COMPUTER AIDED STRUCTURAL DESIGN IN ARCHITECTURAL INSTRUCTION

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Abstract:-

In schools of architecture there is a tendency to associate the use of computers solely with the production of graphic images as part of the architectural design process. However, if the architecture is to work as a building it is also essential that technical aspects of the design are adequately investigated.
One of the problem areas for most architectural students is structural design and they are often reluctant to use hand calculations to determine sizes of structural elements within their projects.
In recent years, much of the drudgery of hand calculation has been removed from the engineer by the use of computers, and this has, hopefully, allowed a more thorough investigation of conceptual ideas and alternatives. The same benefit is now becoming available to architectural students. This is in the form of structural analysis and design programs that can be used, even by those having a limited knowledge of structural engineering, to assess the stability of designs and obtain approximate sizes for individual structural elements.
The paper discusses how the use of such programs is taught, within the School of Architecture at Nottingham. Examples will be given of how they can assist students in the architectural design process. In particular, the application of GLULAM, a program for estimating sizes of laminated timber elements and SAND, a structural analysis and design package, will be described.

1. Introduction

Traditionally in the UK the architect has been responsible for aesthetics, space planning and the generation of detailed drawings and specifications for the production of buildings. The technical aspects of the architectural design have generally been carried out by specialists acting as consultants to the architect who co-ordinates the design team. However, technical considerations often have a significant influence on the architecture (and *vice versa)* and it is important that the architect has an understanding of this interaction. Provision of an adequate structure may have a profound effect on the architectural concepts if not considered at an early stage in the design process. For instance, column spacing in buildings affects the structural depth of floors which in turn may affect floor-to-floor heights, the overall height of the building, the proportions of cladding elements on the elevations etc. Therefore, it is advantageous if the architect is able to assess these effects approximately without having to involve the structural engineer.

There are several rules of thumb that can be used to estimate the depth of simply-supported beams and trusses of various structural materials. However, architects and architectural students today are frequently keen to explore innovative structural solutions. The simple design rules do not necessarily apply to these structures and more sophisticated procedures must often be adopted. These are most easily performed with the aid of commercially available structural analysis and design software on micro-computers.

· Use of Computer-Aided Structural Design at the Nottingham School of Architecture

In the School of Architecture in the University of Nottingham, UK, students are encouraged to use computer analysis to assist in assessing the feasibility of their structural solutions. Currently, in the second year students are given a studio design project in which they must use timber as the main structural material. For this project they are shown how to use computer software (described in detail in the following section) to estimate the approximate sizes of the timber elements.

For other design problems students throughout the school may use a general structural analysis and design program SAND which is described later in section ??

2.1 Computer Program – GLULAM [1]

This computer software is produced for the Glued Laminated Timber Association in the UK and is commercially available at low-cost. It is produced to assist in preliminary design of GLULAM structures by practising engineers and architects. Although not specifically designed for educational use, its simple menu system makes it suitable for students. Most design data is input by selecting items from menus whilst the only numerical information required is readily available, such as the span of beams and their spacing. From this the user is able to obtain approximate sizes for glued-laminated elements designed to the current British Standard for timber structures BS5268.

2.2 Menu system of GLULAM Program

After input of a job name or reference a selection is made from the Main Option menu (Fig.1). For roof elements there is then a choice from the Beam Option menu (Fig.2) and for floor elements from the Floor Option menu (Fig.3).

MAIN OPTIONS

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ROOF MEMBER	[X]
FLOOR MEMBER	[ ]
COLUMN	[ ]
BATCH PRINT	[ ]
TERMINATE	[ ]

Fig. 1 - Main Option Menu of Glulam Program

BEAM OPTIONS

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PURLIN	[X]
RAFTER	[ ]
MAIN BEAM	[ ]
EAVES BEAM	[ ]
PORTAL FRAME	[ ]
TIED RAFTER	[ ]

Fig. 2 - Beam Option Menu of Glulam Program

FLOOR OPTIONS

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JOIST	[X]
MAIN BEAM	[ ]
EDGE BEAM	[ ]

Fig. 3- Floor Option Menu of Glulam Program

Generally, after selection of the specific element type from the Beam or Floor Option menu, geometrical information such as the span, spacing of elements and roof pitch (if appropriate) are input. Subsequently, dead loads are either specified directly (as a load/m^2) or the type and thickness of the supported material layers can be selected from a series of menus. Imposed loads, which depend on element location and/or building use, can be selected from other menus and any special loads can be stipulated. Finally, structural integrity in fire is considered by choosing the required duration of the fire resistance in hours.

For columns, their height and the imposed axial loads of various durations must be input directly by the student and the degree of fire resistance selected from a menu.

The program then selects three appropriate standard sized glued-laminated timber sections for the student to choose from. As not all sizes of glulam are readily available, the appropriate stock sizes held by the suppliers in the UK are also given. A summary of the data input and information about the timber section selected can then be printed.

2.3 Teaching and use of the GLULAM Program

From the experience of the author, use of the program can be taught in about 15 minutes to students having a basic knowledge of the design of timber structures. The current method is by demonstration (to groups of about 12 students at one time). They are shown how to use the menu system and the various structural options available to them are illustrated.

Therefore, by using the GLULAM program, students may try several alternative structural solutions very quickly by using the computer to carry out the tedious calculations. Whereas, when they are required to justify the sizes of the timber elements in their structure by hand calculation, they tend to opt for the simplest solution to calculate, which would not necessarily be their favoured architectural solution. The speed with which the calculations are performed by the computer also allows the student to experiment and assess the effect on the structure of his or her choice of cladding and insulation materials.
Feedback from students has indicated that they find the program simple to use once they have mastered the basics of the menu system.

2.4 Computer Program - Structural Analysis and Design (SAND) [2]

SAND is a sophisticated structural analysis and design program which can be used to perform complex calculations normally beyond the requirements of the average architectural student. For students with a particular interest in structures there is a Graphical User Interface (GUI) to produce data files for subsequent structural analysis of plane frame and truss structures (or even 3-dimensional structures for the really adventurous). The output from the analysis can then be used directly to determine the sizes of steel, reinforced concrete and timber elements in the structure.
However, the structural design part of the package, which is known as SCALE (Structural CALculations Ensemble), can be used independently and provides a set of pro-forma calculation sheets for the design of many common elements found in building structures. A further facility within the SAND system is to produce additional pro-formas for calculations that are frequently carried out by the user. This enables the tutor to "customise" the standard calculation sheets so that they are more acceptable to the less technically orientated students. An easy way to do this, which also economises on the use of printer paper, is to arrange for the pro-formas to only produce summaries of the detailed calculations.

2.5 Teaching and use of the SAND Program

As the program suite is not so "user-friendly" as the GLULAM program it is usually only used by students in the fifth and sixth years of the architecture course. At present no formal teaching of the use of SAND is undertaken and the limited number of students who wish to avail themselves of the program are shown how to use it either individually or in small groups.

During the last year the structural analysis section of SAND was used very successfully by a final year student to contribute to her dissertation on low-cost, self-build, timber housing in Chile'. The rigidity of a prototype frame was assessed and then alternative structures were proposed and their rigidity was assessed under the same loading. The results were easily compared using the plotting facility of the program (Fig.4). Suggestions were then made for a more economical design that was also more efficient structurally and easier to construct by unskilled labour.

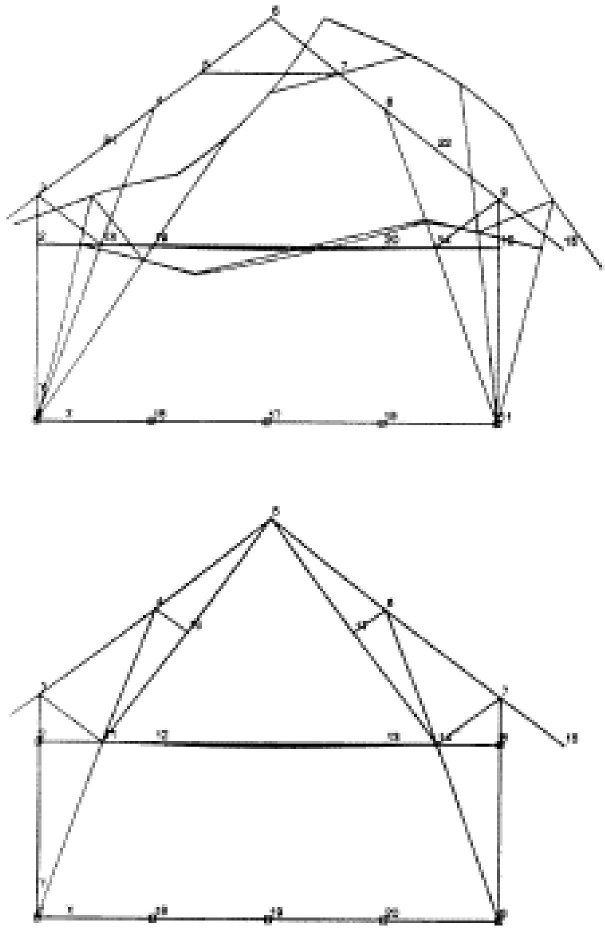
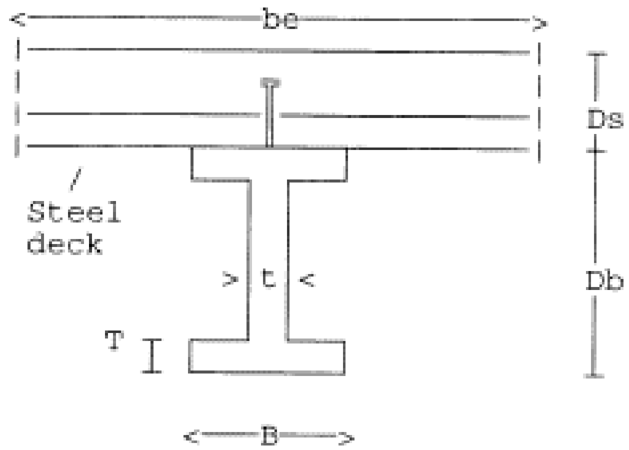


Fig.4 Deformed shape of timber-framed house under lateral wind loading (a) original design (b) proposed solution

2.6 Use of SCALE pro-formas in SAND

The standard pro-formas are a type of spreadsheet with the user responding to a series of questions. Data provided is then used to perform structural design calculations to the current British Standards. Each pro-forma has a sample set of responses that can be used to produce a typical calculation so that the form of response required to each question can be previewed. Generally, on screen diagrams are provided to show what dimensions are required (see Fig.5) and explanatory notes and guidance are also given to assist the user. However, as the system was produced for use by structural engineers it assumes some knowledge of the structural design codes and structural behaviour.

There are, for instance, a series of pro-formas that permit students to obtain very quickly suitable sizes for the elements in composite floor construction using reinforced concrete cast on permanent profiled steel sheet formwork supported on steel beams. A typical pro-forma summary for this form of construction is shown in Fig.5. As this is currently a very popular form of construction in the UK the students find this useful.

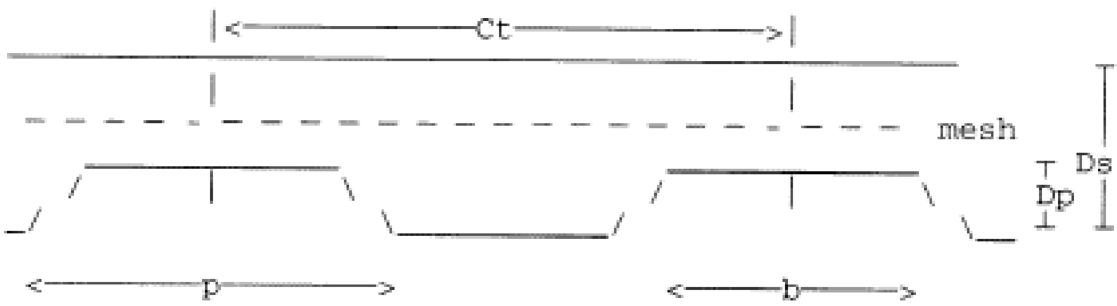


Composite steel deck floor - Internal beam U.D.Loading

Calculations in accordance with BS 5950 Part 3 Section 3.1 'Code of practice for design of simple and continuous composite beams'- July 1990 and with 'BS 5950 Part 1' for construction stage design.
Location: Office Floor

Beam span	Ll=9 m
Beam centres(floor width carried)	C=3 m
Steel Grade (43 or 50)	Grade=50
Concrete cube strength	fcu=25 N/nim2
Air dry density for concrete	Dc=17.6 Mm3
Freshwet density for concrete	D'c= 18.8 kN/m 3
Modular ratio for steel/concrete	ALPe=15

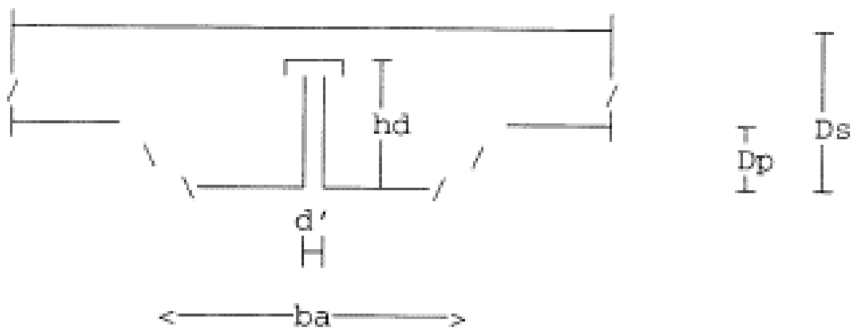
Floor loading - concrete slab



Slab depth	Ds= 115 mm
Centres of profiles	Ct=300 mm
Depth of profiling	Dp=50 mm

Width at inside of profile	b=125 mm
Width at outside of profile	p=175 mm
Profiled steel deck	decwt=0. 12 kN/m2
Reinforcement allowance	reinwt=0.04 kN/m2
Steel beam allowance	selfwt=0. 15 kN/In2
Construction load allowance	wc=0.5 Mm2
Other UDL on beam	w'du=0 kN/m
Ceiling and services	wcs--0.25 kN/m2
Imposed	wi=3 Mm2
Partitions	wp= 1 Mm2
Wall or other UDL	wdu=0 kN/m
Effective length during constrn (0 = fully restrained)	Le=0 mm

Stud connectors



Height of stud after welding	hd=95 mm
Diameter of stud	T=19 mm
Ultimate shear strength	Qk=109 kN
Number of studs across flange	nr=1
Percentage to be provided	per=80 %

COMPOSITE	305 x 102 x 33 UB Grade 50
SECTION	with 34 No. 19 dia. stud
SUMMARY	connectors @ 264 centres.

Section is satisfactory for construction, composite, elastic, plastic, moment, shear, deflection and natural frequency requirements.

Fig.5 Typical SCALE pro-forma summary for design of composite floor construction

Alternatively, within SCALE there are also pro-formas for the analysis of simple structures such as roof trusses and portal fraines. The results of these structural analyses may be plotted on screen or to a printer/plotter and can be used to illustrate grapfflcally the behaviour of such structures under a variety of loading conditions.

Conclusions

The use of the glued-laminated timber design software (GLULAM) in the second year of the course introduces the student to the idea of utilising computers to assist them in the sizing of structural elements in their architectural designs. Those who find this to be a useful tool are then encouraged to employ the more sophisticated software SAND to analyse more complex structural design problems.

It is found that the less technically able students are sometimes discouraged by the complexity of SAND whilst they are very happy to use the GLULAM program where they only have to select from menus. The recently introduced Graphical User Interface in SAND has simplified its use to some extent but it still requires more detailed understanding of structural behaviour and more effort to learn.

References

[1] GLTA GLULAM Selector software, Glued Laminated Timber Association, High Wycombe, U.K. (1991)

[2] Structural ANalysis and Design (SAND) software, Fitzroy Computer Systems Ltd., Cobham, Surrey, U.K.

[3] Jeavons-Fellows, E., A Structural Solution to Low Cost Housing in Chile, dissertation, University of Nottingham, U.K. (1992)