TEACHING AESTHETICS IN STRUCTURAL DESIGN COURSES

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Abstract *¾ In civil engineering education, architectural topics like aesthetics and creative design have received scant attention at many universities. This paper describes how elements of these issues can be introduced in a structural steel design course, with special emphasis on the design of bridges. An important part of the activities described is a project work where the students are required to design a pedestrian bridge at a given site. This project work is discussed in some detail.*

Index Terms ¾ Steel design course, aesthetics of bridges, design of pedestrian bridge, student project.

INTRODUCTION

Like most European technical universities the Norwegian University of Science and Technology (NTNU), previously the Norwegian Institute of Technology (NTH), has throughout its history offered degree programs in the traditional engineering disciplines as well as in architecture. As at many of its peer institutions the engineering faculties have co-operated rather closely in curriculum planning and teaching, while there has been little co-operation with the faculty of architecture. In particular the interaction between architecture and civil engineering students has been almost non-existent at many universities, including NTH/NTNU, and there are even today few opportunities for the students to swap courses as part of their curriculum.

In practice, however, civil engineers and architects normally work closely together, even on rather simple building projects. However, for recent graduates fundamental differences in thinking and problem solving approach hinder the co-operation. Most likely these difficulties are caused by attitudes gained during the educational processes [1]. Civil engineering students are trained to carry out detailed analyses in order to arrive at a required safety level for the structure, which in some sense represents an "optimal" solution. Architecture students, however, are trained to design buildings from a far more creative and holistic point of view, where the structure's ability to sustain the applied loads is only one of the relevant aspects to be considered. Davison et al. [1] discuss these conflicts more thoroughly.

The Department of Structural Engineering at NTNU teaches courses on the design of concrete, steel and timber structures, strength of materials, computational mechanics as well as structural dynamics. Even in the design courses aesthetic considerations are hardly touched upon.

In 1995 the introductory course on design of steel structures was modified in order to remedy some of these shortcomings. Architect K. Selberg joined the teaching staff to give four to six lectures on aesthetics in architecture, with special reference to bridges. A handbook published by Norwegian Road Authority [2], authored in part by K. Selberg, served as textbook for this part of the course. Following the lectures the students were required to form groups and design a pedestrian bridge at a given building site. In the project the students were asked to focus primarily on the process leading up to the choice of a suitable concept for the bridge, and to give higher priority to aesthetics than to economy. The project served as a "creative" break in a course dominated by member and connection design, and was very well received by the students. Hence, the project has been made a permanent part of the course.

THE PROJECT WORK

Initially (in 1995), the case study consisted of a design for a new ski jumping hill for the World Skiing Championship Nordic Disciplines, to be arranged in Trondheim in 1997. This case turned out to be too complicated for the students, who had very limited experience in structural systems, which lead to some unrealistic solutions. Therefore, the case project was changed to the design of a pedestrian bridge in subsequent years. Two different terrain profiles are used in alternating years, preventing the students to copy bridge concepts from the previous class, see Figures 1 and 2.

The prescribed loads on the bridge consist of combinations of people, snow and snow removal equipment, and the students were required to gather the necessary load intensities from the relevant building codes or authorities. The minimum net width of the bridge was set to 2.5 m, and no obstacles to the traffic were allowed within the shaded areas in Figures 1 and 2. Beyond these requirements the students were completely free to choose the structural system for the bridge, and they were encouraged to disregard economical considerations in favour of more spectacular and unusual concepts. The choice of structural material is optional, and not restricted to steel. In addition to simple drawings of the bridge, consisting of an elevation and at least one section, each group has to show by means of some simple calculations that the bridge really could be built. Depending on the selected structural concept, these calculations should cover the resistance of the most important members, possible stability problems and elastic deformations.

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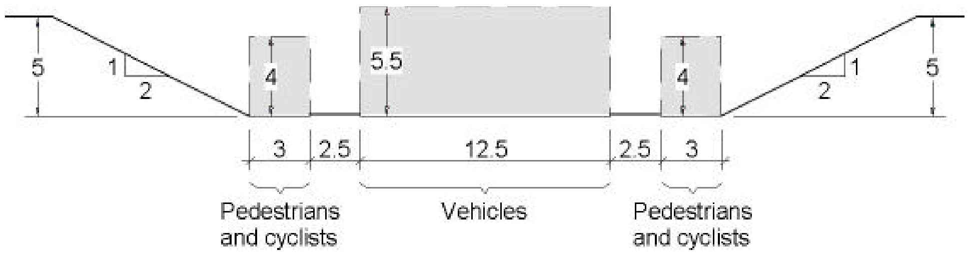

FIGURE 1
TERRAIN FOR PEDESTRIAN BRIDGE ACROSS HIGHWAY.

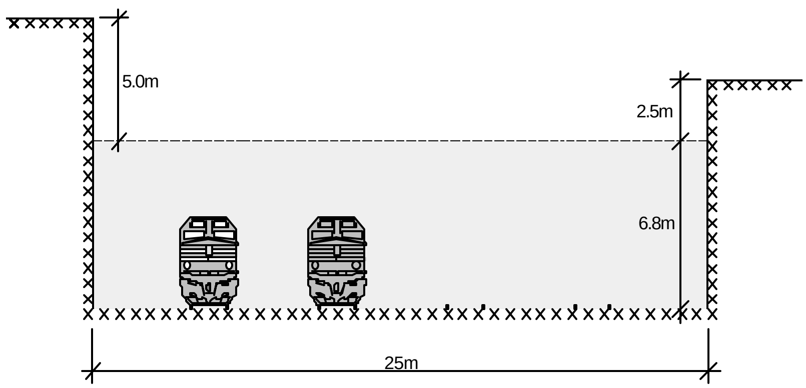

FIGURE 2
TERRAIN FOR PEDESTRIAN BRIDGE ACROSS RAILWAY CUTTING.

PRACTICAL ORGANIZATION AND EXAMPLES

Based on the experience gained during the last six years the practical organisation of the project work has gradually evolved. Currently, the activities are scheduled as shown in Table I.

TABLE I
SCHEDULE OF LECTURES AND EVENTS IN THE PROJECT.

Week	Activity
1	4 lectures in class. Initial information of the project.
2	Each group develops a few possible concepts.
3	Advisory session with the teaching staff prior to selection of final concept, followed by structural analyses and production of required documentation.
4	Presentation of selected concept in class.

The advisory session with the teaching staff was introduced in 1998, as experience showed that many students had difficulties with defining a suitable structural model for the analysis. The main reason for this was primarily lack of experience, as they previously always had been given both the model and the method of analysis to be used. Some proposed bridge concepts also had serious stability problems. The advisory session lasted about 30 minutes, and succeeded in weeding out the most serious mistakes and misunderstandings. The session was compulsory, a fact that forced the groups to work rather continuously with the project during the four-week period scheduled in Table I.

The project work is concluded with a presentation of all group projects in class, with all students and some additional staff members present. The staff members examine the groups on their design and documentation, and subsequently serve as a jury that awards prizes in various categories. These categories may be the most "creative", "spectacular", "expensive" bridge, or the one most "difficult to construct". This type of presentation is commonly used in the architecture study, and has been popular also among the civil engineering students from the very beginning.

Due to limited time and resources each group has consisted of up to seven students. This is not an optimum size by any measure, but was deemed to be acceptable. The students have requested that the group size should be reduced in the future.

Some examples based on the students' original drawings are shown in Figures 3 to 6. Figures 3 and 4 are solutions for the terrain profile given in Figure 1, while Figures 5 and 6 refer to the cutting in Figure 2. All these four concepts received awards.

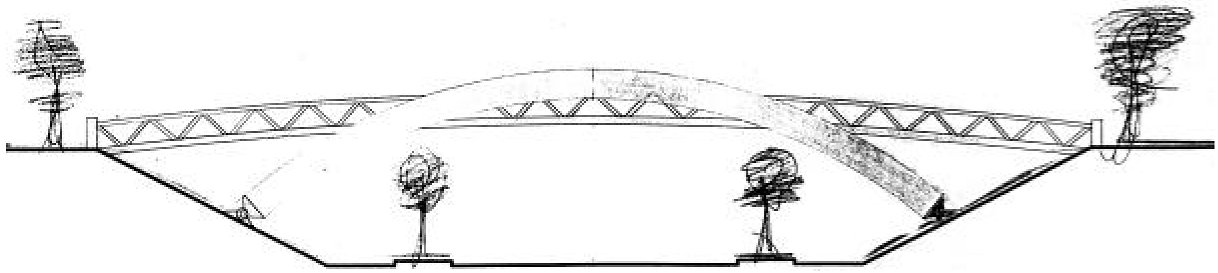

FIGURE 3
MOST "ELEGANT" BRIDGE IN 1996.

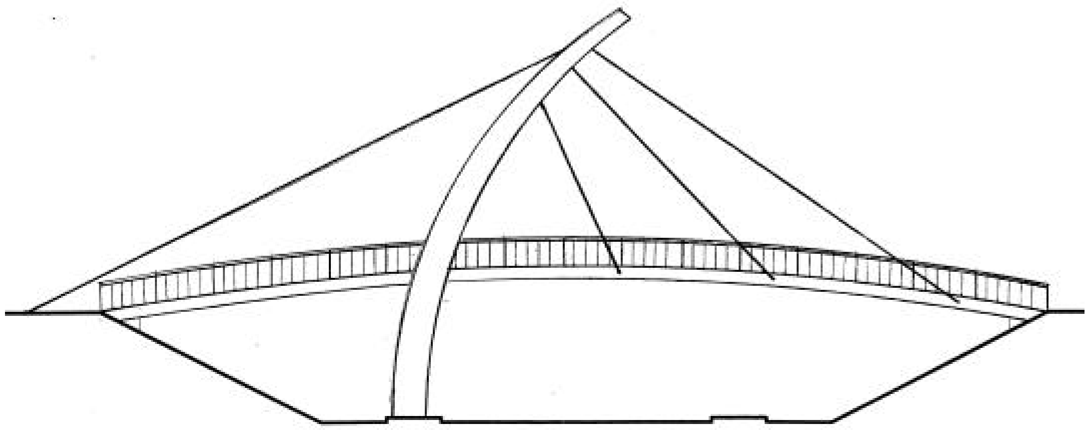

FIGURE 4
MOST "SPECTACULAR" BRIDGE IN 1996.

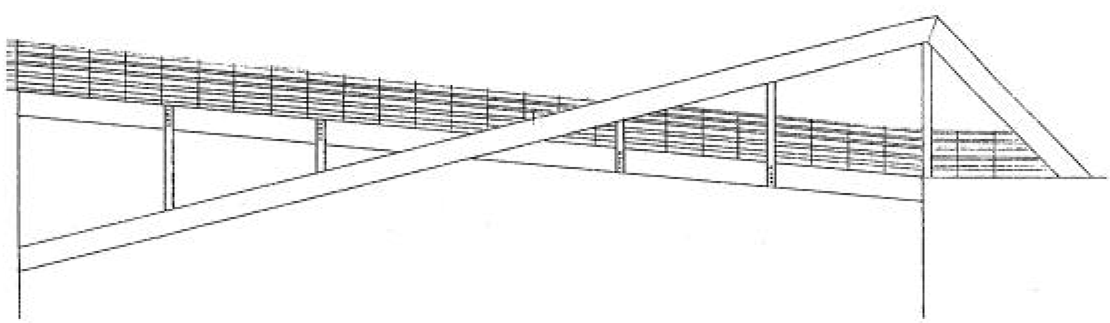

FIGURE 5
MOST "CREATIVE" BRIDGE IN 1999.

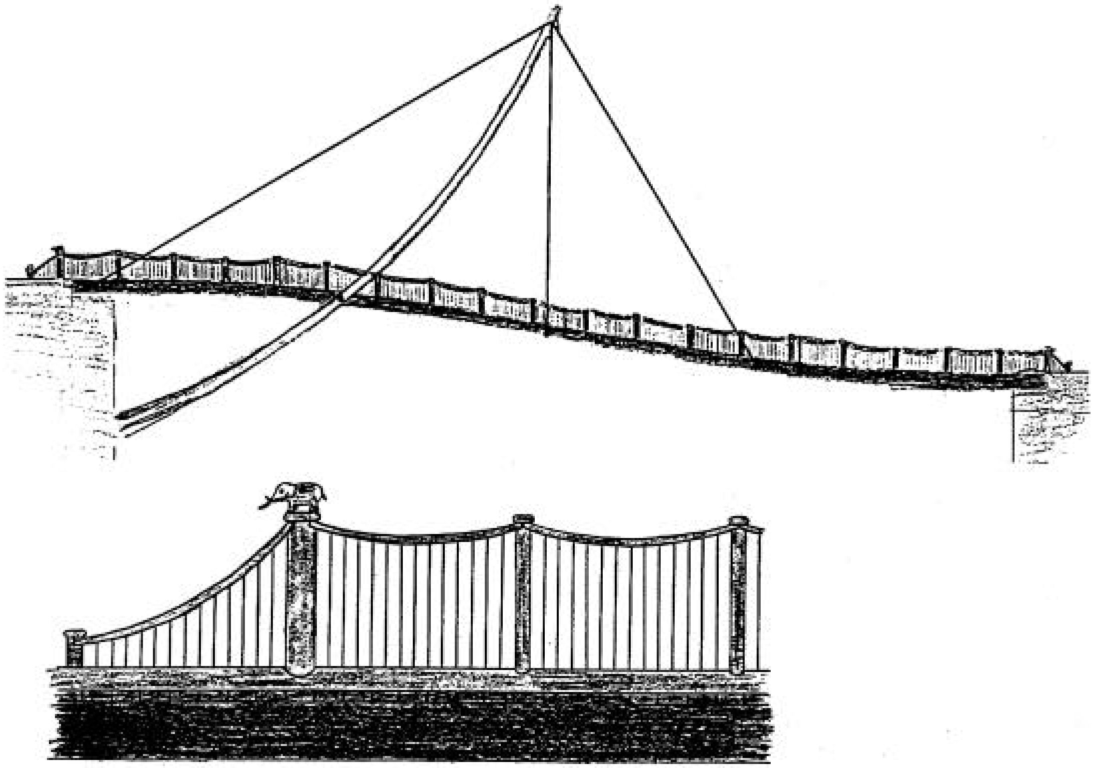

FIGURE 6
MOST "SPECTACULAR" BRIDGE IN 1997.

DISCUSSION

Most of the subjects in the structural engineering courses at NTNU focus on theory and calculation methods, accompanied by individual assignments that are intended to drill the students in these methods. The lectures on architectural design and the subsequent project offered a break in the daily routine, and became very popular among the students. As the number of lectures has been limited to four in recent years, it is of course not possible to provide a comprehensive presentation of aesthetics in a wide sense. Therefore, the topic of the lectures is limited to aesthetics of bridges. This particular choice of structural type is partly caused by K. Selberg's own practical experience, which has resulted in the handbook used as literature reference [2], and partly caused by the fact that bridges are statically rather simple structures with an evident load-carrying system and few complicating elements such as ventilation and insulation. It is also worth noting that the Norwegian Road Authority during the last 15 years have attached increasing importance to the visual design of new bridges, and in particular the large and more monumental projects, where an architectural competition may provide guidelines for the final design. Similar tendencies are observed in other countries as well.

The lectures are mainly based on examples, where different proposed solutions of recent bridge projects are discussed with respect of architectural design as well as choice of structural system, e.g. arch bridge, suspension bridge, or short-span beam-type bridge. Thus, the lectures are not restricted to pedestrian bridges.

The project work has always been supposed to be a more important part of the schedule than the lectures are. However, the first couple of years the staff underestimated the amount of guidance that was needed in order to provide a learning experience for the students. Based in part on suggestions from the students the project organization was changed to that shown in Table I, with the advisory session as the main improvement.

Regarding the choice of material in the project work, gluelam timber has been most popular among the students with steel as a second choice. Generally speaking, these materials are well suited for lightweight, slender pedestrian bridges. Some concrete bridges are also proposed, but it turned out to be a challenging task to avoid a "clumsy" design.

A functional requirement often addressed when the bridge concepts were evaluated is the maximum slope of the bridge. With reference to wheelchair users and baby carriages, the bridge must not be too steep. The gradient of the middle section of the bridge in Figure 6 illustrates this problem.

In addition, practical problems related to fabrication and erection were in general not handled well. Although thorough detailing was not a part of the project, the staff has frequently asked the groups how to connect the rail with the main load-carrying structure. Another common – and quite practical – problem discussed in the advisory sessions is how to "translate" the selected bridge design to a structural model well-suited for static calculations by hand or some computer code.

The most prominent educational benefit from the design project is that the students must take a more holistic approach to structural design than they are used to. The main emphasis is placed on the development of a total concept, where aesthetics is equally important as choice of structural material and structural system. Moreover, the project has been stimulating for the teaching staff, because the students in general have been much more engaged and enthusiastic than they normally are in class or in the traditional exercises. The project has also given insight into what the students consider difficult in structural analysis and design, and thereby it induces improvements in the more "classical" steel structures lessons.

Of course, some of topics had to be removed from the original course on steel structures when the lectures and project on aesthetics were incorporated. The removed lessons covered more specialized topics such as fatigue and plastic design of joints, and these were not considered to be very important in an introductory course.

ACKNOWLEDGEMENT

Professor emeritus Petter Aune has been a key member of the jury during all years since 1995, and has also participated in the advisory sessions with great encouragement. Credits are also given to Professor Magnus Langseth, who originally launched the aesthetics including the design project as a part of the structural steel design course.

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