A PARAMETER STUDY OF COST VERSUS MATERIAL AND SERVICEABILITY VARIABLES IN UNSHORED NON-COMPOSITE AND COMPOSITE FLOOR SYSTEMS

by

Steven James Tschetter

Report submitted to the faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Master of Engineering

in

Civil Engineering

APPROVED:

W. Samuel Easterling, Chairman

Thomas M. Murray

Richard M. Barker

July, 1994

Blacksburg, Virginia 24061

A PARAMETER STUDY OF COST VERSUS MATERIAL AND SERVICEABILITY VARIABLES IN UNSHORED NON-COMPOSITE AND COMPOSITE FLOOR SYSTEMS

by

Steven James Tschetter

Committee Chairman: W. Samuel Easterling
Civil Engineering

(ABSTRACT)

Composite floor systems are designed using a commercially available computer program, SDI Floor. A wide variety of possible floor configurations are explored, which cover the likely range of actual floor variations. Results from computer aided design using SDI Floor is presented with respect to dollars per square foot of floor area. A regression analysis is done using the data obtained from SDI Floor. Suggestions are made to assist the designer in creating an economical composite floor design.

ACKNOWLEDGMENTS

My thanks and appreciation go to Dr. Easterling. His guidance and assistance made this project possible. I also wish to express my thanks to Dr. Murray who provided the computer program SDI Floor, which he helped to develop; without this contribution none of this investigation could have taken place. I am also grateful for Dr. Barker's guidance with regard to statistical analysis, and agreement to serve on my committee. I am in debt for the knowledge I have gained from all the professors of the structures' division, which has contributed to my understanding of structural engineering as a whole.

Special thanks go to my close friend Kristine Lumadue who has been encouraging and supporting throughout my years at Virginia Tech. I would also like to thank my family who has supported me financially and emotionally. My colleagues and peers also deserve thanks for their help and friendship during my course work.

TABLE OF CONTENTS

TABLE OF CONTENTS, Continued

Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Composite design of floors utilizing steel H-shapes, steel shear studs, steel floor decking and concrete have become common place for structural engineers. As with all designs there is an optimum cost for a given set of variables. With the introduction of the American Institute of Steel Construction (AISC) Load and Resistance Factor Design (LRFD) manual in 1986, composite beam and girder design is well defined and reliable. (*Load* 1986) Although composite design is an efficient method for floor design, the interacting between design parameters may produce some unexpected results and consequences when the parameters are imposed arbitrarily. The purpose of this project is to clearly identify the effect major variables have on the economy of a composite floor excluding floor vibration criterion.

1.1 Background

Composite steel-concrete structures became economical with respect to construction cost and load carrying ability in the 1950's with the introduction of steel decking. (Evans and Wright 1988) The purpose of the steel decking is to act as a stay-in-place form and provide tensile reinforcing for the concrete slab. Rolling a corrugated shape into the steel decking provides enough stiffness and strength so that in most cases no shoring is needed during construction for spans up to approximately 15 feet, using currently available deck profiles.

Incorporating steel shear studs along with steel decking greatly changes the behavior of the floor system. Shear studs can be welded to both beams and girders of a floor bay. Welding of shear studs to the steel sections through the deck and then placing concrete around and over the deck and studs allow the concrete and steel to act compositely. Designs are based on a percentage of the horizontal shear force in the steel section being transferred through shear studs and into the concrete. Two possible configurations for attaching shear studs to beams and girders are illustrated in Fig. 1.

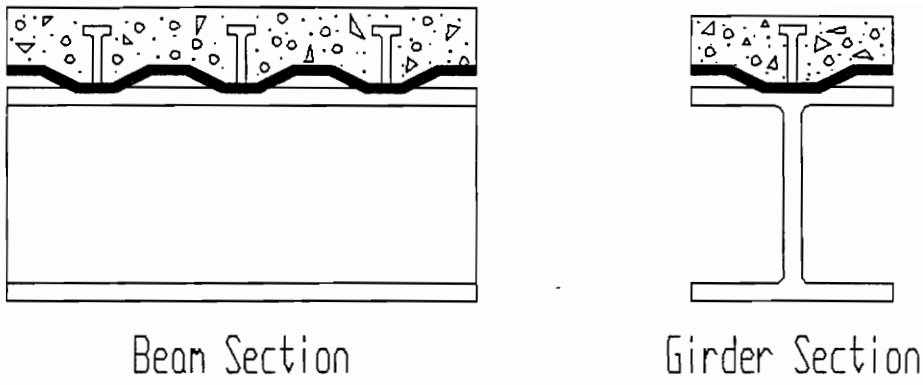


Fig. 1. Steel Deck Configurations

At the present time the AISC LRFD specification contains perhaps the most widely used design criteria for composite floors in the United States. (*Load* 1986) A review of the advantages and disadvantages of composite design follows.

1.2 Advantages, Disadvantages and Suggestions to Obtain an Economic Composite Floor Design

This literature review will present work done by other authors on composite floors, concentrating on economy and the advantages and disadvantages in using composite design as compared with non-composite design. Most of the suggestions made by these authors are in a qualitative form, therefore the design engineer must interpret how to best optimize the composite floor system with experience, trial and error.

Composite design with respect to floor systems is the combination of profiled steel decking, steel reinforcing, concrete, shear studs and a hot rolled steel section to form an interacting unit (Evans and Wright 1988). The percentage composite represents the amount of interaction between these materials. Zero percent representing non-composite and one hundred representing full composite action (no slip between the steel section and the concrete slab). There are both positive and negative aspects to using composite design. Designers need to be aware of the fact that seldom is the use of full composite design necessary. Evans and Wright (1988) state that, "with composite beams it is possible to limit the degree of interaction between slab and beam to that necessary to support the required live load whilst ensuring that the steel beam alone is adequate to support the dead load of the wet concrete." Partial composite design is frequently used today. In fact "current practice utilizes composite action in nearly all situations where

concrete and steel are in contact..." (Salmon and Johnson 1990). The amount of partial composite action used should be based on the economics of the particular design.

Partial composite design is probably the most effective way to reduce a floor's weight and thus cost. If weight reduction is important, then the lowest cost composite design should be utilized because, "... a composite section is generally smaller than alternative designs needed to sustain the same load, thus resulting in the savings of material weight..." (Yam 1981). In addition to a reduction in the weight of the floor, composite design also allows a designer to take advantage of shallower members, increased floor stiffness and the potential to increase the span length of the steel members (Salmon and Johnson 1990).

Weight reduction is important, but does not account for the additional labor costs included with the installation of shear studs, which is labor intensive. Although the decreased weight of a floor can lower the cost of connections throughout the structure. Depending on the amount of weight that can be eliminated when considering a composite versus a non-composite floor, the savings in cost of framing connections can be significant (Carter and Geschwindner 1993).

The difficulty in judging the benefit of designing one way versus another is that each job will have a different optimum condition somewhere between non-composite and full composite. Reaching this "optimum" condition may be an unworkable possibility, since the interaction of the variables in a composite floor is a complex one. The work of the writer should help to guide designers toward an optimum design from an economic point of view.

With all its advantages composite design does have some significant disadvantages designers need to consider. Some limitations of composite design are: 1) that for continuous slabs composite action can not be relied upon in negative moment regions, and 2) that "long-term deflection caused by concrete creep and shrinkage could be important when the composite section resists a substantial part of the dead load..." (Salmon and Johnson 1990). Another downfall as mentioned before is that composite design requires additional labor costs for the installation of shear studs. In some circumstances the additional labor involved in composite design may be significant enough such that the use of additional materials is more economical than additional labor.

AISC has published a design guide for low to medium rise buildings which contains some design recommendations for increased economy in composite floors. (Allison 1991). A basic but important piece of advice is that, "... beams should be spaced as far apart as practical to reduce the number of pieces which must be fabricated and erected" (Allison 1991). The use of high strength steel is also recommended, because

currently mills offer both A36 and Grade 50 steels at approximately the same cost. A designer should not rule out the use of 36 ksi steel, when strength is not a controlling factor, since generally fabricators consider this a "stock" grade. Local price differentials should be assessed at the time of design. The recommendation, "use composite construction", is generally wise advice, except that designers should consider the possibility that in some situations non-composite design may better fit their application.

The subject of composite floor design and economy is an area in which other authors have approached from a qualitative point of view. As a whole this information can be useful, but it is difficult to actually know if the chosen design is an optimal one. With the addition of the work done by the writer, which includes both a qualitative and quantitative approach to the economy of a composite floor design, designers should better be able to obtain an optimal solution for their floor designs.

1.3 The Steel Deck Institute SDI Floor Program

The SDI Floor program is a knowledge based program that is capable of the design of typical bays, beams and girders using composite or non-composite design. (*SDI* 1994) The program is based upon Load and Resistance Factor Design. (*Load* 1986)

The SDI Floor program is capable of designing composite floor systems with a large number of variables to choose from. (*SDI* 1994) These variable choices include:

Bay Size	Uniform Load	Steel Strength
Beam Span	Live Load Reduction	Stud size
% Composite	Loading Combinations	Fabrication Cost
Deck Profile	Shored/Unshored Construction	Steel Cost
Beam Depth Range	Depth of Slab	Stud Cost
Girder Depth Range	Concrete Strength	Live Load Deflection
Beam Spacing	Weight of Concrete	Dead Load Deflection
		Initial Dead Load Deflection

The choice of variables is complete, so that a composite floor system can be completely defined using the input variables and the program's output which include the items shown above. The user has the option of specifying any or all of the input variables, or using the defaults, which are median values.

A sample input screen for SDI Floor is illustrated in Fig. 2. (*SDI* 1994) This screen, in addition to pop-up screens that are activated to define the preferences of the designer, fully determine the design parameters of the composite floor.

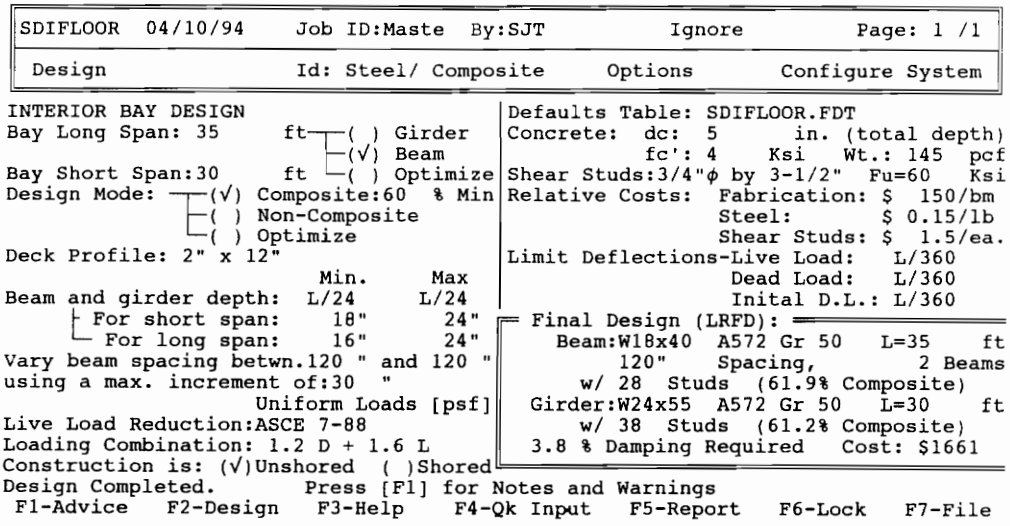


Fig. 2. Sample SDI Floor Input Screen

The pop-up screens include the choices; design, option, system configuration, deck profile, beam / girder depths and uniform loads. The program provides on-line help to the user if any uncertainties arise. Output from this data is partially included with the input data, while the majority of the information including all design and serviceability calculations are included in the report portion of the output. A report can be viewed and or printed so that the designer can double check the design.

1.4 Variable Choice & Range

To explore the range of variables and determine how they affect the cost of a composite floor on a per square foot basis, a selection of significant variables was chosen. Eleven, identified as variables from those available in the SDI Floor program, are selected as being likely to give results that can not readily be observed through intuition. (*SDI* 1994) The variables chosen include:

Bay Size	Live Load	Fabrication Cost
Beam Spacing	Slab Thickness	Steel Cost
Concrete Strength	Live Deflection	Stud Cost
% Composite	Initial Dead Deflection	

A range for each variable was chosen to represent realistic designs. A list of the variables, number of choices and their range is given below. This is the final range that has been used for each variable. The variable percentage composite was initially explored for composite values as low as 25%, but this was changed to 40% after some initial exploration. It was necessary to consider the effects that each of these variables have on the cost of a composite floor two at a time (only two variable ranges are explored at a time) . An asterisk is placed next to the selection that for each variable range is used as a constant, when that variable is not being considered.

Bay Size (ft. x ft.)	Beam Spacing (ft.)	Concrete Strength (ksi)
20' x 35'	6	3
24' x 35'	* 10	* 4
* 30' x 35'	12	5
36' x 35'	15	6

% Composite	Live Load (psf)	Slab Thickness (in.)
0	* 50	4
* 40	70	* 5
60	90	6
80	110	7
100		

Live Deflection	Initial Dead Deflection	Fabrication Cost ($/beam)
L / 240	* L / 240	100
L / 300	L / 300	* 150
* L / 360	L / 360	200
		250

Steel Cost ($ / lb)	Stud Cost ($ / stud.)
0.15	1.00
* 0.20	* 1.50
0.25	2.00
0.30	2.50

Once the above variable ranges were selected, a grid was set up with all the variables in each direction. This was done to aid in the recording of the large number of combinations. An example of the variable selection that has been used when Concrete Strength was being varied is illustrated below.

Example:

Variable	Units	Run 1	Run 2	Run 3	Run 4
Bay Size	ft. x ft.	30 x 35	30 x 35	30 x 35	30 x 35
Beam Spacing	ft.	10	10	10	10
Conc. Strength	ksi	3	4	5	6
% Composite	%	40	40	40	40
Live Load	psf	50	50	50	50
Slab Thickness	in.	5	5	5	5
Live Deflection	L/__	360	360	360	360
Initial Dead Deflection	L/__	240	240	240	240
Fabrication Cost	$/beam	150	150	150	150
Steel Cost	$/lb.	0.20	0.20	0.20	0.20
Stud Cost	$/stud	1.50	1.50	1.50	1.50

CHAPTER II

PARAMETER STUDIES

2.1 Overview

The data obtained from the parameter study conducted with the computer program SDI Floor will be presented in this chapter. Not all of the data obtained are presented, because some of the results were relatively trivial and thus omitted. Each group of similar data is combined together with a qualitative discussion of the trends and their causes.

2.2 Description of Details

Data obtained from the program SDI Floor is given in a dollar value for an entire floor, except for one edge beam and one girder. These two members are assumed to be included in the neighboring bays. In addition to these members the program does not have the means to include costs for steel decking and concrete.

Manually including the costs of steel decking and concrete has been done with the aid of a Vulcraft Steel Floor & Roof Deck design guide. (*Vulcraft* 1994) A 2 inch and 3 inch deep deck profile are needed. Vulcraft profiles 2VLI and 3VLI have been used with the assumption of normal weight concrete. The tables in the design guide list gage thickness required for a given clear span, superimposed live load and total slab depth. Using an assumed steel cost of $0.20 per pound, the cost of steel decking has been included for the appropriate deck required in each floor design.

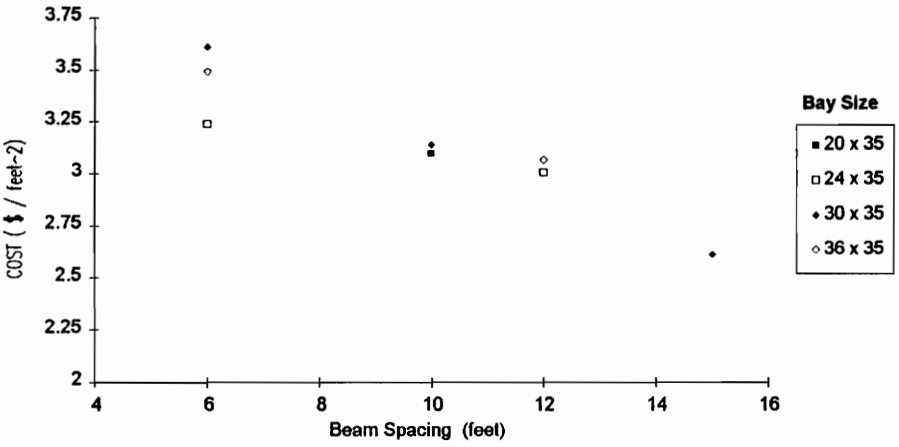
Concrete costs have also been included manually. Since the current local cost differential between 3 ksi and 6 ksi concrete is approximately 10 percent, one cost is used for all strengths. A cost of $ 70.00 per cubic yard is used for all strengths of concrete, which does not include the cost of placement. At the present time this is an upper bound for the local cost for concrete. The total amount of concrete required is obtained from a design aid included in the Vulcraft design guide for the appropriate deck profile. (*Vulcraft* 1994)

To generalize the results, the costs, including steel deck and concrete are presented in dollars per square foot of bay area.

2.3 Cost Plots with Discussion of Results

2.3.1 Cost vs. Beam Spacing & Bay Size

Cost vs. Beam Spacing & Bay Size is illustrated in Fig. 3., which indicates that the larger distance a beam can be spaced, the greater the reduction in cost. This trend is dependent on the ability of the decking used to span the beam spacing without deflecting beyond an acceptable limit. The decking must also have sufficient strength to support the fresh concrete. In order to meet this requirement a heavy 16 gauge deck with a 3 inch deep profile should be selected to satisfy the deflection and strength requirements for the widest beam spacing.



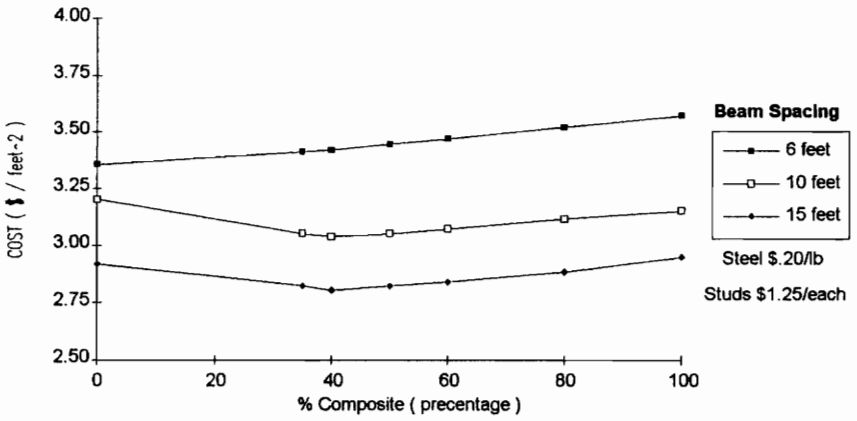
CONSTANTS	
Beam span	35 feet
Bay Size	
Beam spacing	
Conc Strength	4 ksi
% Composite	40
Live Load	50 psf
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	L/240
Fabrication	$150/beam
Steel Cost	$0.20/lb
Stud Cost	$1.50

Fig. 3. Cost vs. Beam Spacing & Bay Size

The amount of slope in this trend depends on the relative costs of structural steel versus steel decking. Costs of $.20 / pound for structural steel and $.20 / pound for steel deck are used in this plot. The vertical separation at each of the different beam spacing is due to the varying number of beams required for each individual bay. Another cause for the vertical separation of the plotted values, is due to the fact that SDI Floor will attempt to approach the desired percentage composite as closely as possible but will not exactly reach this value (the program always gives a design in which the percentage composite is higher than that specified).

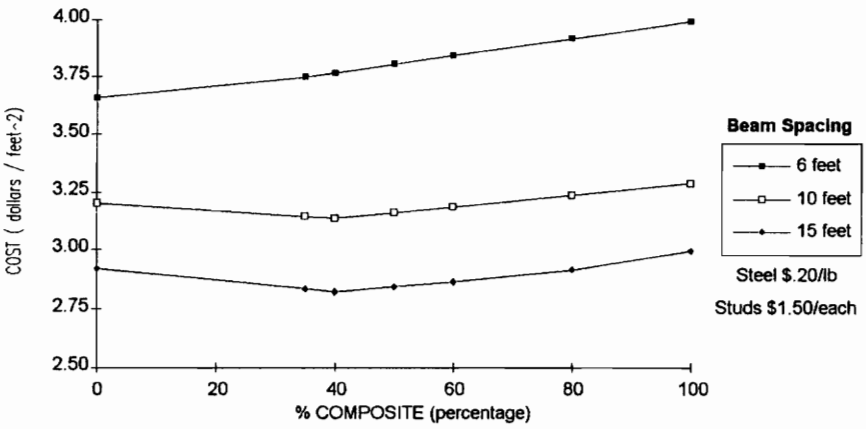
2.3.2 Cost vs. % Composite & Beam Spacing with Variations

Trends showing that the optimum amount of composite action depends on the spacing between beams is illustrated in Fig. 4a., 4b., and 4c. In all three figures the curves representing the 10 and 15 foot beam spacing have a minimum cost at about 40 percent composite action. The 6 foot beam spacing investigated are most economical when used with non-composite construction. Designers should note different beam spacing will be most economical at a distinct percentage composite for a given set of design parameters.



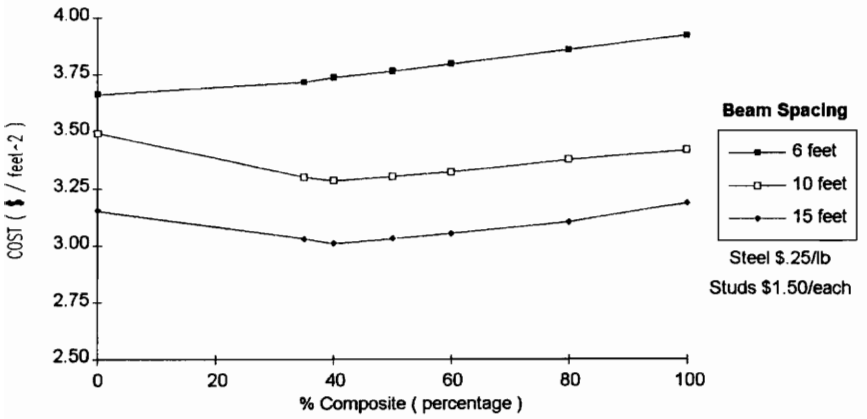
CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	
Conc Strength	4 ksi
% Composite	
Live Load	50 psf
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	L/240
Fabrication	$150/beam
Steel Cost	$0.20/lb
Stud Cost	$1.25/stud

Fig. 4a. Cost vs. % Composite & Beam Spacing with Variations



CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	
Conc Strength	4 ksi
% Composite	
Live Load	50 psf
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	L/240
Fabrication	$150/beam
Steel Cost	$0.20/lb
Stud Cost	$1.5/stud

Fig. 4b. Cost vs. % Composite & Beam Spacing with Variations



CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	
Conc Strength	4 ksi
% Composite	
Live Load	50 psf
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	L/240
Fabrication	$150/beam
Steel Cost	$0.25/lb
Stud Cost	$1.50

Fig. 4c. Cost vs. % Composite & Beam Spacing with Variations

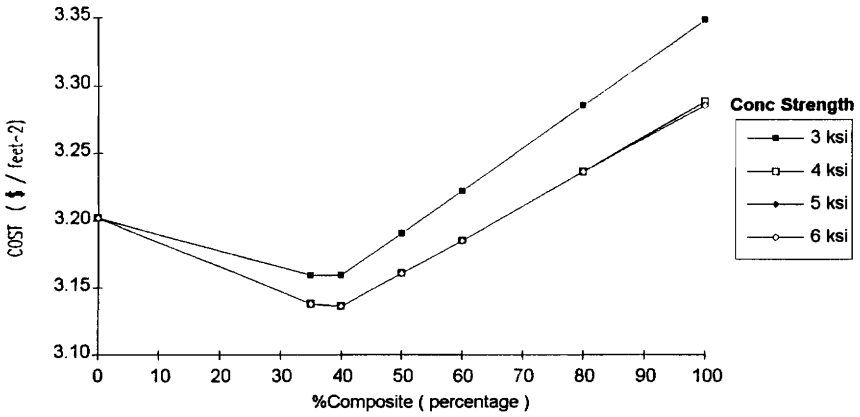
While changing the relative costs of steel versus shear studs does have an effect on the cost of a floor, is did not change the minimum cost points in terms of the percentage composite. Changing of the material costs appears to only shift the curves vertically. It is likely that if the relative costs are drastically changed from the values shown here, there would be some horizontal translation of the minimum cost for the 10 and 15 foot beam spacing with respect to percentage composite.

The location of the minimum cost for a given floor is due to a number of factors. These include: the dimensions of the bay, the live load capacity required (this is probably the most important factor), material costs and material strengths.

Another interesting observation is that about 40% composite appears to be an optimum percentage for beam spacing greater than 10 feet. This trend can be seen in many of the other figures that follow.

2.3.3 Cost vs. % Composite & Concrete Strength

As illustrated in Fig. 5. the minimum cost occurs at the same percentage composite as it does in Fig. 4a, 4b, and 4c. The fact that the same bay size is being considered along with identical live load and material costs, explain the cause of this trend. The most interesting result of this plot is that the use of higher strength concrete does not reduce the amount of material required, assuming approximately equal concrete cost for concrete strengths above 4 ksi. Designers should be aware that unless strength is a controlling factor, which in this floor it is not, using higher strength materials does not always have an economic benefit.

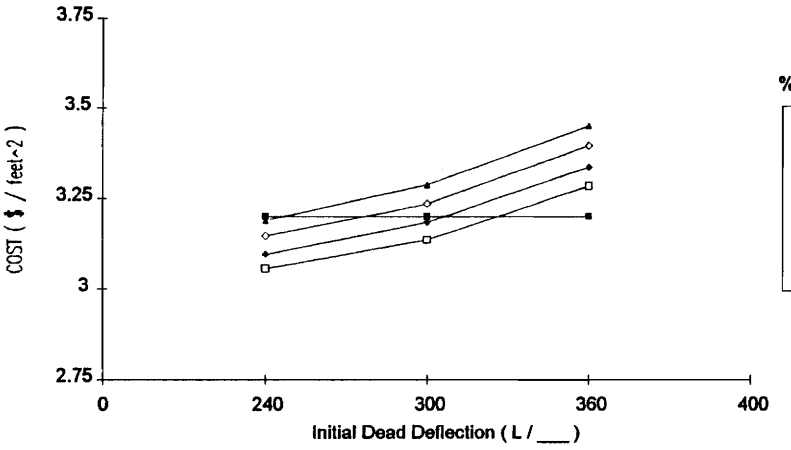


CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	10 feet
Conc Strength	
% Composite	
Live Load	50 psf
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	L/240
Fabrication	$150/beam
Steel Cost	$0.20/lb
Stud Cost	$1.5/stud

Fig. 5. Cost vs. % Composite & Concrete Strength

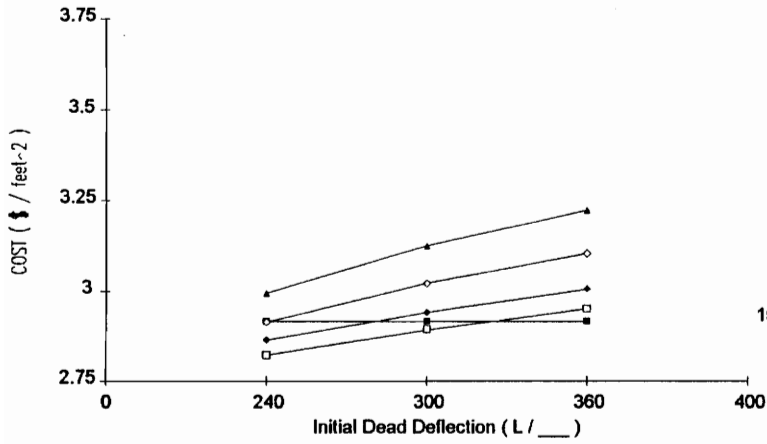
2.3.4 Cost vs. Initial Dead Deflection & % Composite with Variations

Plotting Initial Dead Deflection versus Percentage Composite provided some surprising results which are illustrated in Fig. 6a., 6b., 6c. and 6d. In each investigation the non-composite design resulted in a floor that remained constant with respect to cost, while the initial dead load deflection criteria changed. Initial Dead Load Deflection is the deflection of the floor due to the weight of the hot rolled sections, steel decking and fresh concrete.



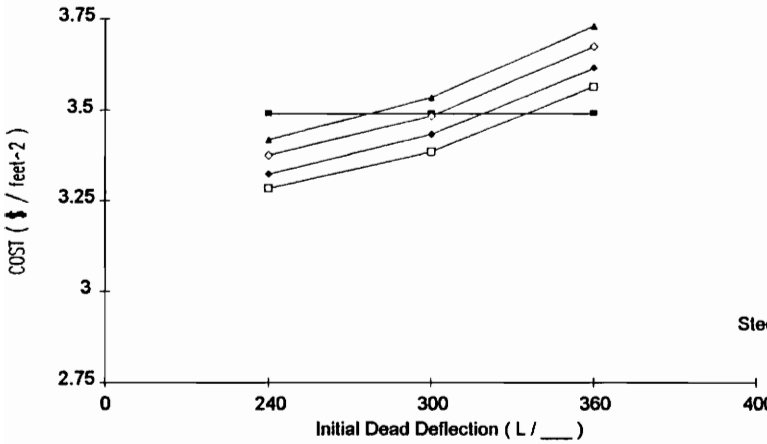
CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	10 feet
Conc Strength	4 ksi
% Composite	
Live Load	50 psf
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	
Fabrication	$150/beam
Steel Cost	$0.20/lb
Stud Cost	$1.50

Fig. 6a. Cost vs. Initial Dead Deflection & % Composite with Variations



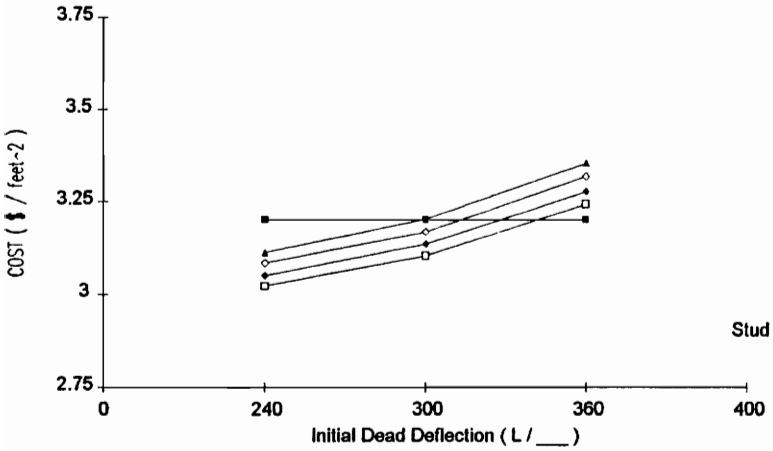
CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	15 feet
Conc Strength	4 ksi
% Composite	
Live Load	50 psf
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	
Fabrication	$150/beam
Steel Cost	$0.20/lb
Stud Cost	$1.50

Fig. 6b. Cost vs. Initial Dead Deflection & % Composite with Variations



CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	10 feet
Conc Strength	4 ksi
% Composite	
Live Load	50 psf
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	
Fabrication	$150/beam
Steel Cost	$0.25/lb
Stud Cost	$1.50

Fig. 6c. Cost vs. Initial Dead Deflection & % Composite with Variations



CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	10 feet
Conc Strength	4 ksi
% Composite	
Live Load	50 psf
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	L/240
Fabrication	$150/beam
Steel Cost	$0.20/lb
Stud Cost	$1.00

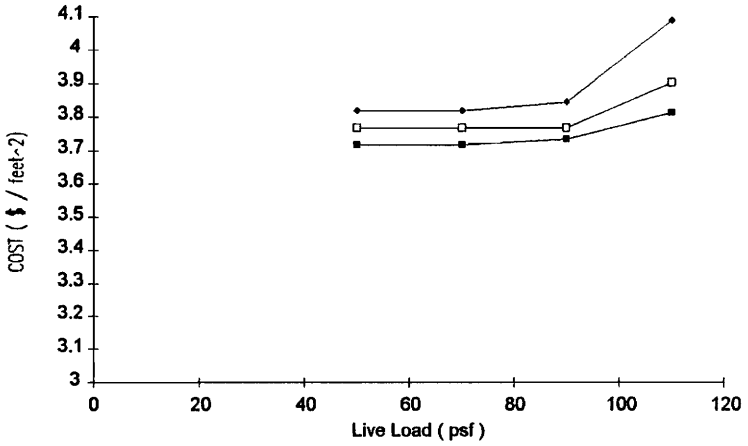
Fig. 6d. Cost vs. Initial Dead Deflection & % Composite with Variations

In the non-composite designs the need for increased stiffness due to the change in the deflection criteria is accomplished by increasing the depth of the beam sections, while keeping the weight per foot constant. For example, the stiffness of a beam can be increased by changing from a W16x40 to a W18x40, without changing the amount of steel. This is not possible for composite designs, since much of the strength and stiffness from the final design is obtained through the use of composite action. Smaller beam sections can be considered when composite design is used at lower deflection limitations. When the Initial Dead Deflection is not controlling the floor design, a significant portion of a composite floors stiffness is obtained through composite action. A composite section can have a moment of inertia much greater than can the steel H-shape alone.

As illustrated in Fig. 6a., 6b., 6c. and 6d. for a live load capacity of 50 psf, 40 percent composite or less is the best economic choice. The variations shown in the four figures indicate the affect of changing other variables, such as beam spacing, steel cost and stud cost. The difference between figures is a vertical shift in the curves, along with some relative movement of the non-composite line with respect to the composite curves.

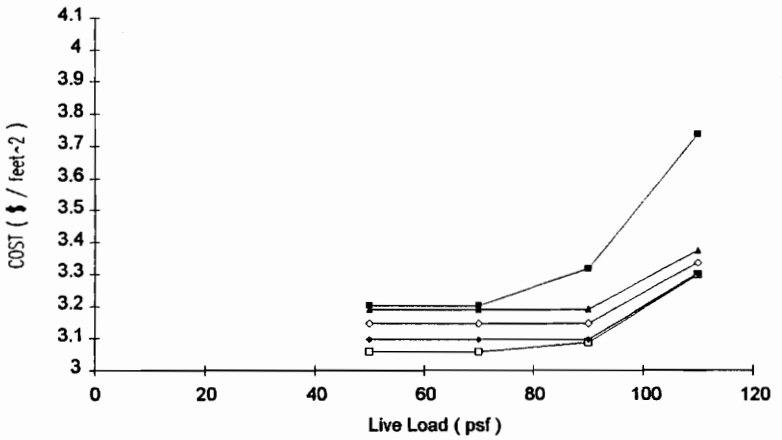
2.3.5 Cost vs. Live Load with Variations

Live load with different variations versus cost are illustrated in Fig. 7a, 7b and 7c . Even though the variations are significantly different (bay size, percentage composite and concrete strength) there is a well defined similarity between the three figures.



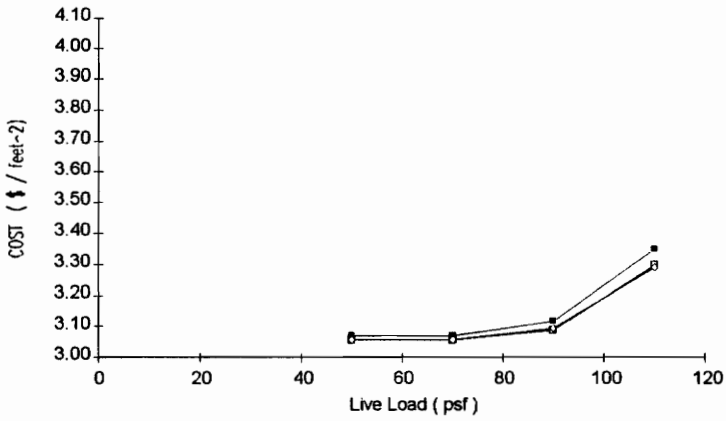
CONSTANTS	
Beam span	35 feet
Bay Size	
Beam spacing	10 feet
Conc Strength	5 ksi
% Composite	40
Live Load	
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	L/240
Fabrication	$150/beam
Steel Cost	$0.20/lb
Stud Cost	$1.50

Fig. 7a. Cost vs. Live Load & Bay Size



CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	10 feet
Conc Strength	5 ksi
% Composite	
Live Load	
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	L/240
Fabrication	$150/beam
Steel Cost	$0.20/lb
Stud Cost	$1.50

Fig. 7b. Cost vs. Live Load & % Composite



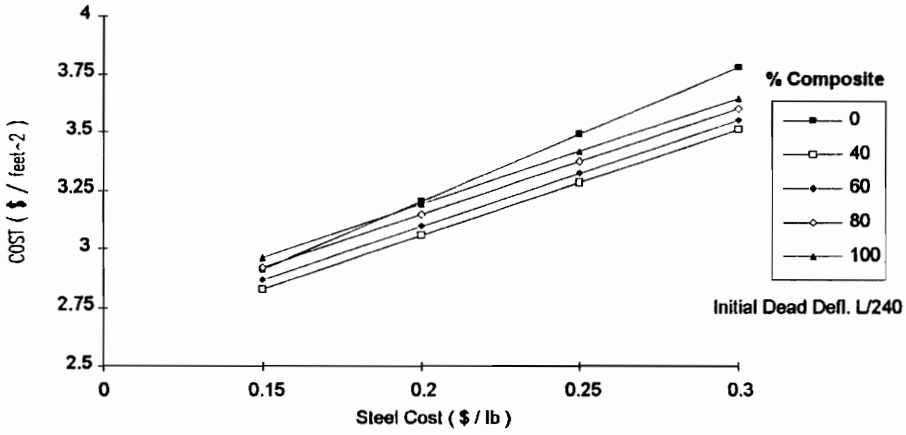
CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	10 feet
Conc Strength	
% Composite	40
Live Load	
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	L/240
Fabrication	$150/beam
Steel Cost	$0.20/lb
Stud Cost	$1.50

Fig. 7c. Cost vs. Live Load & Concrete Strength

Live load is the controlling variable in these floor designs, when a live load of approximately 90 psf is approached (note: live load reduction has not been used for the floor designs). Beyond 90 psf an increase in live load produces an exponential increase in cost. Designers should be aware that floors requiring live load capacities significantly larger than 100 psf will have resulting costs much greater than those designed for live loads less than or equal to 100 psf. Using this information designers could potentially design composite floors with a live load capacity of approximately 90 psf without significantly increasing the floors cost as compared to the same composite floor designed for a lower live load capacity.

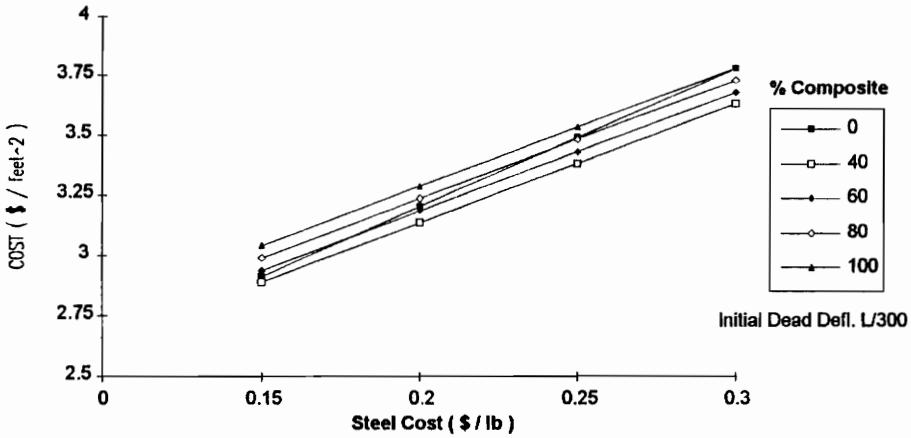
2.3.6 Cost vs. Steel Cost & % Composite with Variations

A trend between the cost of steel and the percentage composite action with varying amounts of restriction in the initial dead load deflection criteria is illustrated in Fig. 8a., 8b., and 8c. As indicated in these plots, all floor designs using composite action have lines parallel to each other, while the non-composite floor designs plot at a different slope. This difference in slope is due to the absence of a shear stud cost in the non-composite designs. Designers should note that as the deflection criteria grows (less deflection allowed), non-composite design for these floors becomes increasingly more economical. This trend is strongly dependent on the bay size, beam spacing, live load capacity and material costs.



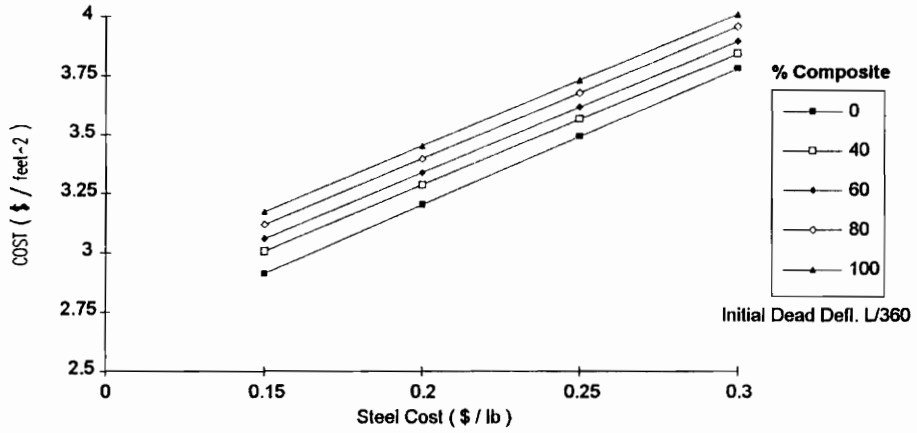
CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	10 feet
Conc Strength	5 ksi
% Composite	
Live Load	50 psf
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	L/240
Fabrication	$1.50/beam
Steel Cost	
Stud Cost	$1.50

Fig. 8a. Cost vs. Steel Cost & % Composite with Variations



CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	10 feet
Conc Strength	5 ksi
% Composite	
Live Load	50 psf
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	L/300
Fabrication	$150/beam
Steel Cost	
Stud Cost	$1.50

Fig. 8b. Cost vs. Steel Cost & % Composite with Variations



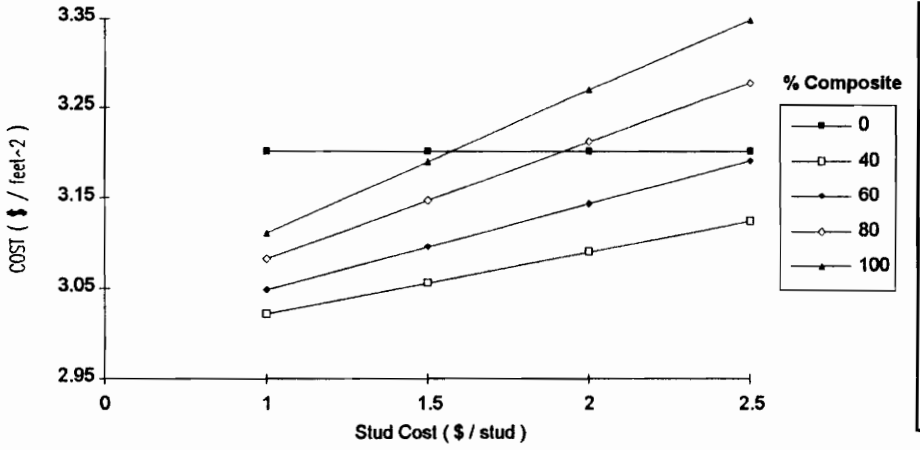
CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	10 feet
Conc Strength	5 ksi
% Composite	
Live Load	50 psf
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	L/360
Fabrication	$150/beam
Steel Cost	
Stud Cost	$1.50

Fig. 8c. Cost vs. Steel Cost & % Composite with Variations

2.3.7 Cost vs. Stud Cost & % Composite

There is a percentage composite at which it is no longer economical to use composite design as the cost of shear studs increase as illustrated in Fig. 9. For this floor a composite action of about 40 percent is an optimal economical choice for all the shear stud costs explored. Extrapolation of these results should show that at high shear stud costs a non-composite design becomes a better economical solution.

The different degrees of composite action have divergent slopes, because as shear studs increase in cost, a larger hot rolled section becomes more economical than additional shear studs.

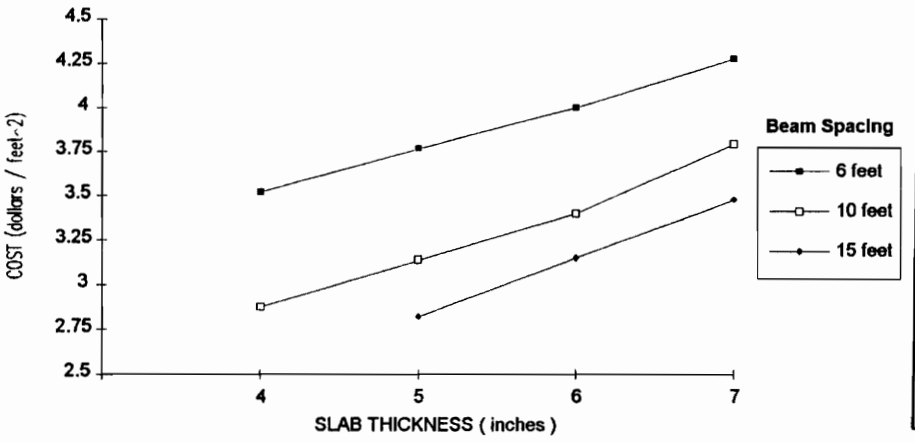


CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	10 feet
Conc Strength	5 ksi
% Composite	
Live Load	50 psf
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	L/240
Fabrication	$150/beam
Steel Cost	$0.20/lb
Stud Cost	

Fig. 9. Cost vs. Stud Cost & % Composite

2.3.8 Cost vs. Slab Thickness & Beam Spacing

Additional economy can be achieved when a designer increases the beam spacing as illustrated in Fig. 10. Another observation from this data is that thinner floor slabs are more cost efficient, except when large beam spacing are required and a thin slab is not possible for reasons of strength. Designers should note that a floor with 10 foot beam spacing and a 4 inch slab is approximately the same cost as a floor with 15 foot beam spacing and 5 inch slab. There is an inverse relationship between beam spacing and floor cost, while a direct relationship exists between slab thickness and floor cost. In order to optimize these variables, designers should compare the relative costs of concrete and steel.



CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	
Conc Strength	5 ksi
% Composite	40
Live Load	50 psf
Slab Thickness	
Live Defl	L/360
Dead Defl	L/240
Fabrication	$150/beam
Steel Cost	$.20/lb
Stud Cost	$1.50/stud

Fig. 10. Cost vs. Slab Thickness & Beam Spacing

CHAPTER III

STATISTICAL ANALYSIS

3.1 Regression Analysis

A regression analysis was done of all the data obtained from the SDI Floor program using a statistical analysis computer program. (*SigmaStat* 1994) The regression analysis was performed on all the data, which includes over six hundred floor designs in order to give a reliable statistical base.

In the initial regression analysis four of the variables had resulting exponents with magnitudes an order less than the other variables. It has been determined these variables do not significantly influence the cost of a composite floor, and have been removed from the regression equation. Although the variable initial dead deflection is not included in the regression equation it is likely that the variable is an important variable that designers should not ignore. These include concrete strength, live deflection, initial dead deflection and shear stud cost. The variables with a strong influence on cost include: bay size, beam spacing, percentage composite, live load, slab thickness, fabrication cost and steel cost. These are contained in the resulting regression equation shown below. The configuration of the regression equation was chosen for its relatively simple form and because it included all of the influential variables. This equation has a 10 percent error with a confidence interval of 95% for the data analyzed (the equation should predict the cost of a composite floor within 10 percent 95 percent of the time). The equation that has been generated through regression analysis is capable of predicting the approximate cost of a composite or non-composite floor system within certain limitations. These are important limitations and assumptions that a designer must be aware of when attempting to utilize this equation. These include;

Rectangular Bay Shapes	
Bay Sizes Ranging from	700 - 1260 ft^2
Beam Lengths of	25 - 40 ft
Beam Spacing	6 - 15 ft
Concrete Strength	4 ksi
Normal Weight Concrete	
Concrete Cost	\$ 70 / yd^3
Percent Composite	0 - 100
Live Load	50 - 110 psf
Slab Thickness	4 - 7 in
Live Load Deflection Limitation	L / 360

Dead Load Deflection Limitation	L / 240
Fabrication Cost per Beam	$100 - $250
Steel Costs	$.15 / lb - $.25 / lb
Shear Studs Priced at (installed)	$1.50 / each

Designers should be aware that this equation is not a substitute for the actual analysis of a composite floor to determine its cost. This equation is presented so that designers can see how a variable influences a composite floor's cost.

OPTIMIZING EQUATION

$$\text{COST} = \left[\text{SLAB} \left(\frac{\text{STEEL}}{\text{BAY} * \text{BEAM}} \right)^{1/4} \text{LIVE}^{.1648} \, \text{FAB}^{.3073} \right] + \left(\frac{\text{COMP}}{\text{BAY}} \right)^{1.341}$$

Notation

COST = The cost of the floor design in $ / ft²
note: this includes the cost of one exterior beam and one girder
SLAB = The thickness of the total slab in inches
STEEL = The cost of hot rolled sections in $ / lb
BAY = The size of the floor (the area inscribed by the columns) in ft²
BEAM = The spacing between adjacent beams in feet
LIVE = The maximum full live load (no live load reduction) to be placed on the floor in psf
FAB = The fabrication cost of one beam (the cost for two simple framing connections) in $ / beam
COMP = The percentage composite action with a range of 0 to 100

This equation when used with the before mentioned limitations should predict floor costs of approximately $2.50 / ft² to $5.00 / ft². Following is an numerical example using the optimizing equation.

Example:

Bay Size	1050 ft2
Beam Spacing	10 ft
Slab Thickness	5 in
Live Load	70 psf
% Composite	60 %
Fabrication Cost	$200 / beam
Steel Cost	$.20 / lb

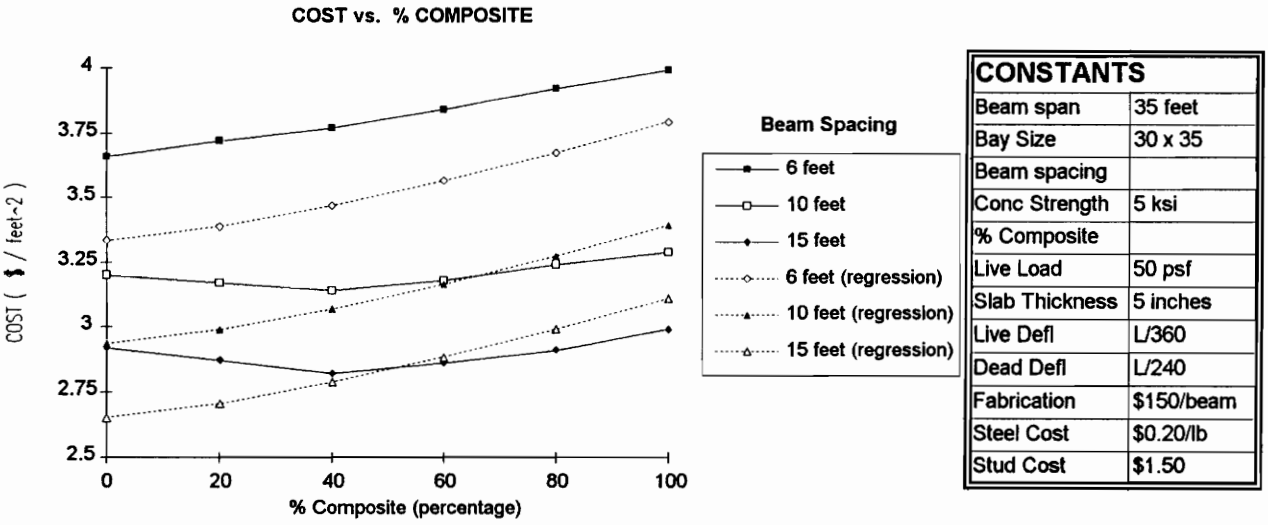
Example cont.:

$$\text{COST} = \left[(5 \text{ in}) \left(\frac{(\$.20 / \text{lb})}{(1050 \text{ ft}^2)(10 \text{ ft})} \right)^{1/4} (70 \text{ psf})^{.1648} (\$200 / \text{beam})^{.3073} \right] + \frac{(60\%)^{1.341}}{1050 \text{ ft}^2}$$

Cost = $ 3.62 / ft²
compared to a cost of $3.84 / ft² for the data
The difference between the two cost is about 6%, which is within the error limitation.

3.2 A Comparison of Data vs. Regression Analysis

To illustrate the positive and negative attributes of the optimizing equation to fit with actual data, an example of the equation plotted with previous Fig. 4b. the resulting plot is shown in Fig. 11. below.



CONSTANTS	
Beam span	35 feet
Bay Size	30 x 35
Beam spacing	
Conc Strength	5 ksi
% Composite	
Live Load	50 psf
Slab Thickness	5 inches
Live Defl	L/360
Dead Defl	L/240
Fabrication	$150/beam
Steel Cost	$0.20/lb
Stud Cost	$1.50

Fig. 11. SDI Floor Data with Optimizing Equation

The percentage error involved in using the Optimizing Equation is illustrated in Fig. 12. with respect to the data presented in Fig. 11.

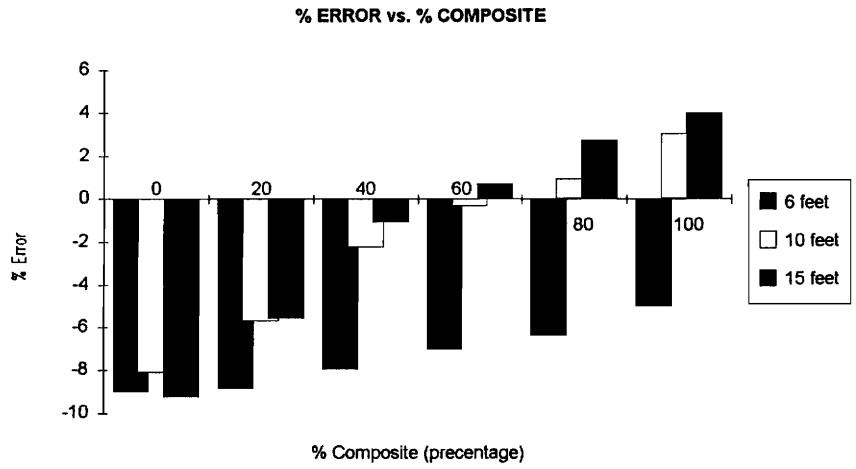


Fig. 12. % Error with Optimizing Equation

Fig. 11. illustrates how dangerous it can be to rely on a regression equation. The resulting plot indicates the fact that much of the composite floor data contained a beam spacing of 10 feet and percentages composite ranging from 40 to 100. Most of the variables contained in the optimizing equation have ranges in which the regression analysis better represents the variables behavior. The Designer should experiment with each variable in order to narrow its best range. Designers should also be cautious and not base their design decisions solely on the optimizing equation.

Even though the regression equation does not include all of the variables explored in the parameter study, it does approximate the behavior of the excluded variables as illustrated in Fig. 12.

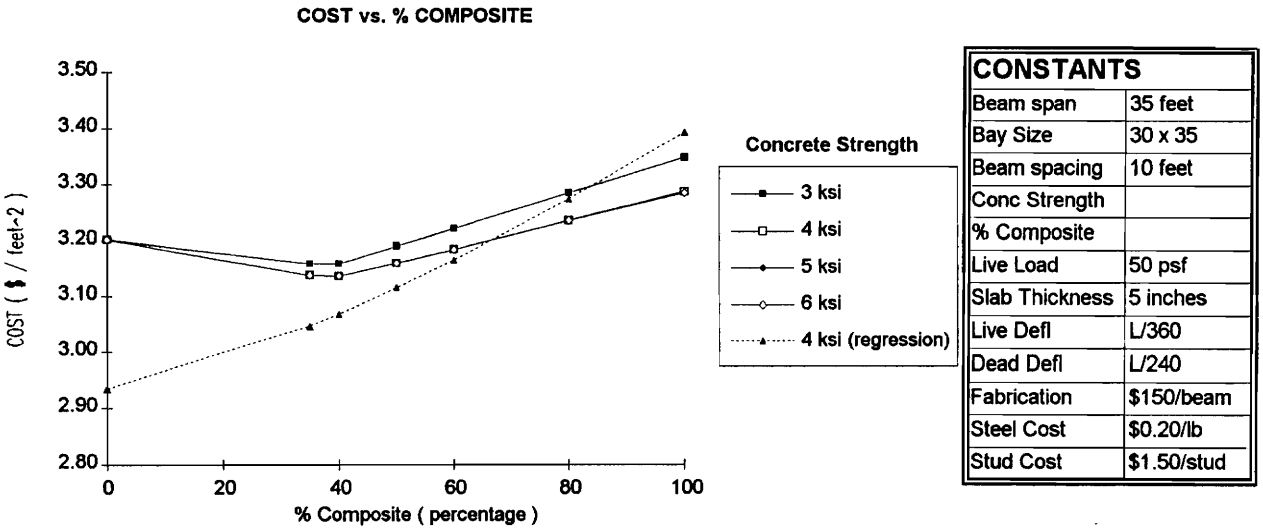


Fig. 13. SDI Floor Data with Optimizing Equation

The percentage error involved in using the Optimizing Equation is illustrated in Fig. 14. with respect to the data presented in Fig. 13. The error is averaged for the range of possible concrete strength choices.

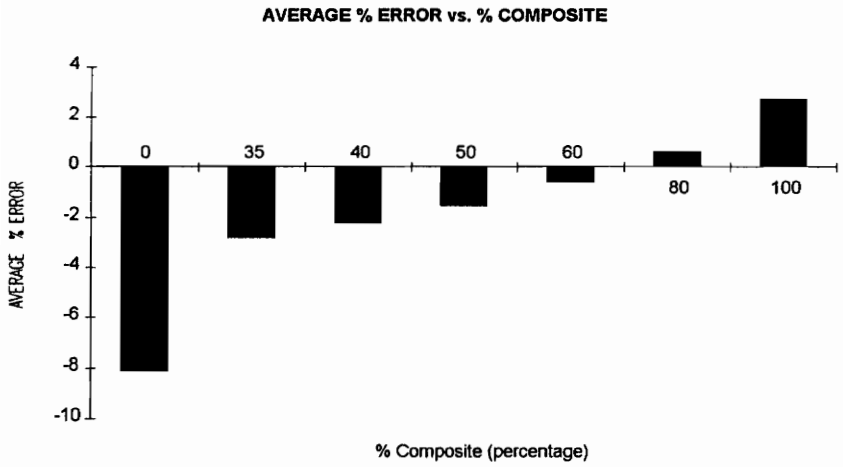


Fig. 14. % Error with Optimizing Equation

For the most common range of composite floors (40 to 100 % composite) the regression equation can be a useful tool in approximating the cost of a floor. As stated earlier the designer should calculate the actual cost when attempting to accurately determine a composite floors cost.

CHAPTER IV

RECOMMENDATIONS & ADDITIONAL DISCUSSION

4.1 Summary

Composite floors are complex structural systems in which the interaction between the variables is more intricate than can be described with a regression equation or a brief qualitative discussion. Because of this interaction the designer realistically can only attempt to optimize the cost of a composite floor with a limited number of design iterations. Following is a number of recommendations that should aid designers attempting to reduce a composite floors cost.

4.2 Recommendations

The design recommendations below are based on the composite and non-composite floor designs explored for this project and may not be applicable to all situations. Designers should also note that these design recommendations are not based on any vibration criterion. It is the writers belief that these recommendations should help designers produce economical floor designs. These recommendation are:

1) Larger bay sizes are generally more economical
2) Use the largest beam spacing possible within the limitations of the deflection criteria
3) Use the maximum acceptable limitation for initial dead deflection
4) Use normal strength concrete (4 ksi)
5) Floors may potentially be designed for up to 90 psf live load without significantly increasing the cost (without live load reduction)
6) Use minimum slab thicknesses appropriate for beam spacing
7) Consider 40% composite action, since it may be the best economical choice for many floor designs
8) Explore partial composite and non-composite designs

4.3 Additional Discussion

Designing composite and non-composite floors to obtain an optimum economical solution results is an iterative process. It is possible to reduce the number of iterations through the use of the above recommendations and engineering experience.

When it comes time to sit down and design a composite floor many of the design possibilities will already be specified. Hopefully these predetermined parameters will have been wisely chosen by an experience engineer, but it is possible that may not be true. The best advice this writer can give is to be willing to explore a reasonable range of design parameters and floor designs that may not be considered standard designs.

BIBLIOGRAPHY

Allison, H.. "Low-and Medium-Rise Steel Buildings." AISC, Steel Design Guide Series. Chicago: 1991.

Carter, Charles J. & Geschwindner, Louis F.. "The Economic Impact of Overspecifying Simple Connections." *American Institute of Steel Construction, Inc., Engineering Journal* 1st Quarter 1993: 34-36.

Evans, H. R., and Wright H. D. (1988) "Steel-Concrete Composite Flooring Deck Structures" *Steel-Concrete Composite Structures*, 21-52.

Load and resistance factor design (LFRD) specification for structural steel buildings. (1986). American Institute of Steel Construction, Inc. (AISC), Chicago, IL.

Salmon, Charles G. & Johnson, John E., *Steel Structures, Design and Behavior.* New York: Harper Collins Publishers Inc., 1990.

SDI Floor. Computer software. The Steel Deck Institute, 1994 MS-DOS, one 1.44 MB disk.

SigmaStat. Computer Software. Jandel Scientific Software, 1994 MS Windows, three 1.44 MB disks.

Steel Floor & Roof Deck. Vulcraft. Blytheville, Arkansas: 1994.

Yam, Lloyd C. P., *Design of Composite Steel-Concrete Structures.* London: Surrey University Press, 1981.

VITA

Steven James Tschetter was born in Sioux Falls, South Dakota on December 6, 1968. He graduated from Grayslake High School in Grayslake, Illinois in 1987. In 1990 he received his Associate of Science degree in General Engineering, with Honors, from Northern Virginia Community College. In December of 1992 he received his Bachelor of Science degree in Civil Engineering, with Honors, from Virginia Polytechnic Institute and State University. Upon completion of this project he will receive his Masters of Engineering degree from Virginia Polytechnic Institute and State University. He is currently employed with Butler Manufacturing Company in Laurinburg, North Carolina.