COMPUTER-AIDED DECK DESIGN USING MSC/PAL AND AUTOCAD

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Abstract

A carefully designed deck can substantially increase the living space of a house and make the outdoors more joyful. This paper presents an integrated computer-based technique to automate the design of a wood deck. The design parameters including geometry, material, boundary conditions, and loads are entered to the computer by the user through the control of an AutoLisp program. A database of design codes is stored in the computer. AutoLisp checks the design parameters and the database and generates an AutoCAD drawing of the deck interactively. From the drawing, MSC/AutoFEM generates a finite element model file. The model file is then fed to MSC/pal 2 for analysis. The result is fed back to the AutoLisp program for evaluation and decision making. Should the design be unsatisfactory, a modified design starts automatically. Several iterations may be necessary. Finally, the finished deck design is presented in the form of a drawing and a bill of material.

Introduction

In his book entitled " Deck Plans ", Beckstrom [1] gives the following design guidelins:

- A deck should offer privacy and a sense of enclosure.
- A deck's size should be appropriate for its intended uses and available space.
- A deck should be accessible and inviting.
- A deck should be comfortable and pleasant.
- A deck should be harmonized with its settings.
- A deck should have a special unifying element.

Theses guidelines are appropriate from an architectural point of view. From the engineering point of view, a deck should be strong enough to withstand various loads. In addition, a deck should be designed with economics in mind such that no material is wasted. The engineering design involves the selection of materials, lumber sizes, joist spacings, joist spans, and post sizes. The traditional design uses building code tables [3] which are available for only a limited number of geometries and load conditions. In order to speed up the design process and widen the design selections, a computer-based method should be developed. This paper demonstrates a technique to automate the design process such that the designer only needs to enter the deck geometry - shapes and heights, material selections, and the anticipated loads. The computer will find a structure which is safe and economical.

Basic Deck Components

The major deck structure consists of the decking material overlaid on the joists which are fastened to beams which are supported by posts and footings. Substructures such as benches and stairs are attached to the main structure. Railings are required for a deck which is over thirty inches above the ground. Figure 1 shows the basic components of a deck.

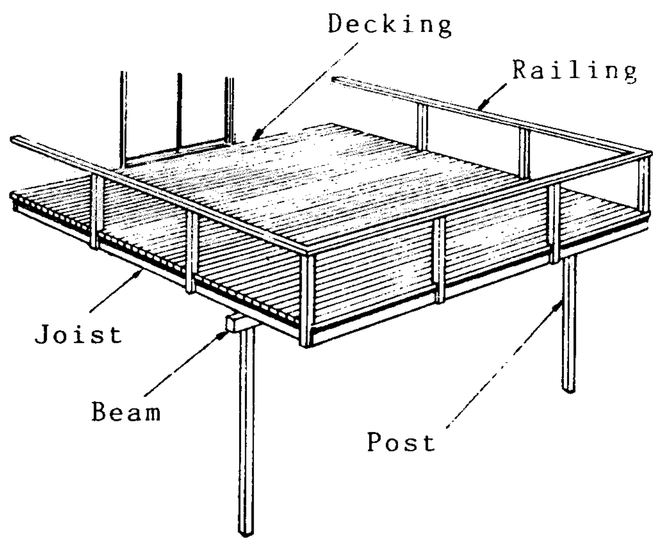


Figure 1 Basic Components of a Deck

Loads Applied to a Deck

There are two kinds of forces applied to a deck structure. One of them is the structural weight which is usually called dead load. The density of a wood is in the range of 0.01 to 0.03 pound per cubic inch. So the dead load of a norminal four-inch thick deck is approximately ten pounds per square foot which is the assumption of residential wood structure building code [2]. The other kind of force is changing dynamically and is usually called live load. Live load includes the weights of people, furniture, and snow as well as the forces exerted by the wind. The building code specifies that the deck structure should be able to withstand forty pounds per square foot live load. So for a eight feet by ten feet deck, the maximum live load should not exceed 3200 pounds which is roughly equal to the weights of ten people plus five pieces of furniture. The actual dead load can be computed very accurately once a deck structure is selected while the actual live load depends on the use of the deck and can only be estimated.

Material Selection

A major decision in building a deck is to choose the wood. Redwood is naturally resistant to moisture but it is expensive. Pressure treated pine, spruce, hemlock, and Douglas fir are rot resistant and relatively inexpensive. The values of the modulus of elasticity for these woods fall between one to two million psi. The allowable bending stresses and compression stresses are around 1000 psi and the allowable shear stresses are around 80 psi. Table 1 lists the mechanical properties for a few woods suitable for deck building.

Table 1 Modulus of Elasticity and allowable stresses for wood

Species	Modulus of Elasticity (Mpsi)	Allowable Bending Stress (kpsi)	Allowable Compression Stress (kpsi)	Allowable Shear Stress(psi)
Cal. Redwood	1.2	1.40	1.20	80
E. White Pine	1.1	0.95	0.70	70
Lodgepole Pine	1.2	1.05	0.75	70
Southern Pine	1.4	1.20	0.90	75
Eastern Spruce	1.2	1.00	0.75	65
Eastern Hemlock	1.1	1.20	0.90	85
Western Hemlock	1.4	1.25	0.98	90
Douglas Fir	1.7	1.45	1.05	95

From the table, it can be seen that a redwood decking with Douglas fir for joists, beams, and posts is a good combination. Hardware for a deck must be rust proof. Use stainless steel, hot-dipped galvanized steel, or aluminum alloy fasteners.

Stress and Strain Analysis

The building codes require that the beams used for dwellings be strong enough to bear loads which means that the maximum bending stress should not exceed the allowable stress for the material. In addition, to ensure the floor will not bounce or shake unduly, the maximum deflection should not exceed 1/360 of the beam span. The maximum bending stress of a simply supported beam subjected to a uniform load occurs at the extreme fiber of the midpoint station and has a value of

$$(3 \times q \times L \times L) / (4 \times b \times h \times h)$$

where q = load per unit length
L = length of the beam
b = width of the beam cross section
h = height of the beam cross section.

The maximum shear stresses occur at both ends with the value of

$$3 \times V / (2 \times b \times h)$$

where V = shear force at the cross section.

The maximum deflection occurs at the midpoint of the beam and can be expressed in the following form

$$(5 \times q \times L \times L \times L \times L) / (384 \times E \times I)$$

where E is the modulus of elasticity of the beam. The loads of a deck are supported by the posts. The heights of the posts are determined by the differences between the deck surface and the ground. A minimum clearance of eight inches is required between the earth and the wood in order to aid the air circulation and prevent the moisture from trapping in. When the post height is greater than five feet, bracing is recomended to reduce the deflection and prevent the post from buckling. The critical load for a cantilever column can be expressed as [4]

$$(pi \times pi \times E \times I) / (4 \times L \times L)$$

where pi = 3.14159
E = modulus of elasticity of the post
I = moment of inertia of the post cross sectional area
L = length of the post.

For a eight feet by ten feet deck, the total load is 4000 pounds based on 50 pounds per square foot. If four posts are used for support, each post will carry 1000 pounds. For a 4"x4" cross section post, the compression stress is about 80 psi which is much less than the allowable compression stress of 1000 psi for most woods. For a 4"x4"x12' spruce post the critical load is about 1800 pounds. Under extreme heavy load conditions (people, snow, wind), buckling is possible. So for posts higher than 8 feet above the ground, x-bracing is usually required.

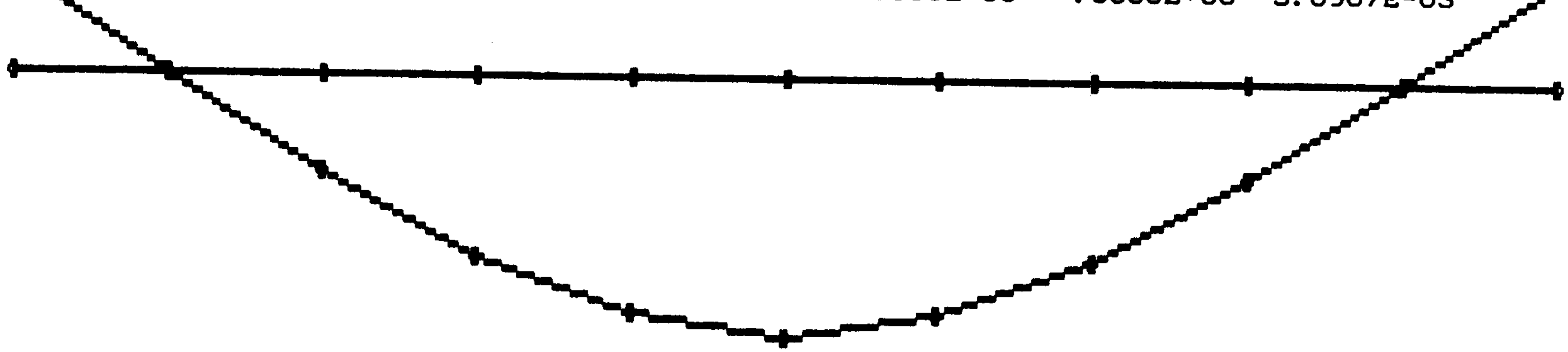
Automation of the Design Process

The structural design process of a deck starts from the selection of the shapes (plane view) and the heights (elevation view). Then the decking - its pattern, crack direction, type of wood, and size of lumber is selected. The guidelines mentioned in the Introduction could be used during the selection. Joist spacings or deck spans are determined by the type and size of wood used for joists and decking. Beam spacings or joist spans are in turn determined by the size and type of wood used for beams. Finally the post sizes are determined by the load areas, post height and the wood type. To accelerate the design process, a computer program written in AutoLisp [6] is created. The program consists of a

COMPUTER-AIDED DECK DESIGN

STATIC DISPLACEMENT COMPONENTS

NODE	X TRANS	Y TRANS	Z TRANS	X ROT	Y ROT	Z ROT
1	.0000E+00	6.1360E-02	.0000E+00	.0000E+00	.0000E+00	-5.0907E-03
2	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	-5.1586E-03
3	.0000E+00	-6.0817E-02	.0000E+00	.0000E+00	.0000E+00	-4.8192E-03
4	.0000E+00	-1.1240E-01	.0000E+00	.0000E+00	.0000E+00	-3.6653E-03
5	.0000E+00	-1.4661E-01	.0000E+00	.0000E+00	.0000E+00	-1.9684E-03
6	.0000E+00	-1.5856E-01	.0000E+00	.0000E+00	.0000E+00	6.6235E-10
7	.0000E+00	-1.4661E-01	.0000E+00	.0000E+00	.0000E+00	1.9684E-03
8	.0000E+00	-1.1240E-01	.0000E+00	.0000E+00	.0000E+00	3.6653E-03
9	.0000E+00	-6.0817E-02	.0000E+00	.0000E+00	.0000E+00	4.8192E-03
10	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	5.1586E-03
11	.0000E+00	6.1360E-02	.0000E+00	.0000E+00	.0000E+00	5.0907E-03



SIZE (S), MOVE (M), ROT (R), NODES (N), AXES (A), GET (G), OTHER (O), QUIT (Q)

Figure 2 A Typical MSC/pal Beam Analysis Result.

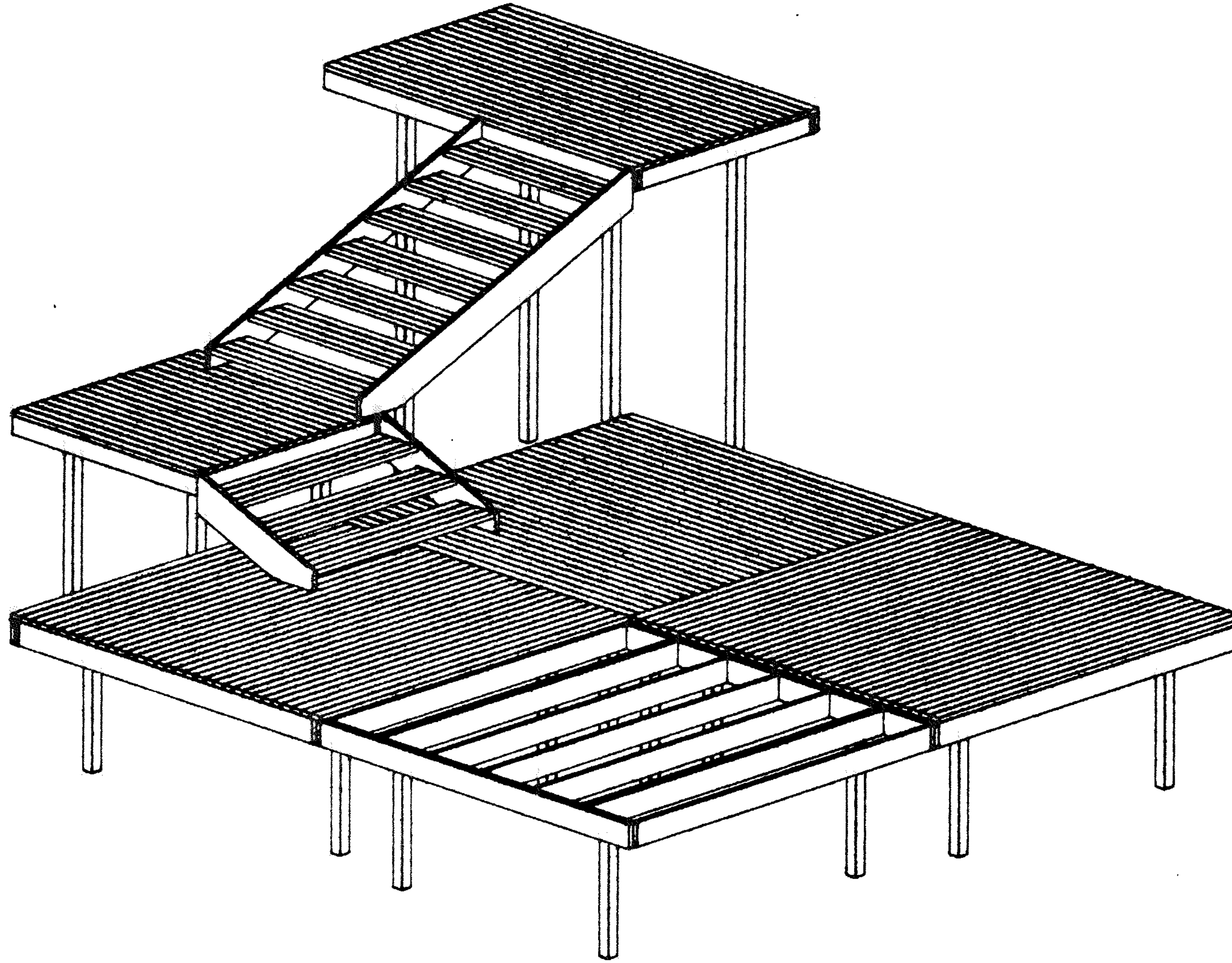


Figure 3 A Multi-level Deck Design.

number of functions. Each function is capable of creating a group of deck components using user specified parameters or performing a certain design operations. The functions can be used as AutoCAD commands [7]. For example, a four-post rectangular deck module can be called by entering the command DECK4 from AutoCAD. The computer will prompt the user to enter the width, depth, height, and location of the deck. A deck structure including the posts, beams, joists, and decking is created automatically. A free form deck can be created by using the command DECKF. The program will ask the user to enter the shape and the height of the deck and create a deck structure interactively. If a series of stairs is required, enter the command STAIRS. The computer will ask the user to enter the rise and width of the stairs. AutoLisp program will figure out the appropriate run and draw the stairs on the screen. The AutoLisp program creates the initial design based on the building code tables stored in the database. The design needs to be checked by some structural analysis program. Here MSC/pal [8] is selected as the analysis tool because of its ease of interface with AutoCAD using MSC/AutoFEM. Using MSC/AutoFEM, deck structure drawing can be converted to a finite element model and fed to MSC/pal for analysis. The result can then be read by AutoLisp program for evaluation and design modification. Figure 2 shows the MSC/pal analysis results of a ten feet long simply supported beam with one foot overhang on each side subjected to a uniform distributed load of 66.66 pounds per foot. The AutoLisp program keeps track of the numbers and the sizes of the material used. Once a design is finalized, the user can issue a BOM (Bill of Material) command to list or print the material list. A finished deck design is shown in Figure 3.

Conclusions

The forgoing studies indicate that the computer-aided drafting package AutoCAD and the computer-aided analysis package MSC/pal can be integrated through the use of AutoLisp programs for deck design. A carefully written application program can greatly simplify the deck design process.

References

1. Deck Plans, Robert Beckstrom, Ortho Books, 1985.
2. Home Improvements Manual, Reader's Digest, 1982.
3. Decks and Patios, Kent Keegan, Creative Homeowner Press, 1980.
4. Formulas for stress and Strain, Roark and Young, McGraw-Hill, 1975.
5. Mechanics of Materials, Timoshenko and Gere, Van Nostrand Reinhold, 1972.
6. AutoLisp Programmer's Reference, AutoDesk, 1986.
7. AutoCAD Reference Manual, AutoDesk, 1986.
8. MSC/pal Application Manual and Reference Manual, MacNeal-Schwendler Corporation, 1984.