh-Qasim	:	Station-Code 1-3

A total of 508 trucks were weighed at these stations and are presented in Table 4.19. About 135 trucks in the survey were found to exceed the weight limit set by MOC, Riyadh.

4.5.5.3 Survey in the Eastern Province

Sample truck load surveys were conducted by the team at the two weighing stations in the Eastern Province:

(i)	Dammam-Riyadh Highway	:	Station: Area Code 1-3
(ii)	Dammam Abu Hadriyah Highway	:	Station: Area Code 2-3

The important aspect of this load survey was to measure the truck loads on the side of the highway where there is no weighing scale. On the Dammam-Riyadh highway, the weighing station No. 1 is located on the Riyadh bound route about 50 km from Dammam and on the Dammam-Abu Hadriyah road, the weighing scale is located on the road to Abu Hadriyah, about 170 km from Dammam. The aim was to

examine the problem of overweights on the uncontrolled route. which is known to exist at an alarming level.

At Station 1-3 (Dammam-Riyadh), sample load survey was conducted on both sides of the highway, at the weighing station for trucks travelling towards Riyadh and on the opposite side of the weighing station for trucks bound for Dammam. The survey was carried out in mid-July 1996 for six days. A total of 502 trucks were surveyed on the Dammam-bound roadway with no weighing scale and 202 trucks were surveyed at the weighing scale. The analysis of data for the no weigh scale side is presented in Table 4.20. Fig 4.22 shows the intensity of overloaded trucks currently on the no weigh scale side of the road.

At Station 2 on Dammam-Abu Hadriyah highway, all truck data were collected on the side with no weighing station, i.e. on the road to Dammam. A total of 207 trucks were weighed using the portable weighing scale over a period of 3 days in mid-October 1996. The results are presented in Table 4.21 and Fig.4.23.

On both routes, many trucks traveling back to Dammam carry heavy loads, mostly in the form of coarse aggregates, sand and other bulk loads, exploiting the advantage that there is no checkpoint to pass through. Many unscrupulous truck drivers load their trucks after crossing the Riyadh-bound checkpoint (Station 1-3). knowing that no checkpoint has to be crossed on their way back to Dammam. Similar situation exists on the Dammam-Abu Hadriyah road, as heavy trucks transport aggregates from Abu Hadriyah to Dammam, completely unchecked.

TABLE 4.20 : Sample Survey of Trucks in the Eastern Province - Station: Riyadh - Dammam (No Scale)

MOC Class	No. of Axles	No. of Trucks Surveyed	No. of Overweight Trucks	Percentage of Overweight Trucks	Maximum Weight (tons)
1	2	18	16	88.89	23.17
2	3	109	87	79.82	46.58
3	3	1	0	0.0	21.26
4 and 5	4	262	217	82.82	69.98
6 and 7	5	104	89	85.58	82.84
8	6	7	7	100	87.46
Others	7 and 8 axle	1	1	100	55.38

TABLE 4.21 : Sample Survey of Trucks in the Eastern Province - Station: Abu Hadriyah - Dammam (No Scale)

MOC Class	No. of Axles	No. of Trucks Surveyed	No. of Overweight Trucks	Percentage of Overweight Trucks	Maximum Weight (tons)
1	2	5	2	40.00	22.23
2	3	36	17	47.22	42.96
3	3	0	0	0.00	0
4 and 5	4	114	49	42.98	60.42
6 and 7	5	52	16	30.77	58.79
8	6	2	2	100.00	61.81
Others	7 & 8 axle	0	0	0.00	0

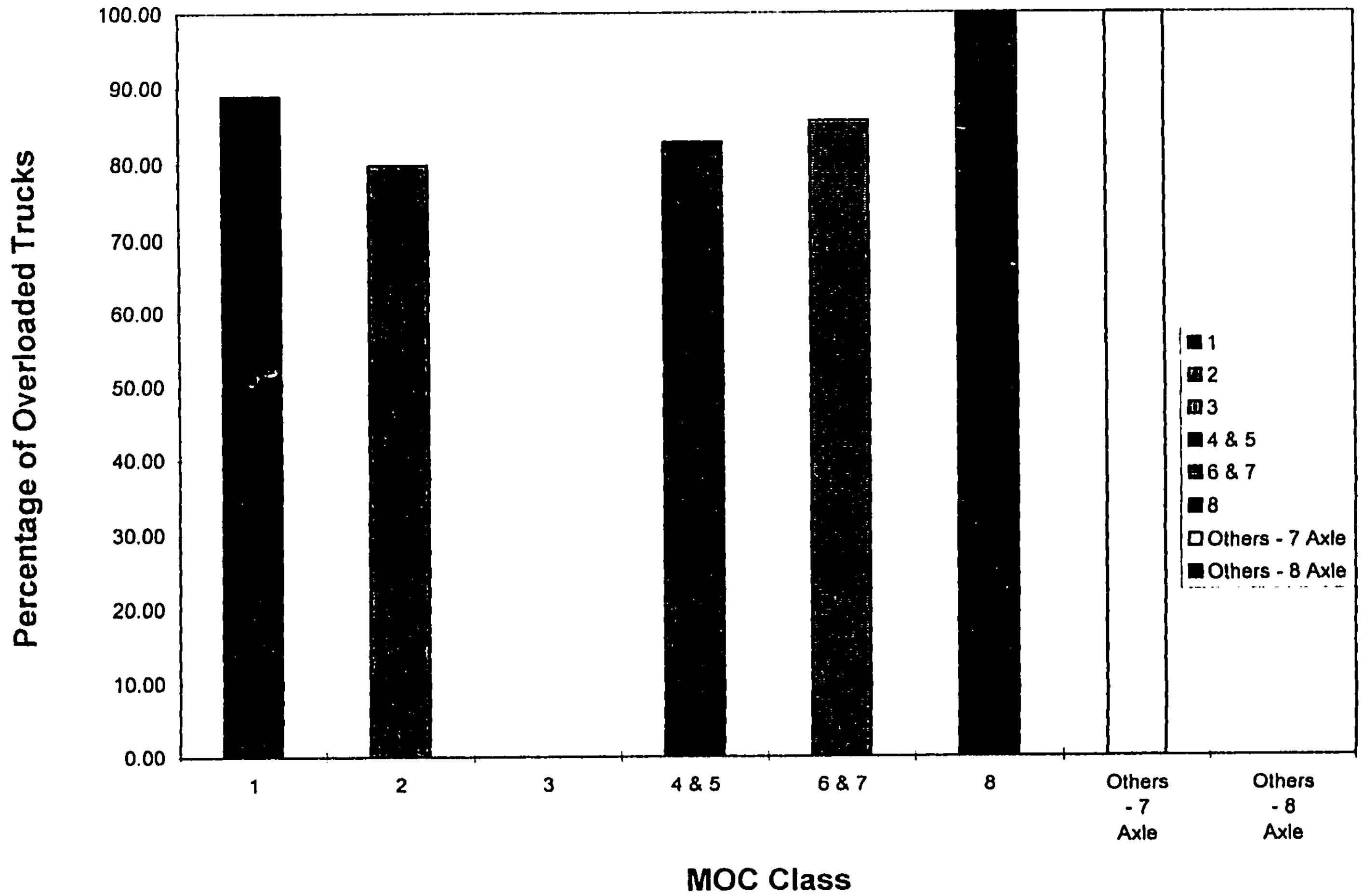


Fig.4.22 Percentage of Overloaded Trucks in Sample Survey on Riyadh - Dammam Road (No Scale)

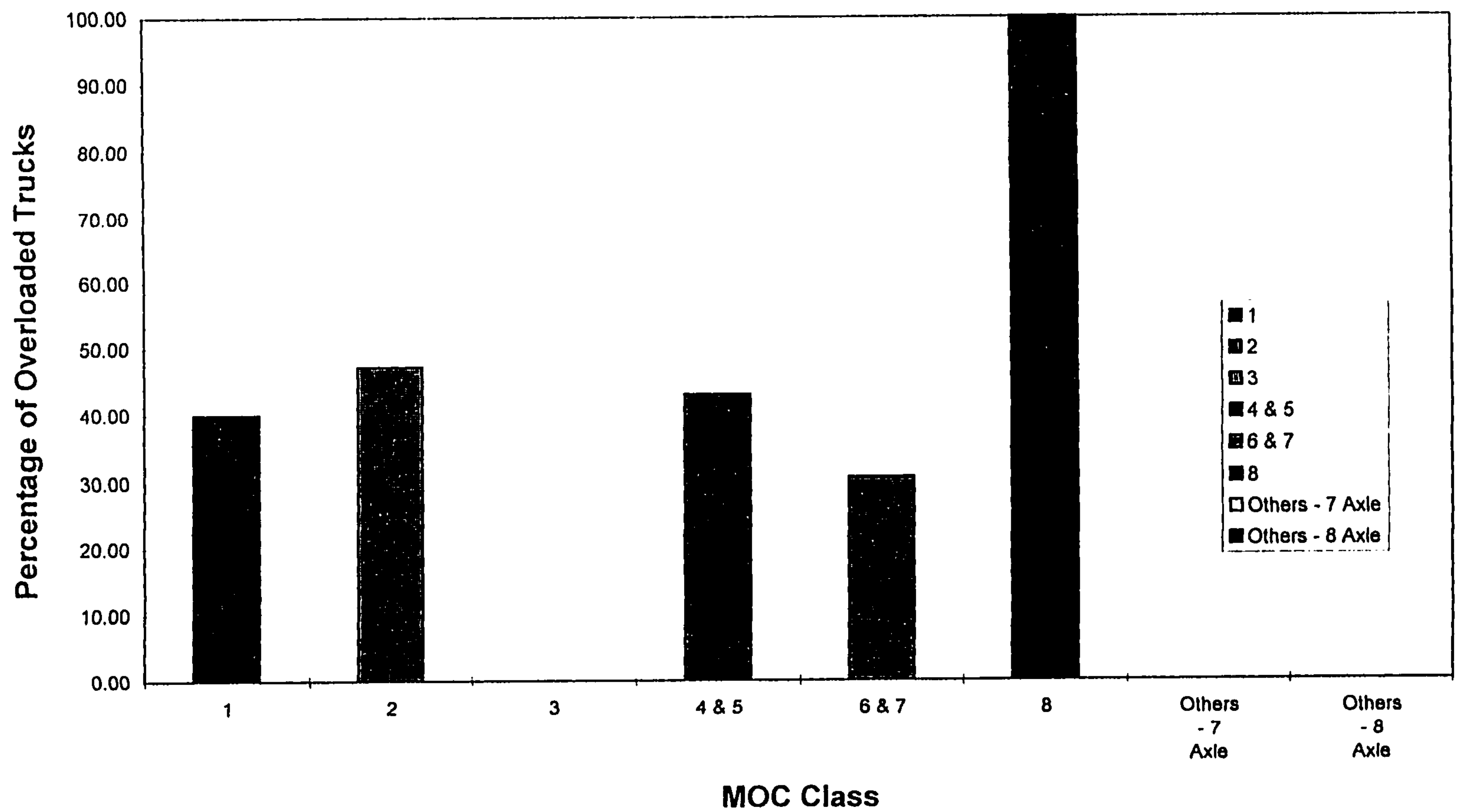


Fig.4.23 Percentage of Overloaded Trucks in Sample Survey on Dammam - Abu Hadriyah Road (No Scale)

4.6 OBSERVATIONS FROM THE FIELD SURVEY

4.6.1 Axle spacings

The limited sample load survey was carried out to draw attention to the problem that prevails within the current regulatory controls. It should be emphasized that the primary objective of the sample load survey was to obtain an idea of the range of axle spacing for different truck types. Although the axle spacing varies considerably in some cases, the variation is generally small in majority of the cases. Table 4.22 shows the range of spacings of axles for different classes of trucks and the usual spacings noticed in each case.

4.6.2 Other observations

Apart from the measurement of axle loads and axle spacings, the following observations were made in the limited sample survey work:

(i) The accuracy of the truck weights recorded at the weighing stations is about ± 2 tons. However, it can vary, depending upon the speed of trucks entering the wayside dynamic weigh-in scale. Inaccuracy of the recorded weights increases with speeds exceeding 5 km/hr.

TABLE 4.22 : Spacing of Axles from Sample Truck Survey

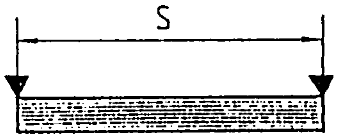
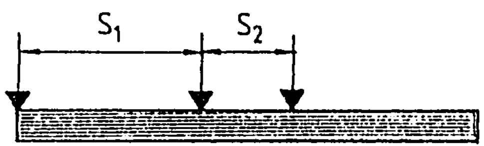
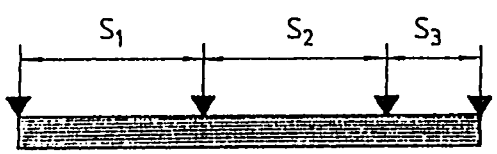
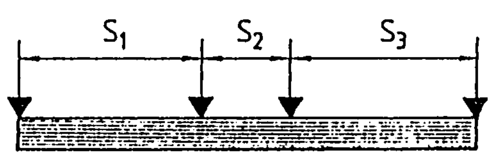
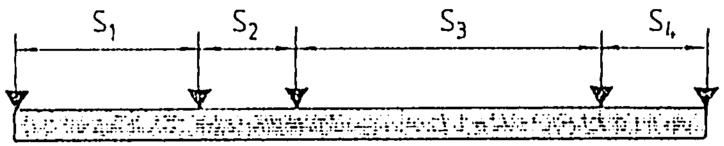
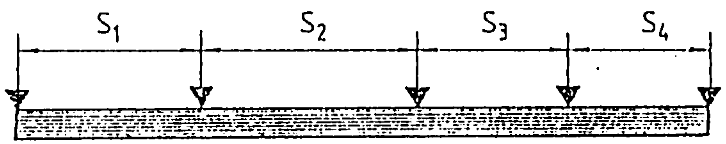
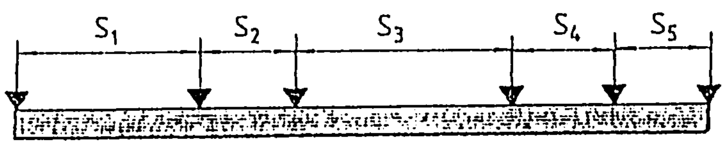
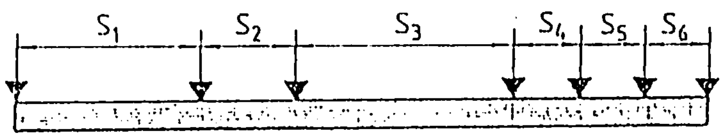
Category	No. of Axles	MOC Class	Spacing of Axles
	2	Class 1	s = 5.0–5.5 m (mostly in 5.2 and 5.4 m)
	3	Class 2 & 3	s_1 = 3.8–5.5 m (mostly in 5.0–5.5 m) s_2 = 1.2–1.4 m (mostly in 1.2 m)
	4	Class 4	s_1 = 3.3–4.0 m (mostly in 3.5–3.7 m) s_2 = 6.2–7.9 m (mostly in 6.5–7.5 m) s_3 = 1.2–1.7 m (mostly in 1.2–1.4 m)
	4	Class 5	s_1 = 3.3–3.8 m (mostly in 3.3–3.4 m) s_2 = 1.4–1.6 m s_3 = 3.8–5.5 m (mostly in 4.5–4.8 m)

TABLE 4.22 Cont.....

Category	No. of Axles	MOC Class	Spacing of Axles
	5	Class 6	$s_1 = 3.4–3.7$ m $s_2 = 1.3–1.5$ m $s_3 = 6.0–7.5$ m (mostly in 6.5–7.5 m) $s_4 = 1.4–1.9$ m (majority in 1.6 m)
	5	Class 7	$s_1 = 3.8–4.0$ m $s_2 = 6.4–6.5$ m $s_3 = 1.2–1.4$ m $s_4 = 1.2–1.4$ m
	6	Class 8	$s_1 = 3.6–4.0$ m $s_2 = 1.2–1.6$ m (mostly in 1.4 m) $s_3 = 9.0–9.6$ m $s_4 = 1.2–1.4$ m $s_5 = 1.2–1.4$m
	7	Other	$s_1 = 3.4$ m, $s_2 = 1.4$ m $s_3 = 6.7$ m, $s_4 = 1.2$ m $s_5 = 1.2$ m, $s_6 = 1.2$ m (only 1 truck found)

(ii) Although fines due to overweights are strictly enforced, trucks overweighing 10% or less in each category are exempted from fines.

(iii) Military vehicles of all types, including heavy ones, are not required to get screened at a truck weighing station. Their weights in many cases may far exceed the legal limits.

(iv) Heavy earth moving trucks with overweight permissions are normally exempted from penalty. The survey recorded a 110 Ton, 6-axle earth moving truck (overweight by more than 250%) which was exempted from fines.

(v) Many heavy-weight trucks use alternative routes or detours to escape fines, according to the personnel working at the stations. This problem is known to exist, as the truck operators cleverly and unscrupulously find their ways to avoid fines. Neither the number of such escapees nor the magnitude of illegal overweights can be realistically estimated.

(vi) On the Dammam-Riyadh highway, the truck movement on the route to Riyadh intensifies in the evenings, which frequently causes a long queue extending over 1.5 km. Consequently, in most peak hours, the trucks are waved away to pass without diverting them to the weighing scales to avoid traffic jam. In accordance with the information from weighing station, truck drivers often take a calculated risk to avoid the penalty by attempting to pass in the congested, evening peak hours.

(vii) At each of the weighing stations, the measurements are carried out properly and penalties are strictly enforced.

(viii) Trucks in GCC countries are not required to pass through the weighing scales.

(ix) It seems that the truck operators always find novel ways to beat the system! On the Dammam-Abu Hadriyah highway, according to observation made at the weighing station, a common practice with the truck operators is to use 3 or 4 legal weight trucks to cross the station and then 5 km or more down the road, the goods from some trucks are transferred to the other to empty them. The empty trucks then return to the base, minimizing the transportation cost. This practice is rewarding, as there is no other checkpoint down the road.

(x) Another recurring problem also seems to exist on the Dammam-Riyadh road. Many empty trucks engaged in transporting aggregates cross the station and, down the road somewhere, the trucks are filled with aggregates from the crusher plants or supply areas and then return unchecked on the road to Dammam. The sample survey has shown the evidence of a high percentage of overweight trucks. Trucks loaded with sand are the worst violators.

(xi) On the Dammam-Abu Hadriyah highway, the truck lane on the road to Dammam is relatively more damaged, providing evidence of overweight problems on this side of the highway which is not

controlled. Most of the heavy weight trucks here were observed to carry coarse aggregates. In the Eastern Province, the good source of coarse aggregates is from Abu Hadriyah and the numerous crusher plants supply the bulk of the aggregates for construction. Trucks carrying aggregates from the plants travel freely with no control and fear of penalty and take advantage of the situation by overloading the trucks.

4.7 CALCULATION OF EQUIVALENT BASE LENGTH

4.7.1 Subset of truck loads

The initial postulation of a hypothetical truck load for the purpose of design will be structured from the envelope of (W_m, B_m), where W_m is the weight of an axle or a group of axle loads for a truck and B_m , the equivalent base length (EBL), is the corresponding length of a uniformly distributed loading of intensity W_m/B_m .

For a given truck with N number of axle loads, there are many subsets of loads to be considered for B_m , taking N = 2,3,...N loads at a time. The number of possible subsets with N number of axles is ${}^{N}C_{N-2}/2$, i.e. N(N−1)/2. Thus, if there are four

axles. total number of subsets is 6. The computation formula for B_m is given in chapter 3.

Once the (W_m, B_m) space is constructed for a large volume of heavy trucks. the upper extreme boundary constitutes the worst scenario of heavy loading for a bridge whose span would exceed B_m . The initial formation of a design truck can therefore be conceived from this extreme boundary.

4.7.2 Calculation

A computer program (Appendix B.2) was written to automatically calculate EBL for sequential combinations of axle loads of a given truck loading.

The truck load survey results have revealed that despite controls, a very high percentage of trucks are overweight, the amount of overweights varying. In order to minimize the storage of EBL data, only overweight vehicles are considered. Thus, the collected truck data are first screened to pick up only those trucks which exceed the maximum limit. Trucks weighing below their legal weight limits are not accounted for in the EBL calculation.

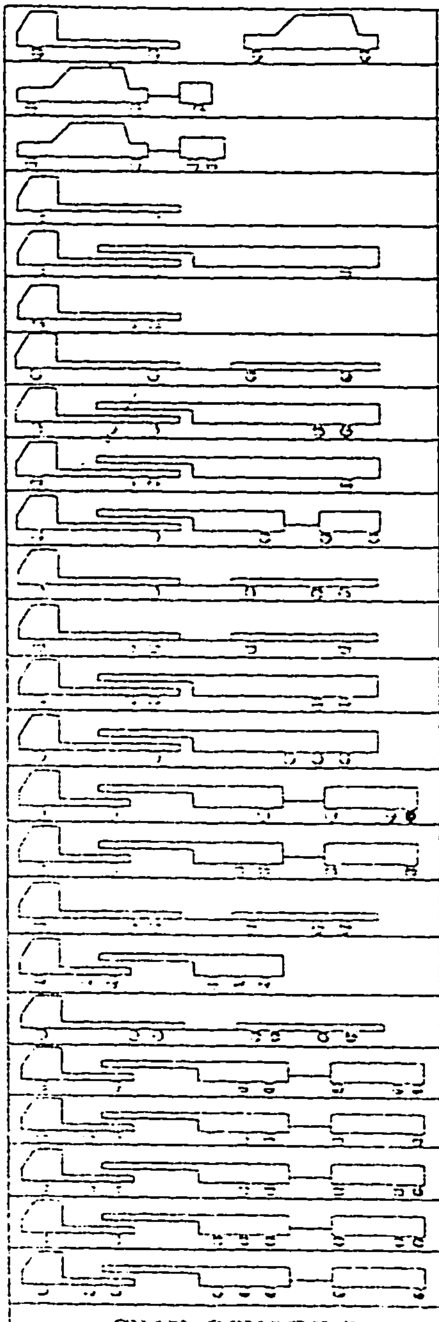
For EBL calculation. the information about a truck is fed into the program by the number of axles, weight of each axle starting from the front and the spacing of axles in the sequential order starting from the front axle. While the truck type and weight of axles are known for all trucks from MOC's data, unfortunately the spacings

of axles are not available. as the weighing stations do not have the capability to record the spacings. This indeed creates some difficulty, as the spacing of axles, whatever considered applicable, has to be entered for each truck manually into the program.

The task of assigning axle spacings was achieved by taking into consideration the known range for each category of truck types (Fig.4.24) and the findings of the survey undertaken by the team. Because of the problem of nonavailability of axle spacings, sample surveys were planned and conducted in Eastern, Western and Central Provinces. The survey results provided a data base for the average axle spacings for common trucks. The range of spacings of axles for various truck types recorded in the survey is shown in Table 4.22.

Based on the applicable ranges of axle spacings, the axle spacings for EBL calculation were selected for each truck, exercising judgement and conservatism. Admittedly, there are errors associated with the chosen spacings, as true spacings were not known for every truck. However, for regular trucks, axle spacings are fairly standard with small variation. In order to be conservative, the axle spacings were taken on the lower end of the range. The small error which may be introduced by the selected values of the axle spacings will not critically affect the end result. As an illustration of how EBL is calculated, an example is provided Appendix A.1.

AXLE SPACE COMBINATION



1	2	3	4	5	6	7	CLASS NO.
B							1
B	BC						2
B	BC	A					2
CD							3
CD	BCD						4
BCD	A						5
CD	BCD	CD					6
CD	CD	AB					7
BCD	A	CD					7
CD	CD	BCD	CD				8
CD	BCD	CD	AB				9
BCD	A	BCD	CD				9
BCD	A	CD	AB				9
CD	CD	A	AB				10
CD	CD	BCD	CD	AB			11
CD	CD	A	BCD	CD			11
BCD	A	BCD	CD	AB			11
BCD	A	CD	A	AB			12
BCD	A	BCD	A	CD	AB		13
CD	CD	A	BCD	CD	AB		13
BCD	A	CD	A	BCD	CD		13
BCD	A	CD	A	BCD	CD	AB	14
CD	CD	A	AB	BCD	CD	AB	14
BCD	A	CD	A	AB	BCD	CD	14
THE OTHERS							15

AXLE DISTANCES

$0.50 < A < 1.80$ (METER)

$1.80 \leq B < 3.30$

$3.30 \leq C < 5.50$

$5.50 \leq D < 10.00$

Fig. 4.24 Vehicle Classification for Traffic Volume Survey

4.7.3 W_m–B_m Plot

W_m and B_m values for 8165 overweight trucks giving a total combination sets of 61,411 were stored. The data points are plotted in Fig. 4.25 to show the entire space. Because of congestion and almost identical values, the coordinates of data get overlapped and this results in a blurred presentation. Nevertheless, Fig. 4.25 captures the space and portrays clearly the cluster or concentration of values and the spread of the points.

As a better perception of the relative concentration of data, Fig. 4.26 is plotted by grouping the values of W_m and B_m into subsets in which weight W_m is incremented in steps of 5 tons, and B_m in steps of 2.5 m. The number of data points belonging to each subset is shown in Fig. 4.26. Thus, for example, the number 417 under the subset of W_m = 35-40T and B_m = 5-7.5 m means 417 values from the entire data set of (W_m, B_m) lie within the subset of W_m = 35-40T and B_m = 5-7.5 m.

Data in Figs. 4.25 and 4.26 are collective presentation of all the values for the years 1413, 1414, 1415H, 1416H and surveys conducted by KFUPM team.

4.7.4 Discussion of Results

The results of W_m and B_m calculated and compiled thus far are shown in Figs. 4.25 and 4.26. Results show that most of the data lie within the range of W_m = 50T and B_m = 18 m. The largest concentration of the number of W_m's (total number =

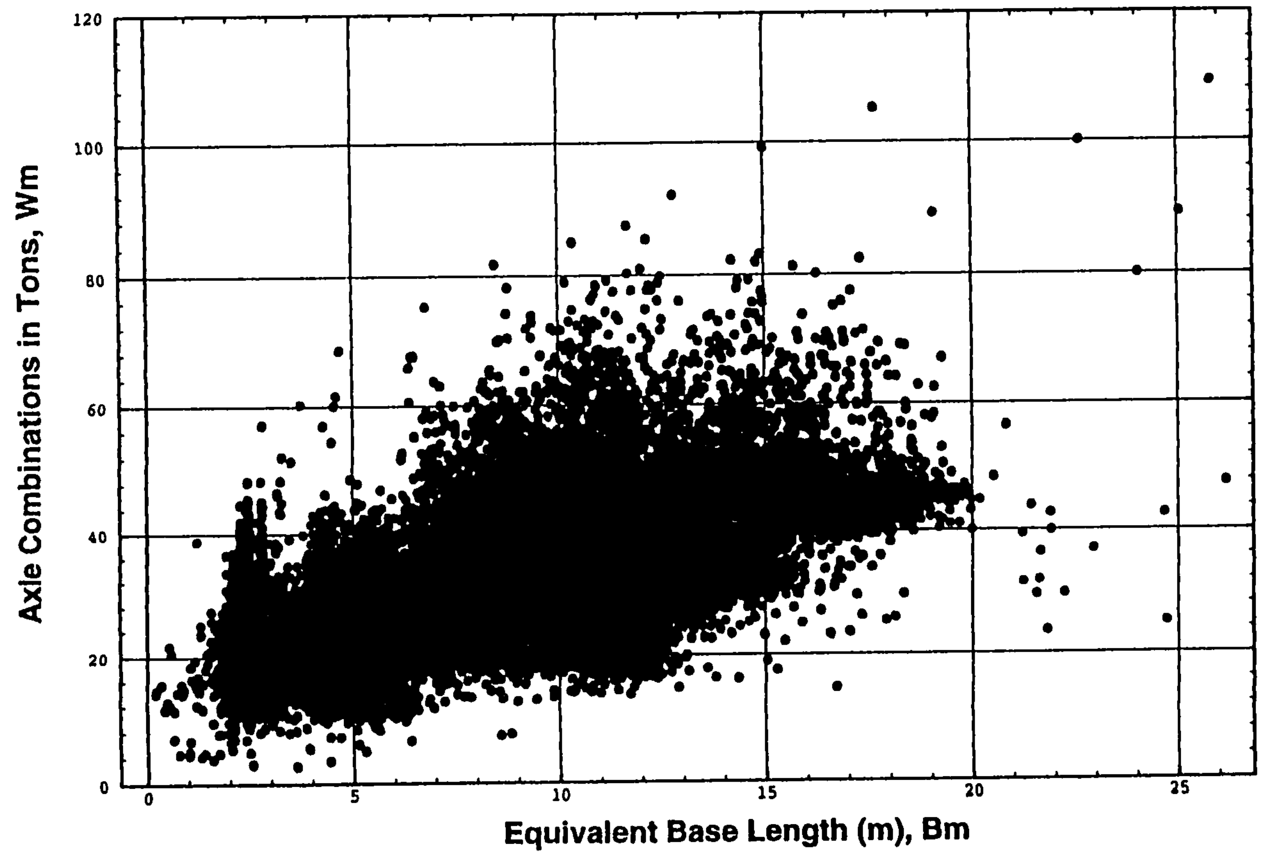


Fig. 4.25 Scatter Diagram of Wm Vs. Bm

Wm (tons) \ Bm (m)	0–2.5	2.5–5	5–7.5	7.5–10	10–12.5	12.5–15	15–17.5	17.5–20	20–22.5	22.5–25	25–27.5
115–120	0	0	0	0	0	0	0	0	0	0	0
110–115	0	0	0	0	0	0	0	0	0	0	0
105–110	0	0	0	0	0	0	0	1	0	0	1
100–105	0	0	0	0	0	0	0	0	0	1	0
95–100	0	0	0	0	0	0	1	0	0	0	0
90–95	0	0	0	0	0	1	0	0	0	0	0
85–90	0	0	0	0	4	0	1	1	0	0	1
80–85	0	0	0	2	8	9	4	0	0	1	0
75–80	0	0	1	4	40	14	5	0	0	0	0
70–75	0	0	0	11	61	28	10	0	0	0	0
65–70	0	1	4	24	110	43	26	7	0	0	0
60–65	0	4	15	67	196	84	47	5	0	0	0
55–60	0	2	33	148	291	141	61	12	1	0	0
50–55	0	10	62	307	466	263	141	32	0	0	0
45–50	17	16	88	498	1535	1724	847	277	2	0	1
40–45	76	81	222	1345	1257	1089	949	274	2	1	0
35–40	149	192	417	2306	2681	1361	103	9	3	1	0
30–35	400	525	1125	2823	2483	1475	74	1	2	0	0
25–30	1501	1383	1695	2755	2417	294	14	3	2	1	0
20–25	3759	5258	2514	745	584	38	4	0	1	0	0
15–20	2589	2100	1039	650	624	13	2	0	0	0	0
10–15	279	959	843	13	9	1	1	0	0	0	0
5–10	31	21	12	2	0	0	0	0	0	0	0
0–5	7	3	0	0	0	0	0	0	0	0	0

Axle Combinations, Wm in Tons

Bm in m.

Fig. 4.26 Frequency Plot Wm Vs. Bm

5258) falls into the range of W_m= 20 to 25T with the B_m in the range of 2.5-5 m. The next largest concentration (3759) lies within W_m= 20-25T with B_m = 0-2.5 m.

Due to the existence of heavier and longer trailer type trucks (although their number is relatively small but not statistically insignificant), the (W_m, B_m) space contains few points away from the normal concentration. Results show that heavier loads are associated mostly with longer trucks (B_m increasing with increasing W_m). This is encouraging, as heavier trucks of shorter lengths would be more critical for design.

CHAPTER 5

5. PROPOSED BRIDGE LOADING

5.1 INTRODUCTION

The hypothetical truck load for the purpose of design was structured from the envelope of (W_m, B_m), where W_m is the weight of an axle or a group of axle loads for a truck and B_m, the equivalent base length (EBL), is the corresponding length of a uniformly distributed loading of intensity W_m/B_m. W_m and B_m values for about 8165 overweight trucks having 61,411 possible combinations were evaluated in this work. The plot of W_m vs. B_m is shown in Fig. 4.26. This plot was used to build a model truck load for design of short span bridges in Saudi Arabia. From the point of view of application it is evident that a simple, continuous function of B_m is required.

5.2 DEVELOPMENT OF A FUNCTION OF B_M

The distribution of subsets of W_m and B_m, as depicted in Fig.4.26, shows a trend which can be represented by a non linear relationship between W_m and B_m. After several trials, the following format is adopted, which appears to fit well with the envelope.

$$Wm = W_o + a_1 B_m - a_2 B_m^2. \qquad (5.1)$$

Interestingly, this format is similar to the one adopted by Ontario Bridge Formula developers (24). In determining the three constants in Eq. 5.1, the following considerations were made:

1. When $B_m = 0$, $W_m = W_o$. Consequently, W_o can be defined as the maximum single axle weight for design. The MOC Riyadh specifies 13 Ton (130 kN) as limit for ordinary single axles and 6 Ton (60 kN) for steering axles. The extensive survey conducted in this study revealed that an axle as heavy as 30 Ton (300 kN) or more is occasionally observed. The survey results showed that less than 0.005% of weighed single axle loads exceeded 20 Ton (200 kN). However, in recognition of the fact that axle loads as high as 30 Ton can be occasionally encountered in highways, a single axle load of 26 Ton is adopted as the design load for bridges keeping

it same as the current MOC's maximum truck axle load of 260 kN (Fig 1.3). Thus, W_o is taken as 260 kN.

2. Current Saudi Arabian national truck standard forbids vehicles or vehicle trains longer than 18 m without a special permit. B_m plot in Fig. 4.26, shows that beyond B_m = 20m, only a handful of points (a total of 21 out of over 61000) exists and these longer B_m values correspond to 8 - axled special long trailer type trucks whose numbers are relatively small. Thus a maximum length of B_m = 20m can be established with a strong conviction.

3. Currently the maximum permissible weight of a vehicle is 40 tons. However, the survey data presented in Chapter 4 show that the overloading phenomenon still exists to a high degree in the Kingdom. It is anticipated that in those roadway networks where there is no control, the overweight problem is more prevalent. The W- B_m plot in Fig. 4.26 also shows very few overweight trucks beyond W= 80 T, only a few overweight trucks are observed. Consequently, it was adopted that the formula should satisfy the combination: B_m = 20 m and W_m = 80 T ($\cong$ 800 kN).

4. Equation 5.1 should cover majority of the data in Figs. 4.25 and 4.26 with only few points lying outside.

5.3 PROPOSED BRIDGE LOAD FORMULA

Using the above postulations and taking into consideration the permissible over stress for extremely heavy trucks which are statistically not very significant, the values of the coefficients a_1 and a_2 in Eq. 5.1 were sought. From several trials, values were determined as $a_1 = 4.80$ and $a_2 = 0.105$. Consequently the equation of W_m (in kN) becomes:

$$W_m = 260 + 48\ B_m - 1.05\ B_m^2 \quad \text{.... for } Bm \leq 20m. \qquad (5.2)$$

The maximum value of B_m = 20m with W_m = 800 kN.

Figs.5.1 and Fig. 5.2 shows the plot of Eq. 5.2 on the W_m and B_m plot. As seen, the proposed equation envelopes most of the data. Any attempt to push the curve further upward so as to include more points, would be unreasonably uneconomical and to extend the curve further down would be less conservative and risky.

Equation 5.2 can be used to find the design moments on a given span. However, for smaller span lengths ($L \leq 3$ m), the use of single axle load of 260 kN

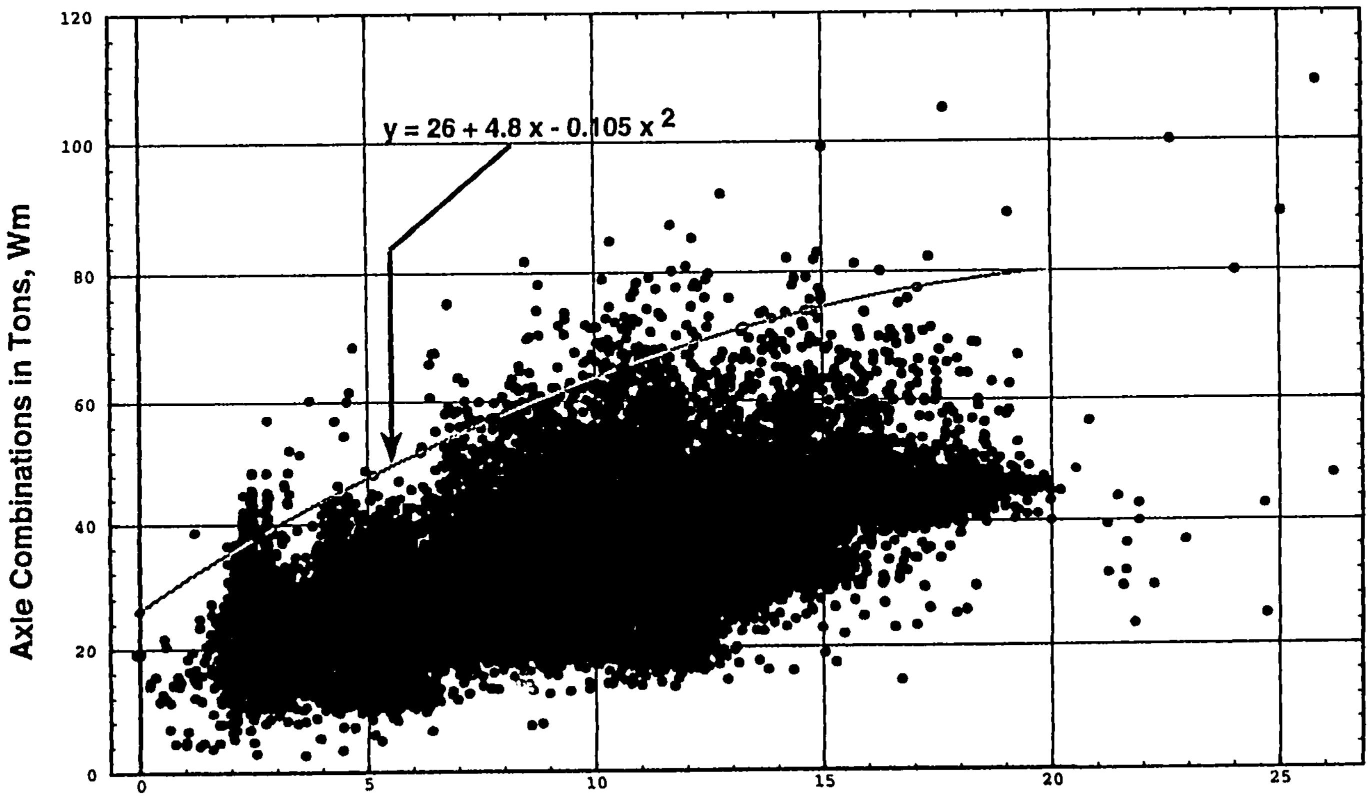
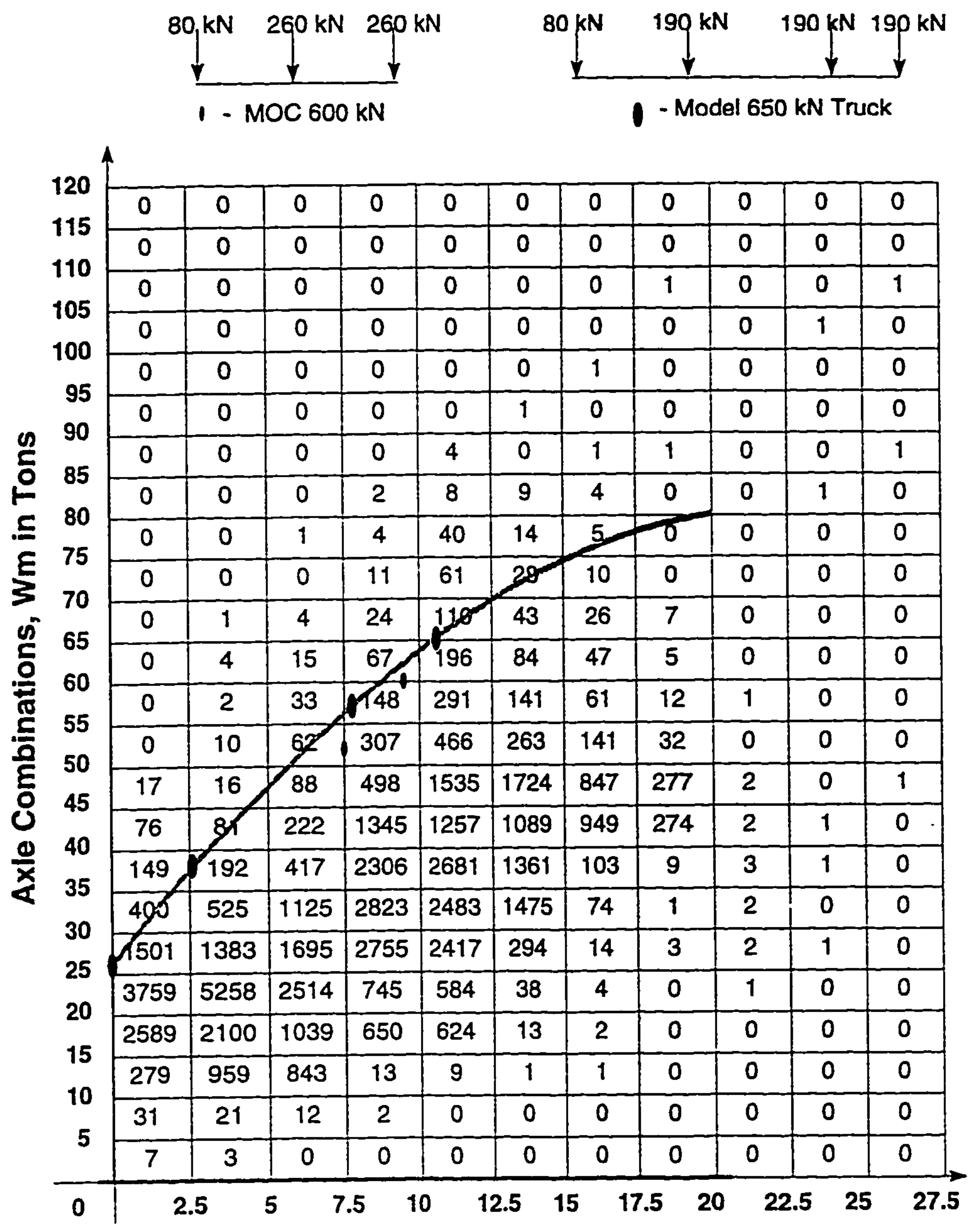


Fig. 5.1 Proposed Bridge Load Envelope on Scatter plot.



0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0
0	0	0	0	4	0	1	1	0	0	1
0	0	0	2	8	9	4	0	0	1	0
0	0	1	4	40	14	5	0	0	0	0
0	0	0	11	61	29	10	0	0	0	0
0	1	4	24	110	43	26	7	0	0	0
0	4	15	67	196	84	47	5	0	0	0
0	2	33	148	291	141	61	12	1	0	0
0	10	62	307	466	263	141	32	0	0	0
17	16	88	498	1535	1724	847	277	2	0	1
76	81	222	1345	1257	1089	949	274	2	1	0
149	192	417	2306	2681	1361	103	9	3	1	0
400	525	1125	2823	2483	1475	74	1	2	0	0
1501	1383	1695	2755	2417	294	14	3	2	1	0
3759	5258	2514	745	584	38	4	0	1	0	0
2589	2100	1039	650	624	13	2	0	0	0	0
279	959	843	13	9	1	1	0	0	0	0
31	21	12	2	0	0	0	0	0	0	0
7	3	0	0	0	0	0	0	0	0	0

Fig. 5.2 Proposed Bridge Load Envelope

will govern. Therefore for L ≤ 3 m. a single concentrated load of 260 kN should be considered for the maximum moment.

The Proposed Bridge Load (PBL) equation (Eq. 5.2) cannot, however, be used directly in a design, as the two parameters, B_m and the corresponding W_m are not known apriori for a given bridge span, L. However, it is possible to determine the value of B_m which will maximize the moment in a simple beam, of span L.

5.3.1 Determination of the value of Bm which maximizes the moment

At any given point of a simply supported beam, maximum moment caused by a load uniformly distributed over a finite length B_m can be expressed by the following formula (24):

$$M = \xi W(1 - Bm/2L) \qquad (5.3)$$

Where: ξ = maximum influence line ordinate;

W = gross load, and

L = Span length.

If load W corresponds to the Proposed Saudi Bridge Formula (Equation 5.2). Equation 5.3 becomes:

$$M = (\xi / 2L)[2L - Bm][260 + 48Bm - 1.05Bm^2] \tag{5.4}$$

In order to obtain maximum moments, Equation 5.4 should be differentiated with respect to B_m . After equating the differential to zero and regrouping, B_m can be expressed thus:

$$B_m = \frac{(2a_1 + 4a_2L) \pm \sqrt{(2a_1 + 4a_2L)^2 - 12a_2(2a_1L - W_{o})}}{6a_2} \tag{5.5}$$

Thus for a given bridge span L, the value of B_m for maximum moment has to be first determined by Eq. 5.5 ($B_m \leq 20$ m). Once, B_m is known, the corresponding value of W_m can be determined from Eq. 5.2. The applied distributed load would be then W_m / B_m over a length of B_m. If the calculated value of B_m exceeds 20m, the value of B_m shall be taken as 20m with W_m = 800 kN. Table 5.1 shows the calculated values of B_m from Eq.5.5 for each 5m interval of simple span L, the corresponding value of W_m from Eq. 5.2 and the maximum moment at midspan due to this load.

The Proposed bridge load formula (PBL) is as follows:

(i) for $L \leq 3$ m, use a single concentrated load of 260 kN.

(ii) for $L > 3$ m, find the value of B_m from Eq. 5.5 ($B_m \leq 20$ m) and then the value of corresponding W_m from Eq. 5.2. With

TABLE 5.1 Maximum Moments from Proposed Bridge Load Formula (PBL)

Span 'L' (m)	B_m from Eq. 5.5 (m)	W_m (kN)	Max. Moment M_{PBL}(kN.m)
5	1.986	352	352
10	5.855	505	893
15	9.040	608	1594
20	11.560	674	2398
25	13.500	716	3270
30	14.990	743	4184
35	16.130	761	5125
40	17.010	772	6084
45	17.710	780	7055
50	18.270	786	8034

the distributed load of W_m / B_m over a length of Bm, calculate the maximum moment from the following relationship:

$$M_{max} = \frac{W_m(2L - B_m)}{8} \tag{5.6}$$

5.4 PROPOSED TRUCK LOADING

A design truck load system that would give the same moments as the proposed W_m - B_m equation within an acceptable deviation limit has also been developed. In developing a model truck load, the following factors were considered.

(i) The W_m- B_m values of the subsets of the proposed truck should lie as close as possible to the W_m- B_m curve (Figs. 5.1 and 5.2).

(ii) Since over 80% of truck population corresponds to MOC class 4 and 5 (4 axle), a four axled model truck should be more representative of the current scenario.

(iii) The truck length should be kept to a minimum to conform with the smaller dimensions observed in the survey.

Several truck configurations were tried such that the equivalent base length envelope of the truck is close to the proposed W_m - B_m curve. Trucks with gross loads of 62 tons to 68 tons of MOC class 4 type were frequently noted in the KFUPM sponsored surveys on the non-regulated freeways in the Eastern Province. It was therefore, decided to adopt a 650 kN truck of 10 m length between the front and the rear axle as shown in Fig. 5.3. This truck is similar to the MOC Class 4 truck. The EBL envelope of this truck, shown in Fig. 5.2, follows the pattern of the Eq. 5.2, almost coinciding with the EBL curve. The center to center spacing between the axles approximately represent the shorter 'real' truck dimensions found during the survey. The lateral dimensions of this truck are kept unchanged from those prescribed for the current MOC 600 kN truck, as the survey showed that the transverse distance between the wheels of the truck (wheel base) is only slightly more than 1.8 m.

To prove the adequacy of the proposed 650 kN Model Truck, the values of calculated maximum moments are shown in Table 5.2 as M_{PTL} along with the values of M_{PBL}. Results show that upto about 20m, the values of M_{PBL} and M_{PTL} are almost identical. However, the results for longer span (L > 20m) clearly show the divergence in two sets of values as the moments due to the proposed truck, M_{PTL}, fall short of the values from EBL approach, M_{PBL} with an increasing error. This clearly indicates that only for spans upto 20m, the truck load can be used. For spans greater than 20m, the B_m formula has to be used to calculate the moments.

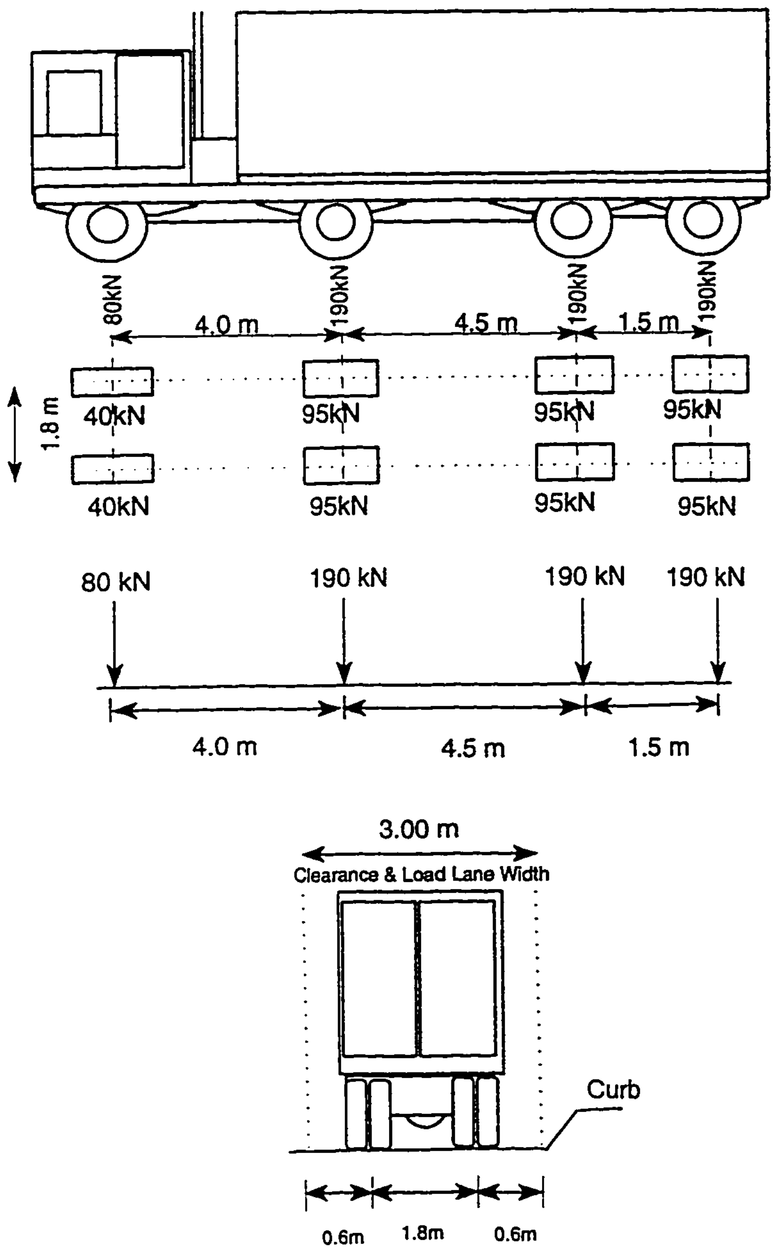


Fig. 5.3 Proposed Truck Loads - 650 kN

TABLE 5.2 Maximum Moments due to Proposed Bridge Load Formula(PBL), Proposed 650 kN Truck Model (PTL), and MOC 600 kN Truck Model (MOC).

Span 'L' (m)	Max.Moment M_{PBL}(kN.m)	Max.Moment M_{PTL} (kN.m)	Percentage error *	Max.Moment M_{MOC} (kN.m)	Percentage error **
5	352	343	−2.55	325	−7.67
10	893	903	+1.12	769	−13.88
15	1594	1568	−1.63	1519	−4.70
20	2398	2340	−2.42	2269	−5.38
25	3270	3153	−3.57	3019	−7.67
30	4184	3965	−5.23	3769	−9.92
35	5125	4778	−6.77	4518	−11.84
40	6084	5590	−8.12	5269	−13.39
45	7055	6403	−9.24	6019	−14.68
50	8034	7215	−10.20	6769	−15.74

* Percentage error = $(M_{PTL} - M_{PBL}) / M_{PBL}$

** Percentage error = $(M_{MOC} - M_{PBL}) / M_{PBL}$

In order to elucidate how MOC 600 kN is represented by EBL, W_m and the related B_m are plotted in Fig.5.2 for this truck. The points lie slightly below the W_m-B_m envelope of Eq.5.2. This is an encouraging finding, as it demonstrates that the current MOC 600 kN is a reasonably sound design truck load. The proposed truck loading is slightly heavier and more reflective of the current truck loading situation, and therefore its adoption in design is more appropriate.

5.5 COMPARISON OF MOMENTS FROM PBL WITH THOSE FROM MOC LOADING

The proposed bridge loading, PBL, is based on B_m values. The maximum values of moments for various simple spans are shown in Table 5.2. The values of the maximum moments for the proposed truck load, PTL, are also shown in Table 5.2 along with the values obtained from MOC loading. The current MOC truck loading comprises of a MOC 600 kN truck load or a uniformly distributed lane load of 11 kN/m plus a concentrated load of 100 kN for moments (Fig. 1.3 and Fig. 1.4), whichever controls. The MOC lane load does not govern the maximum moments for simple span range considered herein.

The comparison of loading shows the following:

(i) PTL values are acceptable only for $L \leq 20$ m. For this range, PBL and PTL values are almost the same.

(ii) For $L > 20$ m, PBL values are to be used, as PTL would not govern i.e. distributed load intensity of W_m / B_m over B_m is a more critical loading.

(iii) Moments from MOC truck are obviously lower than PBL and PTL values and the difference in values between M_{PBL} and M_{PTL} increases with increasing L. This observation is important, as it demonstrates that for longer spans, MOC truck may not be appropriate, as it yields moment values much lower than PBL values, the error exceeding the acceptable limit of say 5%.

5.6 MODIFIED BRIDGE LOADING

In order to present a simplified approach to compute maximum moment from the proposed bridge load formula without requiring the calculation of the required B_m from Eq. 5.5, an effort was made to use $B_m = L$, for $L \leq 20$ m (as the maximum value of $B_m = 20$ m). However, this simplification would inevitably introduce an unacceptable error in the design. The degree of error associated with the proposition of $B_m = L$, for $L \leq 20$ m is indicated in Table 5.3 which shows the maximum values of moment for simple spans using first the value of B_m from Eq. 5.2 (exact) and then the value of $B_m = L$ for $L \leq 20$ m. In Table 5.3, the value of W corresponds to

Table 5.3 : Maximum Moments due to Proposed Bridge Load Formula (PBL) and Modified Bridge load formula (MBL)

Span 'L' (m)	B_m from Eq.5.5 (m)	W_m (kN)	Max. Moment from PBL M_{PBL} (kN.m)	B_m from Sec.5.6 (m)	W from Sec.5.6 (kN)	Max.Moment due to W M_{MBL} (kN.m)	Percentage error
5	1.986	352	352	5	474	296	−15.90
10	5.855	505	893	10	635	794	−11.08
15	9.040	608	1594	15	744	1395	−12.48
20	11.560	674	2398	20	800	2000	−16.59
25	13.500	716	3270	20	800	3000	−8.24
30	14.990	743	4184	20	800	4000	−4.38
35	16.130	761	5125	20	800	5000	−2.40
40	17.010	772	6084	20	800	6000	−1.38
45	17.710	780	7055	20	800	7000	−0.8
50	18.270	786	8034	20	800	8000	−0.4

the case of $B_m = L$ and is calculated from Eq. 5.2 by substituting the value of B_m by L. For $L \leq 20$ m, the maximum moment due to W is therefore equal to:

$$M_{max} = WL/8. \qquad (5.7\ a)$$

For the case of $L > 20$ m, $B_m = 20$m, W = 800 kN and the corresponding maximum moment is given by:

$$M_{max} = W\,(2L - 20)/8 \qquad (5.7\ b)$$

Two sets of moment values presented in Table 5.3 clearly show that M-values, corresponding to W are smaller than the maximum moment values, as expected. The percentage error however decreases with increasing L. For those spans, where the value of B_m from Eq. 5.5 equals or exceeds 20m, the two sets of M-values (M_{MBL} and M_{PBL}) would be equal and this happens with $L \geq 70$m.

In order that moment values calculated with W can be used, as it is simpler to calculate them, it is necessary to find an appropriate multiplying factor 'α' by which the moment values calculated with W can be made equal to maximum moment values calculated with B_m from Eq. 5.5, (i.e.) α (M_{MBL}) would be close to M_{PBL} values.

Through a regression analysis, the proposed multiplying factor ' α ' is given as :

$$\alpha = 1.014 + 0.0158(L) - 0.00046(L)^2 \quad \text{......for } L \le 35 \text{ m.} \qquad (5.8)$$

$$\text{and} \quad \alpha = 1.0 \quad \text{........ for } L > 35 \text{ m.}$$

The values of α for different span lengths and the corrected Moment ' α M_{MBL}' are shown in Table 5.4. The excellent agreement between M_{PBL} (the actual maximum values from PBL) and α M_{MBL} (from modified formula) shows that the simplified method of calculating maximum moment can be used. In Fig. 5.4 three sets of moment values corresponding to (i) the modified load model, (ii) MOC 600 kN truck, and (iii) the proposed 650 kN truck are shown for a comparative study.

5.6.1 Proposed Modified Bridge Loading for Simple spans.

For the purpose of design, the following modified loading is proposed which obviates the need of a specified truck load and the lane load for calculation of maximum moments. The proposed approach is applicable for all simple spans. However, it should be recognized that truck load would govern the maximum shear values for live load.

Table 5.4. Comparison of Load Models

Span L (m)	M_{PBL} (kN.m)	M_{MBL} (kN.m)	α from Eq.5.8	αM_{MBL} (kN.m)
5	352	325*	1.0815	352
10	893	794	1.1260	894
15	1594	1395	1.1475	1600
20	2398	2000	1.1460	2292
25	3270	3000	1.1215	3364
30	4184	4000	1.0740	4296
35	5125	5000	1.0	5000
40	6084	6000	1.0	6000
45	7055	7000	1.0	7000
50	8034	8000	1.0	8000

* - Moment Calculated from application of Single 260 kN Axle load.

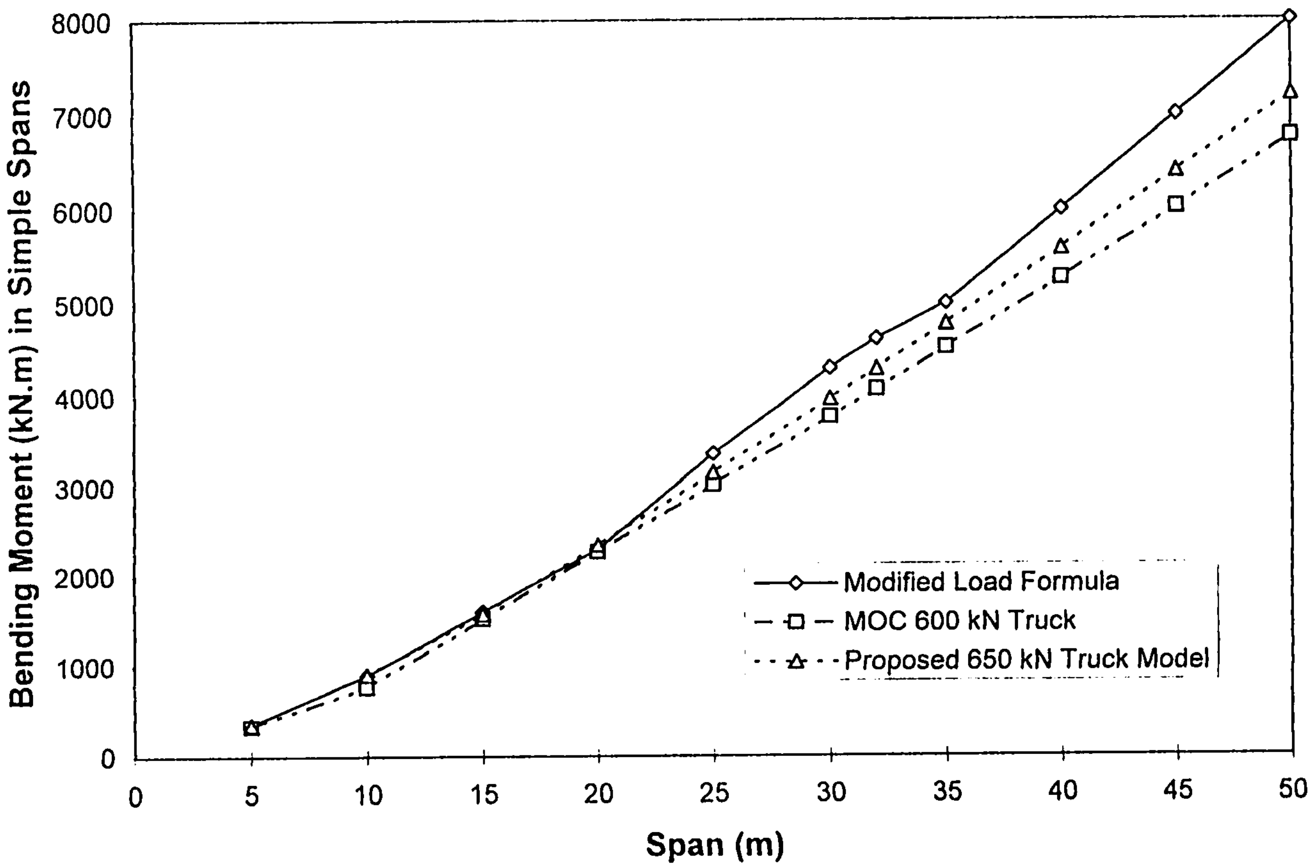


Fig. 5.4 Comparison of Load Models

(i) For $L \leq 6.3$m, use a single axle load of 260 kN .

$$M_{max} = 260 \times L/4 \text{ kN.m.}$$

(ii) For $6.3 < L \leq 20$ m; $B_m = L$.

$$M_{max} = \alpha \, W \, L/8 \text{ kN.m.}$$

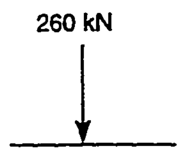
(W is calculated from Eq.5.2 with $B_m = L$); α is given by Eq. 5.8.

(iii) For $L > 20$m, $B_m = 20$ m

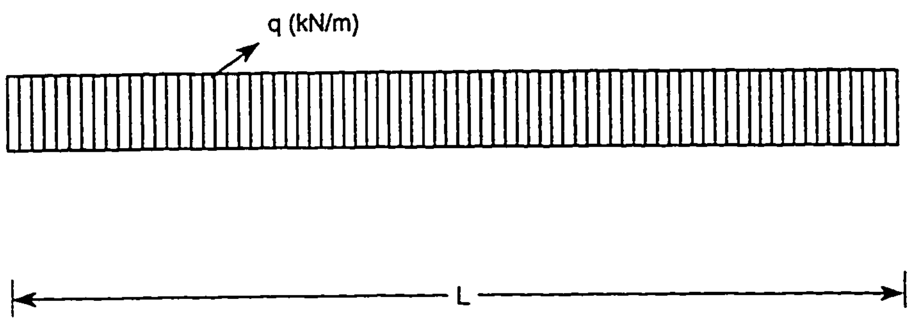
$$M_{max} = \alpha \, W_m .(2L - 20)/8 \text{ kN.m}$$

where $W_m = 800$ kN and 'α' is given by Eq. 5.8.

Fig. 5.5 shows the presentation of the proposed modified bridge loading. Although the accuracy of the proposed uniformly distributed loading yields highly accurate results for simple spans, its accuracy needs to be checked for continuous spans.



(a) Proposed Single Axle Load (For Spans < 6.3 m)



(b) Uniformly distributed load q (For Spans > 6.3 m)

(i) For 6.3 m < L < 20 m;

$B_m = L$ and $q = W_m/L$ (W_m from Eq.5.2)

(ii) L > 20m;

q = 40 kN/m over a length of 20m.

Fig. 5.5 Proposed Modified Bridge Loading for Maximum Moments

CHAPTER 6

6. COMPARATIVE STUDY OF THE LOAD MODELS

6.1 INTRODUCTION

One of the reliable ways to evaluate the adequacy of the MOC 600 kN Truck Load Model for design of short span highway bridges is to compare the results of maximum design forces obtained, with those resulting from the application of actual heavy trucks recorded during the load survey. Also the comparison of Proposed 650 kN Truck load model with the present MOC 600 kN load model can assure the reliability and efficiency of the present load model, as the Proposed Load model has been developed based on a comprehensive truck traffic weight survey. In order to ensure the adequacy of the present MOC loading, bridges of different spans, both simple and continuous, must be considered. Furthermore, as slab-type and girder-slab

type bridges are often used in short span bridges, both types need to be included in this comparative study of the maximum design forces.

Analysis of bridge decks, simple and continuous, is performed using: (a) the MOC 600 kN Truck, (b) the proposed 650 kN Truck, and (c) an actual 790 kN Class 4 type truck which is taken as representative of the worst loaded trucks for bridges. This truck loading was encountered in the survey. In the simple spans, truck load produces the worst force effects for short span, simple bridge decks. For continuous spans, use of uniformly distributed lane loads determine the maximum negative moments. However, only truck loads are used to analyze the two span continous bridge decks to have a global comparison.

6.2 BRIDGE DECK GEOMETRY

As indicated earlier, only two types of bridge decks will be studied: (a) slab type and (b) girder-slab type. The width of the deck to be considered will correspond to one-lane and two-lane only.

The geometry of the slab-type bridge deck is shown in Fig.6.1. The total width *b* including curb and parapet is taken as 5m for a one-lane and 8.5m for a two-lane bridge deck. The span of the simple bridge deck is varied from 6.0m to 21.0m in steps of 3.0 m. The span range for two span continuous bridge decks varies from 12.0m to 18.0m each, in increments of 3.0m.

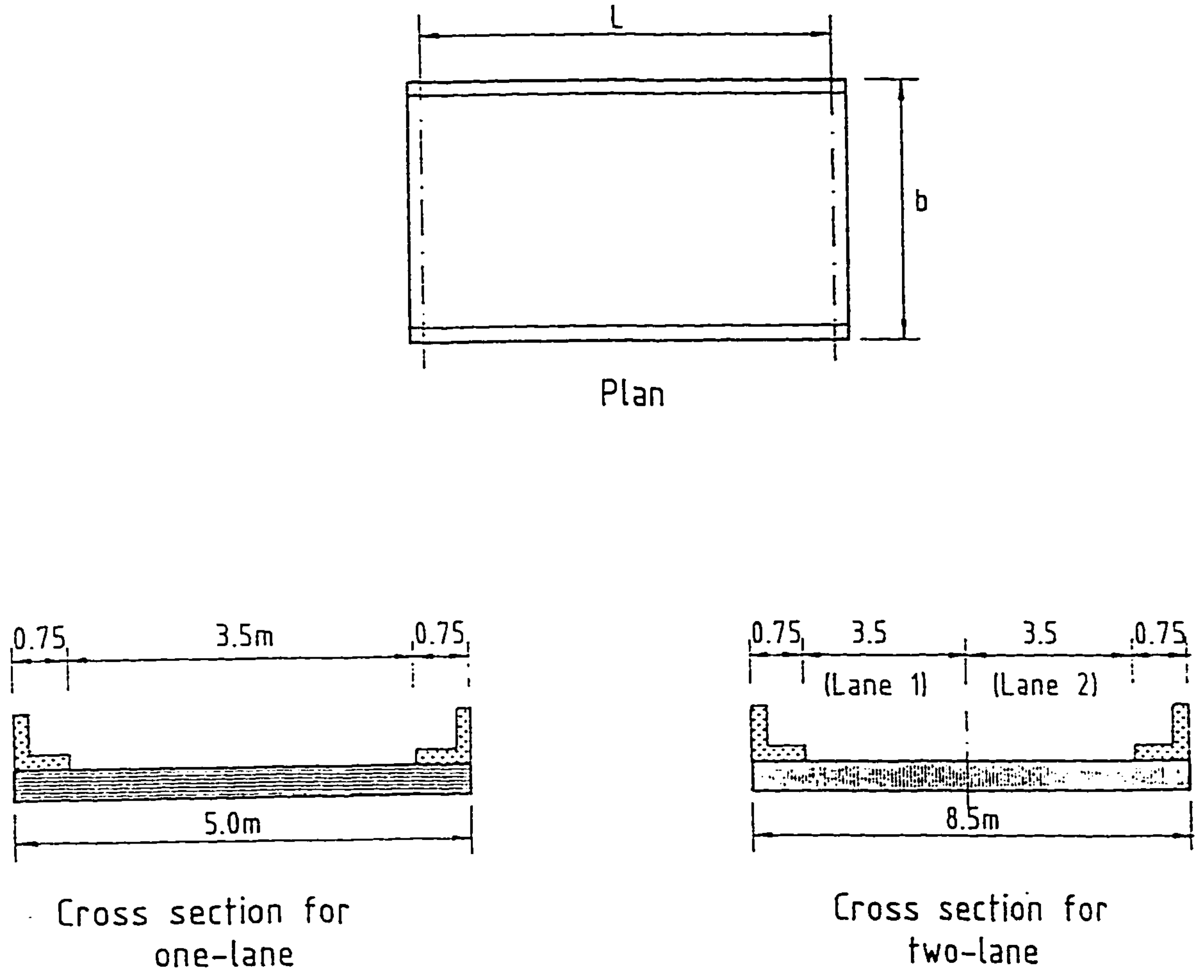


Fig. 6.1 Geometry of Slab-type Bridge Decks

The geometry of the girder-slab type bridge deck is shown in Fig.6.2 for both one-lane and two-lane decks. Three values of the spacing of girders, *s*, are used: *s* = 2.25 m, 2.50 m and 2.75 m. The span *L* for simple spans is varied from 8.0 m to 24.0 m in increment of 4 m. Spans 32.0m and 40.0m are also included in the study. The span range for two span continuous bridge decks, under girder type varies from 12.0m to 18.0m in increments of 3.0m. The value of '*s*' chosen falls in the range of commonly used values. Although steel I-girders are shown in Fig.6.2, the girders can be of reinforced concrete or prestressed concrete members. The analysis would require the applicable values of the material and structural properties.

6.3 ANALYSIS

Each bridge deck was analysed using MOC 600 kN, proposed 650 kN Truck, and a sample 790 kN Class 4 type truck vehicle. The line sketches for the three vehicles are shown in Fig. 6.3. The 790 kN vehicle is not common. However, it has been used. The vehicles were positioned in accordance with the AASHTO guidelines which prescribe a minimum edge distance of 0.61 m (2.0 ft) from the curb and a distance of 0.61 m from the lane line for placement of a wheel load on the deck. This was followed by positioning the truck(s) on the deck for computation of the maximum bending moments in the girders. For girder-slab type bridge decks, the

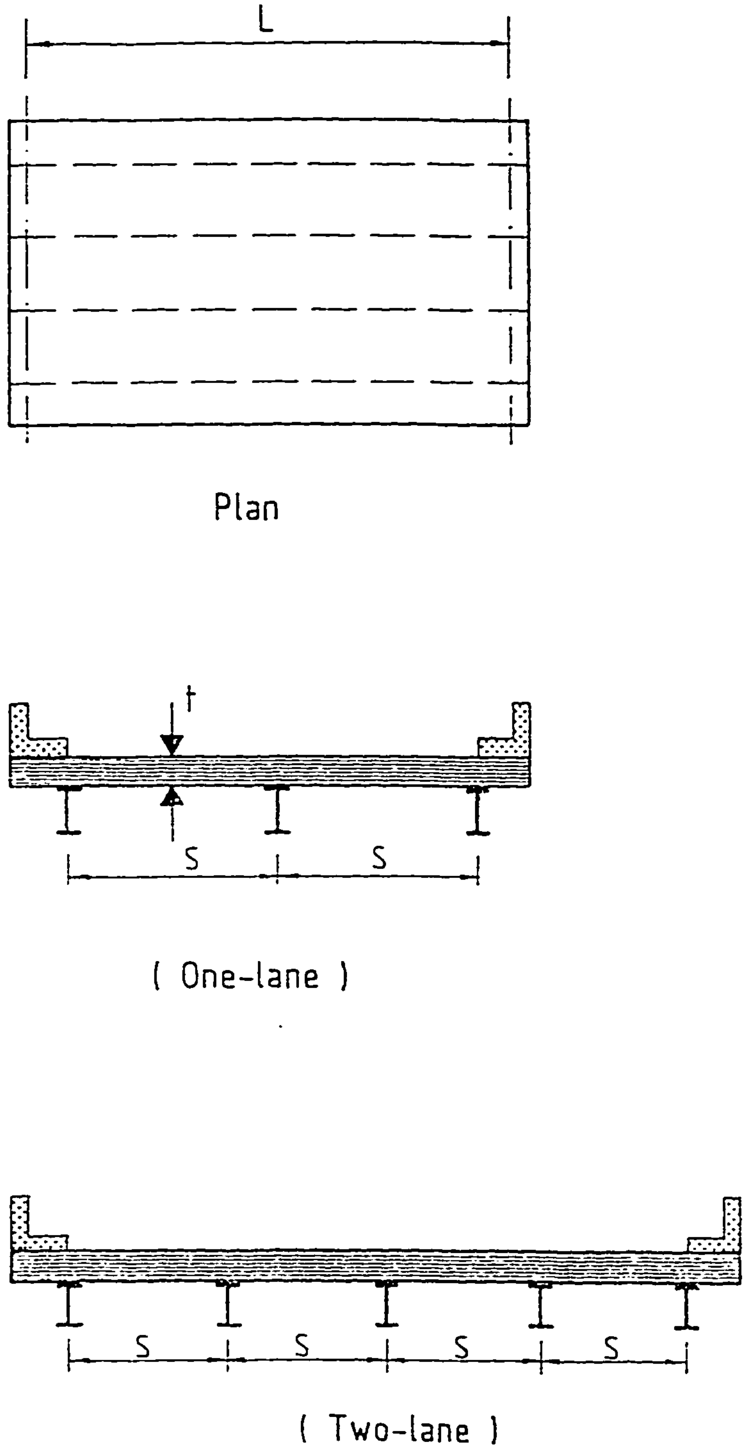
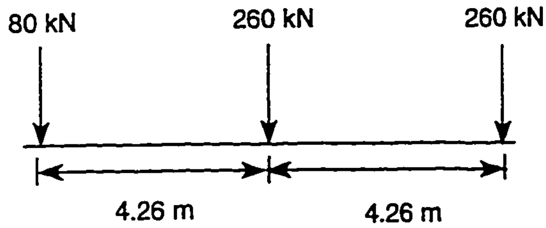
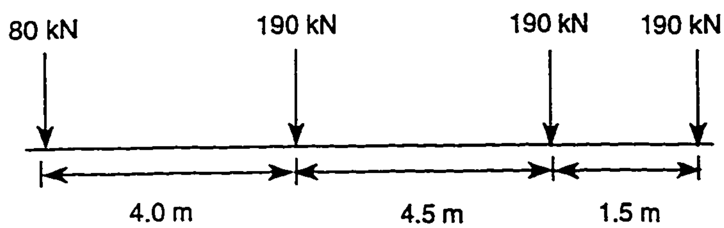


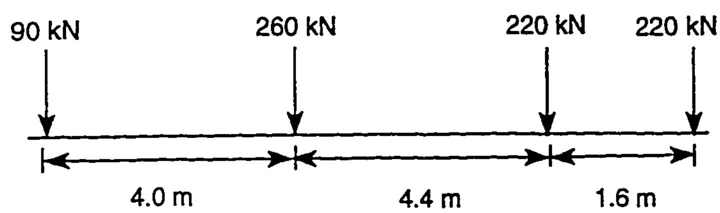
Fig. 6.2 Geometry of Girder-slab type Bridge Decks



(a) MOC 600 kN Truck



(b) Proposed 650 kN ModelTruck



(c) Sample 790 kN Truck

Fig. 6.3 Line Sketches of Trucks used in Girder slab and Slab Type Analysis .

maximum values of bending moments were calculated for the exterior girder and the critical interior girder.

A linear elastic analysis was carried out for each case using a finite element code of GT STRUDL package. The deck slab was discretized as a two-dimensional quadrilateral plate element with six degrees of freedom and the longitudinal beams were idealized as a one-dimensional beam element.

The following material properties were used:

for concrete: $E = 24.8 \times 10^3$ MPa; $G = 10 \times 10^3$ MPa; $\nu = 0.17$

for steel : $E = 200 \times 10^3$ MPa; $G = 76.9 \times 10^3$ MPa, $\nu = .3$

when E = modulus of elasticity, G = shear modulus and ν = Poisson's ratio.

As the transverse load distribution is affected by the girder stiffness and the slab stiffness, the moment of inertia, I, of the girder was gradually increased as the span L increased to present a realistic proportion of girders. The deck slab thickness t was kept constant at 200 mm for all values of s. Although in the comparative study of different trucks, the values of I and t would not matter, as same bridge geometry and properties will be used in all the cases, it is more proper if the analysis is carried out with a more realistic properties of usual design.

Table 6.1 shows the values of I used for girders for different spans. All girders were considered to be identical. For the slab-type bridge decks, the deck slab

Table 6.1: Moment of Inertia of Girders Used in the Analysis

Span L (m)	Girder Inertia (m^4)
8	0.006
12	0.014
16	0.020
20	0.030
24	0.040
32	0.066
40	0.090

thickness was increased gradually in relation to the span. Table 6.2 shows the values of slab thickness for different spans used in the analysis.

6.3.1 Slab-type Bridge Decks

A typical discretization of the slab into finite elements for one-lane and a two-lane deck, simple and two span continuous, is shown in Appendix C. The element widths in both x and y-directions are indicated. The loading position of trucks for the maximum longitudinal bending moment is shown in Fig.6.4. The load position of three axles (or two axles as the case may be) for the maximum moments corresponds to the absolute maximum moment theorem which stipulates that the midspan of the member divides equally the distance between the centre of gravity of the load group (resultant load) and the nearest point load (which is the middle axle load).

The plots of the values of the maximum longitudinal moment M_{yy} and transverse moment M_{xx} are shown in Fig. 6.5 and Fig. 6.6, respectively, for one-lane decks, considering the entire span range of 6.0-21.0 m. The results for the two-lane decks are shown in Fig. 6.7 and Fig. 6.8. Tabulated values for the above results are presented in Table D.1 and Table D.2 in Appendix D.

Figs. 6.9, 6.10 and 6.11 compare the bending moments along the longitudinal and transverse direction of the three Truck loads studied for Two span continous type

Table 6.2 : Slab Thickness Used in the Analysis

Span *L* (m)	Slab Thickness (m)
6	0.20
9	0.22
12	0.24
15	0.26
18	0.28
21	0.30

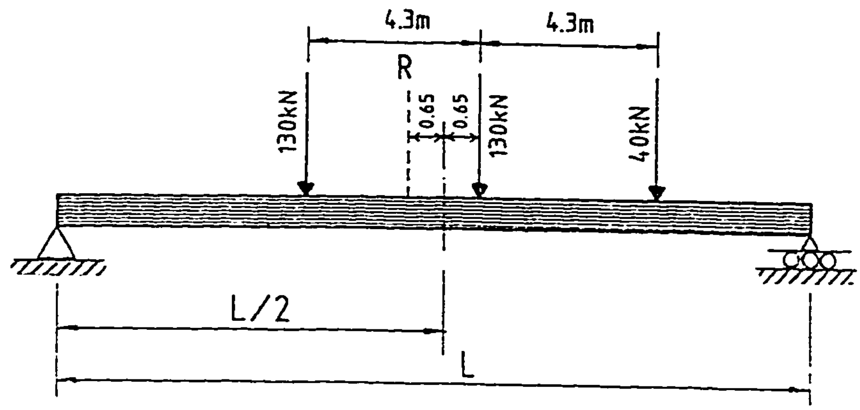


Fig. 6.4 Longitudinal Load Position for Maximum Bending Moment in MOC 600 kN Truck.

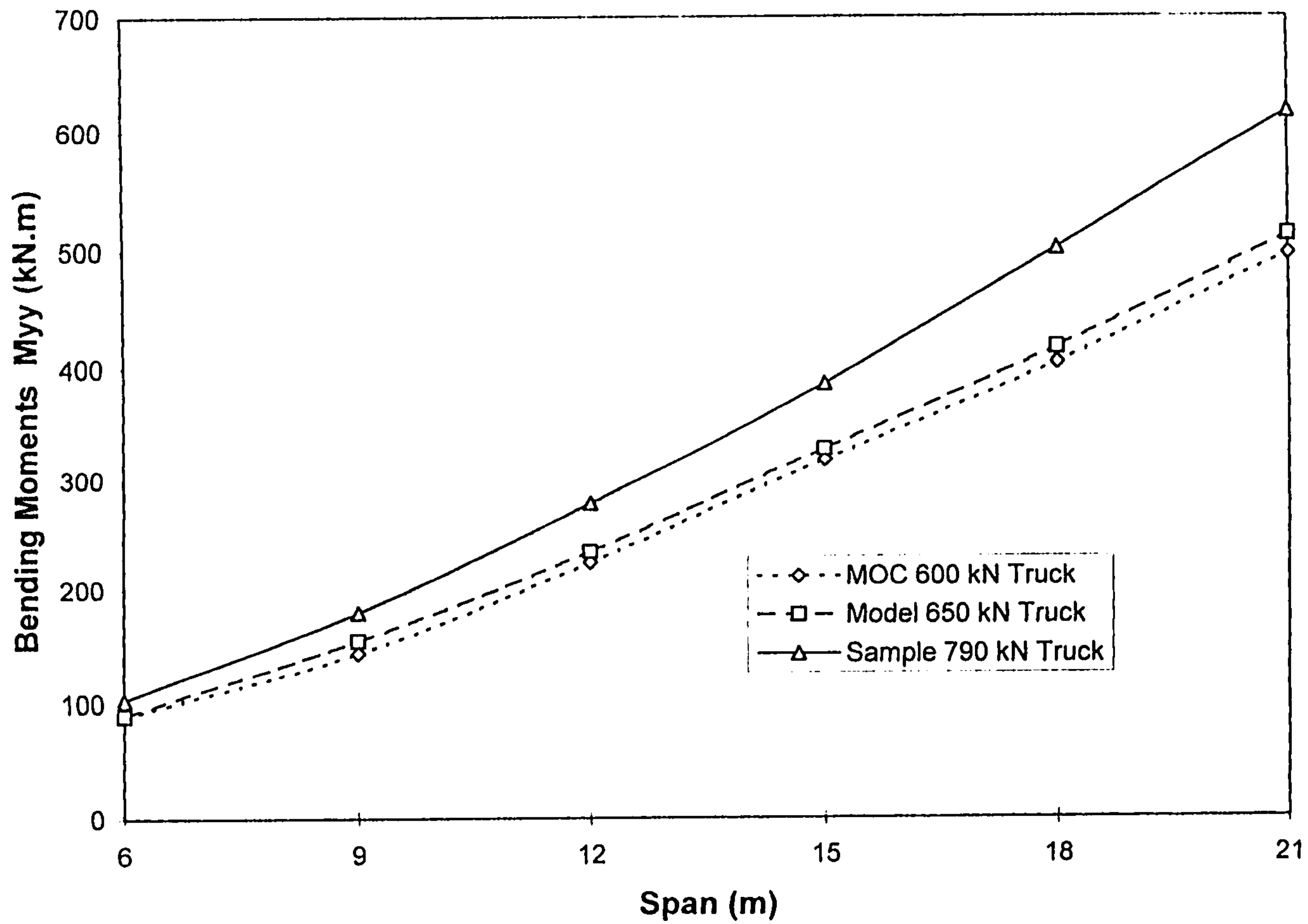


Fig. 6.5 Maximum Bending Moments - Myy in Simple Span Slab Type Bridge - One lane

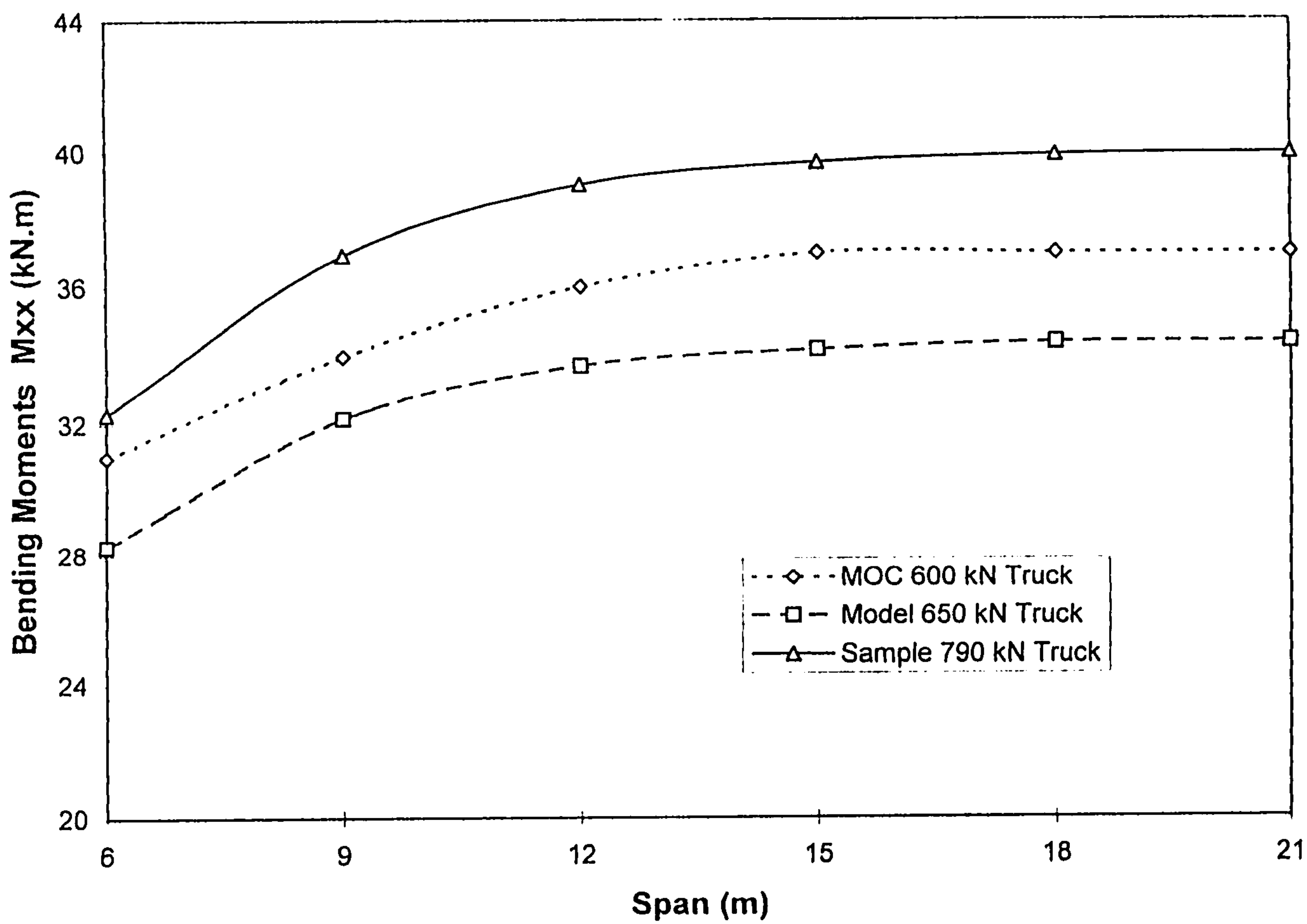


Fig. 6.6 Maximum Bending Moments - Mxx in Simple Span Slab Type Bridge - One lane

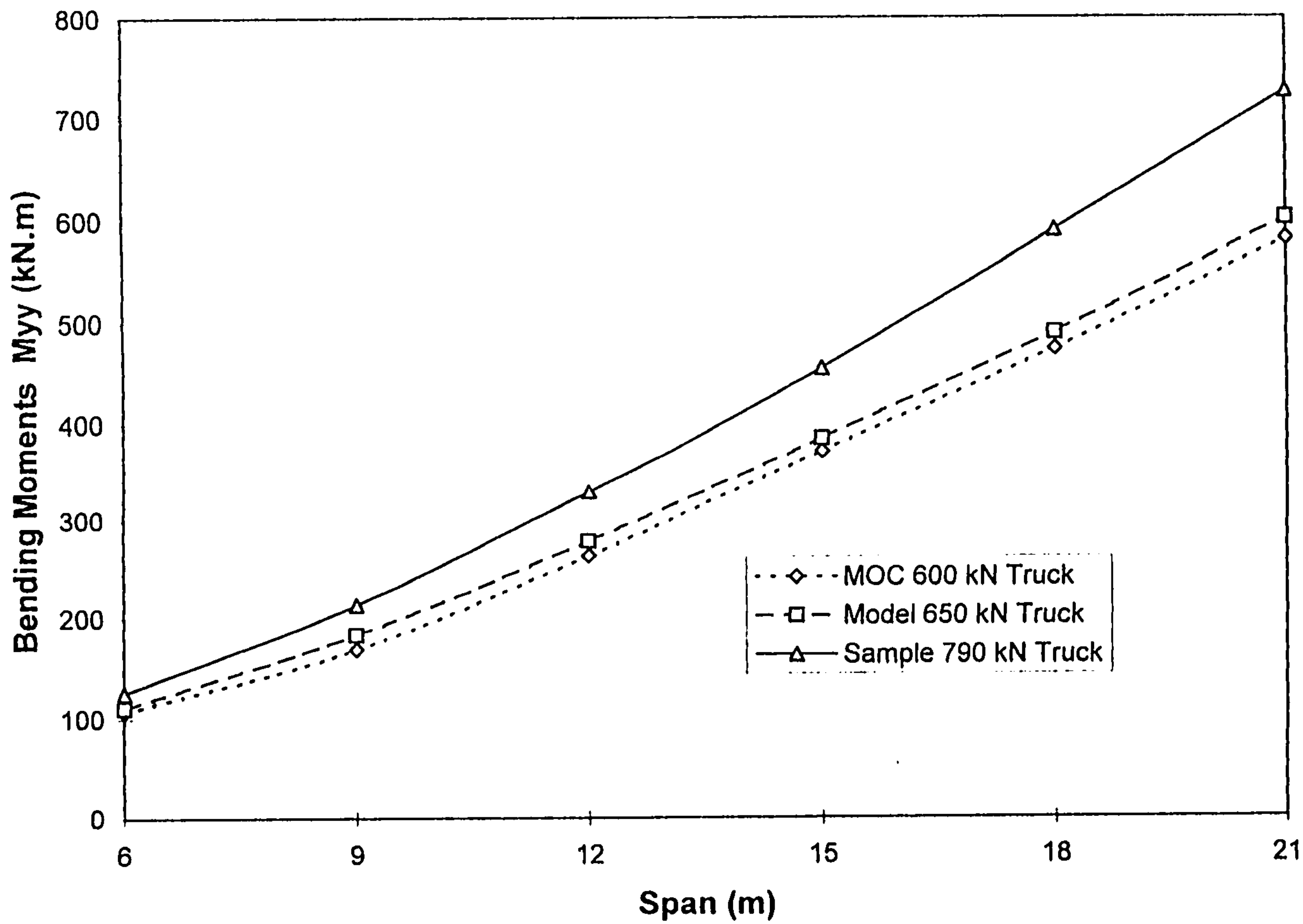


Fig. 6.7 Maximum Bending Moments - Myy in Simple Span Slab Type Bridge - Two lane

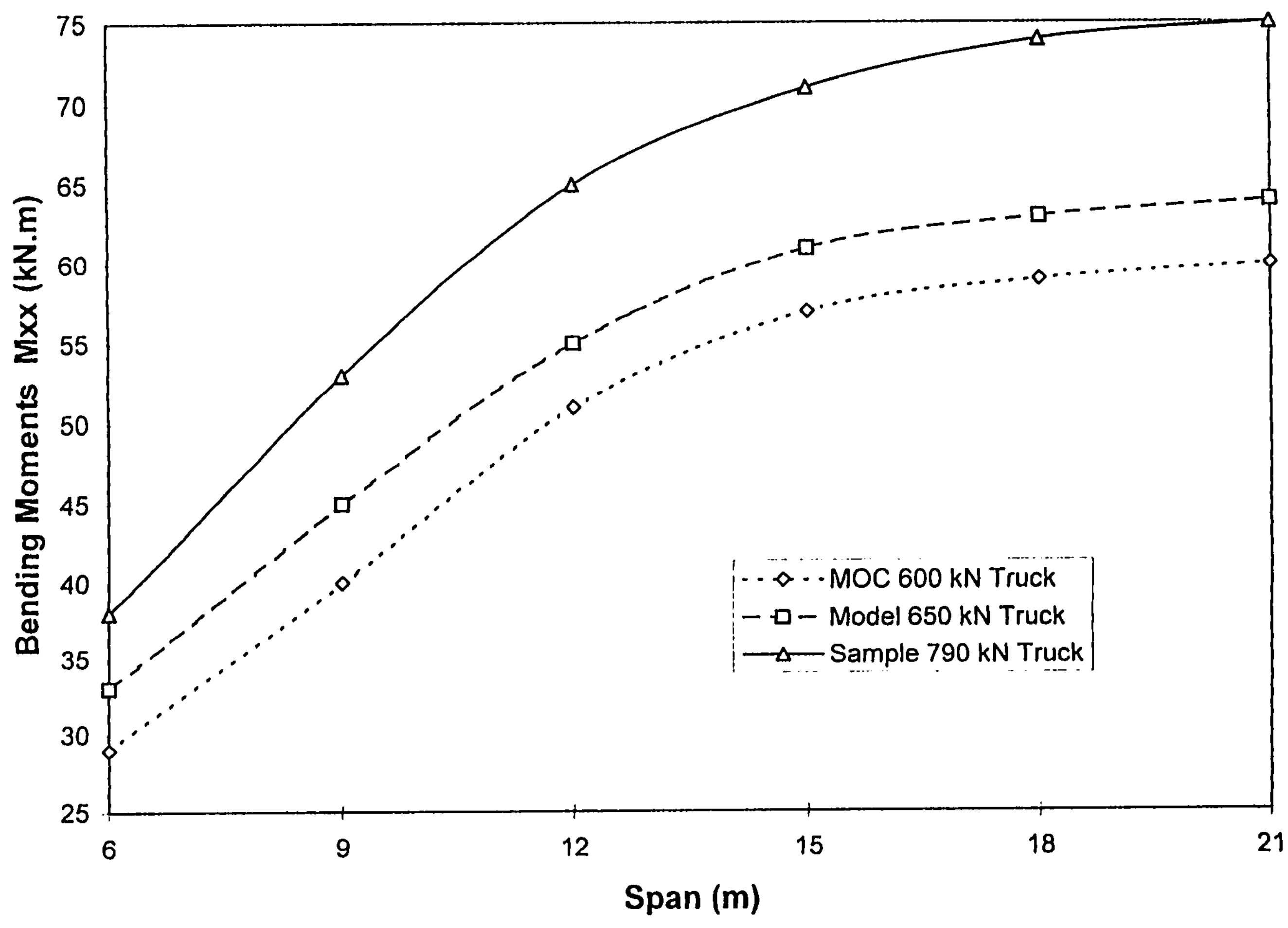


Fig. 6.8 Maximum Bending Moments - Mxx in Simple Span Slab Type Bridge - Two lane

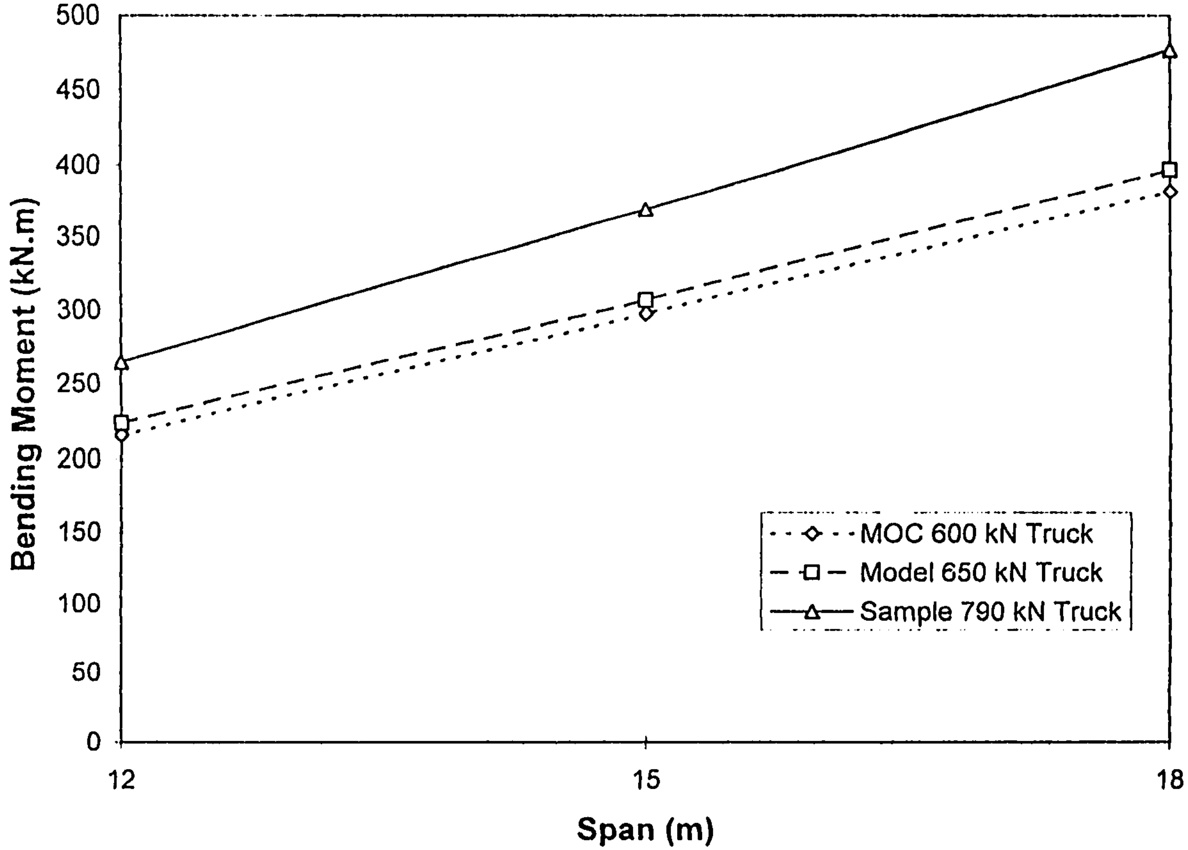


Fig. 6.9 Comparison of Maximum Positive Bending Moment (Myy)in Two Span Continuous Slab Type Bridge Decks (Two lane)

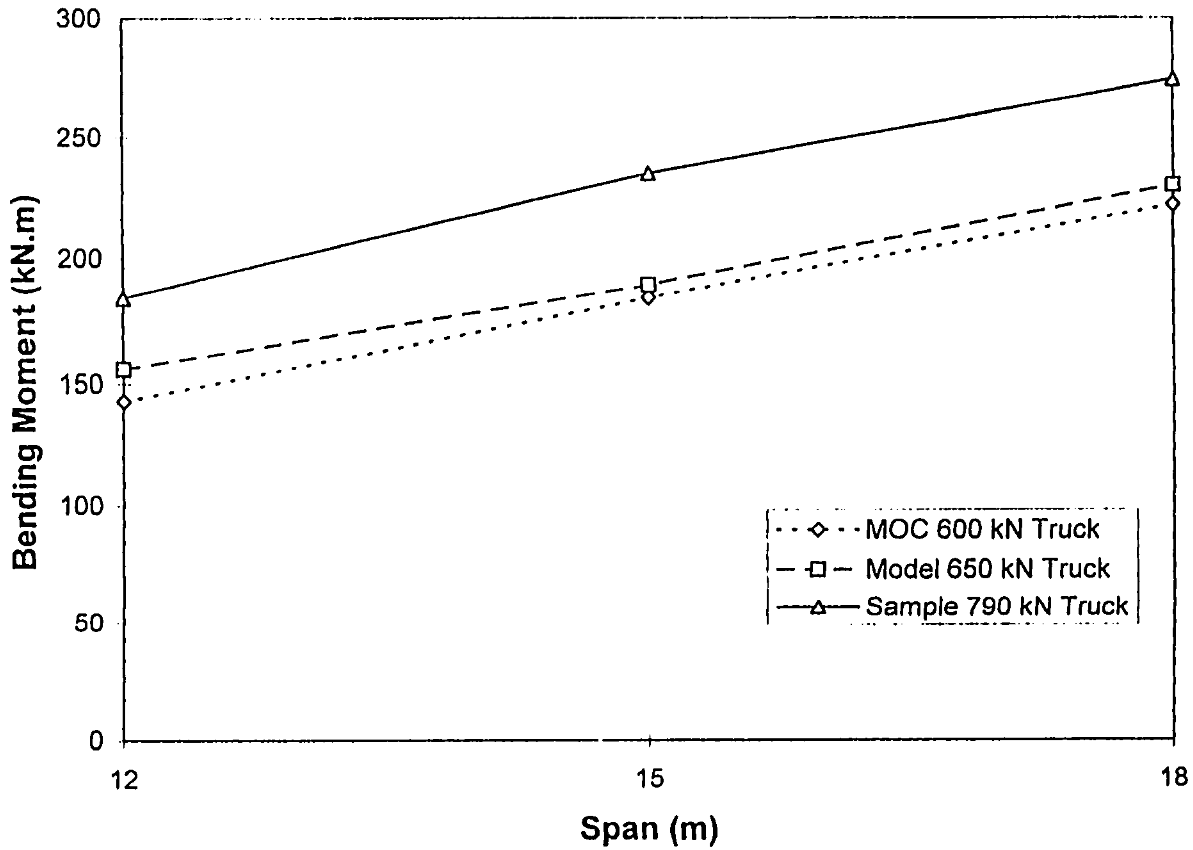


Fig. 6.10 Comparison of Maximum Negative Bending Moment (Myy)in Two Span Continuous Slab Type Bridge Decks (Two lane)

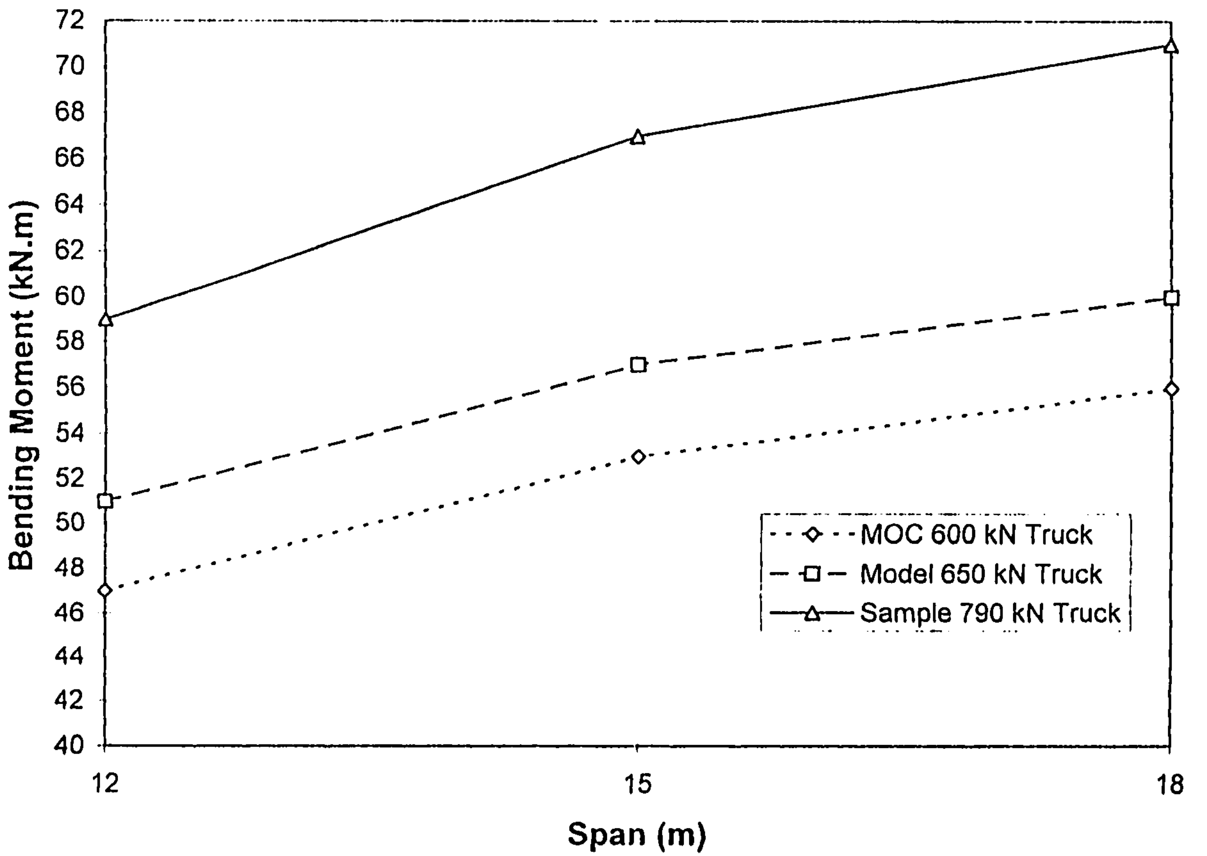


Fig. 6.11 Comparison of Maximum Positive Bending Moment (Mxx)in Two Span Continuous Slab Type Bridge Decks (Two lane)

bridge decks. Table D.4 and Table D.5 in Appendix D, present the results in tabular form.

6.3.2 Girder-slab type Bridge Decks

Typical discretization for a one-lane and a two-lane Girder-slab type bridge decks is shown in Appendix E, for both simple and continuous spans, respectively, for s = 2.25 m. The element widths in the x and y-directions are shown. The beam elements (shown with double lines) are numbered from 101–120 for the first girder, 201 to 220 for the second girder and so on. The longitudinal loading position of the axles for the maximum moment is same as shown in Fig.6.3. However, the transverse load position will be such so as to produce maximum force effects on the critical girder. For a one-lane deck, the transverse load position for the interior and exterior girders is shown in Fig.6.12. For a two-lane deck, Fig. 6.13 shows the positions of truck loads for the maximum force in the interior and exterior girders.

The maximum values of bending moment in the interior and exterior girders are shown collectively for all cases in Table 6.3, in Table 6.4 for one-lane and in Table 6.5 and Table 6.6 for two-lane decks. Using these data, typical Fig. 6.14 and Fig. 6.15 are plotted to show graphically the variation in bending moment in the interior and exterior girders for one-lane decks considering the spacing of girder s =

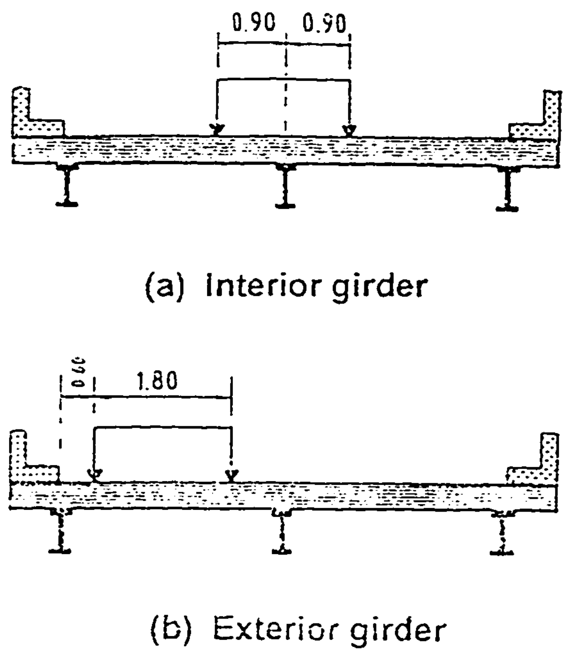


Fig. 6.12 Transverse Load Position for One-lane Deck

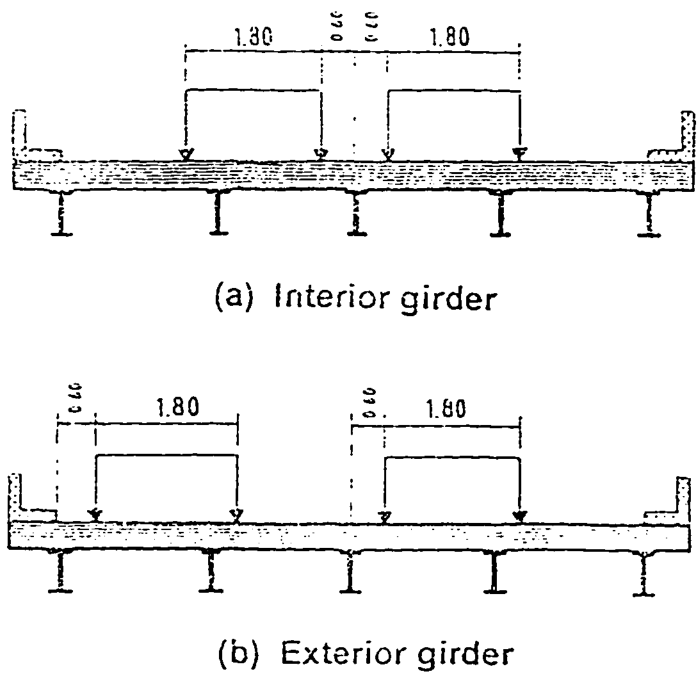


Fig. 6.13 Transverse Load Position for Two-lane Deck

Table 6.3: Comparison of Maximum Bending Moments in Simple Spans for Interior Girders (One lane)

Span L (m)	Spacing s (m)	MOC 600 kN Truck Bending Moments (kN.m)	Model 650 kN Truck Bending Moments (kN.m)	Sample 790 kN Truck Bending Moments (kN.m)
	2.25	272	327	372
8	2.50	289	348	396
	2.75	304	366	417
	2.25	527	568	674
12	2.50	566	610	725
	2.75	603	649	772
	2.25	733	794	921
16	2.50	785	836	986
	2.75	837	880	1053
	2.25	945	997	1196
20	2.50	1004	1058	1270
	2.75	1066	1123	1348
	2.25	1150	1216	1462
24	2.50	1209	1277	1536
	2.75	1273	1345	1618
	2.25	1572	1668	2012
32	2.50	1631	1729	2085
	2.75	1695	1796	2166
	2.25	1990	2118	2559
40	2.50	2046	2176	2629
	2.75	2106	2237	2704

Table 6.4: Comparison of Maximum Bending Moments in Simple Spans for Exterior Girders (One lane)

Span L (m)	Spacing s (m)	MOC 600 kN Truck Bending Moments (kN.m)	Model 650 kN Truck Bending Moments (kN.m)	Sample 790 kN Truck Bending Moments (kN.m)
	2.25	195	236	269
8	2.50	207	251	286
	2.75	224	271	309
	2.25	434	460	557
12	2.50	459	493	589
	2.75	489	527	629
	2.25	719	746	899
16	2.50	758	798	950
	2.75	802	839	1004
	2.25	1004	1060	1271
20	2.50	1061	1110	1343
	2.75	1119	1171	1417
	2.25	1288	1392	1643
24	2.50	1364	1437	1741
	2.75	1438	1516	1834
	2.25	1842	1954	2368
32	2.50	1957	2077	2518
	2.75	2066	2193	2658
	2.25	2363	2518	3053
40	2.50	2518	2683	3254
	2.75	2662	2838	3440

Table 6.5: Comparison of Maximum Bending Moments in Simple Spans for Interior Girders (Two lane)

Span *L* (m)	Spacing *s* (m)	MOC 600 kN Truck Bending Moments (kN.m)	Model 650 kN Truck Bending Moments (kN.m)	Sample 790 kN Truck Bending Moments (kN.m)
8	2.25	365	438	499
	2.50	394	473	539
	2.75	430	516	588
12	2.25	759	815	970
	2.50	818	878	1047
	2.75	885	951	1133
16	2.25	1138	1193	1424
	2.50	1229	1287	1539
	2.75	1321	1384	1657
20	2.25	1496	1567	1889
	2.50	1621	1700	2049
	2.75	1742	1829	2203
24	2.25	1810	1906	2300
	2.50	1968	2073	2502
	2.75	2120	2235	2697
32	2.25	2377	2518	3042
	2.50	2587	2806	3312
	2.75	2797	3012	3580
40	2.25	2857	3035	3671
	2.50	3090	3283	3971
	2.75	3336	3610	4287

Table 6.6: Comparison of Maximum Bending Moments in Simple Spans for Exterior Girders (Two lane)

Span *L* (m)	Spacing *s* (m)	MOC 600 kN Truck Bending Moments (kN.m)	Model 650 kN Truck Bending Moments (kN.m)	Sample 790 kN Truck Bending Moments (kN.m)
8	2.25	188	228	259
	2.50	202	244	278
	2.75	219	265	302
12	2.25	406	436	520
	2.50	433	466	556
	2.75	467	503	599
16	2.25	662	695	829
	2.50	701	731	878
	2.75	748	790	937
20	2.25	928	971	1148
	2.50	976	1022	1250
	2.75	1034	1084	1309
24	2.25	1210	1274	1542
	2.50	1265	1332	1613
	2.75	1331	1442	1696
32	2.25	1798	1908	2313
	2.50	1870	2022	2405
	2.75	1951	2071	2509
40	2.25	2413	2573	3121
	2.50	2508	2674	3242
	2.75	2607	2780	3370

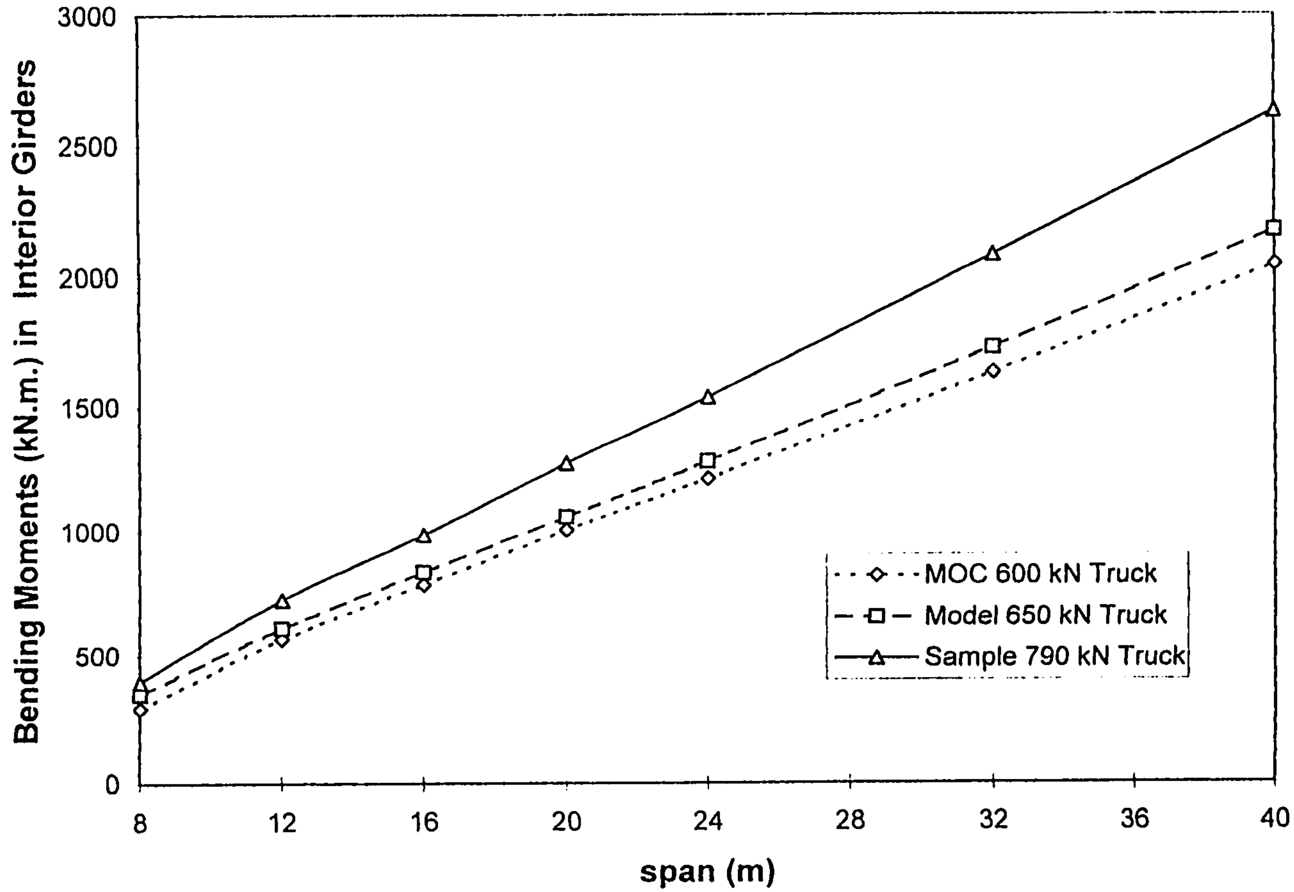


Fig. 6.14 Maximum Moment in Interior Girder for One-lane Girder-slab Type Decks - Girder spacing -2.50 m

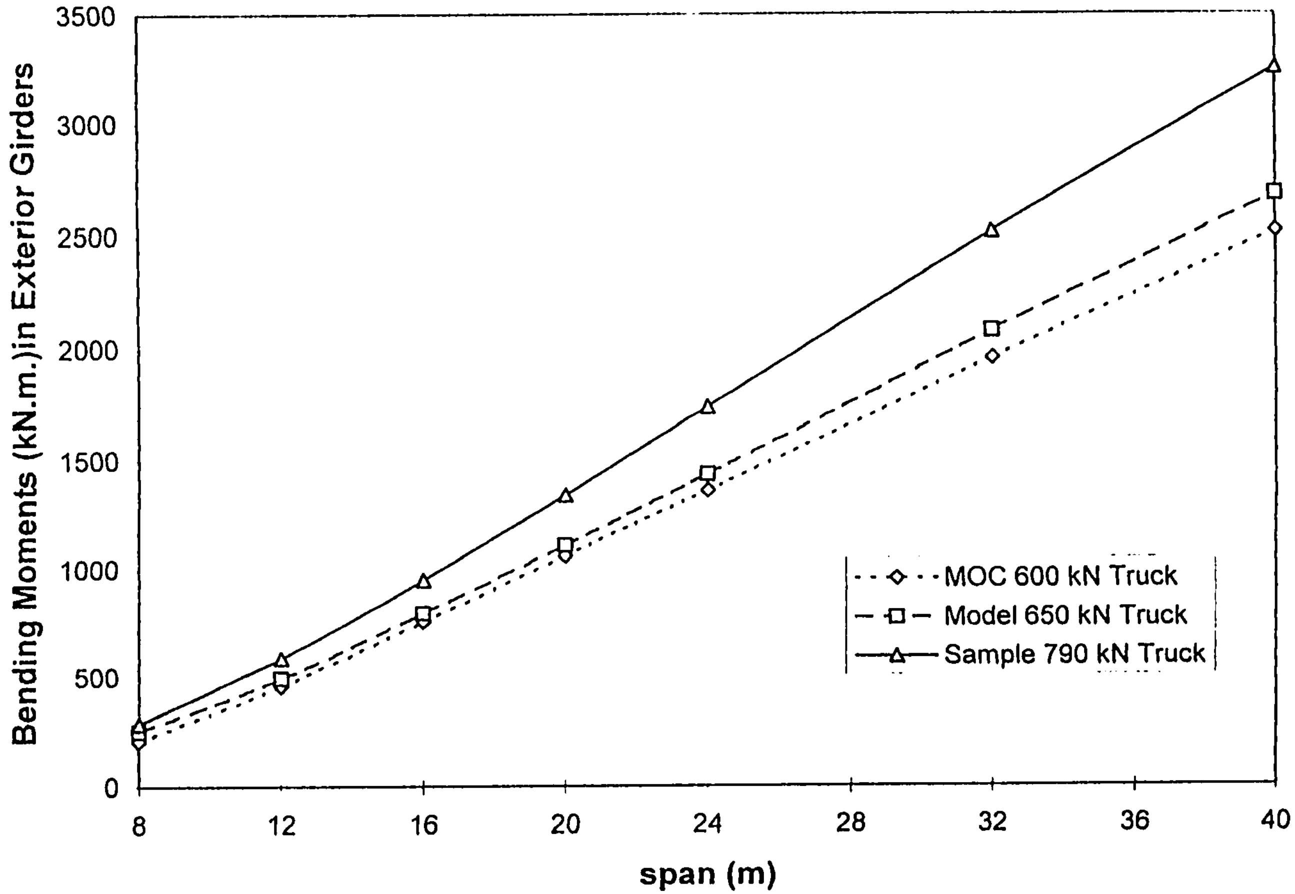


Fig. 6.15 Maximum Moment in Exterior Girder for One-lane Girder-slab Type Decks - Girder spacing -2.50m

2.5m. The other plots for s=2.25m and s=2.75m are shown in Fig. F.1 to Fig. F.4 under Appendix F.

Fig. 6.16 and Fig. 6.17 give the bending moment variation for girder spacing s=2.5m, for two-lane decks. The other plots are shown in Fig. F.5 to F.8 in Appendix F. Figs. 6.18 through 6.21 show the bending moments in the interior and exterior girders respectively, for two span continuous girder type bridges. The values are tabulated in Table F.1 and Table F.2 in Appendix F. Only two lane loading is considered for continous bridge deck analysis.

6.4 DISCUSSION OF RESULTS

Results of the maximum bending moments are presented in this section for simply supported and continuous bridge decks of varying spans, having one or two lanes.

6.4.1 Slab Type Bridge Decks

For a slab-type bridge deck which behaves essentially like a beam, the longitudinal bending moment plot in Fig. 6.5 and Fig. 6.7 is essentially linear as expected after about 9 m span. The kink between the span range of 6-9 m for the MOC tuck is due to the fact that the whole truck loading can only be accommodated

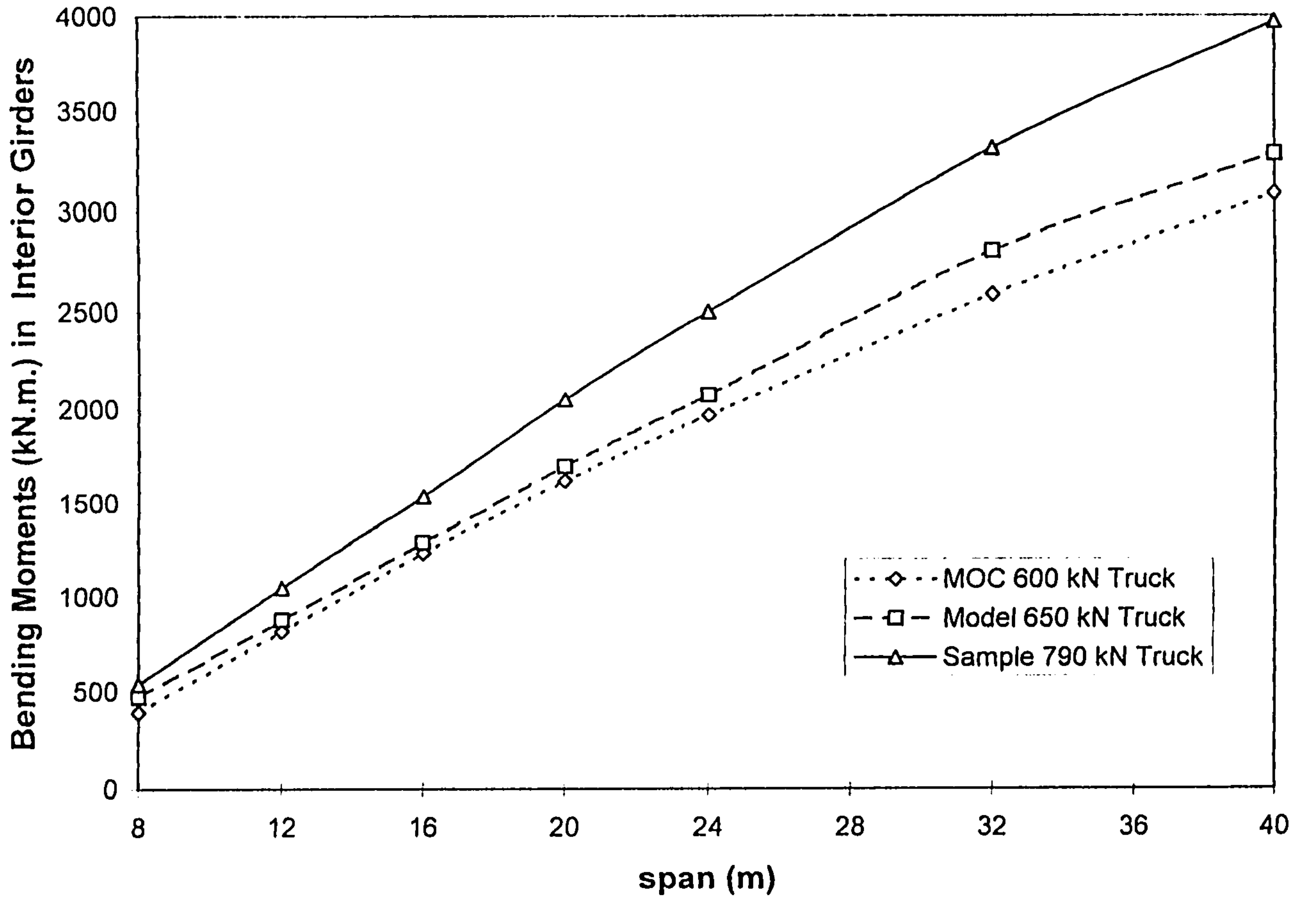


Fig. 6.16 Maximum Moment in Interior Girder for Two-lane Girder-slab Type Decks - Girder spacing -2.50m

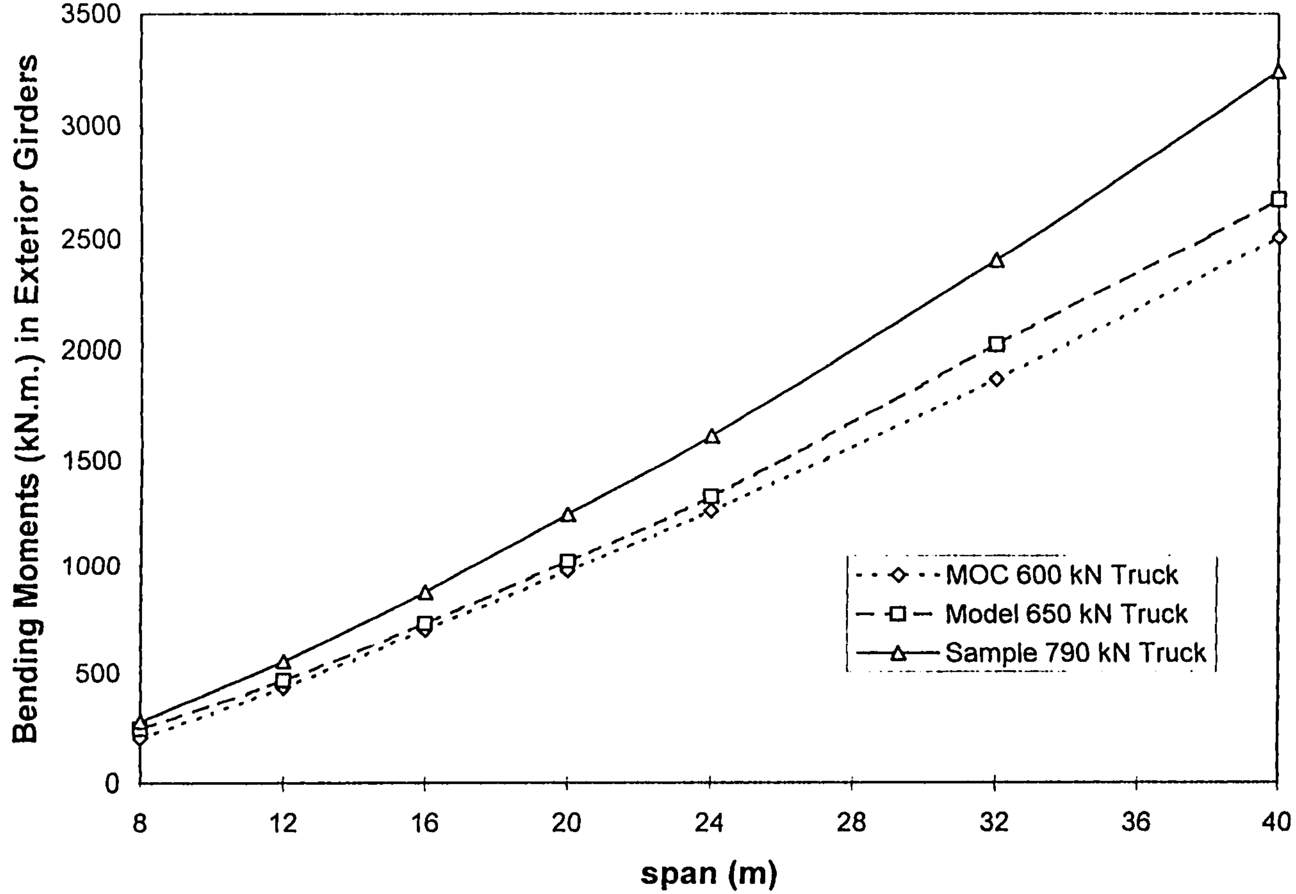


Fig. 6.17 Maximum Moment in Exterior Girder for Two-lane Girder-slab Type Decks - Girder spacing -2.50m

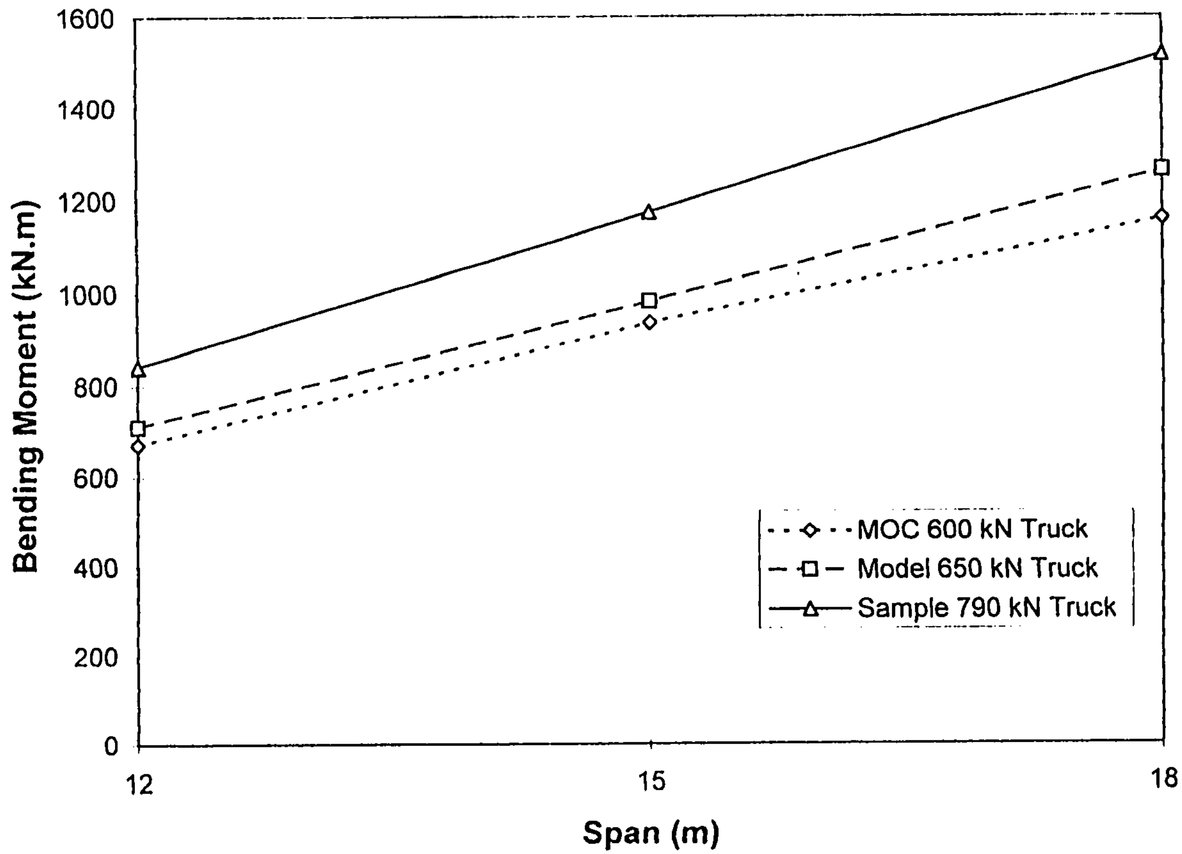


Fig. 6.18 Comparison of Maximum Positive Bending Moment in Two Span Continuous Girder Type Bridge Decks - Interior Girder(Two lane: S= 2.50m)

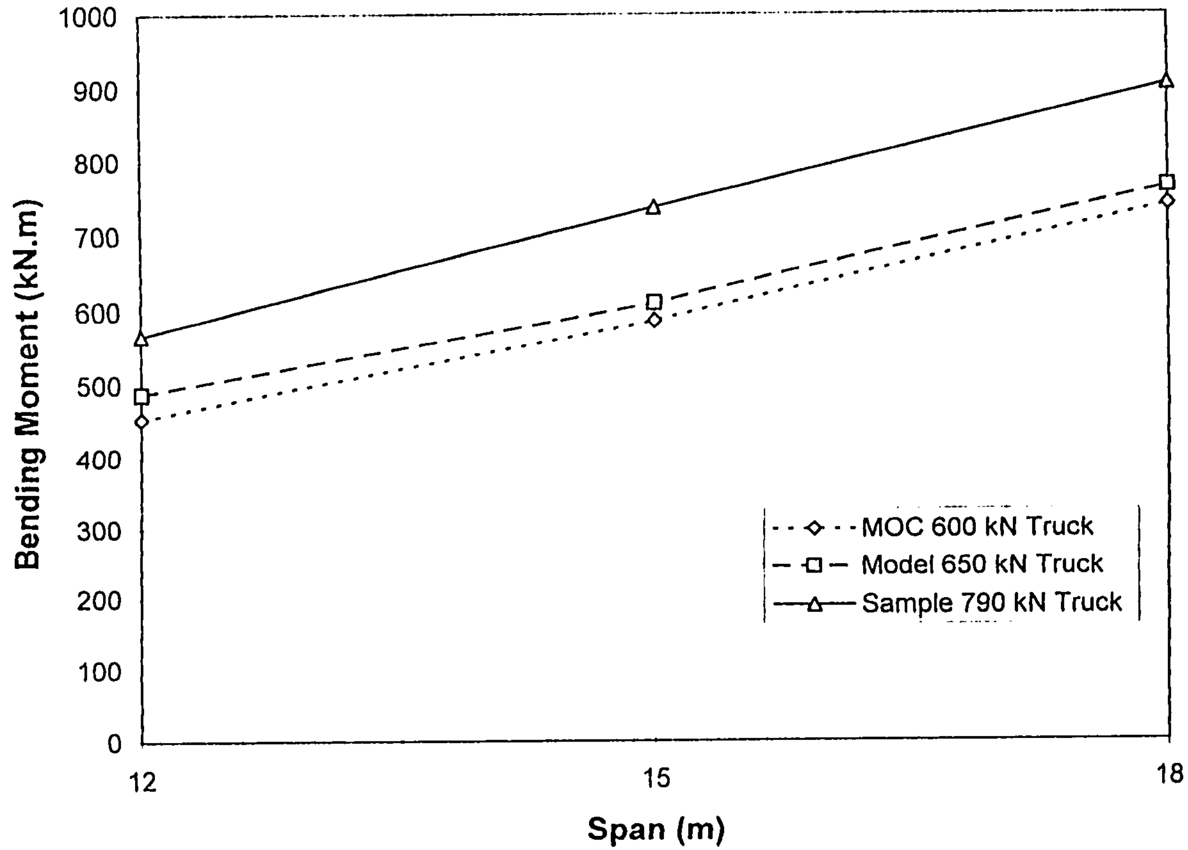


Fig. 6.19 Comparison of Maximum Negative Bending Moment in Two Span Continuous Girder Type Bridge Decks - Interior Girder(Two lane: S=2.50m)

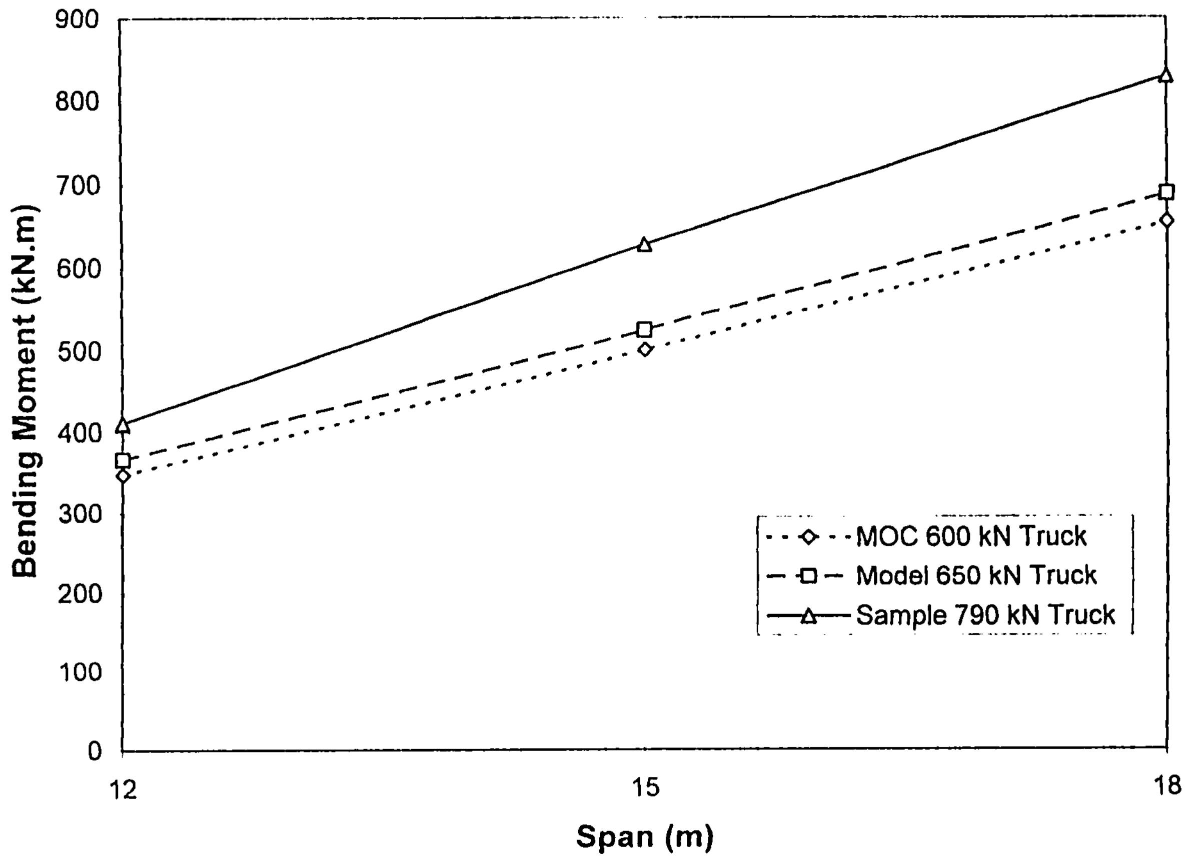


Fig. 6.20 Comparison of Maximum Positive Bending Moment in Two Span Continuous Girder Type Bridge Decks- Exterior Girder(Two lane: S=2.50m)

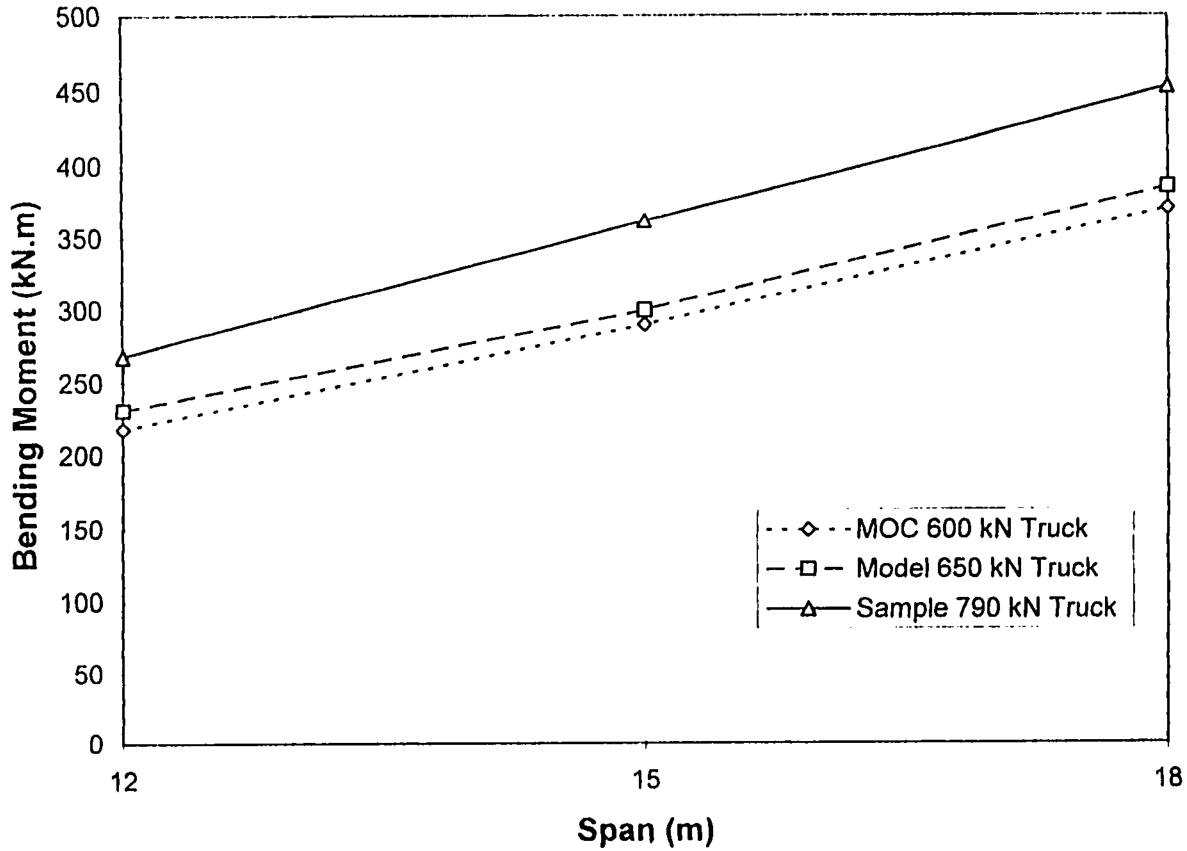


Fig. 6.21 Comparison of Maximum Negative Bending Moment in Two Span Continuous Girder Type Bridge Decks- Exterior Girder(Two lane: S=2.50m)

over a span greater than 8.54 m, as the total minimum distance between the front and the rear axle of the MOC vehicle (Fig. 1.3) is 8.54 m. For spans less than 9 m (say), only the rear or the rear and the middle axle can be placed to produce maximum moments and shearing forces. Similar is the situation with the Proposed 650 kN and Sample 790 kN Trucks which are 10.0m long (Fig. 6.3). Fig. 6.5 and Fig. 6.7 also compare the maximum bending moments for the three trucks. The MOC truck results are close to but smaller than the results of the Proposed Truck Model. The design bending moments with MOC model is about 6% to 8% less, on an average, than those produced by the Proposed Model. On the other hand, the MOC truck when compared with the Sample 790 kN Truck on an average falls by 20% to 30% of the value of the bending moments. It is encouraging to find the results of the MOC 600 kN Truck so close to the values of the Proposed Truck Model which was developed based on the current truck traffic weight data.

The value of the transverse moment in one lane bridge decks increases gradually up to about 15 m and thereafter remains essentially constant. This is due to the fact that the slab is assumed to have free longitudinal edges and as the span to width ratio exceeds say about 3, the transverse curvature remains basically a constant. This gives rise to a constant transverse moment for longer span decks with free opposite longitudinal edges. A two lane slab shows similar behaviour after the span of 18.0m, but the effect is not that pronounced as in the one-lane type bridge decks. The transverse moments in one lane slabs of MOC 600 kN model, gives better results than those produced by the proposed 650 kN Truck. This may be due to the heavier

260 kN axle load of the MOC truck as compared to the 190 kN axle load of the proposed Truck. The bending moment with the sample truck is about 10% more than those predicted by the MOC truck. In the case of two lane, the MOC 600 kN predicts on an average about 8% lower than the longitudinal bending moment predicted by the Proposed Truck. The Sample 790 kN truck produces forces 25% to 30% greater than predicted by MOC 600 kN Truck. The sample vehicle considered in this survey is a very rare case, which is short in length and heavy. It may not be statistically significant but can be dangerous when it traverses on old and improperly designed bridge. Table D.3 and Table D.4 in Appendix D present the results of longitudinal and transverse bending among the 12m, 15m and 18m two span continous slab type decks. Further the difference between the MOC 600 kN and Proposed 650 kN Truck Model is very small. Although in the continuous spans, uniformly distributed loads govern the design forces, the MOC 600 kN is not a bad hypothecation of a design load.

6.4.2 Girder slab Type bridge decks

The variation of the moment for the three trucks in the interior girder with spacing s=2.50 m is shown in Figs. 6.14 and 6.15 for one-lane and Fig. 6.16 and Fig.6.17 for two-lane decks, respectively. Figures F.1 through F.8, in Appendix F, show the plots for s=2.25 m and s=2.75 m. Results show that the variation is no

longer linear in the two lane loading, as with increasing span, the girders behave somewhat more flexibly (even though moment of inertia of girders have been increased) for a given spacing *s*, thereby reducing its share of load. As the spacing *s* increases, the moment increases due to sharing of higher proportion of truck loads.

Although the maximum design moment is not given by Truck load for spans greater than 20 m in the Proposed Bridge Load formula, only a comparison between truck to truck was made in this study.

In a girder-slab deck, the transverse distribution of wheel loads among the supporting longitudinal beams is influenced by (i) the flexibility of the girder (dependent upon the span and the flexural rigidity), (ii) the deck slab thickness, and (iii) the spacing of the girders. Basically, the ratio of the girder stiffness to deck slab stiffness controls the lateral load distribution.

The results for the MOC 600 kN Truck are very close to those for proposed Model 650 kN Truck. For small spans of say less than 8m, the difference between the MOC and proposed Model is quite pronounced, the variation being as high as 20%. This may be due to the effect of the dual axle of the Proposed Truck load when compared to the single axle 260 kN load of the MOC Truck. As the span increases, the difference narrows down to an average of 6% which is quite encouraging. This is observed for both the one and two lane loadings considering the interior and exterior girders. The variation in the bending moments is more pronounced for the sample 790 kN Truck. The difference is in the range of 30% to 40 % more than those produced by the MOC Truck.

Similar is the situation with the MOC 600 kN truck, for the two span continuous case. The maximum positive moment produced by the MOC 600 kN Truck hardly differs with that produced by the proposed Model 650 kN Truck by about 6% on an average. The difference in the negative moment is also negligible. The proposed Model 650 kN truck predicts negative moments about 4% to 7% more than those given by MOC 600 kN truck. It should also be noted that the truck load may not govern the maximum negative moment in continuous spans. The Sample 790 kN Truck produces about 30% more forces than predicted by MOC for the positive moments and about 22% to 25% more in the negative moments.

It is clear that for shorter spans, MOC 600 kN truck yields reasonable results which can be used in design with proper load factors or safety factor. However, the loading is inadequate for longer simple spans (Table 6.3 to 6.6). The proposed Model 650 kN truck is a better truck load to serve as design load for design of bridges.

CHAPTER 7

7. SUMMARY AND CONCLUSIONS

7.1 SUMMARY

This study deals with the development of truck loading for design of bridges in Saudi Arabia. The MOC's 600 kN truck loading was hypothetically adopted as the design load for bridges in 1985. No effort were then made to examine the adequacy of the load model. In this study a rigorous load survey of the heavy trucks was made to obtain informative data on truck configurations and axle loads. Based on the survey data, a 650 kN Model truck load was developed using the concept of 'equivalent base length'. A simplified approach of calculating maximum moments using distributed lane loading has been proposed, which can be used for all span lengths. The adequacy of the Current MOC 600 kN Model is compared with the Proposed 650 kN Model Truck. A critical and heavy truck encountered in the truck

survey was also included for comparison purposes and to get an impression about the degree of overloading still prevalent in the Kingdom.

7.2 CONCLUSIONS

Based on this study, the following conclusions can be made:

1. The data obtained for the years 1414H, 1415H and 1416H into MOC's classes shows that the four-axle trucks (MOC Class 4 & 5) constitute the bulk of the truck volume in Saudi Arabia, exceeding over 80%. In 1413H the count of the above truck stands at 73%. The number of three-axle articulated or trailer type trucks (MOC Class 3) is considerably less than the 3-axle rigid type trucks (MOC Class 2).
2. A province wise breakdown of trucks into different classes reveals a strikingly similar pattern at all the weighing stations.
3. A large proportion of trucks carry overweight, their number varying from a few to over 100% of the legal weight. In some classes of trucks, the percentage of overweight trucks exceeds 50% of the population in the same class.
4. A substantial number of overweight trucks exceeded the legal limits by less than 25% while a heavy concentration of these trucks was in the range of 5-15%. This is an encouraging finding in the sense that it demonstrates the

effectiveness of the weight control measures implemented within the Kingdom. However, despite such regulatory controls, some long trailer type trucks still continue to operate with heavy loads in excess of 50% of the legal limits of 40 tons, negating the full effectiveness of the weighing stations.

5. As expected, overweight problem also exists at an alarming proportion on the roadways not controlled by a weighing station. On the heavy traffic corridors of Dammam-Riyadh and Dammam-Abu Hadriyah highways, overweight trucks, mostly filled with aggregates, are frequently observed to commute towards Dammam. Truck operators cleverly find manipulative ways to beat the system and the penalty.

6. The W_m - B_m envelope shows a heavier concentration of points within the domain of $W_m \leq 60T$ and $B_m \leq 20$ m. Several points corresponding to heavier and longer trailer-type trucks lie outside the major concentration zone, enlarging the envelope. The proposed design load based on this B_m envelope is given by Eq.5.2 which gives the value of W_m for calculation of maximum moments.

7. Based on the 'equivalent base length' concept, a 650 kN Truck Model for Saudi Arabia is proposed. This model load is slightly heavier than the current MOC 600 kN truck and is more appropriate. This truck load is applicable for calculation of moments in simple spans of lengths less than 20 m.

8. A simplified lane loading in the form of distributed load is proposed for calculation of maximum moment, which can be used for all span lengths over

6.3m. The proposed method which utilizes Eq. 5.2 with Bm = L (Bm ≤ 20m) with a correction factor 'α' (Eq. 5.8) is given in Section 5.6. This approach is simpler, and straightforward and is recommended for its adoption.

9. A comparison of MOC 600 kN Truck load and the proposed 650 kN truck model shows that the former consistently yields smaller moment values for all cases. The presence of occassional heavily overloaded trucks suggests development of proper load factor in design to reduce the damages.
10. The MOC 600 kN Truck Model is not adequate for longer spans and continuous spans. Unless higher load factors are adopted, the moment values from MOC 600 kN Truck may be unacceptably lower than the expected values under prevailing loading environment. It is, therefore, suggested that the Proposed Bridge Loading (PBL) or the simplified bridge loading be used to ensure greater reliability.

7.3 RECOMMENDATIONS AND GUIDE LINES FOR FURTHER STUDIES

Based on the comprehensive work done in this study, the following recommendations are made:

1. Current weight limit enforcement is not enough. To eliminate the overloading problem, which still exists, albeit, in a reduced level, a more rigorous enforcement program is needed. In addition to building new weighing

stations on other major corridors of the Kingdom, the enforcement agencies should conduct periodic checks along the uncontrolled road networks using a portable weigh scale and penalize the defaulters heavily. Such a practice would surely curb the practice of overloading to a great degree on the uncontrolled routes.

2. Truckers must be penalized for violating the axle load limits as well as truck weight limits.

3. The proposed loading is developed with consideration given to bending moments on simple spans and further investigation is therefore required for continuous spans and ` shear forces.

4. More information and statistical analysis is required on the likelihood of multiple presence of vehicles on various classes of highways.

5. Structural analysis on continuous spans using uniformly distributed lane loads need to be carried out as the lane loads may be more critical for negative moments in a continuous span.

6. Appropriate load factors for the Load Resistance Factor Design have to be developed based on probabilistic approach for the current or the proposed truck loading taking into consideration the degree of possible overloading.

Appendix A

A.1 Sample Calculation of Equivalent Base Length

A.2 Axle Weights and Spacing Form

Appendix A.1

Sample Calculation of Equivalent Base Length

An illustration of how EBL is calculated is presented herein. Fig.A.1 shows the axle loads and spacings of a hypothetical four-axle truck. Out of a possible combinations of (4x3)/2 = 6, only three combinations are shown as illustrations.

Combination 1

Referring to Fig. A.1 (b), a combination of two axles: P_1 = 6T and P_2 = 10T; N = 2 and b = 4.0 m; the centre of gravity of the load group will be closer to P_2; $\Sigma |P_i X_i| = 6 \times 4 = 24.0$; $\Sigma(P_i X_i) = 24.0$ also; $W = 6 + 10 = 16$T.

B_m is given as (from Eq.3.5)

$$B_m = \frac{4\Sigma|P_i X_i|}{W} - \frac{2(N-1)}{bN}\left(\frac{\Sigma(P_i X_i)}{W}\right)^2$$

Thus,

$$B_m = \frac{4 \times 24}{16} - \frac{2 \times 1}{4 \times 2}\left(\frac{24}{16}\right)^2 = 5.44\,\text{m}$$

Combination 2

Referring to Fig. A.1(c), a combination of three axles: P_1 = 6T, P_2 = 40T, P_3 = 12T; N = 3 and b = 10 m; the centre of gravity is closest to P_2; $\Sigma |P_i X_i| = 6\times4 + 12\times6 = 96$; $\Sigma(P_i X_i) = 12\times6 - 6\times4 = 48$; $W = 6 + 10 + 12 = 28$T.

Thus,

$$B_m = \frac{4 \times 96}{28} - \frac{2 \times 2}{10 \times 3}\left(\frac{48}{28}\right)^2 = 13.32 \text{ m}$$

Combination 3

Referring to Fig.A.1(d), a combination of all four axles: $P_1 = 6$T, $P_2 = 10$T, $P_3 = 12$T, $P_4 = 12$T; $N = 4$ and $b = 12$ m; as the centre of gravity is 4.4 m from P_4, it is closest to P_3; $\Sigma\,|P_iX_i| = 6\times10 + 10\times6 + 12\times2 = 144$; $\Sigma(P_iX_i) = 6\times10 + 10\times6 - 12\times2 = 96$; $W = 40$T.

Thus,

$$B_m = \frac{4 \times 144}{40} - \frac{2 \times 3}{12 \times 4}\left(\frac{96}{40}\right)^2 = 13.68 \text{ m}$$

Similarly, other three combinations using (P_2, P_3), (P_2, P_3, P_4) and (P_3, P_4), W and corresponding B_m can be calculated.

Using all truck data for heavy trucks, B_m values were calculated and stored along with the corresponding values of W.

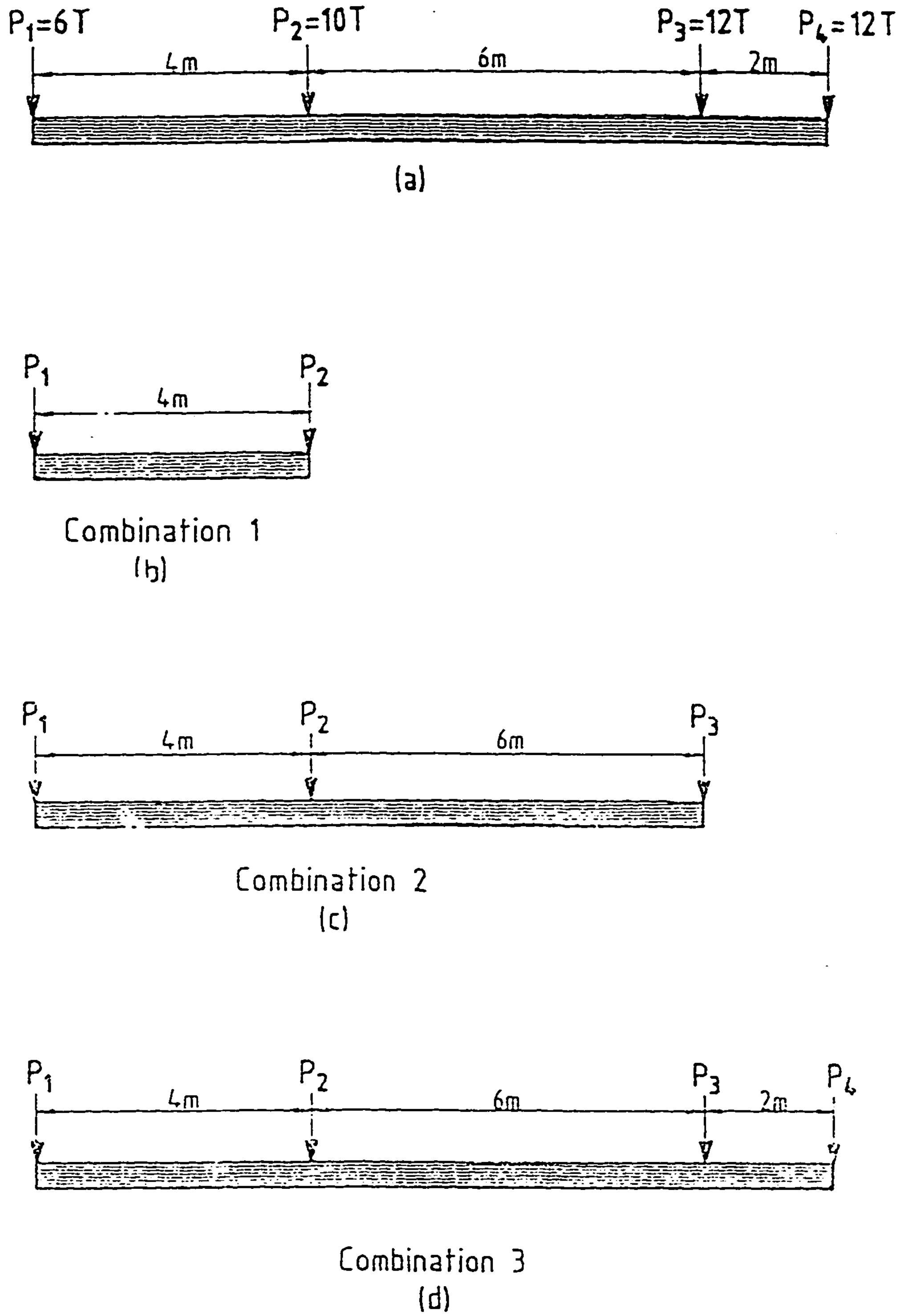


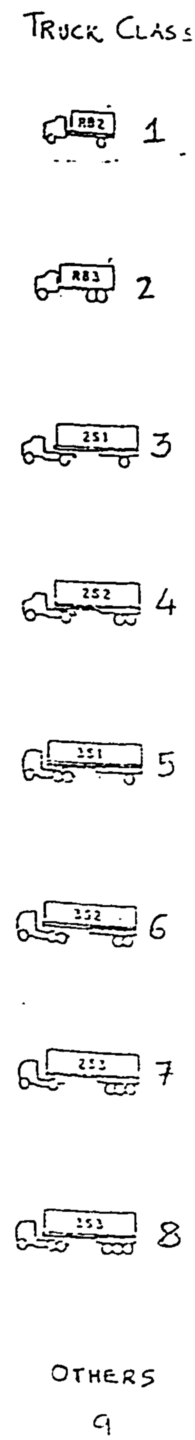
Fig. A.1 : Example for Calculation of B_m

Appendix A.2

Development of Truck Loading for Short Span Highway Bridges in Saudi Arabia

Axle weights and Spacing Form

#	Truck Type	Plate #	Axle Weight/Axle Spacing						Remarks
			1	2	3	4	5	6	



Appendix B

B.1 Computer Program in Mathematica 2.2 for the statistical analysis of truck population

B.2 Computer Program in Fortran for calculation of Equivalent Base Length

Appendix B.1

analysis.nb

ì Loading Packages

```
<<Statistics`DataManipulation`
```

```
<<Graphics`Graphics`
```

ì Reading Data

```
dataFile = "~/dataset6/Da-Ri142.dat";
```

```
data = ReadList[dataFile, Number,
    RecordLists -> True];
```

ì Total Number of Cars

```
totalCars = Length[data]
```

```
17604
```

ì Number and Percentage of 2, 3, 4, 5, 6, 7 and 8 Axel Cars

```
nonZeros[nums__]:=
Module[{count = Length[nums]},
    count = count - Count[nums, 0]
]
```

```
Clear[numberOfAxels];
numberOfAxels[row__]:=
Module[{axels},
    axels = row[[Range[2, 9]]];
    nonZeros[axels]
]
```

```
data = Select[data, (numberOfAxels[#] > 0)&];
```

```
allPossibleAxels = Union[Map[numberOfAxels, data]]
```

```
{2, 3, 4, 5, 6, 7, 8}
```

```
numberAndPercent[axels_, totalCars_]:=
Module[{len},
    len = Length[Select[data, (numberOfAxels[#] == axels)&]];
    {len, N[len/totalCars * 100]}
]

axelNoAndPercent =
    Map[
        Flatten[{#, numberAndPercent[#, totalCars]}]&,
        allPossibleAxels
    ];

TableForm[axelNoAndPercent,
    TableHeadings -> {None,
        {"Axels",
        "Number of Cars",
        "Percentage"}}]
```

Axels	Number of Cars	Percentage
2	644	3.65826
3	179	1.01681
4	15093	85.7362
5	1636	9.29334
6	44	0.249943
7	7	0.0397637
8	1	0.00568053

ì Number of 3 axle Trailer Type cars

```
number[axels_] :=
Module[{len},
    len = Length[Select[data,(numberOfAxels[#] ==axels)&]]
    ]

Clear[nTrailermAxels]
nTrailermAxels[trailerType_, axels_] :=
Module[{recs},
    recs = Select[data, ((numberOfAxels[#] == axels) &&
                        (Take[#,-1][[1]] == trailerType) )&]
    ]

nTrailermAxels[30, 3]

{{14560, 3950, 4530, 6080, 0, 0, 0, 0, 0, 0, 30}}
```

```
noOf3AxleTrailerTypeTrucks = Length[nTrailermAxels[30,3]]
```

1

```
trailer30Axel3 = nTrailermAxels[30,3];
```

ì Heaviest of 3 axle trailer type truck

```
Clear[heaviestTruck]
heaviestTruck[dataSet_] :=
Module[{max},
    max = Max[ Map[First, dataSet] ];
    Select[dataSet, (#[[1]] == max)&]
]
```

```
heaviestTruck[trailer30Axel3]
```

{{14560, 3950, 4530, 6080, 0, 0, 0, 0, 0, 0, 30}}

ì For each category given by Number of Axels, Give the Maximum Weight and its Axel Weights

```
maxWeight[axels_]:=
Module[{recs, max},
    recs = Select[data, (numberOfAxels[#] == axels)&];
    max = Max[Map[First, recs]];
    Select[recs, (#[[1]] == max)&]
]
```

```
maxWeights = Map[{#, maxWeight[#]}&, allPossibleAxels];
```

```
TableForm[maxWeights,
    TableHeadings -> {None, {"Axels", "Maximum Weight"}}]
```

Axels	Maximum Weight									
2	21530	5840	15690	0	0	0	0	0	0	0
3	29920	7330	11110	11480	0	0	0	0	0	0
4	48500	6100	13810	14390	14200	0	0	0	0	0
5	60340	5690	9100	8820	17990	18740	0	0	0	0
6	73240	7140	13160	13260	13590	13080	13010	0	0	0
7	77820	6090	8620	8520	16710	14020	12700	11160	0	0
8	41290	7210	5540	5360	4300	3690	3890	3820	3810	3670

Average Mass of cars

```
avrWeight[axels_]:=
Module[{recs,rec1,sum,len,avr},
    recs = Select[data, (numberOfAxels[#] == axels) &];
    rec1 = ColumnTake[recs,{1}];
    sum  = Apply[Plus,rec1];
    len  = Length[rec1];
    avr  = N[sum/len]
    ]

avrWeights = Map[{#, avrWeight[#]}&, allPossibleAxels];

TableForm[avrWeights,
    TableHeadings -> {None, {"Axels", "Average Weight"}}]
```

Axels	Average Weight
2	16049.4
3	21502.1
4	37820.
5	37606.2
6	44042.5
7	55580.
8	41290.

ì Find the Number of Trucks and Maximum overload Percentage in each Category

```
maxAllowedWeight[axels_]:=
Module[{t},
    t = Select[{
    {2, 19000},
    {3, 26000},
    {4, 39000},
    {5, 40000},
    {6, 40000},
    {7, 40000},
    {8, 40000}
    },
    (axels == #[[1]])&];
    If[t === {},
        Print["Error::Unexpected Number of Axels ..."];
        999999,
        t[[1,2]]
    ]
];
```

```
TableForm[Map[{#, maxAllowedWeight[#]}&, allPossibleAxels],
    TableHeadings -> {None, {"Axels", "Allowed Weight"}}]
```

Axels	Allowed Weight
2	19000
3	26000
4	39000
5	40000
6	40000
7	40000
8	40000

```
Clear[overload];
overload[axels_, data_, allowedWeight_]:=
Module[{func, chosen, chosenWeights, maxWeight},
    func =
        ((numberOfAxels[#] == axels) &&
        (#[[1]] > allowedWeight) )&;
    chosen = Select[data, func];
    If[chosen === {},
        {0, 0},
        chosenWeights = Map[#[[1]]&, chosen];
        maxWeight = Max[chosenWeights];
        {   Length[chosen],
            N[(maxWeight - allowedWeight)/allowedWeight * 100]
        }
    ]
]

Map[overload[#, data, maxAllowedWeight[#]]&,
    allPossibleAxels
]

{{169, 13.3158}, {29, 15.0769}, {9178, 24.359}, {879, 50.85}, {24,
  {1, 3.225}}
```

Overload counts in terms of percentage in each category

```
Clear[overloadInRange];
overloadInRange[axels_, data_, minAllowedWeight_,
    maxAllowedWeight_]:=
Module[{func, chosen, chosenWeights, maxWeight},
    func =
        ((numberOfAxels[#] == axels) &&
        (#[[1]] > minAllowedWeight) &&


        (#[[1]] <= maxAllowedWeight)  )&;
    Length[Select[data, func]]
]

ranges = {
    {2, 19000, 19950},
    {2, 19950, 20900},
    {2, 20900, 21850},
    {2, 21850, 22800},
    {2, 22800, 23750},
    {2, 23750, 24700},
    {2, 24700, 28500},
    {2, 28500, 34200},
    {2, 36100, 38000},
    {2, 38000, 47500},

    {3, 26000, 27300},
    {3, 27300, 28600},
    {3, 28600, 29900},
    {3, 29900, 31200},
```

```
{3, 31200, 32500},
{3, 32500, 33800},
{3, 33800, 39000},
{3, 39000, 46800},
{3, 46800, 52000},
{3, 52000, 65000},

{4, 39000, 40950},
{4, 40950, 42900},
{4, 42900, 44850},
{4, 44850, 46800},
{4, 46800, 48750},
{4, 48750, 50700},
{4, 50700, 58500},
{4, 58500, 70200},
{4, 70200, 78000},
{4, 78000, 97500},

{5, 40000, 42000},
{5, 42000, 44000},
{5, 44000, 46000},
{5, 46000, 48000},
{5, 48000, 50000},
{5, 50000, 52000},
{5, 52000, 60000},
{5, 60000, 72000},
{5, 72000, 80000},
{5, 80000, 100000},

{6, 40000, 42000},
{6, 42000, 44000},
{6, 44000, 46000},
{6, 46000, 48000},
{6, 48000, 50000},
{6, 50000, 52000},
{6, 52000, 60000},
{6, 60000, 72000},
{6, 72000, 80000},
{6, 80000, 100000},

{7, 40000, 42000},
{7, 42000, 44000},
{7, 44000, 46000},
{7, 46000, 48000},
{7, 48000, 50000},
{7, 50000, 52000},
{7, 52000, 60000},
{7, 60000, 72000},
{7, 72000, 80000},
{7, 80000, 100000},

{8, 40000, 42000},
{8, 42000, 44000},
{8, 44000, 46000},
{8, 46000, 48000},
{8, 48000, 50000},
{8, 50000, 52000},
{8, 52000, 60000},
```

```
    {8, 60000, 72000},
    {8, 72000, 80000},
    {8, 80000, 100000}

    };

overLoadedInRanges = Map[
    Flatten[{#,
     overloadInRange[#[[1]], data, #[[2]], #[[3]]]
    }]&,
    ranges];

TableForm[overLoadedInRanges]
```

2	19000	19950	47
2	19950	20900	66
2	20900	21850	52
2	21850	22800	5
2	22800	23750	1
2	23750	24700	0
2	24700	28500	0
2	28500	34200	0
2	36100	38000	0
2	38000	47500	0
2	47500	57000	0
3	26000	27300	20
3	27300	28600	25
3	28600	29900	22
3	29900	31200	2
3	31200	32500	0
3	32500	33800	0
3	33800	39000	0
3	39000	46800	0
3	46800	52000	0
3	52000	65000	0
3	65000	78000	0
4	39000	40950	1000
4	40950	42900	1070

4	42900	44850	377
4	44850	46800	5
4	46800	48750	3
4	48750	50700	0
4	50700	58500	1
4	58500	70200	0
4	70200	78000	0
4	78000	97500	0
4	97500	117000	0
5	40000	42000	68
5	42000	44000	55
5	44000	46000	32
5	46000	48000	4
5	48000	50000	0
5	50000	52000	1
5	52000	60000	0
5	60000	72000	0
5	72000	80000	0
5	80000	100000	0
5	100000	120000	0
6	40000	42000	1
6	42000	44000	0
6	44000	46000	1
6	46000	48000	0
6	48000	50000	0
6	50000	52000	0
6	52000	60000	0
6	60000	72000	0
6	72000	80000	0
6	80000	100000	0
6	100000	120000	0
7	40000	42000	0

7	42000	44000	0
7	44000	46000	0
7	46000	48000	0
7	48000	50000	0
7	50000	52000	0
7	52000	60000	0
7	60000	72000	0
7	72000	80000	0
7	80000	100000	0
7	100000	120000	0
8	40000	42000	0
8	42000	44000	0
8	44000	46000	1
8	46000	48000	0
8	48000	50000	0
8	50000	52000	0
8	52000	60000	0
8	60000	72000	0
8	72000	80000	0
8	80000	100000	0
8	100000	120000	0

ì Heavy Vehicles

```
Clear[heavyAxels];
heavyAxels[data_, axels_, needed_]:=
Module[{t},
    t = Select[data, (numberOfAxels[#] == axels)&];
    If[Length[t] > needed,
        Take[Sort[t], -needed],
        Sort[t]
    ]
]
```

```
heavyAxels[data, 2, 10]

{{21720, 7020, 14700, 0, 0, 0, 0, 0, 0, 0, 10},
  {21740, 6970, 14770, 0, 0, 0, 0, 0, 0, 0, 10},
  {21740, 7230, 14510, 0, 0, 0, 0, 0, 0, 0, 10},
  {21830, 6480, 15350, 0, 0, 0, 0, 0, 0, 0, 10},
  {21860, 6630, 15230, 0, 0, 0, 0, 0, 0, 0, 10},
  {21900, 7580, 14320, 0, 0, 0, 0, 0, 0, 0, 10},
  {21930, 6150, 15780, 0, 0, 0, 0, 0, 0, 0, 10},
  {21930, 6290, 15640, 0, 0, 0, 0, 0, 0, 0, 10},
  {21950, 6660, 15290, 0, 0, 0, 0, 0, 0, 0, 10},
  {23600, 7130, 16470, 0, 0, 0, 0, 0, 0, 0, 10}}

heavyAxels[data, 3, 25]

{{28540, 7780, 10560, 10200, 0, 0, 0, 0, 0, 0, 20},
  {28630, 7520, 10750, 10360, 0, 0, 0, 0, 0, 0, 20},
  {28730, 7410, 10860, 10460, 0, 0, 0, 0, 0, 0, 20},
  {28890, 7570, 10680, 10640, 0, 0, 0, 0, 0, 0, 20},
  {29010, 7100, 11400, 10510, 0, 0, 0, 0, 0, 0, 20},
  {29040, 9760, 9570, 9710, 0, 0, 0, 0, 0, 0, 20},
  {29040, 10250, 9440, 9350, 0, 0, 0, 0, 0, 0, 20},
  {29160, 6820, 11450, 10890, 0, 0, 0, 0, 0, 0, 20},
  {29160, 9880, 9360, 9920, 0, 0, 0, 0, 0, 0, 20},
  {29180, 7040, 11160, 10980, 0, 0, 0, 0, 0, 0, 20},
  {29240, 4860, 8930, 15450, 0, 0, 0, 0, 0, 0, 20},
  {29290, 7480, 11020, 10790, 0, 0, 0, 0, 0, 0, 20},
  {29370, 10760, 9350, 9260, 0, 0, 0, 0, 0, 0, 20},
  {29450, 7180, 11590, 10680, 0, 0, 0, 0, 0, 0, 20},
  {29470, 6250, 11420, 11800, 0, 0, 0, 0, 0, 0, 20},
  {29470, 7910, 11100, 10460, 0, 0, 0, 0, 0, 0, 20},
  {29490, 7190, 11930, 10370, 0, 0, 0, 0, 0, 0, 20},
  {29520, 7270, 11120, 11130, 0, 0, 0, 0, 0, 0, 20},
  {29540, 10470, 9660, 9410, 0, 0, 0, 0, 0, 0, 20},
  {29610, 7490, 10690, 11430, 0, 0, 0, 0, 0, 0, 20},
  {29700, 7530, 10900, 11270, 0, 0, 0, 0, 0, 0, 20},
  {29720, 7780, 10680, 11260, 0, 0, 0, 0, 0, 0, 20},
  {29880, 10980, 9840, 9060, 0, 0, 0, 0, 0, 0, 20},
  {29910, 7480, 11180, 11250, 0, 0, 0, 0, 0, 0, 20},
  {29960, 8340, 10980, 10640, 0, 0, 0, 0, 0, 0, 20}}

heavyAxels[data, 4, 100]

{{43690, 5970, 14360, 11230, 12130, 0, 0, 0, 0, 0, 30},
  {43690, 6370, 14670, 11440, 11210, 0, 0, 0, 0, 0, 30},
  {43690, 6500, 14890, 11290, 11010, 0, 0, 0, 0, 0, 30},
  {43690, 6980, 14940, 11030, 10740, 0, 0, 0, 0, 0, 30},
  {43690, 7230, 12630, 11700, 12130, 0, 0, 0, 0, 0, 30},
  {43700, 5900, 15570, 11160, 11070, 0, 0, 0, 0, 0, 30},
  {43700, 6820, 13880, 11070, 11930, 0, 0, 0, 0, 0, 30},
  {43700, 7130, 15340, 10480, 10750, 0, 0, 0, 0, 0, 30},
  {43700, 7450, 14690, 10780, 10780, 0, 0, 0, 0, 0, 30},
  {43710, 5970, 14940, 11320, 11480, 0, 0, 0, 0, 0, 30},
  {43710, 6220, 15120, 10680, 11690, 0, 0, 0, 0, 0, 30},
  {43710, 6880, 14770, 11000, 11060, 0, 0, 0, 0, 0, 30},
  {43710, 7050, 13880, 11370, 11410, 0, 0, 0, 0, 0, 30},
  {43710, 7080, 13930, 10960, 11740, 0, 0, 0, 0, 0, 30},
  {43710, 7160, 14470, 10860, 11220, 0, 0, 0, 0, 0, 30},
  {43720, 5850, 16400, 10840, 10630, 0, 0, 0, 0, 0, 30},
  {43720, 6260, 15300, 11210, 10950, 0, 0, 0, 0, 0, 30},
  {43720, 6640, 12270, 12890, 11920, 0, 0, 0, 0, 0, 30},
  {43720, 7800, 15160, 10510, 10250, 0, 0, 0, 0, 0, 30},
  {43740, 6560, 13120, 12030, 12030, 0, 0, 0, 0, 0, 30},
  {43750, 6600, 12460, 12180, 12510, 0, 0, 0, 0, 0, 30},
  {43750, 6950, 14420, 10850, 11530, 0, 0, 0, 0, 0, 30},
  {43750, 7210, 12490, 12090, 11960, 0, 0, 0, 0, 0, 30},
  {43750, 7450, 13900, 10880, 11520, 0, 0, 0, 0, 0, 30},
  {43760, 6110, 8780, 14040, 14830, 0, 0, 0, 0, 0, 30},
```

```
{43760, 7470, 15760, 10230, 10300, 0, 0, 0, 0, 0, 30},
{43760, 7570, 12500, 10150, 13540, 0, 0, 0, 0, 0, 30},
{43770, 6480, 17550, 9040, 10700, 0, 0, 0, 0, 0, 30},
{43770, 6730, 14860, 11510, 10670, 0, 0, 0, 0, 0, 30},
{43770, 6840, 12680, 11670, 12580, 0, 0, 0, 0, 0, 30},
{43780, 6740, 15430, 10720, 10890, 0, 0, 0, 0, 0, 30},
{43780, 7210, 13160, 11900, 11510, 0, 0, 0, 0, 0, 30},
{43790, 6320, 13940, 11350, 12180, 0, 0, 0, 0, 0, 30},
{43800, 5790, 14760, 11500, 11750, 0, 0, 0, 0, 0, 30},
{43800, 6060, 15350, 11460, 10930, 0, 0, 0, 0, 0, 30},
{43800, 6260, 14770, 11080, 11690, 0, 0, 0, 0, 0, 30},
{43800, 6640, 13730, 11540, 11890, 0, 0, 0, 0, 0, 30},
{43810, 6120, 10670, 12680, 14340, 0, 0, 0, 0, 0, 30},
{43810, 6310, 14910, 11720, 10870, 0, 0, 0, 0, 0, 30},
{43810, 7090, 13820, 11690, 11210, 0, 0, 0, 0, 0, 30},
{43810, 7120, 12060, 12330, 12300, 0, 0, 0, 0, 0, 30},
{43820, 5160, 16250, 10790, 11620, 0, 0, 0, 0, 0, 30},
{43820, 7750, 17520, 9350, 9200, 0, 0, 0, 0, 0, 30},
{43830, 4960, 13920, 12090, 12860, 0, 0, 0, 0, 0, 30},
{43830, 6020, 17020, 10310, 10480, 0, 0, 0, 0, 0, 30},
{43830, 6120, 14680, 11430, 11600, 0, 0, 0, 0, 0, 30},
{43830, 6150, 13590, 11940, 12150, 0, 0, 0, 0, 0, 30},
{43830, 6320, 13800, 12000, 11710, 0, 0, 0, 0, 0, 30},
{43830, 6640, 13100, 12540, 11550, 0, 0, 0, 0, 0, 30},
{43830, 6960, 12580, 12150, 12140, 0, 0, 0, 0, 0, 30},
{43840, 6420, 15030, 10940, 11450, 0, 0, 0, 0, 0, 30},
{43840, 7130, 12690, 12850, 11170, 0, 0, 0, 0, 0, 30},
{43850, 5690, 12100, 12830, 13230, 0, 0, 0, 0, 0, 30},
{43850, 7090, 14860, 10710, 11190, 0, 0, 0, 0, 0, 30},
{43860, 6350, 15580, 10920, 11010, 0, 0, 0, 0, 0, 30},
{43860, 6760, 14810, 11100, 11190, 0, 0, 0, 0, 0, 30},
{43860, 6920, 13030, 12070, 11840, 0, 0, 0, 0, 0, 30},
{43870, 6480, 14740, 11420, 11230, 0, 0, 0, 0, 0, 30},
{43870, 6870, 15280, 11550, 10170, 0, 0, 0, 0, 0, 30},
{43870, 7000, 12700, 11870, 12300, 0, 0, 0, 0, 0, 30},
{43880, 6360, 16620, 10190, 10710, 0, 0, 0, 0, 0, 30},
{43880, 6920, 13420, 11680, 11860, 0, 0, 0, 0, 0, 30},
{43880, 7590, 14770, 10730, 10790, 0, 0, 0, 0, 0, 30},
{43890, 5510, 15630, 11470, 11280, 0, 0, 0, 0, 0, 30},
{43890, 7040, 14820, 11520, 10510, 0, 0, 0, 0, 0, 30},
{43890, 7140, 14030, 10950, 11770, 0, 0, 0, 0, 0, 30},
{43900, 6730, 13170, 11750, 12250, 0, 0, 0, 0, 0, 30},
{43900, 6960, 16180, 10140, 10620, 0, 0, 0, 0, 0, 30},
{43910, 7100, 12800, 11960, 12050, 0, 0, 0, 0, 0, 30},
{43920, 6150, 17490, 10280, 10000, 0, 0, 0, 0, 0, 30},
{43920, 6590, 14570, 10950, 11810, 0, 0, 0, 0, 0, 30},
{43920, 7000, 13970, 11630, 11320, 0, 0, 0, 0, 0, 30},
{43930, 6100, 7770, 14680, 15380, 0, 0, 0, 0, 0, 30},
{43930, 6600, 16990, 9370, 10970, 0, 0, 0, 0, 0, 30},
{43930, 6810, 16660, 10710, 9750, 0, 0, 0, 0, 0, 30},
{43940, 6040, 14910, 9790, 13200, 0, 0, 0, 0, 0, 30},
{43940, 6220, 15510, 10870, 11340, 0, 0, 0, 0, 0, 30},
{43940, 6370, 15600, 10760, 11210, 0, 0, 0, 0, 0, 30},
{43940, 6750, 13770, 11620, 11800, 0, 0, 0, 0, 0, 30},
{43950, 6590, 14910, 11200, 11250, 0, 0, 0, 0, 0, 30},
{43950, 7820, 13770, 11010, 11350, 0, 0, 0, 0, 0, 30},
{43960, 6430, 14230, 11790, 11510, 0, 0, 0, 0, 0, 30},
{43970, 6100, 13150, 12510, 12210, 0, 0, 0, 0, 0, 30},
{43970, 6450, 14550, 11010, 11960, 0, 0, 0, 0, 0, 30},
{43970, 6550, 13300, 11840, 12280, 0, 0, 0, 0, 0, 30},
{43970, 6880, 13500, 11750, 11840, 0, 0, 0, 0, 0, 30},
{43980, 6370, 15940, 10990, 10680, 0, 0, 0, 0, 0, 30},
{43980, 6690, 12730, 12470, 12090, 0, 0, 0, 0, 0, 30},
{43980, 6830, 14110, 11270, 11770, 0, 0, 0, 0, 0, 30},
{43990, 6120, 11960, 13170, 12740, 0, 0, 0, 0, 0, 30},
{43990, 7330, 16290, 9970, 10400, 0, 0, 0, 0, 0, 30},
{45040, 6130, 13400, 12990, 12520, 0, 0, 0, 0, 0, 30},
{45320, 6850, 15020, 11500, 11950, 0, 0, 0, 0, 0, 30},
{45470, 6610, 15630, 11240, 11990, 0, 0, 0, 0, 0, 30},
{45830, 6710, 17110, 11000, 11010, 0, 0, 0, 0, 0, 30},
{46260, 6460, 15610, 12460, 11730, 0, 0, 0, 0, 0, 30},
{47190, 6680, 15640, 11950, 11900, 0, 0, 0, 0, 0, 30},
```

```
{47180, 6080, 10040, 11500, 11500, 0, 0, 0, 0, 0, 30},
 {47260, 7300, 16290, 11820, 11850, 0, 0, 0, 0, 0, 30},
 {47360, 7240, 14230, 12640, 13250, 0, 0, 0, 0, 0, 30},
 {52080, 8420, 18770, 12540, 12350, 0, 0, 0, 0, 0, 30}}
```

heavyAxels[data, 5, 100]

```
{{41820, 5520, 8080, 8400, 9870, 9950, 0, 0, 0, 0, 40},
 {41890, 5710, 8140, 8010, 9800, 10230, 0, 0, 0, 0, 40},
 {41910, 5780, 7250, 7120, 10770, 10990, 0, 0, 0, 0, 40},
 {41940, 5110, 8320, 8410, 9750, 10350, 0, 0, 0, 0, 40},
 {41940, 6160, 7250, 7540, 10470, 10520, 0, 0, 0, 0, 40},
 {41950, 5770, 1830, 12280, 11280, 10790, 0, 0, 0, 0, 40},
 {41990, 4570, 9100, 8920, 9710, 9690, 0, 0, 0, 0, 40},
 {42000, 3990, 8410, 8690, 10330, 10580, 0, 0, 0, 0, 40},
 {42110, 4950, 8580, 8510, 9760, 10310, 0, 0, 0, 0, 40},
 {42110, 5650, 6850, 6910, 11330, 11370, 0, 0, 0, 0, 40},
 {42130, 4730, 7710, 7900, 10570, 11220, 0, 0, 0, 0, 40},
 {42160, 5340, 3890, 3840, 14570, 14520, 0, 0, 0, 0, 40},
 {42250, 6670, 8180, 8340, 9440, 9620, 0, 0, 0, 0, 40},
 {42280, 5890, 12950, 7620, 7950, 7870, 0, 0, 0, 0, 30},
 {42320, 6110, 7590, 7360, 9430, 11830, 0, 0, 0, 0, 40},
 {42340, 5980, 7770, 8010, 10200, 10380, 0, 0, 0, 0, 40},
 {42400, 5120, 10130, 9970, 8480, 8700, 0, 0, 0, 0, 40},
 {42440, 6030, 7870, 8050, 10240, 10250, 0, 0, 0, 0, 40},
 {42460, 6470, 13590, 7050, 7320, 8030, 0, 0, 0, 0, 30},
 {42580, 5040, 8570, 8170, 10440, 10360, 0, 0, 0, 0, 40},
 {42620, 6120, 8980, 8880, 8320, 10320, 0, 0, 0, 0, 40},
 {42650, 6140, 8100, 7760, 9310, 11340, 0, 0, 0, 0, 40},
 {42700, 4820, 7530, 7520, 11100, 11730, 0, 0, 0, 0, 40},
 {42740, 4150, 8250, 7900, 10810, 11630, 0, 0, 0, 0, 40},
 {42770, 5680, 8180, 8400, 10290, 10220, 0, 0, 0, 0, 40},
 {42790, 5010, 7830, 7390, 11310, 11250, 0, 0, 0, 0, 40},
 {42800, 6250, 8360, 7950, 8920, 11320, 0, 0, 0, 0, 40},
 {42850, 4720, 9450, 9010, 9720, 9950, 0, 0, 0, 0, 40},
 {42870, 4980, 7950, 8010, 10710, 11220, 0, 0, 0, 0, 40},
 {42880, 5610, 9060, 9050, 9670, 9490, 0, 0, 0, 0, 40},
 {42910, 6570, 8340, 8410, 9840, 9750, 0, 0, 0, 0, 40},
 {42930, 6600, 11470, 9430, 9010, 6420, 0, 0, 0, 0, 30},
 {42950, 5910, 12750, 7700, 8360, 8230, 0, 0, 0, 0, 30},
 {43000, 5860, 7960, 7950, 10600, 10630, 0, 0, 0, 0, 40},
 {43110, 4790, 12770, 10520, 8570, 6460, 0, 0, 0, 0, 30},
 {43180, 5430, 8540, 8040, 10650, 10520, 0, 0, 0, 0, 40},
 {43230, 5800, 8220, 8130, 10600, 10480, 0, 0, 0, 0, 40},
 {43230, 6330, 8450, 8510, 9190, 10750, 0, 0, 0, 0, 40},
 {43260, 5600, 7860, 7940, 10690, 11170, 0, 0, 0, 0, 40},
 {43280, 6030, 10050, 9790, 9070, 8340, 0, 0, 0, 0, 40},
 {43290, 4850, 8130, 8160, 11040, 11110, 0, 0, 0, 0, 40},
 {43360, 6680, 7450, 7540, 10600, 11090, 0, 0, 0, 0, 40},
 {43390, 5830, 7940, 7770, 10820, 11030, 0, 0, 0, 0, 40},
 {43420, 5280, 8880, 8860, 9270, 11130, 0, 0, 0, 0, 40},
 {43430, 5000, 8910, 9240, 9800, 10480, 0, 0, 0, 0, 40},
 {43500, 6470, 7080, 7010, 11440, 11500, 0, 0, 0, 0, 40},
 {43590, 6020, 8400, 8450, 10300, 10420, 0, 0, 0, 0, 40},
 {43650, 6440, 12790, 9080, 7580, 7760, 0, 0, 0, 0, 30},
 {43660, 6070, 8470, 8370, 10400, 10350, 0, 0, 0, 0, 40},
 {43670, 5180, 8660, 9220, 9830, 10780, 0, 0, 0, 0, 40},
 {43680, 4930, 10300, 9170, 10640, 8640, 0, 0, 0, 0, 40},
 {43760, 4980, 8600, 8790, 10750, 10640, 0, 0, 0, 0, 40},
 {43780, 4340, 7400, 7560, 12630, 11850, 0, 0, 0, 0, 40},
 {43790, 4740, 9530, 9830, 9680, 10010, 0, 0, 0, 0, 40},
 {43800, 6400, 12680, 8330, 8460, 7930, 0, 0, 0, 0, 30},
 {43820, 5360, 8910, 8790, 10400, 10360, 0, 0, 0, 0, 40},
 {43820, 5730, 8450, 8220, 10820, 10600, 0, 0, 0, 0, 40},
 {43900, 4930, 7330, 6590, 12640, 12410, 0, 0, 0, 0, 40},
 {43930, 5870, 8320, 8470, 10560, 10710, 0, 0, 0, 0, 40},
 {43960, 5600, 8300, 7920, 10510, 11630, 0, 0, 0, 0, 40},
 {43960, 5760, 7580, 7800, 11270, 11550, 0, 0, 0, 0, 40},
 {43960, 5830, 8130, 8440, 10640, 10920, 0, 0, 0, 0, 40},
 {43980, 5420, 8780, 8960, 10340, 10480, 0, 0, 0, 0, 40},
 {44010, 5070, 8580, 8310, 10270, 11780, 0, 0, 0, 0, 40},
```

```
{44060, 5220, 8270, 8090, 11280, 11200, 0, 0, 0, 0, 40},
{44080, 5260, 9180, 9540, 9640, 10460, 0, 0, 0, 0, 40},
{44080, 5610, 8640, 8650, 10700, 10480, 0, 0, 0, 0, 40},
{44090, 6150, 7190, 7070, 11210, 12470, 0, 0, 0, 0, 40},
{44100, 5990, 13350, 6720, 8570, 9470, 0, 0, 0, 0, 30},
{44110, 5340, 7040, 7150, 11890, 12690, 0, 0, 0, 0, 40},
{44160, 5750, 8320, 8520, 10720, 10850, 0, 0, 0, 0, 40},
{44160, 6300, 14130, 6450, 8030, 9250, 0, 0, 0, 0, 30},
{44170, 5540, 8510, 8590, 10670, 10860, 0, 0, 0, 0, 30},
{44200, 5340, 9260, 9550, 10830, 9220, 0, 0, 0, 0, 40},
{44240, 5640, 8380, 8640, 10660, 10920, 0, 0, 0, 0, 40},
{44280, 5810, 8580, 8700, 10440, 10750, 0, 0, 0, 0, 40},
{44300, 7260, 10720, 7400, 8660, 10260, 0, 0, 0, 0, 30},
{44320, 6230, 7720, 7620, 11760, 10990, 0, 0, 0, 0, 40},
{44350, 5570, 8230, 8150, 11480, 10920, 0, 0, 0, 0, 40},
{44360, 5450, 8970, 8840, 10530, 10570, 0, 0, 0, 0, 40},
{44390, 5960, 8710, 9050, 10280, 10390, 0, 0, 0, 0, 40},
{44430, 5940, 8330, 8350, 11090, 10720, 0, 0, 0, 0, 40},
{44680, 5280, 8800, 8560, 11190, 10850, 0, 0, 0, 0, 40},
{44680, 6180, 8450, 8380, 10820, 10850, 0, 0, 0, 0, 40},
{44690, 5270, 9780, 9900, 9900, 9840, 0, 0, 0, 0, 40},
{44710, 5590, 8520, 8530, 10740, 11330, 0, 0, 0, 0, 40},
{44730, 5920, 7810, 7440, 11650, 11910, 0, 0, 0, 0, 40},
{44770, 5200, 9020, 9080, 10100, 11370, 0, 0, 0, 0, 40},
{44810, 6190, 7990, 8210, 11200, 11220, 0, 0, 0, 0, 40},
{44840, 6540, 7410, 7290, 11140, 12460, 0, 0, 0, 0, 40},
{44850, 5080, 10430, 10200, 10140, 9000, 0, 0, 0, 0, 40},
{44880, 6550, 8760, 8780, 10120, 10670, 0, 0, 0, 0, 40},
{44930, 6960, 8630, 8410, 9960, 10970, 0, 0, 0, 0, 40},
{44940, 6230, 8470, 8580, 9360, 12300, 0, 0, 0, 0, 40},
{44950, 4590, 9110, 9080, 11080, 11090, 0, 0, 0, 0, 40},
{46300, 6140, 6110, 6180, 13850, 14020, 0, 0, 0, 0, 40},
{46600, 5890, 9910, 10020, 10450, 10330, 0, 0, 0, 0, 40},
{47190, 5590, 9520, 9360, 11630, 11090, 0, 0, 0, 0, 40},
{47510, 4050, 7490, 7310, 13630, 15030, 0, 0, 0, 0, 40},
{50480, 5960, 9220, 9160, 12700, 13440, 0, 0, 0, 0, 40}}
```

```
heavyAxels[data, 6, 10]
```

```
{{28120, 4090, 4850, 4650, 4830, 4880, 4820, 0, 0, 0, 40},
 {29100, 5220, 4950, 5130, 4180, 4190, 5430, 0, 0, 0, 40},
 {29720, 5150, 5540, 5600, 4690, 4450, 4290, 0, 0, 0, 40},
 {29970, 4410, 6170, 6300, 4120, 4370, 4600, 0, 0, 0, 40},
 {31520, 4690, 5130, 5300, 6100, 5590, 4710, 0, 0, 0, 40},
 {34030, 5580, 5520, 5460, 7440, 5640, 4390, 0, 0, 0, 40},
 {35600, 6640, 6270, 6130, 3380, 4780, 8400, 0, 0, 0, 40},
 {36160, 5260, 5860, 5860, 6840, 6920, 5420, 0, 0, 0, 40},
 {41090, 5680, 6000, 5650, 8390, 7410, 7960, 0, 0, 0, 40},
 {44230, 4660, 8000, 8520, 8830, 7980, 6240, 0, 0, 0, 40}}
```

```
heavyAxels[data,7, 10]
```

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{}
```

```
heavyAxels[data,8, 10]
```

```
{{44770, 6910, 6830, 7000, 3950, 4430, 4560, 3770, 3580, 3740, 40}
```

Appendix B.2

```
C    ------------------------------------------
C    PROGRAM TO CALCULATE THE EQUIVALENT BASE LENGTH
C    ------------------------------------------
C    THIS PROGRAM DOES NOT REQUIRE THE SPAN OF THE MEMBER.

     DIMENSION P(10),SP(10)
      open (unit=10,file='ebl.dat',status='old')
      open (unit=11,file='ebl.out',status='old')
C    READ THE NUMBER OF AXLES
     READ(10,*) NA
     WRITE(11,31) NA
31   FORMAT(/,18HTHE NUMBER OF AXES,I5)

C    READ THE SERIAL NUMBER OF CARS
     READ(10,*)IC,LC
     DO 999 KJ = IC,LC
     WRITE(11,2) IC
2    FORMAT(/,27HTHE SERIAL NUMBER OF CAR IS,I5)


C    READ THE AXLE LOADS
     DO 10 I=1,NA
     READ(10,*) P(I)
10   P(I) = P(I)/1000


C    READ THE SPACING BETWEEN AXLES
     DO 11 I=1,NA-1
11   READ(10,*) SP(I)


     IA = 0
     M = 0
202  M = M+1
     IF (M.EQ.NA) GO TO 999
     J=M

201  J=J+1
     N = J +1 -M

     IA = IA + 1

C    CALCULATE THE BASE LENGTH OF THE VEHICLE
     RSP = 0.0
     DO 44 I = M, J-1
44   RSP = RSP + SP(I)

C    CALCULATE THE SUM OF THE AXLE LOADS
     W = 0
      DO 20 I=M,J
20   W = W + P(I)

     IF( (J-M).EQ.1) GO TO 83
83    IF (P(M).EQ.P(J)) GO TO 87
```

```
C   CALCULATION OF THE POSITION OF THE RESULTANT LOAD -W
    MMT = 0.0
    K =M
    XSP =0.0
    DO 25 I =M+1,J
    XSP = XSP + SP(K)
    MMT = MMT + P(I)*XSP
    K = K+1
    XR = MMT/W
25  CONTINUE

    SSP=0.0
    DO 70 I=M,J-1
    SSP=SSP + SP(I)
    IF (XR.GT.SSP) GO TO 70

    IF (XR.LT.(SSP-SP(I)/2)) THEN
    PM = P(I)

    SSP1= SSP - SP(I)

    ELSEIF (XR.GT.(SSP-SP(I)/2)) THEN

    PM = P(I+1)
    SSP1 = SSP
    ENDIF
    GO TO 71
70  CONTINUE
71  CONTINUE


    PX = 0.0
    A= 0.0
    K = M
    DO 91 I=M,J

    PX = PX + P(I) *(SSP1-A)
    IF (K.EQ.J ) GO TO 91
    A = A + SP(K)

    K = K + 1
91  CONTINUE

    PXW = PX/W
    PXW2 = PXW * PXW

    B=0.0
    ABSPX = 0.0
    L=M
    DO 92 I =M,J
    ABSPX =ABSPX + P(I) * ABS(SSP1-B)
    IF (L.EQ.J ) GO TO 92
    B = B+SP(L)
```

```
      L = L + 1
92   CONTINUE

C    EQUIVALENT BASE LENGTH
      BM = 4 * (ABSPX /W)  -  2* (N-1)*( PXW2) /(RSP*N )
      WRITE(11,93)W,BM
93   FORMAT(F10.2,F12.3)
      GO TO 88
87   BM = 1.75*SP(M)
      WRITE(11,97)W,BM
97   FORMAT(F10.2,F12.3)
88   continue
      IF (J.LT.NA) GO TO  201
      IF (J.GE.NA) GO TO  202
999 IC=IC+1
      CONTINUE
200   END
C    ****************************************************************
```

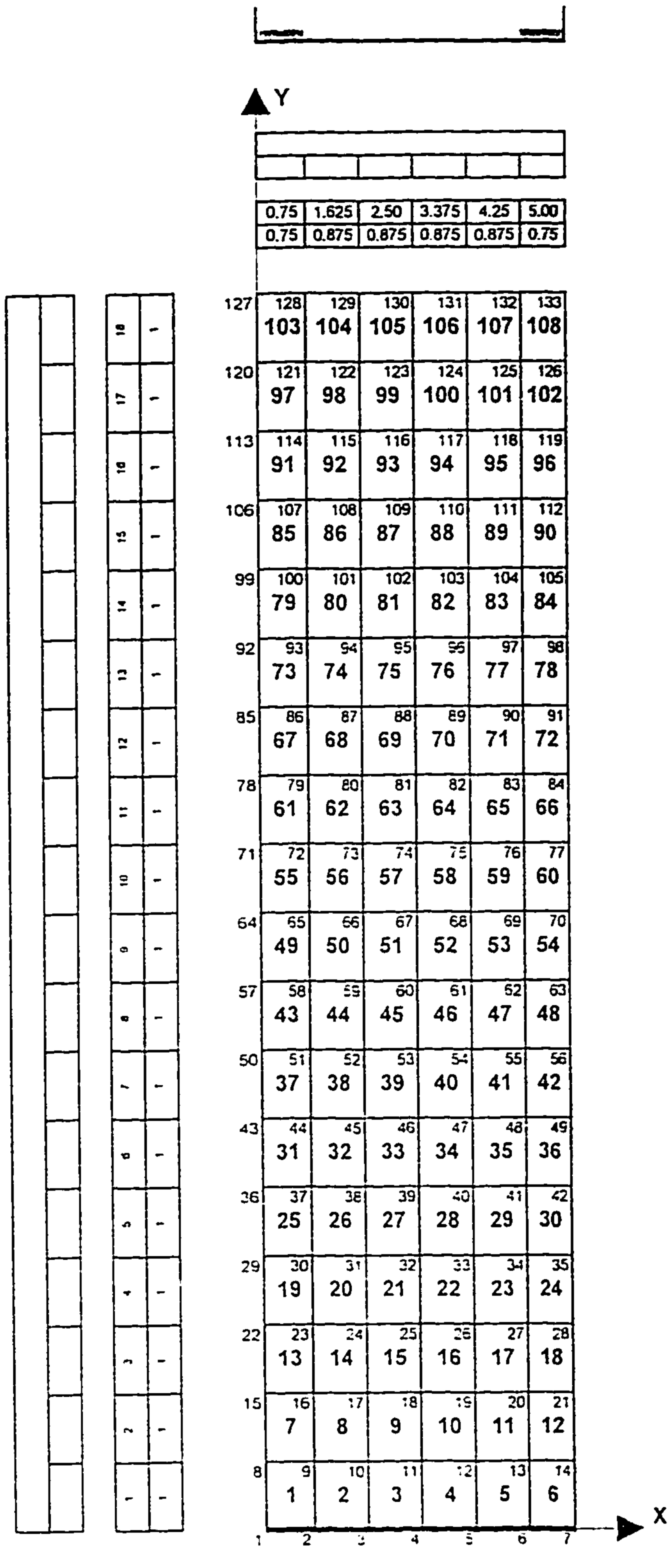
Appendix C

C.1 Finite Element discretization for simple span one lane slab type bridge of L=18m

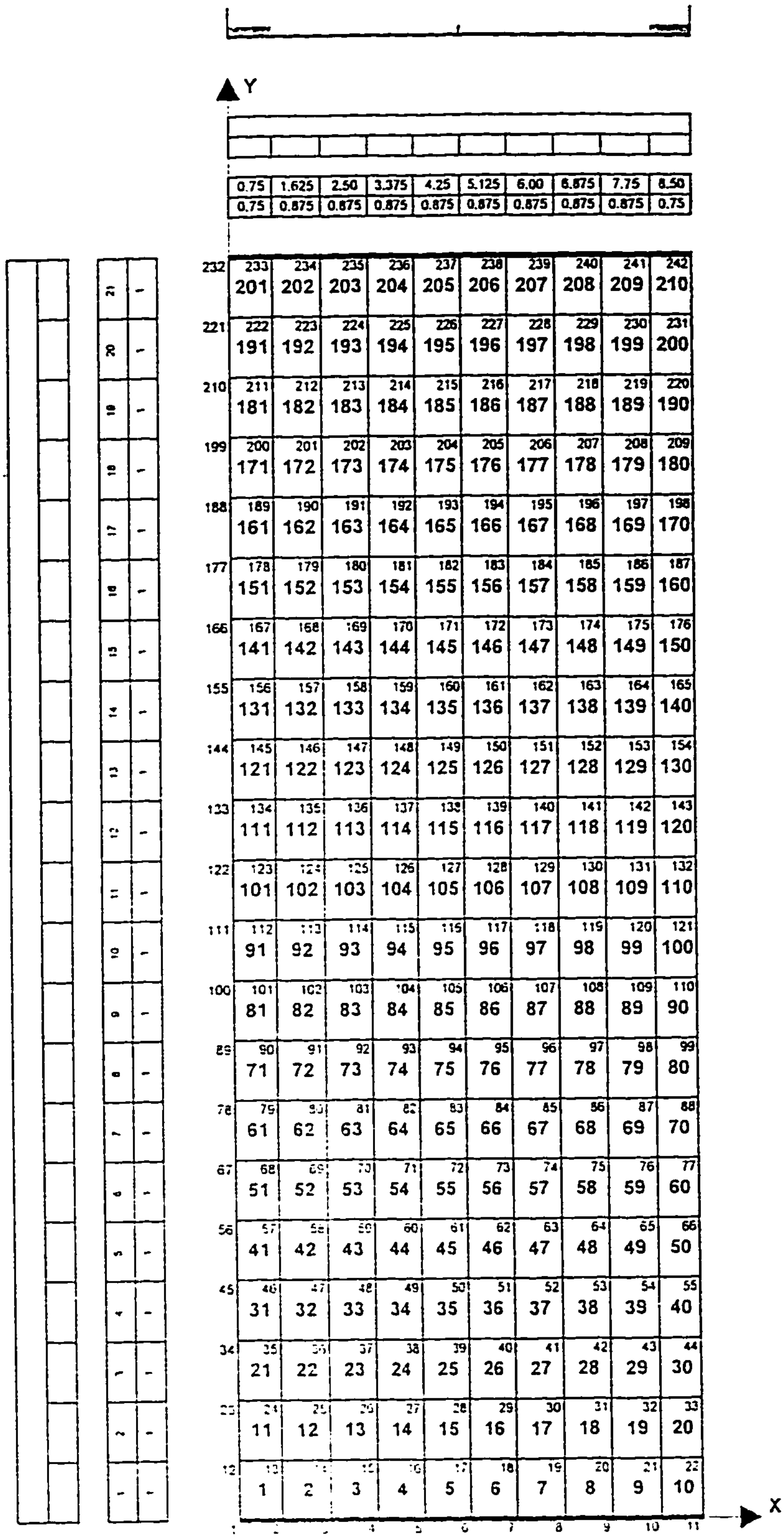
C.2 Finite Element discretization for simple span two lane slab type bridge of L=21m

C.3 Finite Element discretization for two span continuous two lane slab type bridge of L=18m

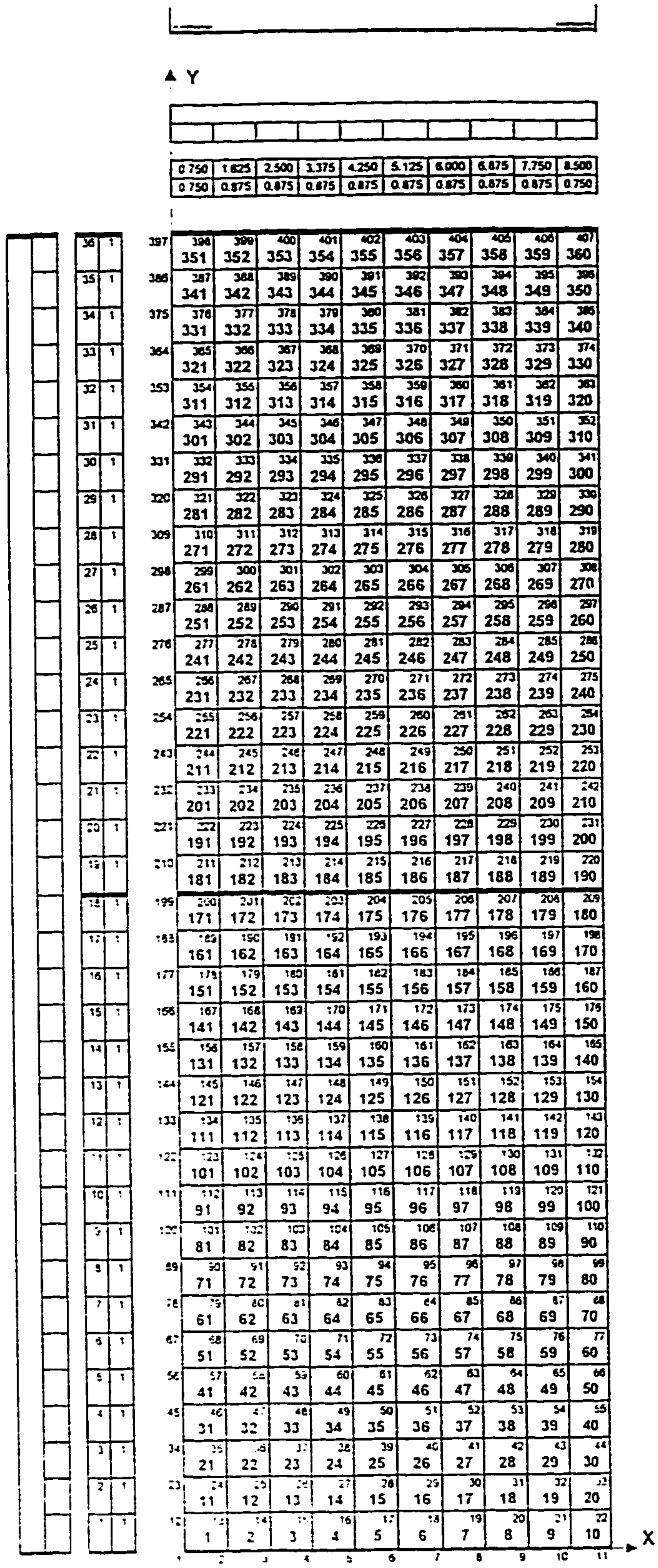
Appendix C.1



Appendix C.2


Y
0.75 1.625 2.50 3.375 4.25 5.125 6.00 6.875 7.75 8.50
0.75 0.875 0.875 0.875 0.875 0.875 0.875 0.875 0.875 0.75
X

Appendix C.3


Y
0.750
1.625
2.500
3.375
4.250
5.125
6.000
6.875
7.750
8.500
0.750
0.875
0.875
0.875
0.875
0.875
0.875
0.875
0.875
0.750
X

Appendix D

Results for Slab type Bridge Deck Analysis

Table. D.1: Comparison of Maximum Bending Moments in Simple Spans for Slab Type Bridges (One lane)

Span *L*	MOC 600 kN Truck		Model 650 kN Truck		Sample 790 kN Truck	
(m)	Myy (kN.m)	Mxx (kN.m)	Myy (kN.m)	Mxx (kN.m)	Myy (kN.m)	Mxx (kN.m)
6	89	31	90	28	103	33
9	143	34	154	33	179	37
12	224	36	234	34	278	39
15	318	37	328	35	386	40
18	404	37	417	35	502	40
21	497	37	513	35	617	40

Table. D.2: Comparison of Maximum Bending Moments in Simple Spans for Slab Type Bridges (Two lane)

Span *L* (m)	MOC 600 kN Truck		Model 650 kN Truck		Sample 790 kN Truck	
	Myy (kN.m)	Mxx (kN.m)	Myy (kN.m)	Mxx (kN.m)	Myy (kN.m)	Mxx (kN.m)
6	107	29	111	33	125	38
9	168	40	183	45	213	53
12	263	51	278	55	329	65
15	372	57	385	61	455	71
18	474	59	490	63	591	74
21	582	60	602	64	726	75

Table. D.3: Comparison of Maximum Bending Moments - Myy in Two Span Continous Slab Type Bridges - (Two lane)

Span *L* (m)	MOC 600 kN Truck		Model 650 kN Truck		Sample 790 kN Truck	
	Max. +ve Moment (kN.m)	Max. -ve Moment (kN.m)	Max. +ve Moment (kN.m)	Max. -ve Moment (kN.m)	Max. +ve Moment (kN.m)	Max. -ve Moment (kN.m)
12	216	143	224	156	265	184
15	298	184	307	189	369	235
18	382	222	397	230	477	274

Table. D.4: Comparison of Maximum Positive Bending Moments - Mxx in Two Span Continous Slab Type Bridges - (Two lane)

Span *L* (m)	MOC 600 kN Truck	Model 650 kN Truck	Sample 790 kN Truck
12	47	51	59
15	53	57	67
18	56	60	71

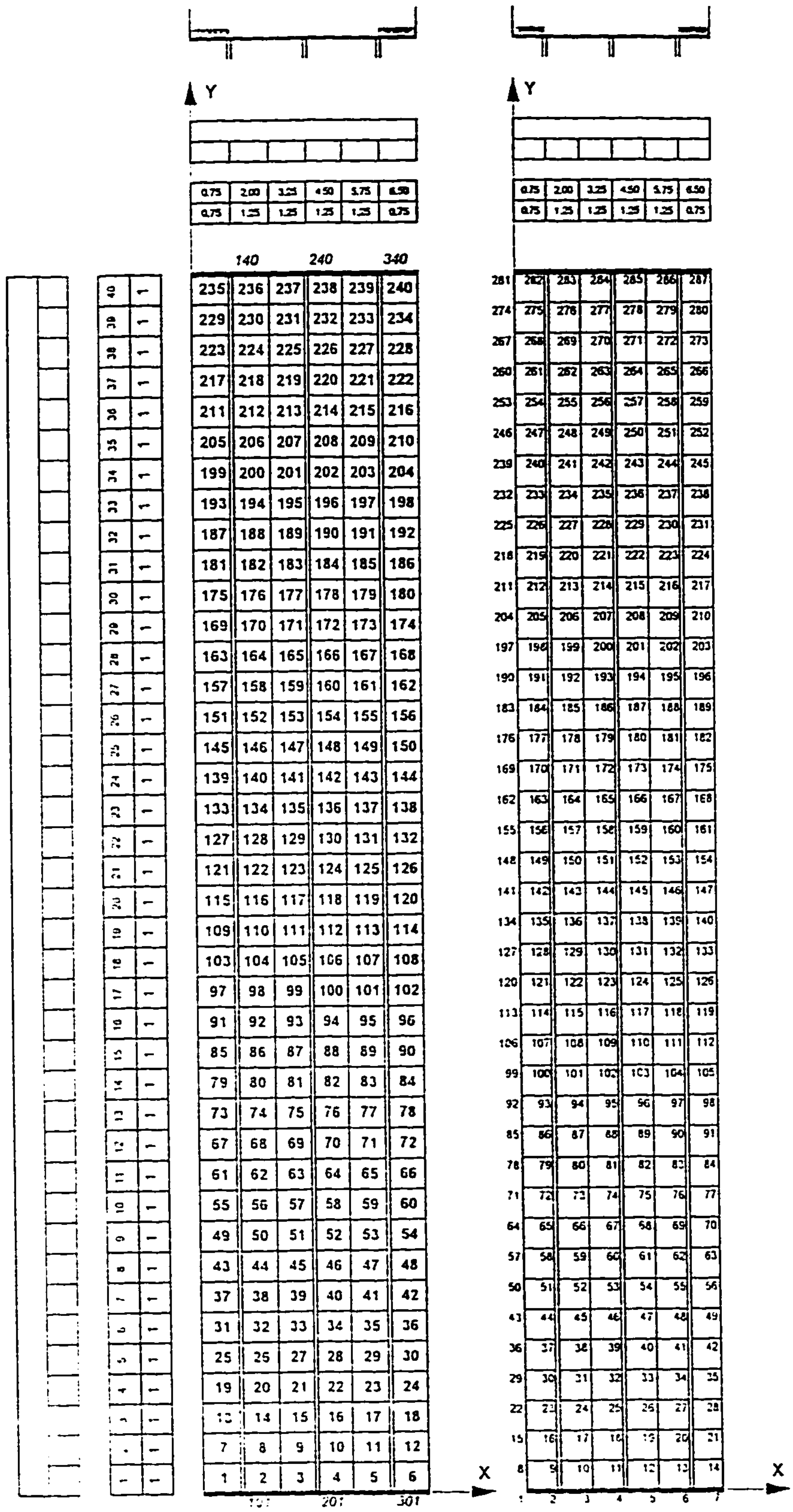
Appendix E

E.1 Finite Element discretization for simple span one lane Girder slab type bridge of L=40m

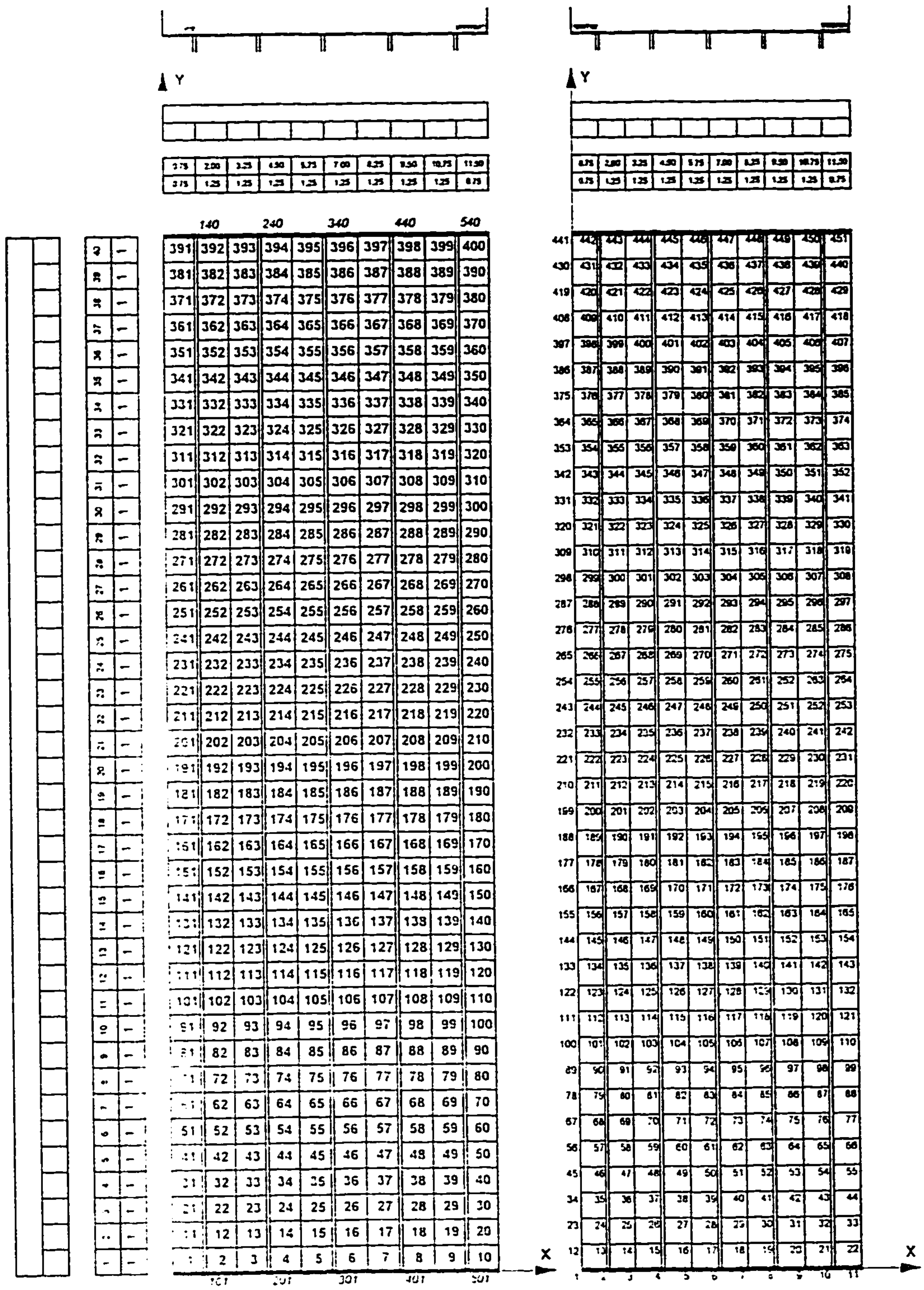
E.1 Finite Element discretization for simple span two lane Girder slab type bridge of L=40m

E.3 Finite Element discretization for two span continuous two lane, Girder - slab type bridge of L=18m

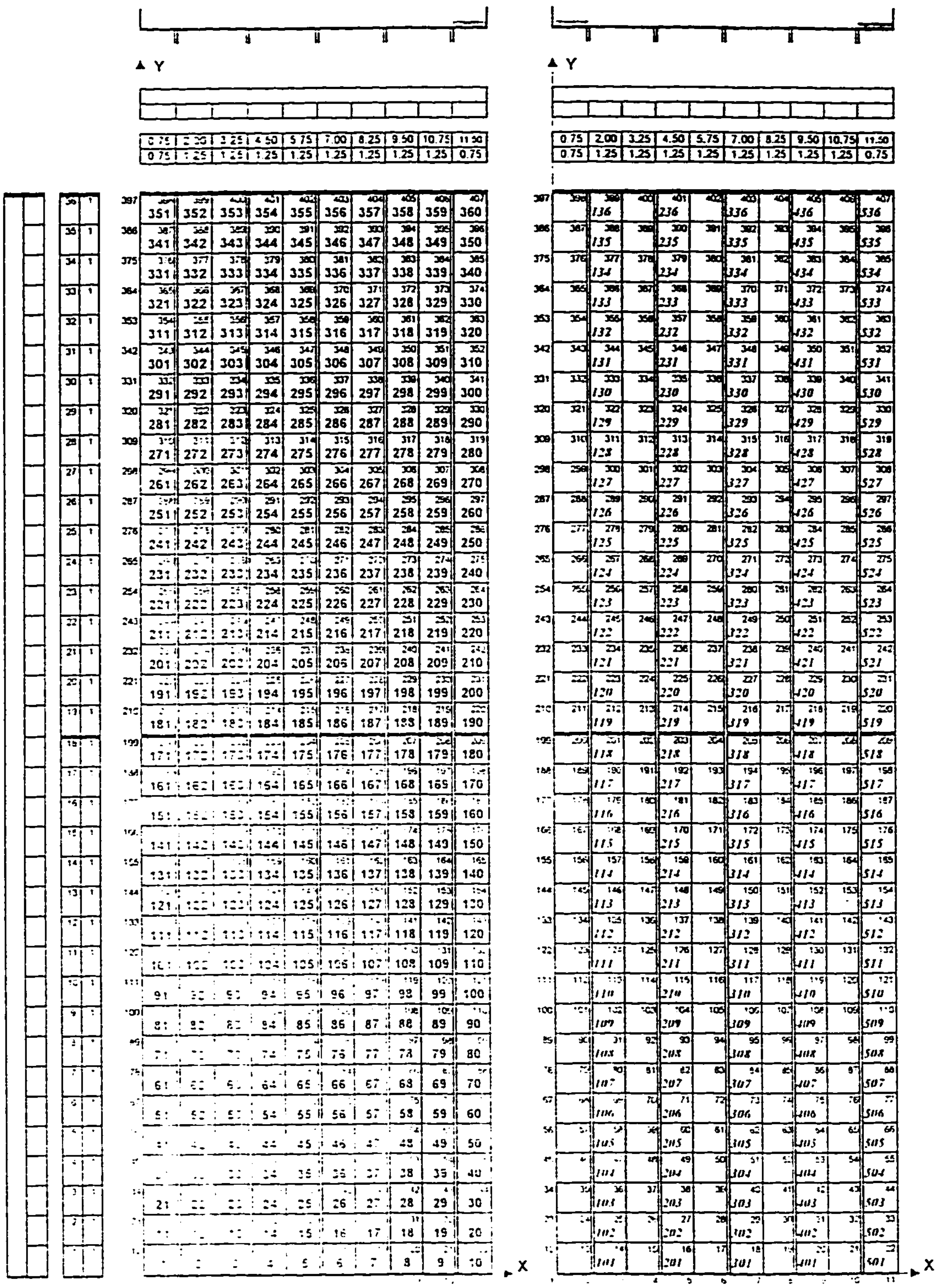
Appendix E.1



Appendix E.2



Appendix E.3


Y
0.75 2.00 3.25 4.50 5.75 7.00 8.25 9.50 10.75 11.50
0.75 1.25 1.25 1.25 1.25 1.25 1.25 1.25 1.25 0.75
X
Y
0.75 2.00 3.25 4.50 5.75 7.00 8.25 9.50 10.75 11.50
0.75 1.25 1.25 1.25 1.25 1.25 1.25 1.25 1.25 0.75
X

Appendix F

Results for Girder - Slab type Bridge Deck Analysis

Table F.1: Comparison of Maximum Bending Moments in Two Span Continous Girder Type Bridges - Interior Girder (Two lane)

Span *L* (m)	MOC 600 kN Truck		Model 650 kN Truck		Sample 790 kN Truck	
	Max. +ve Moment (kN.m)	Max. -ve Moment (kN.m)	Max. +ve Moment (kN.m)	Max. -ve Moment (kN.m)	Max. +ve Moment (kN.m)	Max. -ve Moment (kN.m)
12	671	454	710	487	841	567
15	935	587	982	610	1174	738
18	1160	741	1263	766	1517	906

Table F.2: Comparison of Maximum Bending Moments in Two Span Continous Girder Type Bridges - Exterior Girder (Two lane)

Span *L* (m)	MOC 600 kN Truck		Model 650 kN Truck		Sample 790 kN Truck	
	Max. +ve Moment (kN.m)	Max. -ve Moment (kN.m)	Max. +ve Moment (kN.m)	Max. -ve Moment (kN.m)	Max. +ve Moment (kN.m)	Max. -ve Moment (kN.m)
12	347	218	366	231	411	268
15	500	290	524	300	628	362
18	655	371	688	386	828	453

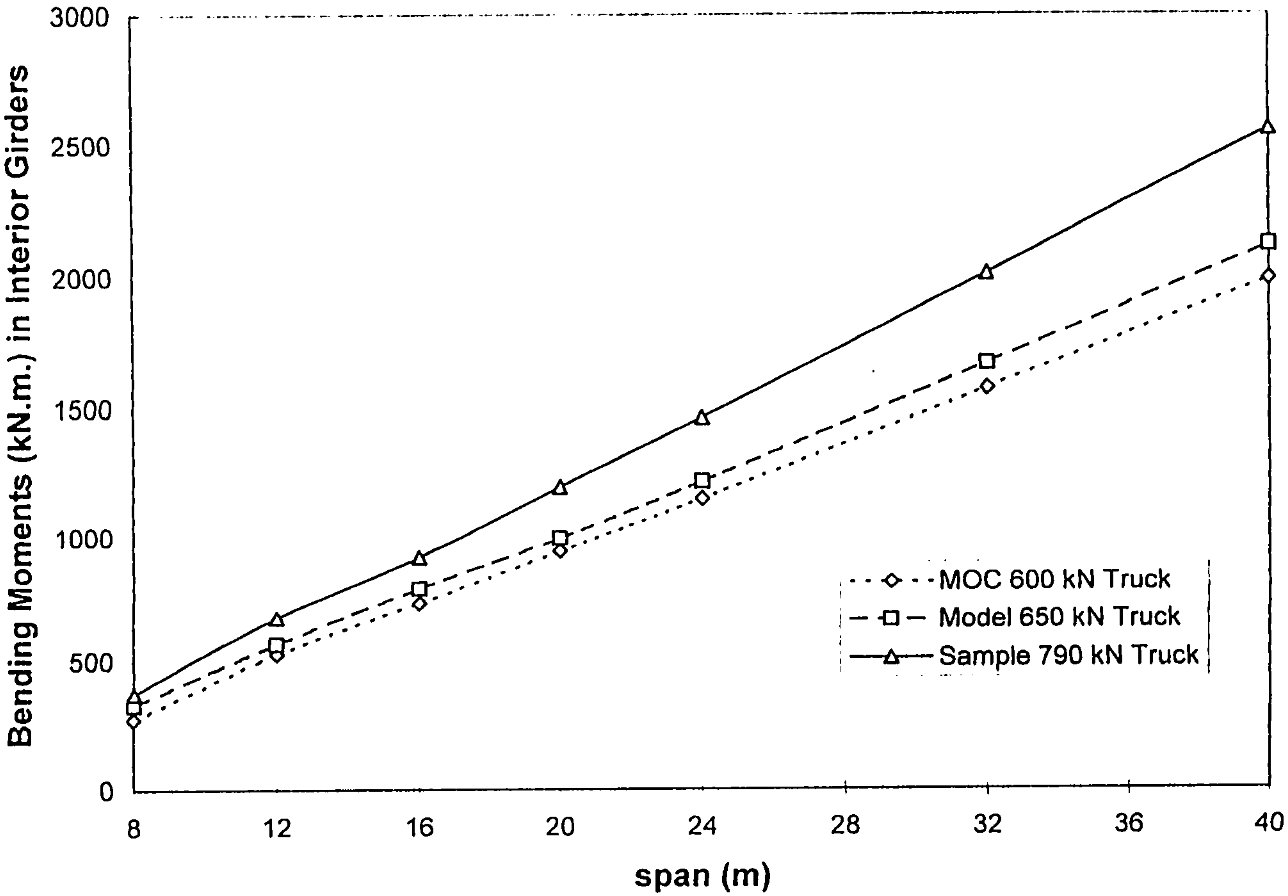


Fig. F.1 Maximum Moment in Interior Girder for One-lane Girder-slab Type Decks - Girder spacing -2.25m

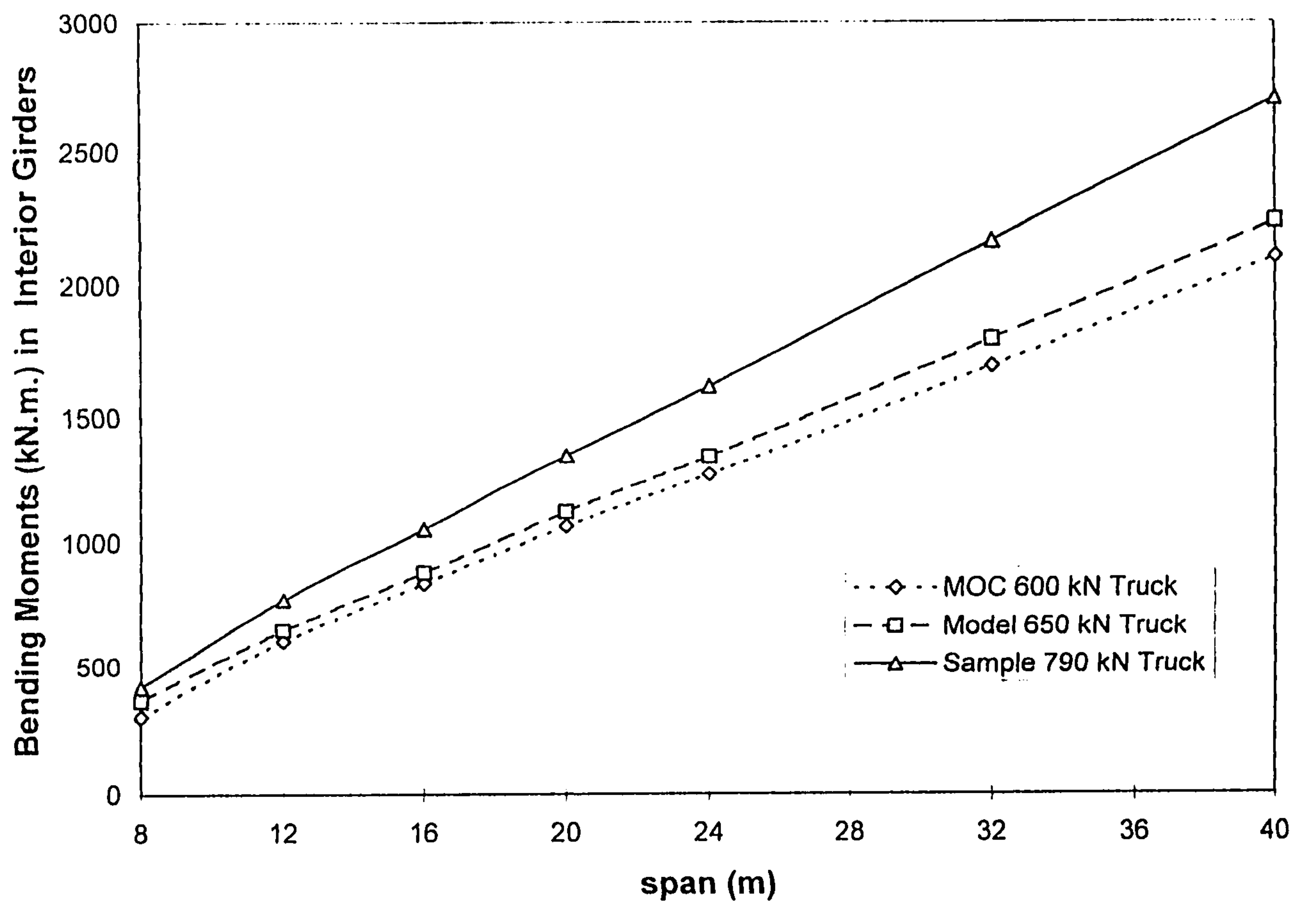


Fig. F.2 Maximum Moment in Interior Girder for One-lane Girder-slab Type Decks - Girder spacing -2.75m

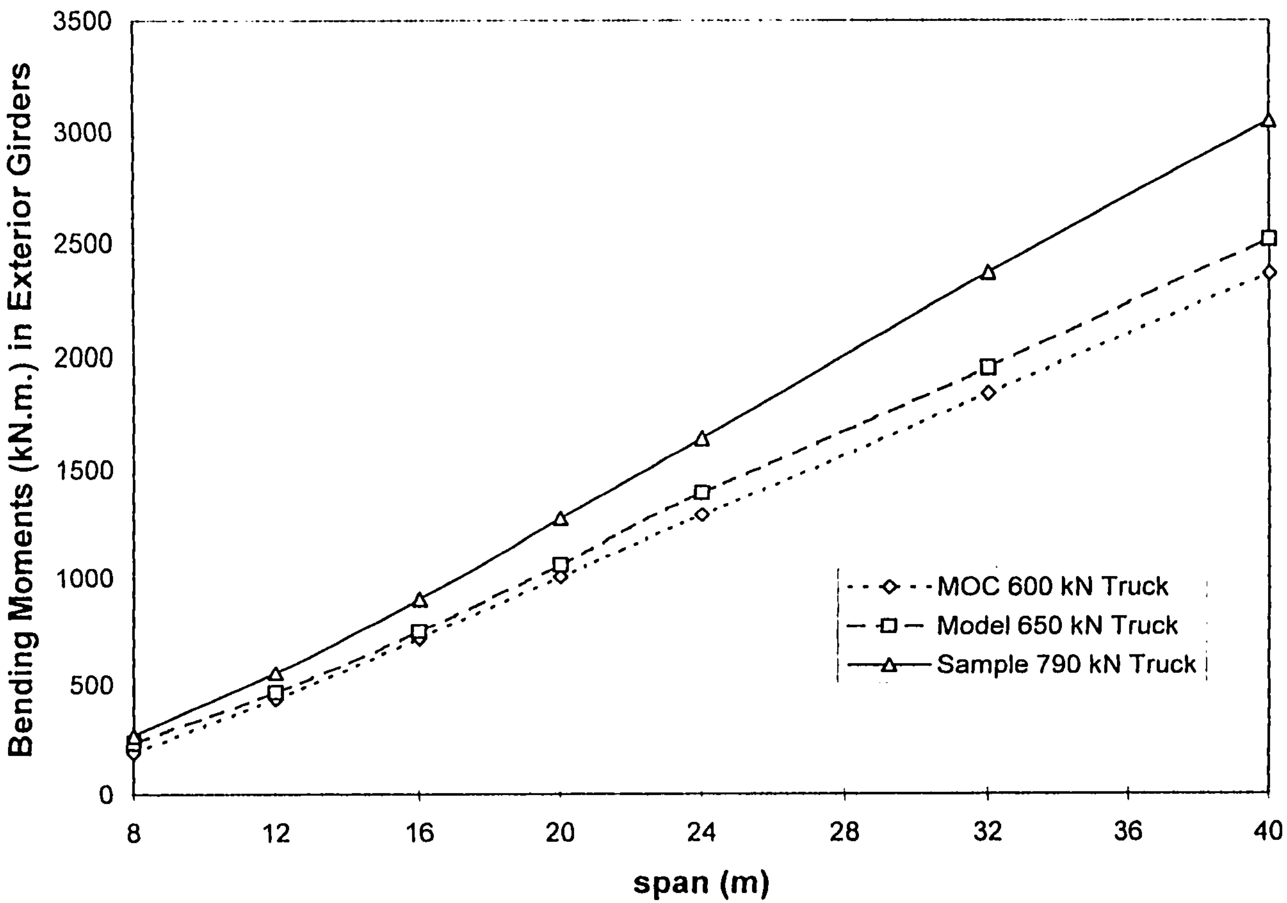


Fig. F.3 Maximum Moment in Exterior Girder for One-lane Girder-slab Type Decks - Girder spacing -2.25m

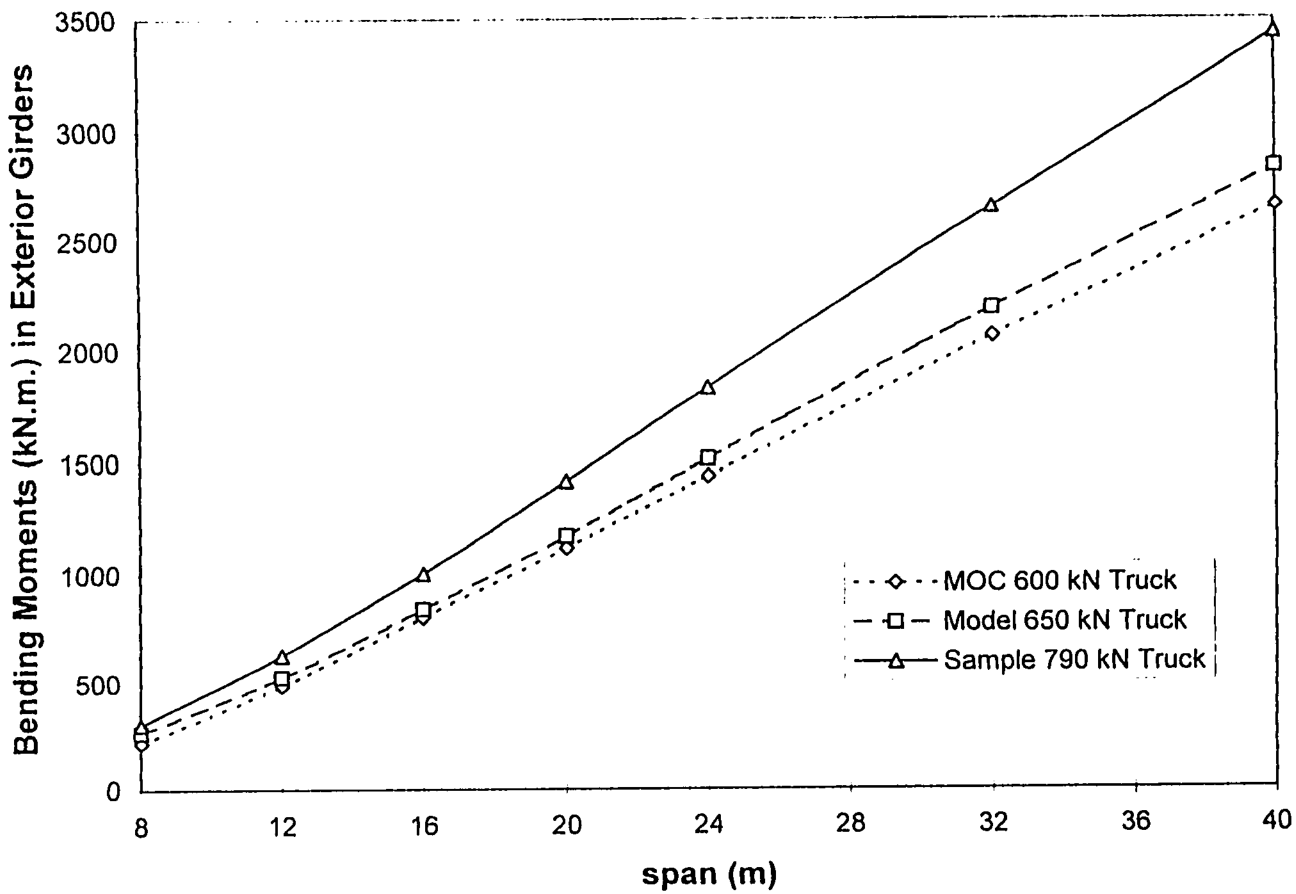


Fig.F.4 Maximum Moment in Exterior Girder for One-lane Girder-slab Type Decks - Girder spacing -2.75m

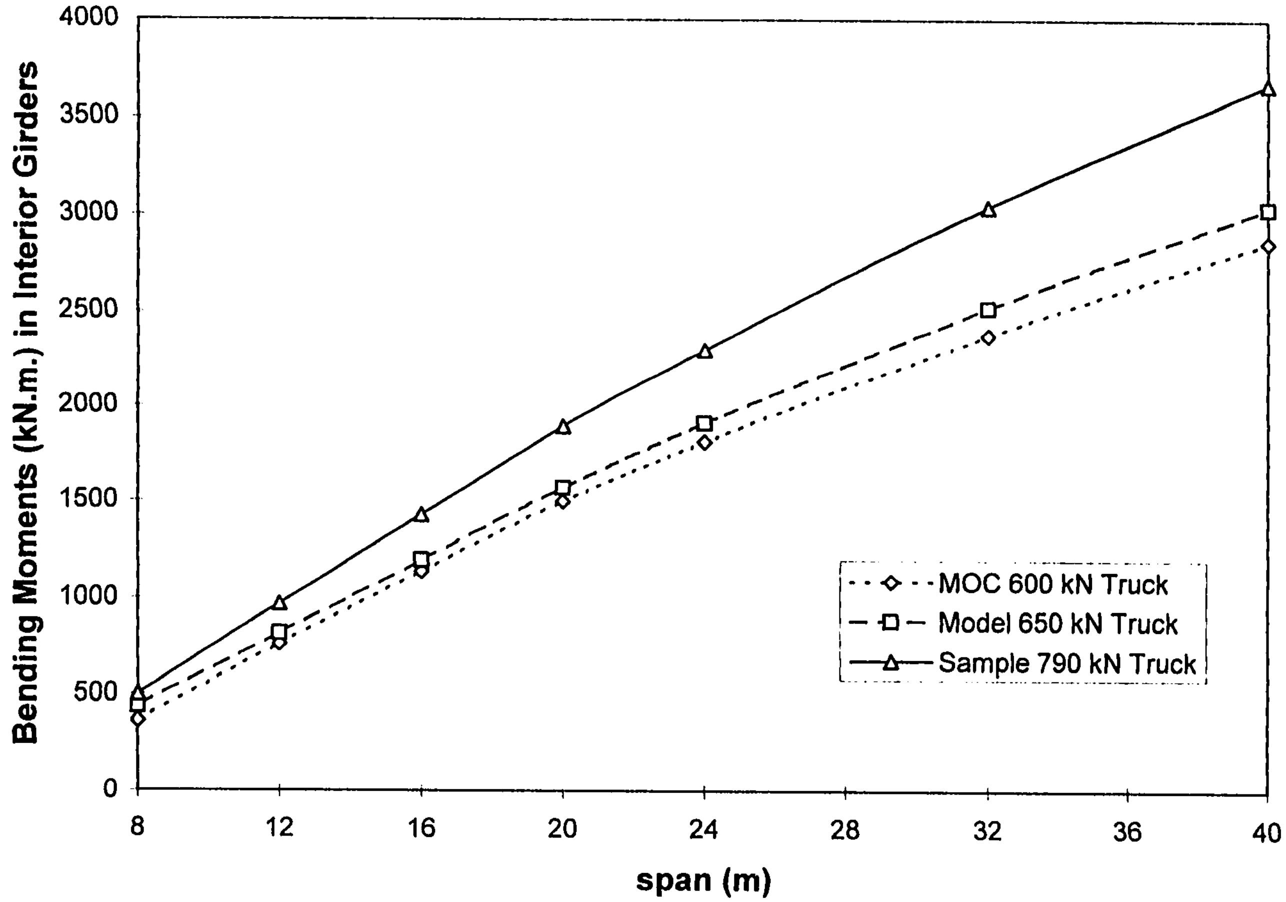


Fig. F.5 Maximum Moment in Interior Girder for Two-lane Girder-slab Type Decks - Girder spacing -2.25m

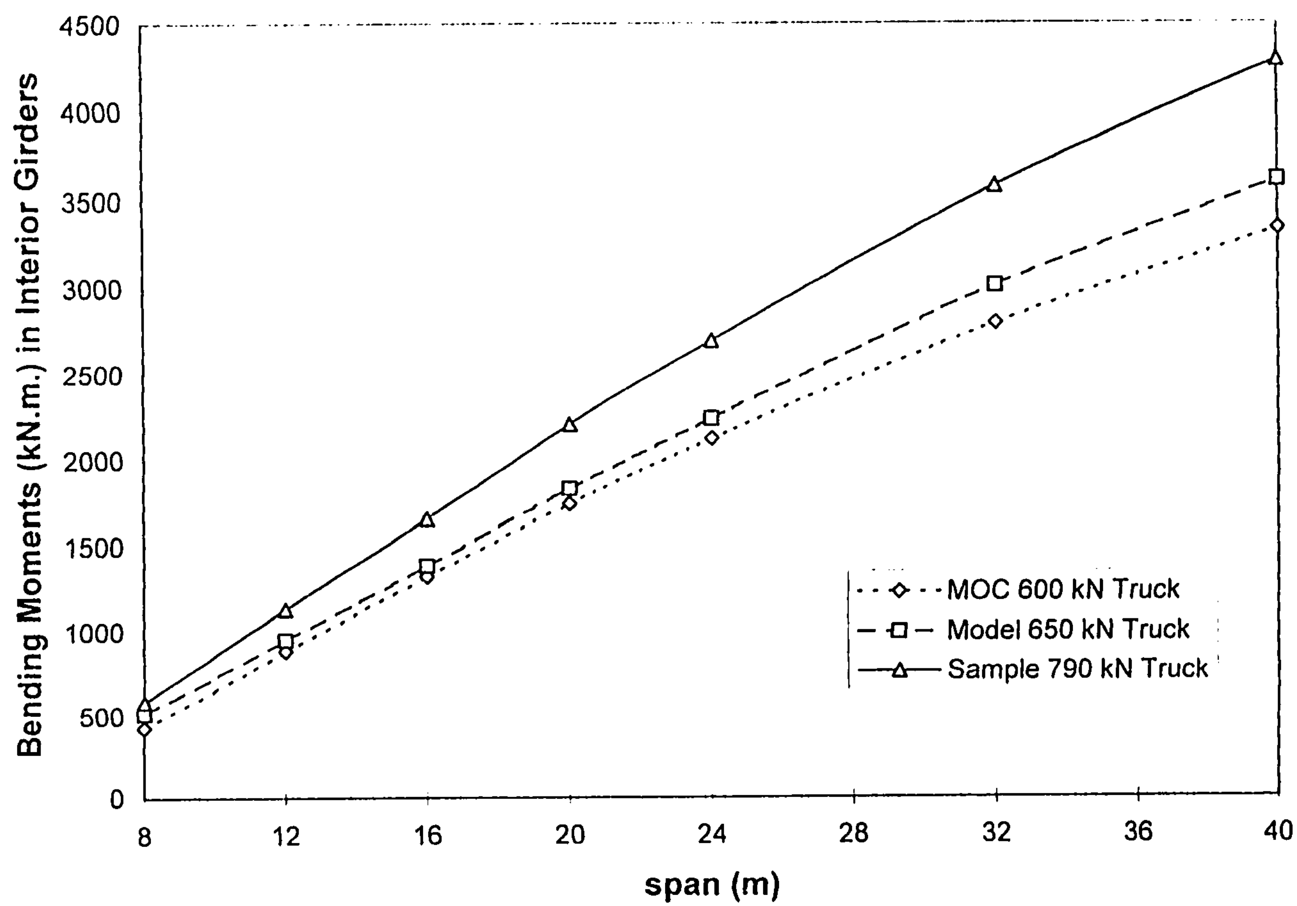


Fig.F.6 Maximum Moment in Interior Girder for Two-lane Girder-slab Type Decks - Girder spacing -2.75m

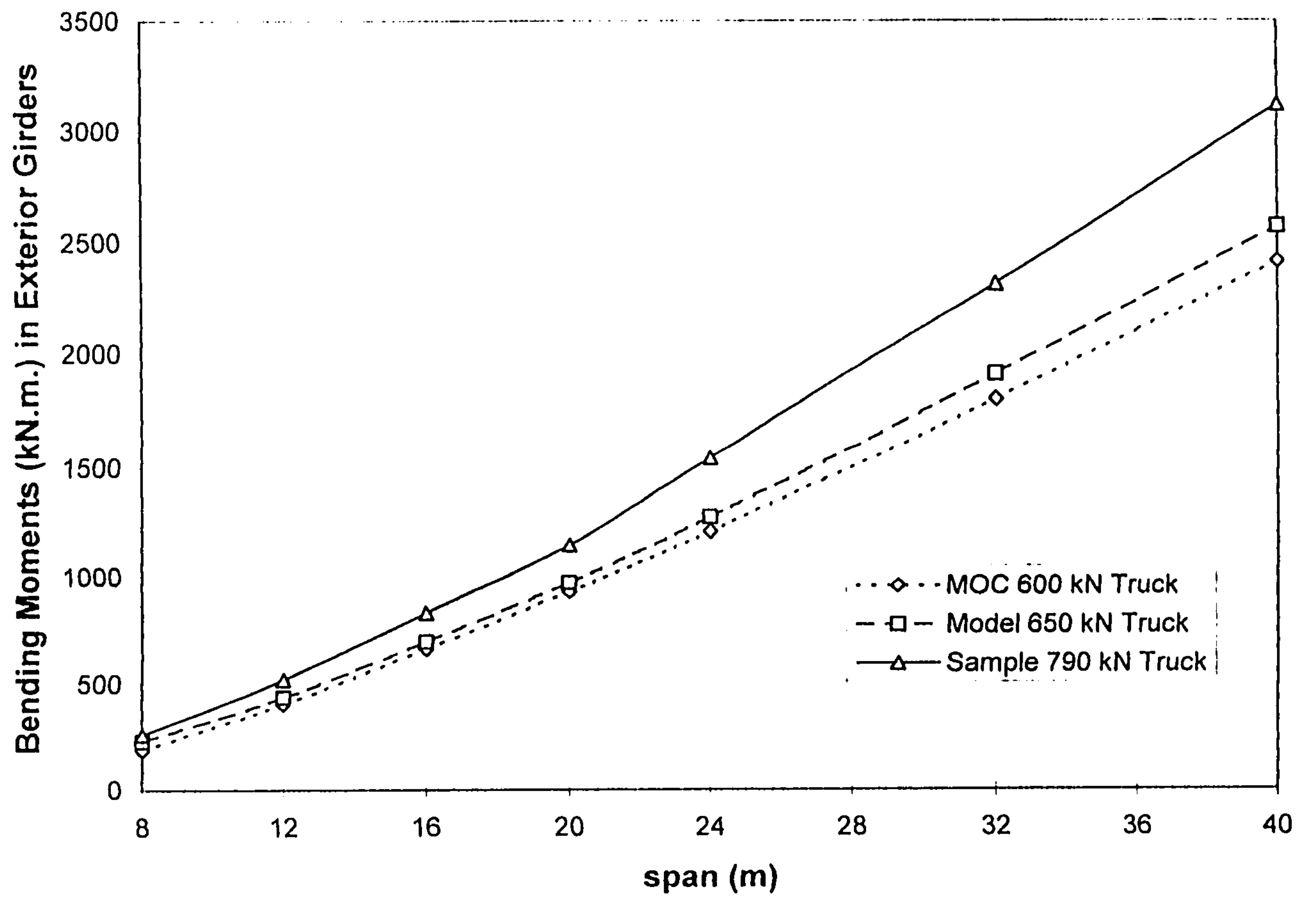


Fig. F.7 Maximum Moment in Exterior Girder for Two-lane Girder-slab Type Decks - Girder spacing -2.25m

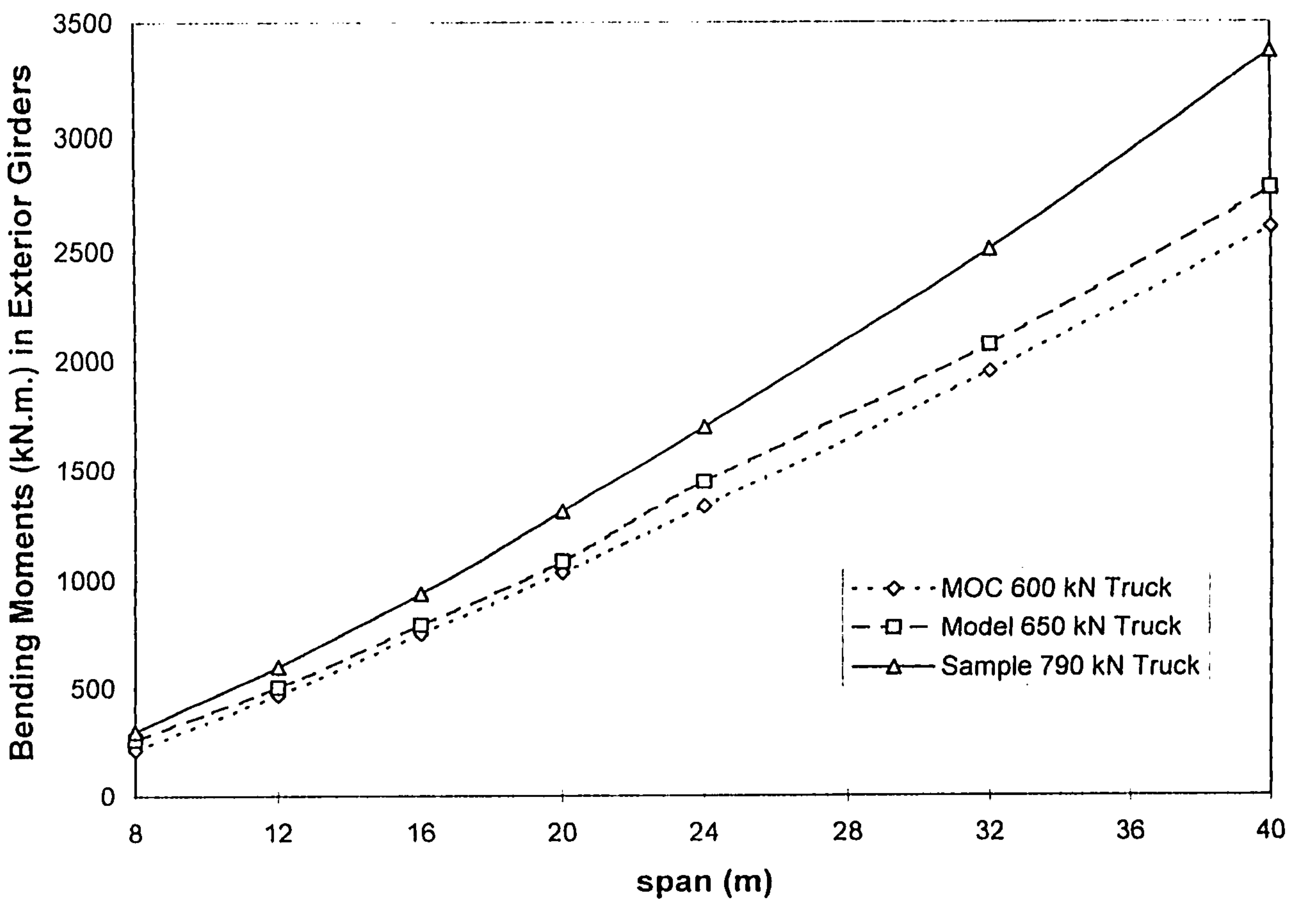


Fig. F.8 Maximum Moment in Exterior Girder for Two-lane Girder-slab Type Decks - Girder spacing -2.75m

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Vitae

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He hopes that this work of his thesis could be of immense benefit in formulation of new bridge design load not only for Saudi Arabia, but also provide guidelines to researchers from any country adopting the methodology of '*Ontario Bridge formula*'.