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Knowledge-Based System Using Graphics and Image Processing

Système expert avec traitement de graphiques et d'images

Expertensystem mit Bildverarbeitung

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SUMMARY

Conventional knowledge bases are limited to symbolic representation of the knowledge using frames and rules. This paper presents a knowledge-based system for pedestrian bridge design which includes graphics and images. The object-oriented approach is applied to model the design objects graphically and to manipulate the constraints attached to them. It is shown how a graphics system can be used as the core element in an interactive, integrated preliminary design system that supports stress and vibration checking, cost estimation and three-dimensional landscape simulation.

RÉSUMÉ

Les banques de données traditionnelles se limitent à la représentation symbolique de la connaissance sous forme de masques et de règles. L'article présente un système expert pour le dimensionnement de passerelles piétonnières; ce système est en mesure de traiter des graphiques et des images. Les objets à étudier sont modélisés graphiquement, puis les conditions particulières à ces objets sont traitées de façon adéquate. Il est possible d'utiliser un système graphique en tant qu'élément central d'un système d'avant-projet intégral et interactif, qui sert de support à la vérification des contraintes et des caractéristiques vibratoires, à l'estimation des coûts et à la simulation tridimensionnelle.

ZUSAMMENFASSUNG

Herkömmliche Expertendatenbanken beschränken sich auf die symbolische Darstellung des Wissens in Masken und Regeln. Im folgenden wird ein Expertensystem für den Entwurf von Fussgängerbrücken vorgestellt, das Graphiken und Bilder darstellen kann. Die Entwurfsobjekte werden graphisch modelliert und die zugehörigen Nebenbedingungen in objektorientierter Weise gehandhabt. Es wird gezeigt, wie ein Graphiksystem als Kernstück eines integralen, interaktiven Entwurfssystems eingesetzt wird, das die Ueberprüfung der Spannungen und Schwingungseigenschaften, die Kostenschätzung und die dreidimensionale Lagevisualisierung unterstützt.

1. INTRODUCTION

Bridge design has been continuously profiting from the rapid development in the CAD/CAM systems. Automatic design and drawing systems are gradually taking over the manual and half automated design and drawing methods. Some automatic design systems are available for the preliminary design stage. These systems automate the algorithmic calculations of the loads and the structural analysis. Many CAD applications are available to help designers in the *graphical* representation of their ideas. These systems can be classified into two major groups: general purpose CAD and geometric modelling systems and specific domain CAD systems. However, the vocabulary that the general purpose systems offer is too primitive for expressing bridge design concepts. Specific domain drawing systems, on the other hand, expect a complete design data as input and therefore, they can be used only after the design is completed. As a result, bridge designers are still using manual drawing extensively in the first stage of the preliminary design when conceptual decisions about the bridge type and the main dimensions of the bridge are made [4].

Realizing these facts, in 1963, Sutherland developed Sketchpad [11] which is a pioneering computer drawing system with support for constraint specification and solution. The scope of Sketchpad and other similar systems is limited to very simple theoretical problems. In the field of civil and architectural engineering, Martini [5] proposed the Monge model for representing geometrical constraints. However, this model has not been implemented because of its complexity in representing real structures.

Some expert systems have been also developed to help selecting a bridge type that is satisfactory from different points of view such as economy, maintenance, landscape, etc. [7, 8]. Such expert systems do not consider the interactive nature of the design process and neglect the importance of graphics as a basic engineering media for design although some of them are concerned with bridge landscape evaluation [7].

In order to make computers more helpful in the preliminary design stage, there is a need for a new approach. The approach suggested in this paper emphasizes the total design system concept. The total system is centralized around a specialized graphics sub-system that can assist effectively in the preliminary design. The user of the system selects and graphically edits the prototype of the profile and the cross section of the bridge while the system insures that none of the geometric constraints is violated. The graphics sub-system is considered as the core element in an interactive, integrated preliminary design system that supports stress and vibration checking, cost estimation and three dimensional landscape simulation. Pedestrian bridges are chosen as a first step of applying the new approach because of the relative freedom in their design and the simplicity of calculating the live loads acting on them.

2. DESCRIPTION OF THE PROTOTYPE SYSTEM

2.1 The Concept of the System

The system is designed to fulfill, among others, the following requirements:

i) A rich library of prototypes of the components used in the design: These prototypes not only help in the graphical representation of the components, but also have knowledge about the default values, dimensional and positional constraints, and other attributes not directly related to graphics such as the material of the component.

ii) The ability to manipulate the components interactively: While doing free-hand drawing, designers express and amend some concepts in many iterations. To make the computer a substitute for the free hand drawing, the graphics sub-system should allow for maximum flexibility in processing the graphical components. Processing includes: (1) editing functions such as copy, cut, and paste, (2) graphical manipulation functions such as translation, rotation, and scaling, (3) graphical attributes setting (patterns, colors, lines) and (4) other functions for file management (save, load, etc.).

iii) The ability to check the effect of the graphical editing commands: Before executing any editing command, it is necessary to confirm that they do not violate any of the design constraints imposed by the design specifications or common sense rules.

iv) The ability to use the data resulting from the 2D graphics for analysis, cost estimation and landscape evaluation: In the preliminary design of pedestrian bridges, it is difficult to find the design that satisfies all the design conditions from the first trial and thus iteration is necessary. In each design cycle, the stresses in the critical cross sections are checked as well as the vibration characteristics of the bridge. The output of the graphics sub-system can be used for creating the input of the stress and vibration analysis. In addition, the same graphical data can be used for the cost estimation and landscape estimation with 3D drawing.

This system is intended to be used by novice designers or people with little design background and experience such as bridge planners. In addition, this system can be further developed to serve as an educational tool.

2.2 System Environment

The system is implemented on a workstation (SUN SPARC Station). C++ [9] is used as the main language for the system development. The system uses a library called Unidraw[12] for the 2D graphics system. Unidraw is a library of C++ classes that facilitate the development of domain-specific graphics object editors. Unidraw includes basic graphical components such as lines and polygons, commands for manipulating components, tools for selecting, transforming, and otherwise modifying graphical components. C++ is selected as the main language for developing the system because of its particular suitability for structured graphics editing. The well established advantages of C++ such as inheritance, encapsulation, code reusability and rapid prototyping are used in deriving new classes from the Unidraw library to fit the requirements of the system.

The 3D graphics module is developed in C language while the stress and vibration analysis modules are written in FORTRAN. The 3D graphics module is written using PHIGS library [10]

3. STRUCTURE OF THE PROTOTYPE SYSTEM

A prototype system has been developed that emphasizes the use of graphics not only as a group of lines that represent the final design, but as a knowledge representation method that has the power of gradually refining the design while checking the geometrical constraints. The structure of the final system is shown in Fig. 1. The five modules of the system are numbered in the figure and are explained in the following paragraphs:

i) Bridge images database:

The main purpose of the bridge multimedia database is to assist the designer in the preliminary design stage by allowing him to browse through the pictures of available pedestrian bridges and retrieve the ones that may be used as a starting point for the new design. The prototype database has so far more than 100 pedestrian bridge images in Japan taken from different sources[1]. The main table in the image database has one record for each image. Each record has the following fields (1) bridge name, (2) span length, (3) superstructure type, (4) sub-structure type, (5) material, (6) type of the crossing (over a river, a road, etc.), (7) the environment of the bridge (city area, rural area, mountain area), (8) part of the bridge shown in the image, (9) camera location, (10) pointers to related images of the same bridge, and so on.

The data of the main bridge dimensions are included in the database. These data can be used to draw the bridge profile and bridge cross section. Figure 2 shows an example of retrieving the cable-stayed pedestrian bridges with total span length less than 110 m.

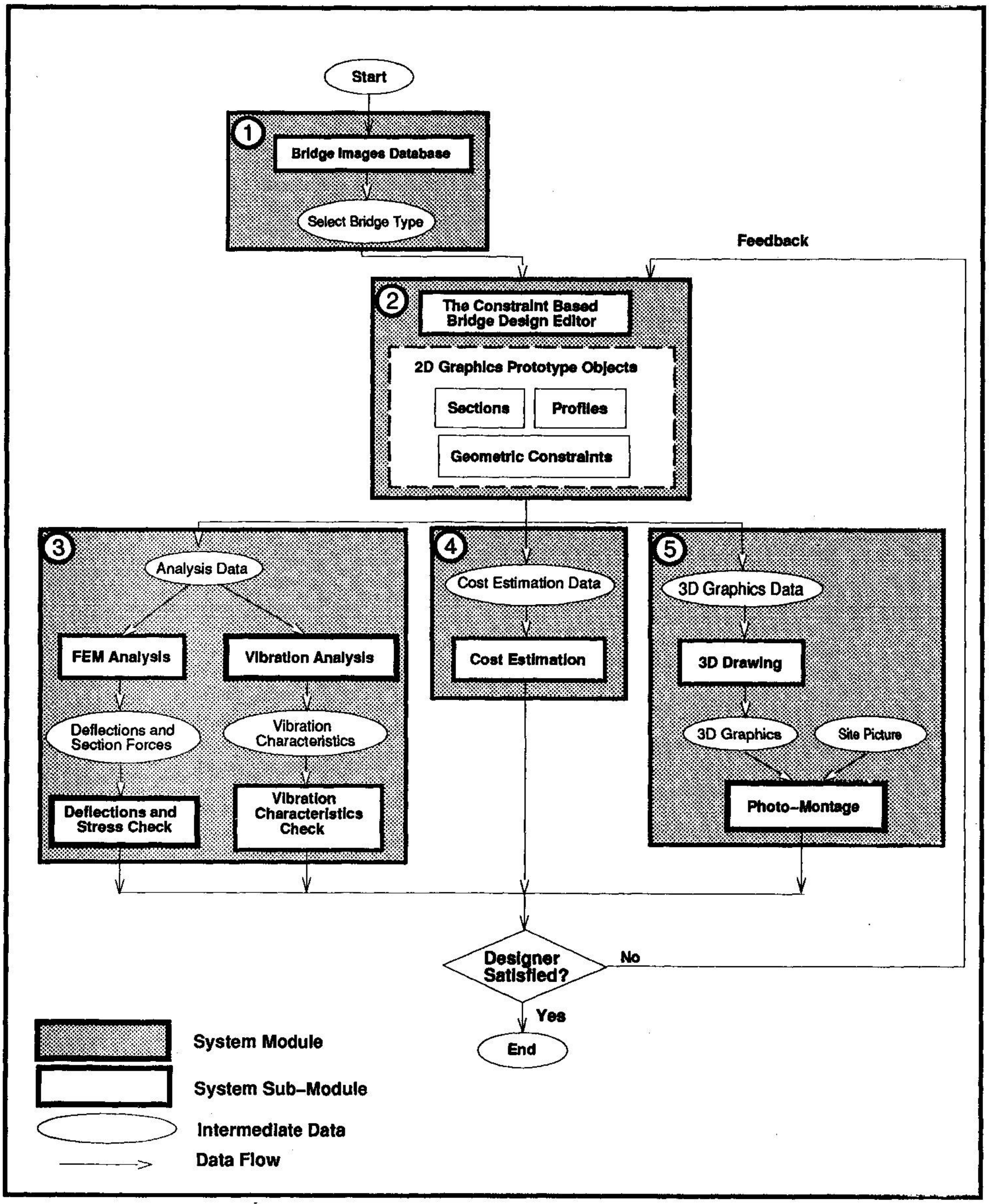


Fig. 1 System structure

ii) Constraint-based bridge graphics sub-system:

This module is the core module of the system. As this sub-system deals mainly with graphics, most of the constraints that are checked interactively are shape-related constraints, i.e. constraints on the dimensions of the members and on the connection between different members. The detailed description of bridge components hierarchy and the method of applying geometrical constraints during direct manipulation will be given in a separate section.

iii) Stress and vibration analysis modules:

In addition to the geometric constraints, other constraints used in design may require the structural analysis of the bridge and the calculation of stresses and displacements in several sections in order to check them against the allowable values. The system is equipped with structural analysis modules that can take the result of the initial design as input. In fact, one reason for choosing pedestrian bridges as the domain of this prototype system is the relative simplicity of calculating the load combinations used in the analysis.

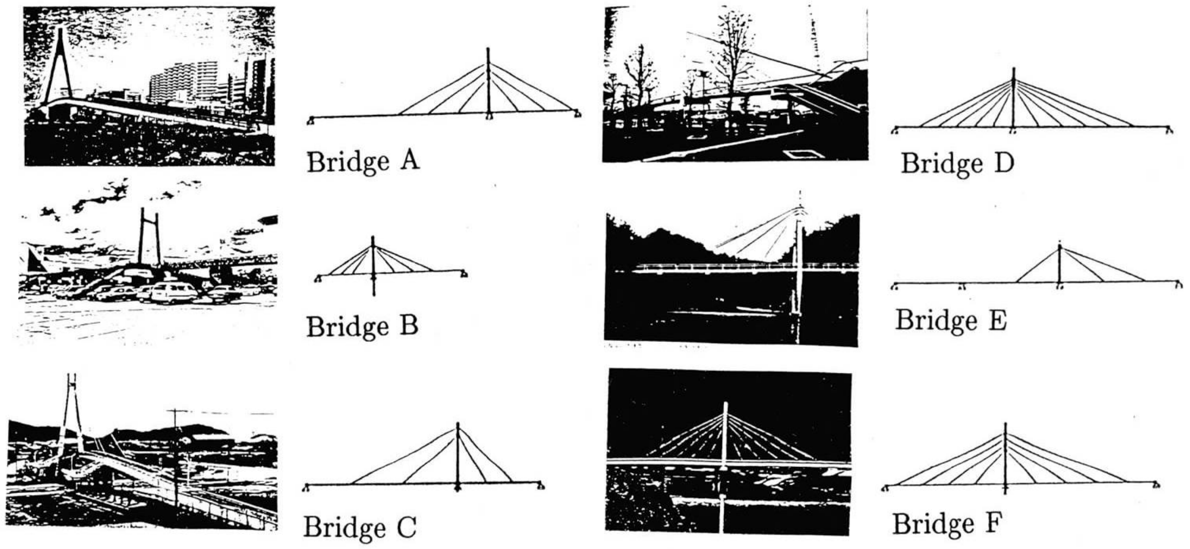


Fig. 2 Example of the images and graphics database retrieval

The natural frequency of pedestrian bridges is another important problem. The range of the frequencies of the steps of the pedestrians is from 1.5 Hz to 2.3 Hz. It is desirable to keep the values of the natural frequencies of the bridge outside this range in order to avoid resonance. In order to check these frequencies, the system is equipped with a vibration analysis module.

iv) Cost estimation module:

Cost is one of the major factors in deciding the type of the bridge to be built. The current trend in Japan is to estimate the cost of steel bridges considering only the steel weight. Although a new approach that considers the work needed in the bridge fabrication is appearing recently, the conventional method of using the steel weight only is acceptable in the initial design stage. This method can be applied directly by using the dimensions and material data resulting from the graphics editing. A special file containing the data necessary for the cost estimation is generated for each component and this data is used by the cost estimation module.

v) 3D drawing and photo-montage module:

Landscape evaluation is becoming more and more important. The photo-montage technique is well known and it has been used for the bridge landscape simulation. The method is based on synthesizing the image of the bridge site with the graphical presentation of the new bridge generated by computer graphics. However, because of the high cost of this method and the long time needed to prepare the data of the computer graphics, the current trend is to postpone the creation of the synthesized image until a later stage when the bridge type is already decided. In this system, the data needed for the 3D computer graphics is generated automatically from the 2D graphical representation resulting from editing the prototype objects. There are some limits on the 3D shapes that can be generated by the system because they are specified by combining the information in the 2D representations of the sections and profiles of the objects.

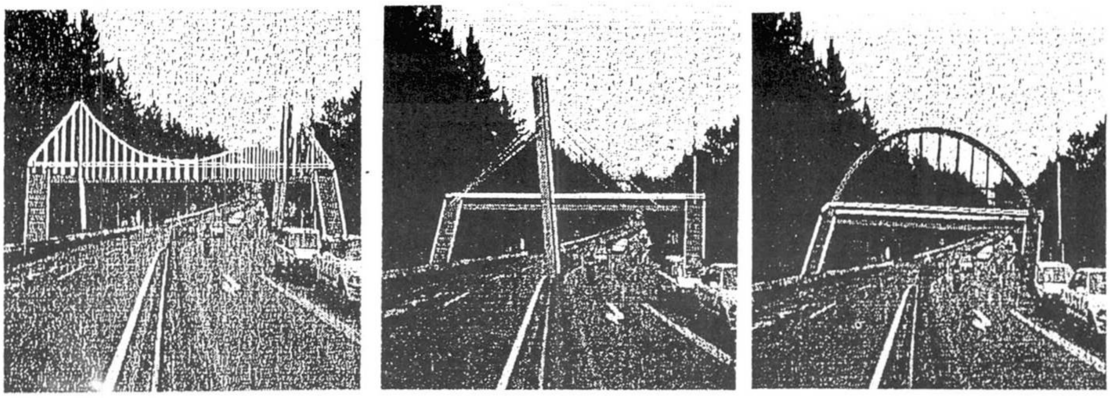


Fig. 3 Examples of the photo-montage

Figure 3 shows three examples of synthesizing the 3D graphics of different bridge types with the background image of a bridge site.

Table 1 Components of the bridge profiles and bridge sections

Bridge type	Components Used in the Profile
Plate Girder Bridge	Girder, Hand rail
Arch bridge	Girder, Hand Rail, Arch, Columns
Cable-Stayed Bridge	Girder, Hand Rail, Tower, Cables
Suspension Bridge	Girder, Hand Rail, Tower(s), Main Cable, Hangers
Cross Section Type	Components Used in the Cross Section
I-Plate Girder	Lower Flange, Web, Upper Flange Horizontal Stiffeners, Vertical Stiffeners
Box.Plate Girder	Lower Flange, Left Web, Right Web, Upper Flange, Horizontal Ribs, Vertical Ribs

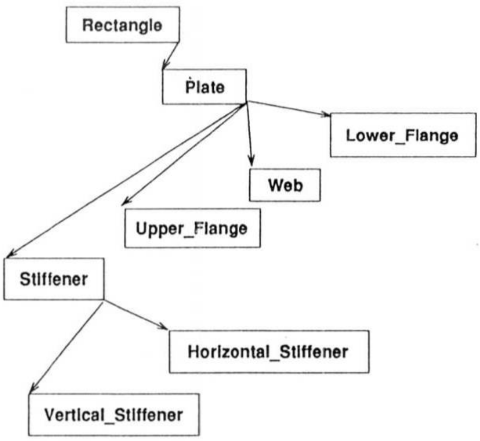


Fig. 4 Part of the components class hierarchy

4. THE SPECIALIZED GRAPHICS SUB-SYSTEM

4.1 Bridge Components Hierarchy

The elements used in the pedestrian bridge design are implemented by creating a graphical component for each of them. In order to facilitate the graphics editing, only two dimensional presentation is used. However, the internal data structure of each class has three dimensional representation. Each object is represented graphically by its cross section and its profile. An expandable library of graphical objects representing the bridge components is built using the object-oriented approach.

Figure 4 shows part of the object classes hierarchy representing the components of the cross section. The **Rectangle** class is used as the super class of the **Plate** class. The **Plate** class is the super-class of the **Upper_Flange**, **Web**, **Lower_Flange** and **Stiffener** classes. The sub-classes will inherit the attributes of their supper classes automatically. This property of the object-oriented approach means saving of time and effort in the system development and maintenance in addition to the possibility of deriving new classes from the available ones.

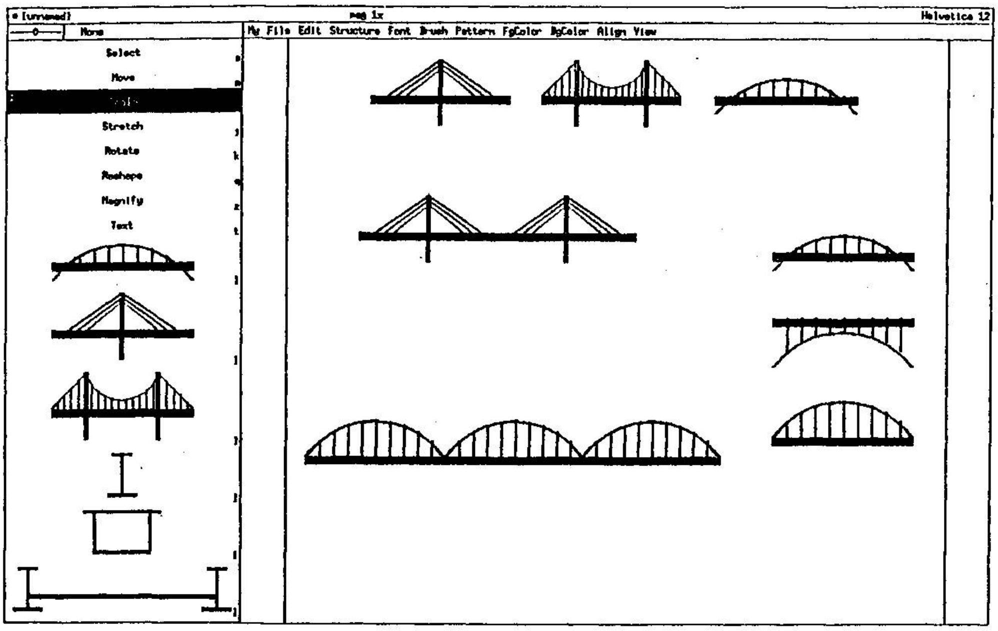


Fig. 5 Examples of the bridge profiles

The components implemented at the time being are shown in Table 1. Figure 5 shows some examples of the bridge profiles generated using the system. Most of the common bridge types such as plate girder bridge, arch bridge, cable-stayed bridge and suspension bridge have been implemented. The cross sections include the I-plate girder and the box girder with steel or concrete slabs.

Figure 6 shows example of some classes implementation. The class *Plate* includes a constructor and another class of type *Constrain**. The class *Flange* is a subclass of *Plate*. *Plate_Girder* is a composite object that has *upper_Flange*, *lower_Flange* and *web* members. The function *Connect* is used to connect the members of composite objects.

In addition to the dimensional parameters, other attributes are attached to the classes such as the color of the girder, the type of the material used and the support conditions. Furthermore, each class has a number of functions that calculate the properties of the object like the area of a cross section or the weight of a girder.

4.2 Constraints Representation and Processing

The constraints used in design can be normally classified into three types:

i) Structural constraints:

Design specifications [2, 3, 6] impose a large number of constraints on the dimensions of each element and the relations between the dimensions of different elements. These constraints are generally expressed by two inequalities in the form:

$$\text{Maximum value} > \text{Design variable} > \text{Minimum value}$$

The design variable in the previous inequalities can be a dimension of some element, the ratio between two dimensions or some more complex relation.

Another example of the structural constraints is the minimum thickness of web plate girder as given in Table 2 [3]. This example shows a variety of cases that can occur when the user changes, for instance, the distance between the flanges *b*, or the material of the web of an I-plate girder. Suppose that the user has selected the I-shaped cross section prototype with the dimensions and materials as shown in Fig. 7(a). If the user increases the height of the web from 110 cm to 120 cm while keeping the same web thickness and web material, the system will add one horizontal stiffener automatically as shown in Fig. 7(b) to satisfy the constraints of Table 2.

```
class Plate {
    Plate(width, thickness, length);
    class Constrain* constrain;
    // The constraints on the plate
    // dimensions.

        :
}

class Flange : public Plate {
    Flange(width, thickness, length);

        :
}

class Plate_Girder {
    PlateGirder();
    class Flange*     upper_Flange;
    class Flange*     lower_Flange;
    class Web*        web;
    web->Connect(upper_Flange);

        :
}
```

Fig. 6 Example of some classes implementation

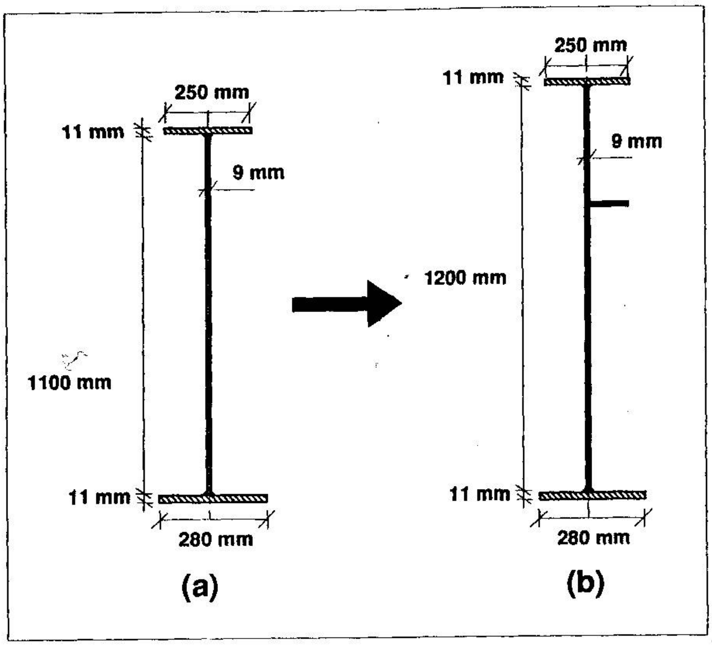


Fig. 7 Example of graphics editing of an I-shaped cross section prototype

ii) Architectural constraints:

Examples of the architectural constraints are the minimum width of the pedestrian bridge that allows two persons to walk side by side or the clearance condition under the bridge.

iii) Fabrication and construction constraints:

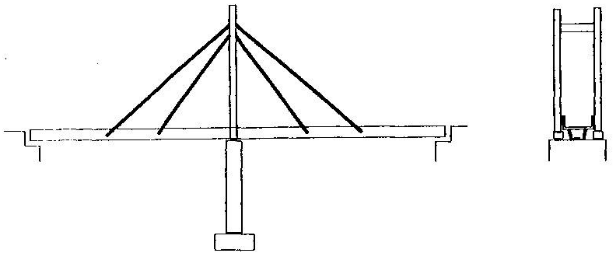
Fabrication imposes many constraints on the shape and dimensions of the bridge elements. An example of the fabrication constraints is that the thickness of the plates used in different members should follow the standard dimensions available in the market.

Design constraints of the previous types are usually forcible, i.e., they should be obeyed, and therefore they will be called here *hard constraints.* Not all design constraints are hard constraints. Other constraints are usually considered which are the result of experience or just the common engineering sense. These constraints will be called here *soft constraints.* The economical span range for each bridge type is an example of the soft constraints. This sub-system is designed to handle hard constraints as well as soft constraints. In the case the user attempts to take an action that violates a hard constraint, the sub-system will prevent this attempt and provide some explanation about the origin of the constraint. In the case of a soft constraint violation, the sub-system will only present a warning message about the constraint and the user should decide whether to execute the action or cancel it.

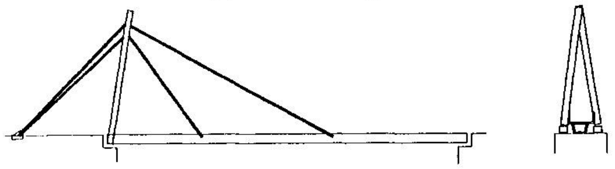
The constraints related to the dimensions and position of different components are implemented as check functions within the corresponding classes. The graphics editing transformation commands are interpreted by each object in a specific manner that guarantees that all the relevant constraints will be checked before the transformation is done. If the object is not a basic one, i.e., it has sub-components, the same process is repeated recursively to check all the sub-components.

4.3 The User-Interface and Processing Scenario

Figure 5 shows the user interface main screen of the system. On the left hand side are the manipulators such as Select, Move, Scale, Stretch and Rotate. The predefined prototypes of the bridge profiles and bridge cross sections and other components are shown under the manipulators. The prototypes are classified into two groups: cross sections and profiles. Above the viewing area is the menu bar which has several pull-down menus for file commands, editing commands, changing the material used in the section, changing the color, the pattern or the line thickness used, etc.



(a) Initial Prototype



(b) Prototype after Editing

Fig. 8 Cable-stayed bridge profiles

Table 2 Minimum thickness of web plates for plate girders

Steel grade	SS41 SM41 SMA41	SM50	SM50Y SM53 SMA50	SM58 SMA58
For girders without horizontal stiffeners	b/152	b/130	b/123	b/110
For girders with single horizontal stiffeners	b/256	b/220	b/209	b/188
For girders with double horizontal stiffeners	b/310	b/310	b/294	b/262

b : web height in cm

The cable-stayed bridge will be given here as an example to show the rich set of possible variations in the geometry of the bridge. Figure 8 shows two possible variations of the cable distribution and tower types. Figure 8(a) shows a conventional cable-stayed bridge with straight H-shaped tower and symmetric cables. Figure 8(b) shows a more innovative design with an A-shaped inclined tower on the extreme left end of the girder and the cables on the left hand side meeting at the anchorage. The user can change the bridge configuration by first selecting the prototype of the cable-stayed bridge and then manipulating it by applying operations like move, rotate, scale, etc. For instance, in order to change the prototypical cable-stayed bridge shown in Fig. 8(a) so that it becomes like the one in Fig. 8(b), the user needs to do the following manipulation: (1) Move the tower from the mid-point of the bridge to the left end. (2) Rotate the tower around its base for the desired angle. (3) Change the distances between the tower base and the anchorage point of the lowest cable on both sides of the tower. (4) Change the distances between the successive anchorage points of the cables.

Fig. 9 A new bridge type by adding an arc to a cable-stayed bridge

4.4 Combining Available Components for Innovative Design

The system has a number of pre-defined prototype objects representing a variety of common profiles and cross sections. If the designer wishes to design a new type that is not one of the pre-defined objects, then it is desirable that the system recognizes the new object. However, it is impossible to predict the infinite number of variations that can appear. Accordingly, the system has the ability to recognize only a finite number of patterns that are not implemented directly as prototypes. Suppose that the user likes to create a new bridge type, like the one shown in Fig. 9, by adding an arc to the cable-stayed bridge profile. The new profile can be created as follows: (1) create an instance of each of the cable-stayed bridge profile and the arc profile, (2) select both of the previous profiles and (3) group the two profiles in one new profile. The new profile can be edited further until it is satisfactory. In such cases, the checking ability of the system is limited to the constraints on the basic components only.

5. CONCLUSIONS AND DISCUSSION

i) A new approach for a total design system centralized around a constraint-based object-oriented graphics sub-system for pedestrian bridge design has been presented. The role of the graphics sub-system has been explained as a core for an integrated preliminary design system that offers, in addition to the functions of conventional CAD systems for bridge type selection, the ability to compare several potential designs visually and to produce a feasible and correct initial design.

ii) The scope of the prototype system was limited to pedestrian bridges because of the relative simplicity of their design and the freedom in adapting different bridges types. The system can handle the conventional bridge types such as plate girder bridges, arches, cable-stayed bridges and suspension bridges as well as innovative types that use combination of the same basic components. The successful results obtained from the prototype system encourage applying the same approach to other civil engineering structures.

iii) It was shown that the results of the two dimensional representation of the bridge section and bridge profile can be used effectively for different purposes in an integrated design system.

iv) It was shown how images of available pedestrian bridges can be integrated in a multimedia database and how this can assist in the selection of the bridge type.

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