TRUCK Bridge Rating Software

Zoran Despot
Rade Hajdin
Dr. J. Grob & Partner AG, Winterthur, Switzerland

ABSTRACT

Road authorities in Switzerland are facing growing numbers of passage requests for special transports, i.e., for oversized, overweight vehicles along specific route. These requests have to be processed quickly and accurately. In particular the effect of overweight vehicles on bridges must be accurately assessed. A software program, TRUCK, assists authorities in this task. It is based on a comparison of internal forces (bending moments and shear forces) under design-code loads and loads induced by special transport. For this purpose the bridge structure is numerically simplified into a sequence of simply supported beams. By virtue of this simplification the application TRUCK is both fast and easy to use.

Development of the TRUCK program was based on object-oriented methodology. The system model resulting from requirement analysis is shown and shortly discussed. During development, special attention was paid to the modeling of code loads. TRUCK's software architecture is based on the three-layer model.

Finally, a TRUCK representation of an actual bridge subjected to special-transport loads is described.

INTRODUCTION

Road authorities need reliable load ratings for bridges in order to decide on requests for special transport. These load ratings include verification of structural safety and serviceability of the affected bridges. In Switzerland, the cantonal bridge authorities decide on special-transport requests. The great number of permissions—about 800 p. a. in a single canton, St. Gall—demands short processing time.

The entire network of bridges, rather than each single bridge, needs assessment. A network-level approach allows several routes to be analyzed in terms of the safety and serviceability of each bridge along several alternative routes. Other special-transport parameters include width and length, as well as traffic impact, etc.

A pre-established verification analysis for typical special-transport load models is not possible due to myriad axle load and spacing combinations. This problem can be only properly solved by a computer program like TRUCK that can consider arbitrary axle-load and axle-spacing combinations. TRUCK is not a structural analysis computer program; it is a kind of filter that provides prompt ratings of special-transport loads for bridges.

The first version of the program was designed and developed under the guidance of Dr. J. Grob in 1991. TRUCK release 1.0 was developed for MS-DOS with a simple ASCII user interface. TRUCK release 2.0 was developed for an MS-Windows 3.1 platform providing a Windows-based interface. Neither of these versions provided any data storage function, so that users had to input structural and special-transport data from the scratch for each load rating. Data saving and retrieval was the main requirement for the new release of TRUCK, presented in this paper.

The second important requirement was an effective interface to the existing KUBA-DB information system. The KUBA-DB is the information system developed under the patronage of Swiss Federal Highway Office. The KUBA-DB database contains inventory, inspection and MR&R data. Furthermore, the KUBA-DB database contains structural and special-transport data that can be used by program TRUCK.

PRINCIPLES OF COMPARISON ANALYSIS

The load rating provided by TRUCK is not based on the structural analysis of the bridge. Although this approach would give more accurate results, it is not suitable in actual practice since structural analysis is both tedious and time-consuming. Consequently, such an approach could not be applied efficiently for the large number of bridges on the specific route. TRUCK is a tool for network level analysis that assists users to analyze several potential routes with hundreds of bridges in order to choose the optimal one.

The load rating in TRUCK is based on comparison analysis, between effects, i.e., stresses, due to the design code loading and the effects of special-transport loading. This approach yields a sufficiently accurate estimation of the safety and serviceability of a structure under special-transport loading, presuming that the bridge has been adequately designed to sustain required code loading. Thus, code loads used in design can be considered as lower bound approximations of load carrying capacity.

The special transports are usually special vehicles carrying exceptionally heavy goods. Their loading can be modeled as a sequence of concentrated forces (Figure 1). The spacings between these forces are given by the axle-spacings of the special vehicle. The dynamic effect is taken into account by a dynamic load factor Φ (Φ>1), which is a function of vehicle velocity v.

Simplified Bridge Structural System

The stress deriving from a given special-transport load model can be readily calculated, assuming the structural system of the bridge is accurately described. In order to minimize the amount and complexity of the input data, the representation of the structural system has been significantly simplified.

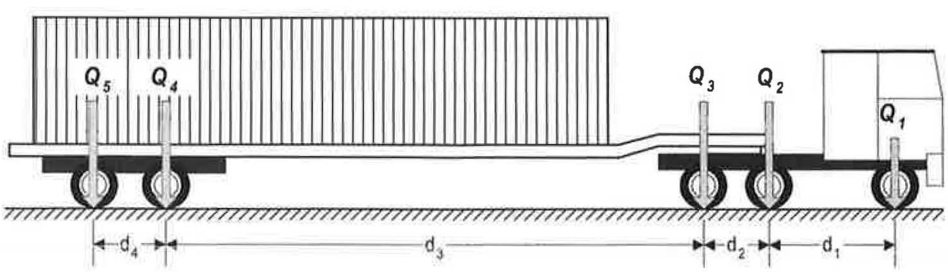

Figure 1: Special-transport load model.

The simplified structural system consists of a sequence of simply supported beams. Experienced engineers often use this simplification both in the preliminary design of bridges and for quick verification of internal forces in existing structures. The accuracy of this simplification is discussed in the section on quality of results. The simplification process for a typical Swiss bridge, presented in Figure 2, will be discussed in this chapter. The guidelines for simplifications for other bridge systems, e.g., arch, slab or cable stayed bridges can be found in the program manual (*6*).

Swiss code requires safety and serviceability checks for bridges. The checks are based on ultimate limit states analysis and service state analysis.

For the serviceability check, the spans of simply supported beams are taken as distances between null-points of the bending moment diagrams, estimated by linear-elastic analysis. These spans are defined in TRUCK as reduced spans L_R.

To perform the safety check, the plastic redistribution of internal forces can be considered. This redistribution changes the position of the null-points of the bending moment diagrams. Thus, the same simplified structural system cannot be used for both safety and serviceability checks. Assuming full plastification (collapse mechanism) under design loads, the spans of simply supported beams may be chosen to be equal to geometric spans, defined in TRUCK as total spans L_T.

The distribution of internal forces in a cross section is governed by the transversal stiffness of the cross section. The special transport is directly loading bridge Figure 3 on a relatively small width, compared to the bridge's width. For flexible cross sections some parts of the bridge cross sections have to sustain a larger portion of the loading than the others. In this case the girder nearest the loading carries more load than those further away (Figure 3).

This unequal stressing of cross-section is taken into account by introducing the effective width, corresponding to the effective width defined in codes of practice. Furthermore, TRUCK considers two locations of the special transport, one for centric and one for eccentric passages. Hence, for both centric and eccentric passages, effective widths b_z and b_e have to be specified. The widths of traffic and pedestrian lanes within the effective widths have to be specified as well. This is necessary if the code loading on pedestrian lanes differs from one on traffic lanes.

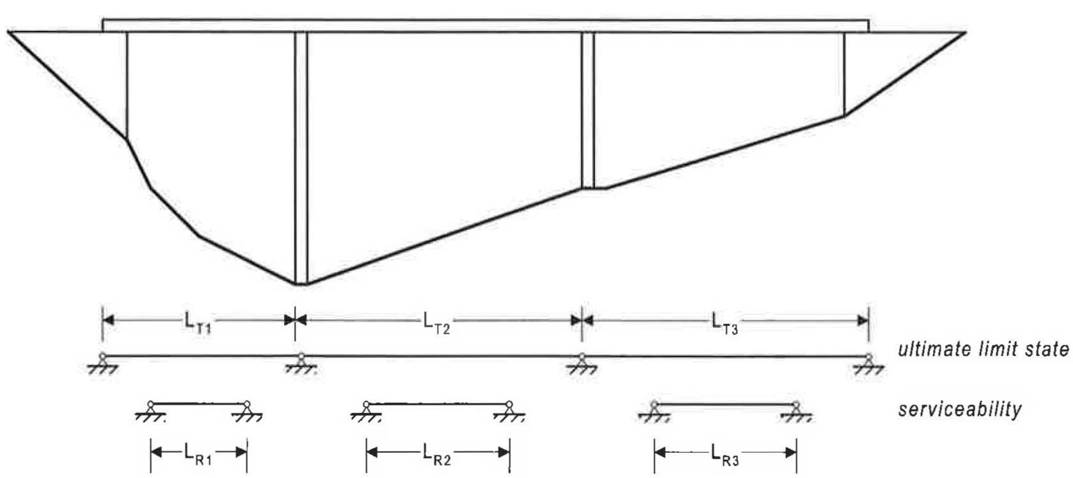

Figure 2: Simplified bridge structural system represented as a series of simple beams.

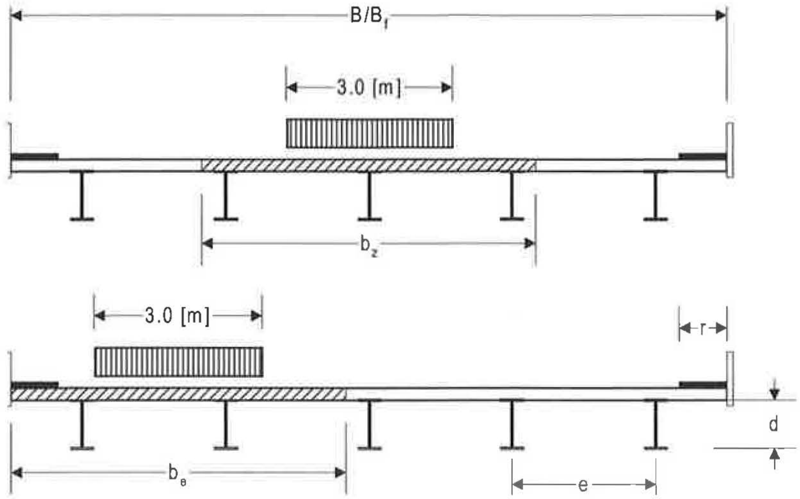

Figure 3: Effective width b_z for centric and b_e for eccentric special-transport crossings.

Code loads

The load requirements that a bridge has to fulfill for assuring safety and serviceability are given by code of practice like SIA-160 or AASHTO. These codes specify magnitudes of loads and their arrangements. If the bridge can fulfill the load requirements given by a certain code of practice, it can be argued that its load-carrying capacity is indirectly given by the code of practice.

During the last 50 years the weight of trucks—the principal loads on road bridges—steadily increased, leading to ongoing revision of the code. A bridge that fulfills the load requirements specified in the 1950s will not fulfill the corresponding requirements at the end of the 1990s. All Swiss codes loads used in the last 100 years for bridge design have been modeled and integrated into TRUCK.

TRUCK also stores and makes available various code loads in its database, and new load provisions can be specified anytime. For this purpose another software (TRUCK Codes) has been developed that enables the user to specify new code provisions. This software is, however, not available for end-users.

Load-effects estimated by influence lines

A general statement for assuring safety in engineering design is that the resistance of the materials and cross-sections R shall exceed the demands of load-effects Q from applied loads:

$$R \geq Q \tag{1}$$

The load-effect Q_N due to code and permanent loads has to fulfill the following inequality.

$$R \geq Q_N \tag{2}$$

The load-effect Q_S due to special-transport and permanent load has to fulfill the following inequality:

$$k \cdot R \geq Q_S \tag{3}$$

The coefficient k represents the influence of the deterioration of the bridge structure, and is smaller than one. The left sides of inequalities (2) and (3) are the same, so that the comparison coefficient c can be expressed as:

$$c = \frac{Q_S}{kQ_N} \tag{4}$$

If comparison coefficient c is smaller then one, then the effect of the code-loads (i.e., the load-carrying capacity) is higher than the effect of the special transport loading. In this case the bridge can carry the special-transport loads. However, if the comparison coefficient is higher then one, then the bridge may not carry the special-transport loads and the crossing should be forbidden.

The comparison coefficients c_M and c_V are calculated for both load effects: bending moment M and shear force V, and for each simple beam i.

For each simply supported beam, the program scans for the maximum value of the comparison coefficients c_M and c_V. The maximum value of the comparison coefficient corresponds to the most critical load placement. To identify such load placements and to estimate maximal load-effects M and V, the influence-lines for mid-span bending moment, left and right reactions, are used (Figure 4).

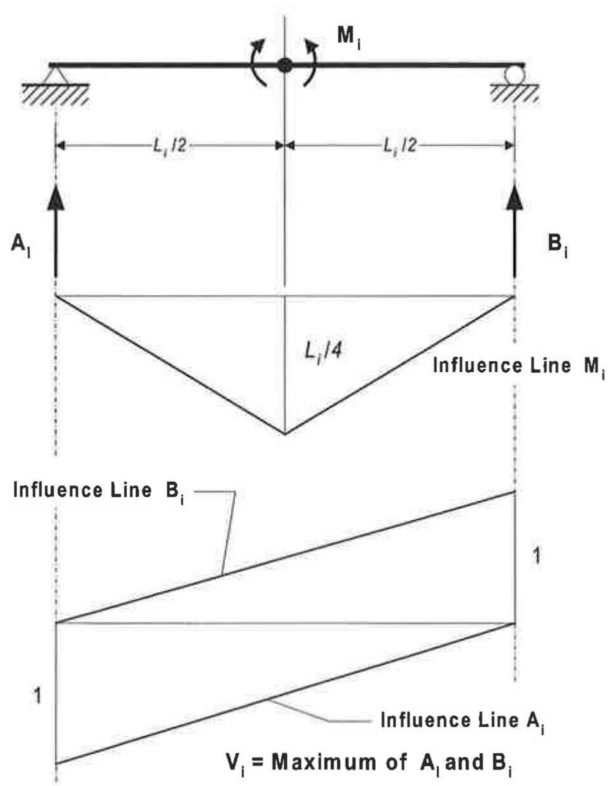

Figure 4: Influence lines for load placement and estimation of load effects M and V.

The comparison analysis is carried out for ultimate limit state and service state. For the ultimate limit state analysis, the load effects M^U and V^U and their respective comparison coefficients c^U_{Mi} and c^U_{Vi} are calculated on the corresponding simplified structural model for ultimate limit state with total spans L_T.

$$c^U_{Mi} = \frac{\gamma_{gS} \cdot M^U_{gi} + \gamma_S \cdot M^U_{Si} + \Delta M^U_{Si}}{\left(\gamma_{gN} \cdot M^U_{gi} + \gamma_N \cdot k_V \cdot M^U_{NVi}\right) \cdot k}$$

$$c^U_{Vi} = \frac{\gamma_{gS} \cdot V^U_{gi} + \gamma_S \cdot V^U_{Si} + \Delta V^U_{Si}}{\left(\gamma_{gN} \cdot V^U_{gi} + \gamma_N \cdot k_V \cdot V^U_{NVi}\right) \cdot k}$$

The load effects due to permanent load are given by M^U_{gi} and V^U_{gi}, M^U_{Si}, V^U_{Si}, ΔM^U_{Si} and ΔV^U_{Si} represent load effects due to special transport load respectively due to additional traffic. M^U_{NVi} and V^U_{NVi} represent load factors due to live code loads. The coefficients γ_{gS}, γ_S, γ_{gN}, and γ_N stand for load factors.

For the service state analysis, the load effects M and V, and respective comparison coefficients c^S_{Mi}, and c^S_{Vi} are estimated on simple beams with reduced span-length L_R corresponding to the simplified structural system for service state.

$$c^S_{Mi} = \frac{M^S_{gi} + M^S_{Si} + \Delta M^S_{Si}}{\left(M^S_{gi} + k_V \cdot M^S_{NVi}\right) \cdot k}$$

$$c^S_{Vi} = \frac{V^S_{gi} + V^S_{Si} + \Delta V^S_{Si}}{\left(V^S_{Si} + k_V \cdot V^S_{NVi}\right) \cdot k}$$

During the passage of the special transport, the bridge can be subjected to that exceptional load and additional traffic loads as well. TRUCK considers these circumstances in the following three cases:

- Bridge subjected to a special-transport load and full additional traffic
- Bridge subjected to a special-transport load and reduced additional traffic
- Bridge subjected to a special-transport load only

The additional traffic load is specified by Dr. J. Grob & Partner Ltd. in agreement with Swiss codes of practice.

Quality of Results

Simplification can yield unreliable results in some cases. It is beyond the scope of this paper to discuss this issue in detail. Investigation carried out by Dr. J. Grob & Partner Ltd. showed that for all bridge systems used in Switzerland, the results are within 10% of the ones obtained using more sophisticated structural systems. The prerequisites to achieve this good level of agreement are as follows:

- Simplification should be done by structural engineers following the rules given in the program manual
- The code load has to contain at least one concentrated load representing a heavy vehicle.

In most cases these conditions are fulfilled. Thus, the TRUCK system is broadly applicable in actual practice.

SYSTEM ARCHITECTURE

As mentioned TRUCK provides an interface to the existing KUBA-DB information system (see introduction). It is therefore necessary to give firstly a brief description of the KUBA-DB system architecture.

KUBA-DB System Architecture

The design of the KUBA-DB information system is based on established client-server architecture that is made up of two tiers: Database and Application, see Figure 5.

The Database Tier has two components: the DBMS (Database Management System) and the KUBA-DB database. Both components are provided by ORACLE relational database server. The KUBA-DB database contains inventory, inspection and MR&R data. Furthermore KUBA-DB can store structural data of bridges and special-transport loads that are needed for comparison analysis.

The Application Tier contains several applications. The main application is a KUBA application, which provides functionality for simple data management.

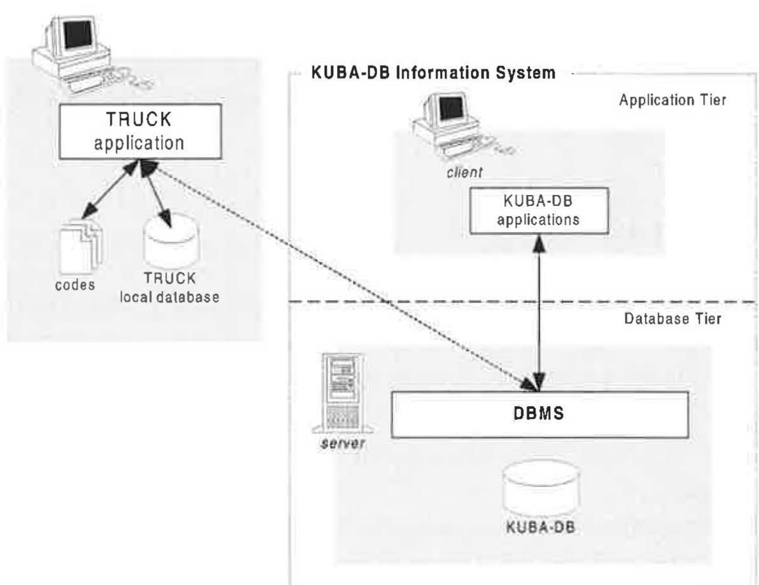

Figure 5: System architecture for the programs TRUCK and KUBA.

TRUCK System Architecture

The design of the TRUCK system was led by the requirement that TRUCK should provide an effective interface to the KUBA-DB information system, so that already existing information in KUBA-DB databases can be used. Besides the default local TRUCK-DB database TRUCK can connect simultaneously to several external KUBA-DB databases. Independent of the database type TRUCK provides the same functionality for navigating, editing and reporting as well as special transport load rating. Users can also copy bridge structural data from KUBA-DB database to the local TRUCK database. The TRUCK consists of three components: TRUCK database, TRUCK Codes and TRUCK application.

TRUCK Database

Bridge identification data, structural data and the special-transport data are stored in the TRUCK database. MS-Access was chosen as a relational database management system. The TRUCK program is conceived as a single-user database.

A local TRUCK database is useful if there is no direct network connection to the KUBA-DB database. Furthermore, there are always bridges that are not stored in KUBA-DB and that may be affected by a special-transport passage.

Codes

Code loads are given by the code of practice and specified by load models and rules for their arrangement. Due to the complexity of the information needed to describe a code load, codes can not be easily modeled and stored in a relational database. Consequently, each code of practice is stored in a separate binary file, referenced in the local database table. Creating new codes of practice and editing the existing ones are managed by a special tool, TRUCK-Codes.

TRUCK Application

The TRUCK application provides functionality for navigating, object editing, reporting and special-transport load rating. There is also a special external interface to the external KUBA-DB database. The interfaces to both local and external KUBA-DB databases are based on an ODBC driver.

SYSTEM ANALYSIS AND DESIGN

The TRUCK system was analyzed, designed and implemented using object-oriented technology. This technology is based on the concept of classes and their instances, i.e., objects. A class is an abstract description of the data and behavior of a set of similar objects, see (*1*). The members of this set are therefore called instances of classes. In an object-oriented program a given task is accomplished by objects exchanging messages.

The TRUCK application is implemented in the programming language C++ using Microsoft Visual Studio and the Microsoft Foundation Classes (MFC) (*3*). The MFC is an object-oriented framework that consists of classes that provide functionality of the user-interface, the database connection, etc.

The system analysis and design of the TRUCK application are done with the help of the tool Rational Rose, 0. Unified Modeling Notation (UML) was used for modeling, 0. In the following sections an overview of the TRUCK application architecture is given and the two layers, with their underlying parts of the analysis model, are described.

Software Architecture Overview

The architecture of the TRUCK application is based on the Layer Pattern (*2*). The basic idea of this architecture is that a class in the given layer may interact with classes in the same layer and with classes in adjacent layers. In this manner the source code is easier to maintain and to enhance since coupling within application is reduced to small interfaces. The classes are divided in three layers: Persistence, Domain and User-Interface that lie one upon another and the fourth System layer that is made up of system classes.

The User Interface and Domain Layer are described in the following two sections. The persistence layer is interesting from a technical point of view, but the description of its role and composition is outside the scope of this article. It can just be said that the persistence layer is made up of classes that encapsulate the behavior needed to store objects in a relational database (local TRUCK-DB and external KUBA-DB). Since TRUCK is a relatively small application with less then 50 domain classes, a simple solution was chosen that divides domain classes from so-called data interface classes which provide connection to the database.

User Interface Layer

The user-interface layer is generally made up of classes that implement views like forms and dialogs, as well as controls like buttons and menu commands. The majority of these classes are subclasses of the Microsoft Foundation Classes, which provides general user-interface functionality.

The classes of the user-interface layer furnish the interaction between the user and the computer system. Thus, the user can navigate through bridge groups, select a bridge

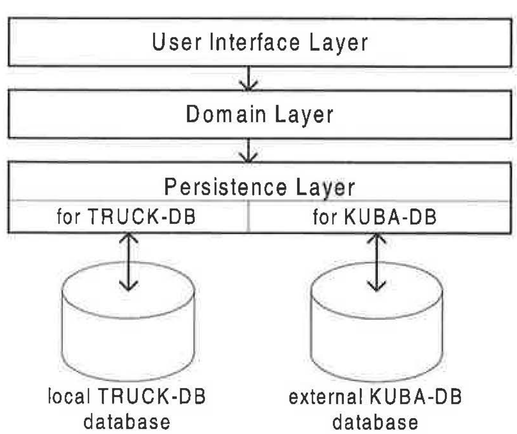

Figure 6: Layered architecture of the TRUCK application.

and change its data, create a new bridge and/or special transport, start a comparison analysis, etc. The user expects that the system behaves in a certain manner. This anticipated behavior was represented using Use Cases during the requirement analysis. A Use Case describes a set of sequences that each represents the interaction between an actor (user) and the system. An actor is a role that the user plays with respect to the system. Actors, use cases and the relationship between them are displayed in Use Case diagrams. An actor is represented as a "stick man" and a use case is shown as an ellipse.

The use case diagram shown in Figure 7 depicts two actors, Permit Authority and Structural Engineer, and their interaction with the TRUCK system. The Structural Engineer builds the simplified structure of the bridge, inputs structural data and chooses the appropriate code of practice. The Permit Authority inputs the special-transport load model, starts comparison analysis and, according to results, grants or declines permission for a special transport.

To give a user an impression of the future application, sketches of windows are often used in connection with Use Cases. In the lower right corner of Figure 7 a sketch of the window from the Use Case "manage bridge collections" is shown. Here, it should also be noted that TRUCK's user-interface is based on two window panes, as are many modern applications. The left one serves for navigation and grouping of bridges or special transports. The right window pane shows the object's identification data (such as the bridge identification number and name) in the upper part and the object's data in the lower part.

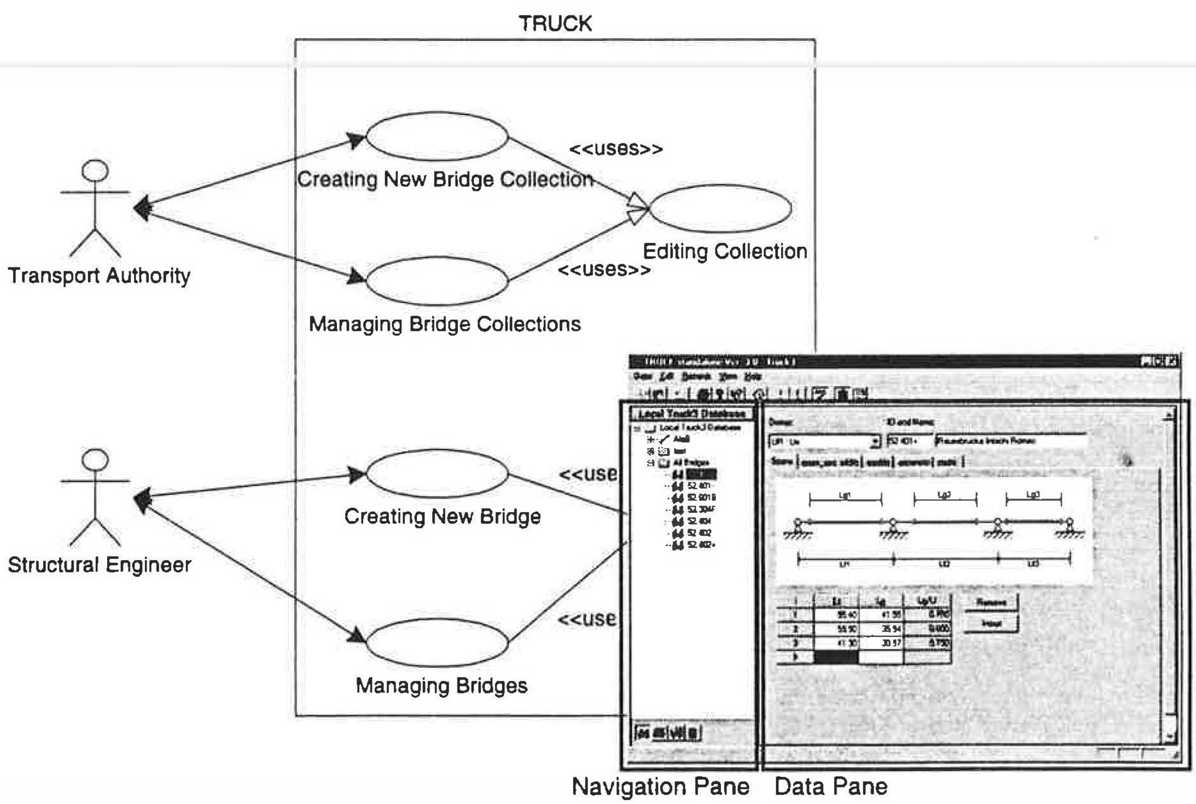

Figure 7: Bridge data management and bridge groups management.

Domain Layer

The classes of the domain layer represent entities involved in special-transport rating like bridge, span, special transport, etc. They implement the functionality for data management and carry out the comparison analysis. In contrast to the UI-layer, the domain layer emerged from the evolution of the analysis model. The classes and their responsibilities were defined according to Use Cases. Class attributes and the relationships between them are specified.

EXAMPLE

The following example illustrates the process of making a simplified structural model of the bridge described in section and gives an impression of the TRUCK user-interface. The bridges on the federal highway A2 between Lucerne and the Gothard Tunnel are used in the example, subject to loads from a representative special-transport of construction equipment.

Special transport weighing more then 100 tons travels from Point A to B on the A2 Highway and crosses three bridges. The special transport load model consisting of ten axle-loads is shown in Figure 10. By using the left navigation windowpane the route "AtoB" consisting of the three bridges is created, see Figure 9. The comparison analysis is shown only for the most interesting bridge called Intschi.

The bridge identified in KUBA-DB Information System as "UR:52.401+" has three spans 55-60-41 and the T-beam cross section. The bridge's outline and dimensions as well as longitudinal and cross sections are shown in Figure 8. The structural system of the bridge is simplified to the sequence of three simply supported beams. Because the bridge's T-beam cross-section poses high transversal stiffness the same effective width of 8.75 [m] is chosen for both centric and eccentric passages. The permanent load of the bridge for the chosen effective width is estimated to be 175 [kN/m].

The simplified bridge's structural system and effective width are graphically represented in TRUCK right windowpane, see Figure 9.

The relevant code loads are given by the Swiss code of practice Sia160/89. The critical load placements can be shown for all combinations of effective widths, centric or eccentric, and for the ultimate limit state the state of service, and for both load effects (bending moment and shear force). Figure 10 depicts the placement of code loads for the ultimate limit state, giving the maximum mid-span bending moment on the eccentric width of the cross-sections.

Finally Figure 11 shows the semaphore-like presentation of results. The results clearly indicate the weakest bridge on the route is bridge UR:52.401+. During the crossing of the special transport, the bridge should be closed for other traffic and the speed of the special transport must be lower than 30 kmph. As for code loads, the critical load placement can also be shown for special transport loads.

CONCLUSIONS AND OUTLOOK

Both predecessors of the current TRUCK program described in this article are installed in almost all Swiss cantons and they are frequently used. The last decade of TRUCK usage has confirmed that comparison analysis offers a reliable and fast method for special-transport load rating. The new release of TRUCK adds new information system functionality and smooth integration into the KUBA-DB environment. Furthermore,

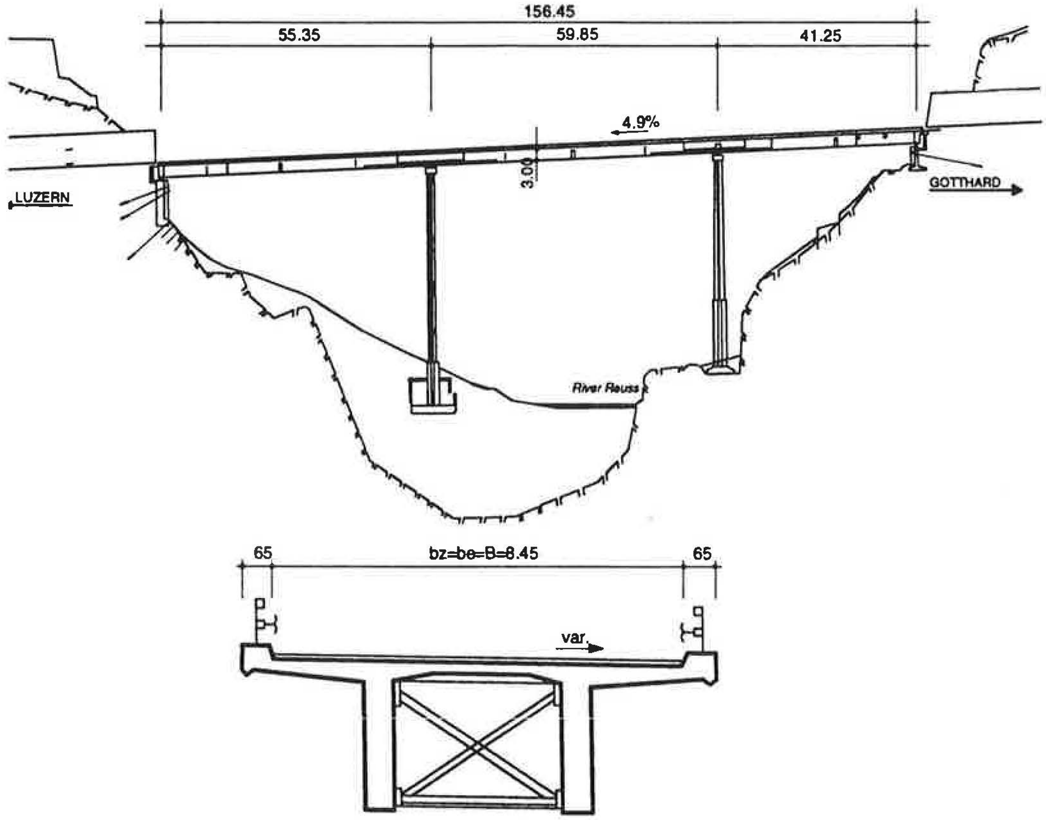

Figure 8: Longitudinal and cross section of the bridge "52.401+."

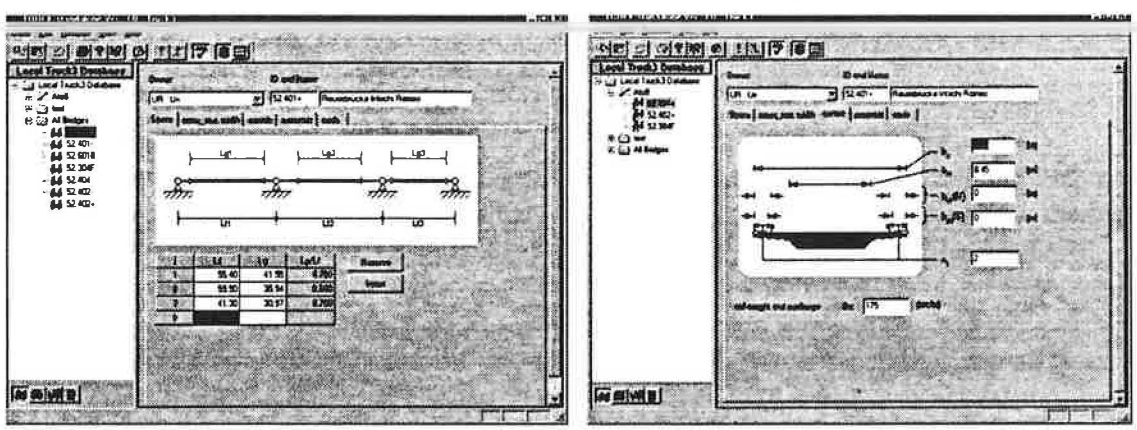

Figure 9: TRUCK windows for specification of the simply supported beams and the effective width for centric passage.

TRUCK is equipped with an effective graphical user-interface that eases data input, control and interpretation of results.

The layered architecture of TRUCK reduces coupling between software modules and therefore minimises maintenance effort. This architecture furthermore enables connection to or other external systems to use TRUCK data and comparison analysis. Such a new system would connect using a COM interface that provides the data and functionality of domain classes to other systems, e.g., web enabled systems.

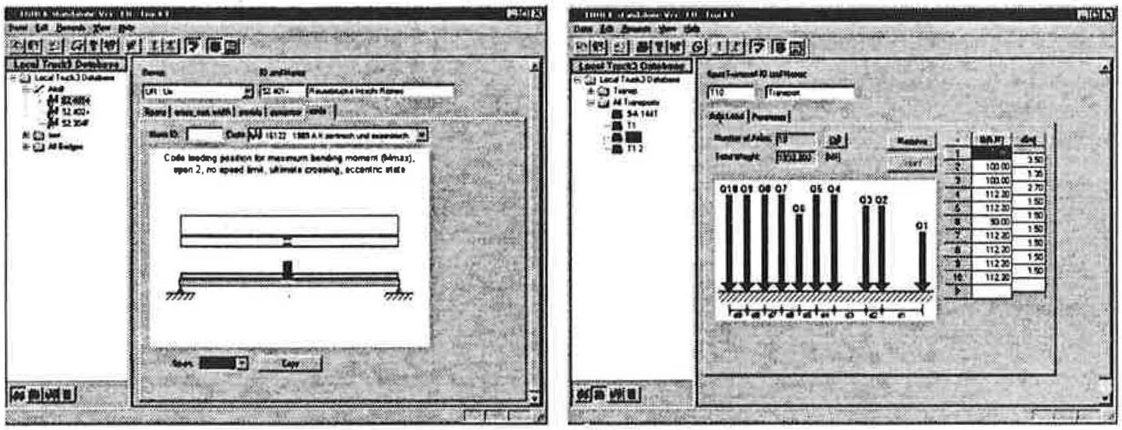

Figure 10: TRUCK windows for code-load selection and special transport load input.

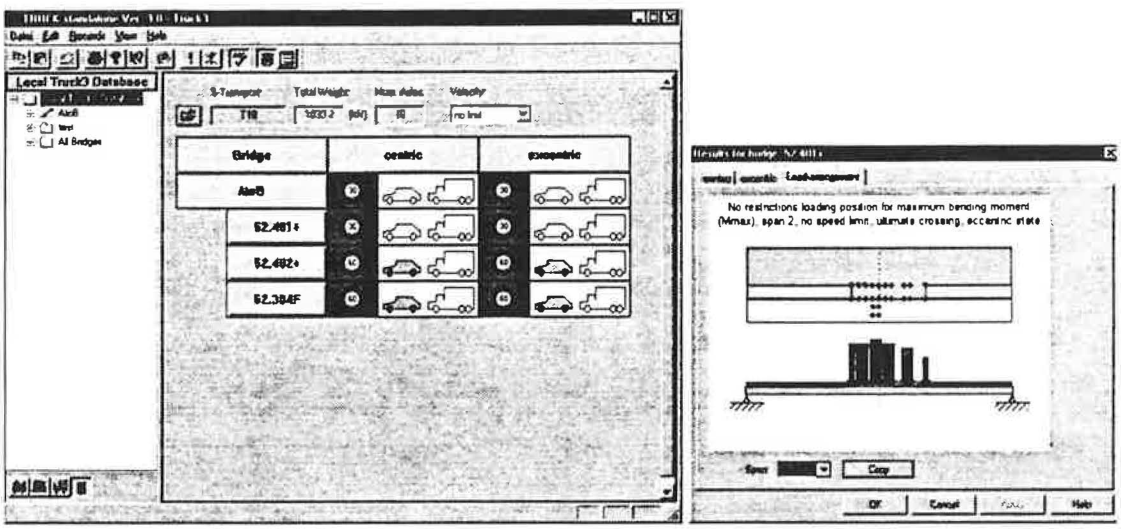

Figure 11: Results presentation.

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