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Probabilistic Assessment of Sandwiched Concrete Slabs in Deflection

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Abstract: This study presents a probabilistic evaluation of concrete sand-witched hollow core slabs in accordance with the design requirements of BS8110 (1985; 1997) and Eurocode 2 (2008). The First Order Reliability Method (FORM) was used in computing the probability of failure. For the deflection failure, the effect of varying the load ratio and the breadth of slab on the reliability analysis were carried out at the following values of concrete strengths f_{cu}: 25N/mm^2, 30 N/mm^2, 40 N/mm^2, 50 N/mm^2. The results indicate that deflection characteristics of the slab are directly affected by the concrete strength, loadings, breadth of slab selected. Thus, the deflection of the slab increases with increases in loading, hollow core, breadth of slab and decrease in concrete strength. This shows that the safety index of reinforced sandwiched concrete slab in deflection generally decreases as the load ratio and breadth of slab increase for each combination of concrete strength.
Keywords: Probabilistic Analysis, Sandwiched Concrete, Reliability Analysis, Stochastic Model, FORM

I. INTRODUCTION

A structure refers to a system of connected elements which function to support and transmit load. A structure may be characterized by its support system, its shape or the behavior of its material under load. The combination of structural elements and the materials from which they are composed is referred to as a structural system. Each system is constructed of one or more of the basic types of structures. Important examples of structures related to civil engineering include buildings, bridges and towers[1].

A structural engineering project can be divided into three phases: planning, design and construction. The planning phase involves a consideration of the various requirements and the factors that affect the general layout and dimensions of the structure and leads to the choice of one or perhaps several alternative types of structures that offer the best general solution. The design phase involves a detailed consideration of the alternative solutions evolved in the planning phase and leads to the determination of the most suitable proportion, dimensions, and the details of structural elements and connections. The construction phase involves procurement of materials, equipment, and personnel; shop fabrication of the members and subassemblies and their transportation to the site, and the actual field construction and erection[2].

Satisfactory design must ensure the achievement of an acceptable probability that the specified life of a structure is not curtailed prematurely due to the attainment of an unsatisfactory condition. The acceptable probability should be chosen in such a way that a satisfactory balance is achieved between the cost of construction and the combined cost of insurance premiums (which are related to the probability of structural failure) and of maintenance. In particular, the study of structural safety is concerned with the violation of the ultimate or serviceability limit states for the structure [3].

Traditionally, structural safety in the design process is ensured by implementing appropriate safety factors to acknowledge shortcomings stemming from a lack of knowledge, insufficient data or inherent variability in the problem parameters. The factor of safety concept does not provide a quantitative measure of the structural reliability. Even with implementation of the safety factor, there exists a finite probability of failure of a structure. This is well recognized in the engineering community, but the concept of safety factor is still widely accepted because of its simple nature and proven effectiveness for achieving safe design. In recent decades, there has been a growing concern among many prominent engineers that there is no such thing as certainty, either of failure or of safety but only a probability of failure or a probability of safety. They concluded that the variations of the loads effects and the variation of the structural resistance should be studied in a statistical manner and the probability of survival or serviceability of a structure estimated [4].

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Analysts and designers are confronted with numerous uncertainties and product variability. To address these variables in traditional (deterministic) design, we apply safety factors. The reliability-based design approach uses probabilistic methods to take a more structured view and explicitly models these uncertainties as random variables. Probabilistic analysis appears to be particularly useful when a number of input parameters have a well-defined distribution.

In probabilistic analysis, variation is expressed by statistical distribution functions instead of single values to characterize each input. A probabilistic analysis can determine the chances of a crucial result exceeding a specific number, as well as the impact that changes in the inputs can have on the outcome. This can be useful as an essential tool for checking the consistency of existing codes with the view of optimizing the codes so as to produce more consistent, safe and economical codes for better design.

The idea of permissible degrees of product failure, however slight, is implicit in this justification and in the use of probabilistic assessments in general. It is fundamentally more applicable to safe product design than the deterministic analysis' illusory absolutism.

Structural reliability can be defined as the probability that a structure will not violate each specification limit state during a specified period. Mathematically, reliability can be expressed thus;

$$R = 1 - P_f \tag{1.1}$$

Where R is the reliability and Pf is the probability of failure. That probability of failure can be expressed as;

$$P_f = P\,[R - S \leq 0] \tag{1.2}$$

Where R= resistance of the structure and S= the applied load. The equation (1.2) represents the probability that the difference between resistance of the structure and the applied loads will be less than or equal to zero.

This study focuses on deflection in simply supported sandwiched concrete slabs under uniformly distributed loading over its entire span. This will help in understanding the safety of sandwiched concrete slabs in deflection and assessing the economic viability of sandwiched concrete slabs.

It is important to realize that there are many factors which may have significant effects on deflections, and are difficult to allow for, thus any calculated values must be regarded as an estimate only. An accurate assessment of deflection can only be achieved if consideration is given to the factors that affect it. The factors are tensile strength, creep, elastic modulus, loading sequence, cracking, shrinkage curvature, degree of restraint, ambient conditions, and stiffening by other elements [5].

II. METHODOLOGY

A. Reliability Analysis

A number of methods are available to speed the probabilistic analysis and minimize the number of finite element computations required. Essentially all methods involve repeated evaluation of the limit-state function, which in many cases will require repeated finite element computations, when finite element methods are employed. For this study, the First-Order-Reliability-Method (FORM) will be employed.

FORM searches the input variables for the combination that is most likely to cause failure (this point is often referred to as the design point or the most probable point (MPP)). It then fits a linear surface at the MPP and uses this surface (along with transformations for any non-normal random variables) to compute probabilities

The development of the methodology for structural reliability methods requires the consideration of the following three components [6]: loads, structural strength and methods of reliability analysis. According to Ellingwood [7] in the second moment First Order Reliability Method (FORM), the random variables are defined in terms of means and variances, considered to be normally distributed. The measure of reliability is based on reliability index.

For the deflection failure, the effect of varying the load ratio and the breadth of slab on the reliability analysis were carried out at the following values of concrete strengths f_{cu}: 25N/mm^2, 30N/mm^2, 40N/mm^2, 50N/mm^2

B. Computation of Reliability Index

The basic approach to develop a structural reliability base strength standard is to determine the relative reliability of the design. In order to do this, reliability assessment of existing structural components is needed to estimate a representative value of the reliability index β. The reliability index is the shortest distance to the failure surface from the origin in reduced coordinates. This first order reliability method is very well suited to perform such a reliability assessment.

For cases of a linear safety function G (x) and normal basic variable X_i the reliability index β can be obtained, as obtained by [6], using the FORM method.

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C. Reliability Data for Deflection in Sandwiched Slabs

Limit state function for deflection in hollow core slab is thus;

$$G(x) = \delta p - \delta a \quad (2.1)$$

Where; δa = Actual Deflection, δp = Permissible deflection

FORM coded in FORM5 [8] is employed in the computation of safety index, making use of the tabulated data in Table 1 and the relevant limit state functions.

TABLE 1

Parameters Of The Stochastic Model For Deflection In Sandwiched Slabs

S/No	Basic Variables	Distribution Type	$COV.$	$E(x_i)$	$S(x_i)$
1.	Span of Slab, L (mm)	Normal	0.03	10000	300
2.	Imposed Load, q_k (KN/m^2)	Log Normal	0.3	$2.0 X 10^{-3}$	$6 X 10^{-4}$
3.	Strength of Concrete, f_{cu} (N/mm^2)	Normal	0.03	30	0.9
4.	Breadth of Slab, b (mm)	Normal	0.03	800	24
5.	Overall Depth of Slab, D (mm)	Normal	0.03	300	9
6.	Width of Concrete Web, W_{cw} (mm)	Normal	0.03	100	3
7.	Depth of compression slab, D_{cf} (mm)	Normal	0.03	50	1.5
8.	Depth of tension slab, D_{tf} (mm)	Normal	0.03	50	1.5

III. RESULTS AND DISCUSSION

Figures 4.01 to 4.04 display the effects of varying the breadth of slab for different load ratios on the reliability analysis of sandwiched slab in deflection for 10m slab span. The safety index decreases as the breadth of slab increases for all the load ratio cases considered. The safety index also decreases with increase in load ratio. The safety index values generally increase with increasing concrete strength. Therefore, it can also be deduced that the deflection capacity of reinforced sandwiched concrete slabs is dependent on the concrete strengths.

Figures 1 TO 4

Safety Index Against Breadth Of Slab For Slab In Deflection On 10 Meters Slab Span

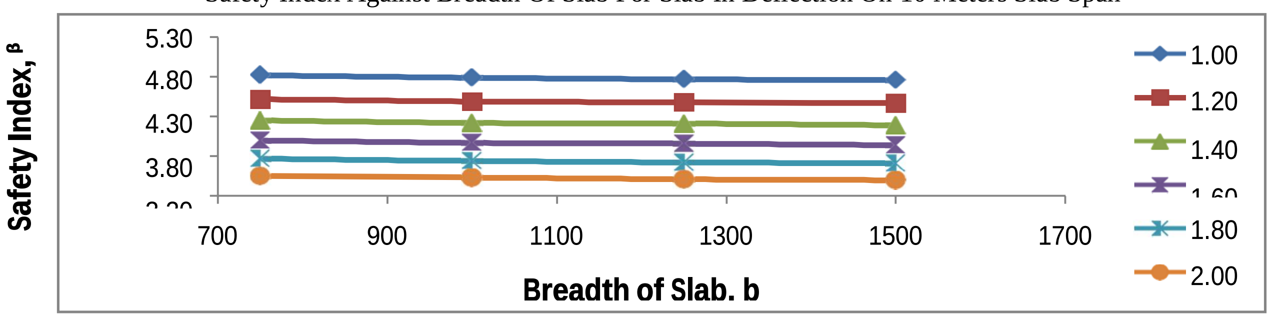

Figure 1: f_{cu} = $25N/mm^2$

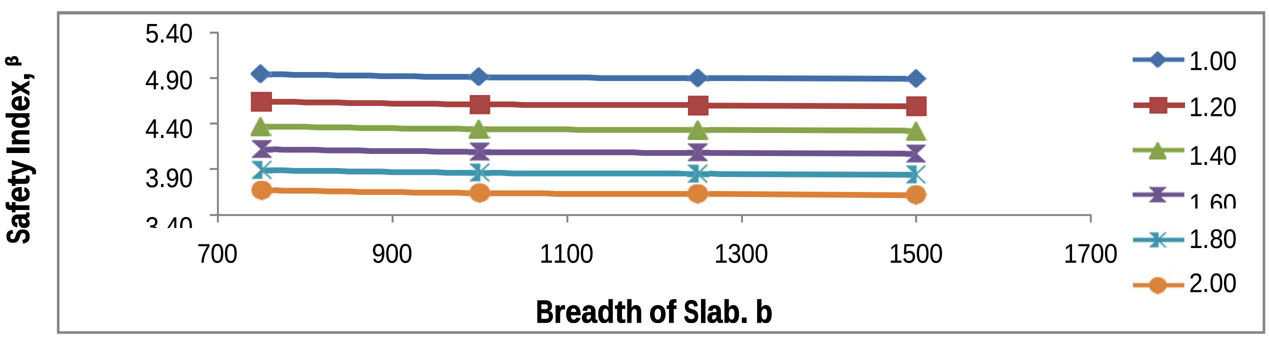

Figure 2: f_{cu} = $30N/mm^2$

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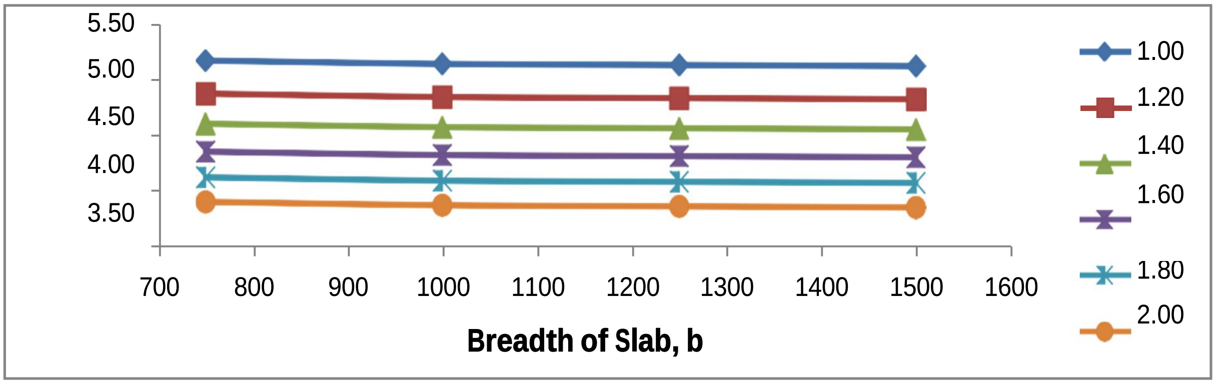

Figure 3: $fcu = 40N/mm^2$

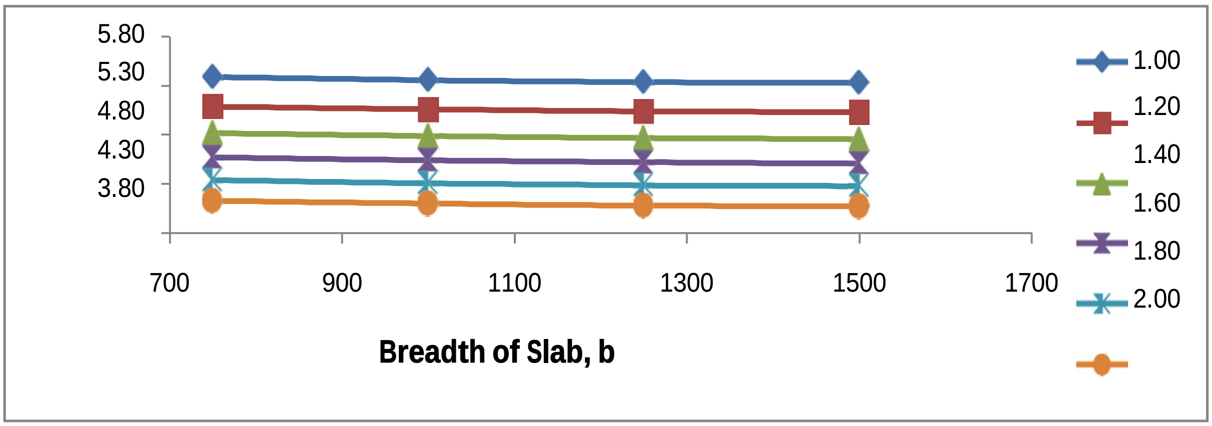

Figure 4: $fcu = 50N/mm^2$

Figures 4.05 to 4.08 display the effects of varying the breadth of slab for different load ratios on the reliability analysis of sandwiched slab in deflection for 15m slab span. The safety index decreases as the breadth of slab increases for all the load ratio cases considered. The safety index also decreases with increase in load ratio. The safety index values generally increase with increasing concrete strength. Therefore, it can also be deduced that the deflection capacity of reinforced sandwiched concrete slabs is dependent on the concrete strengths.

Figures 5 To 8

Safety index against breadth of slab for slab in deflection on 15 meters slab span

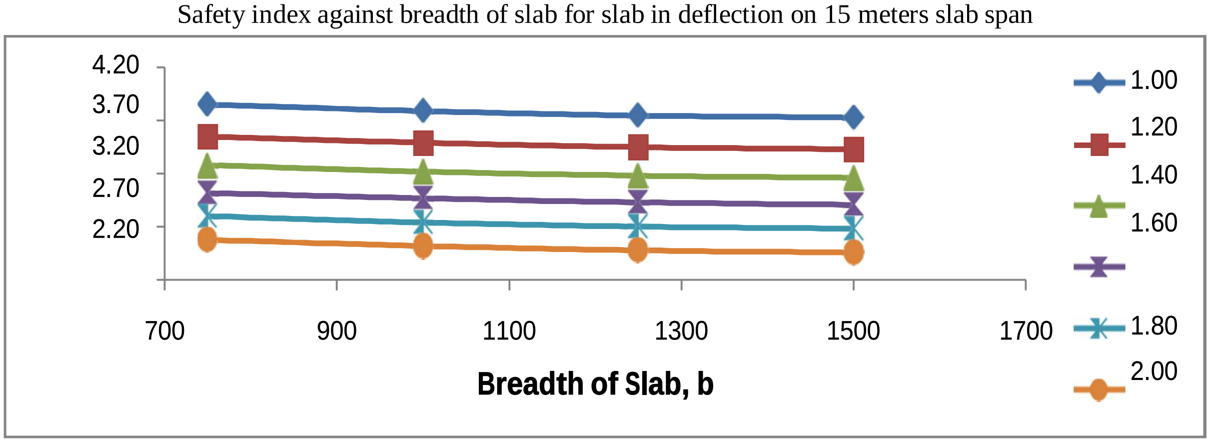

Figure 5: $fcu = 25N/mm^2$

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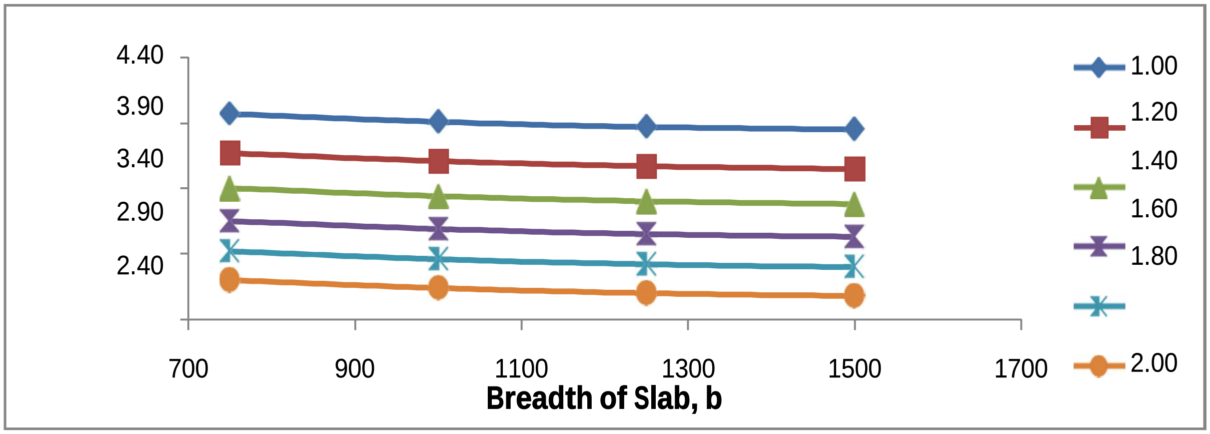

Figure 6: $f_{cu} = 30N/mm^2$

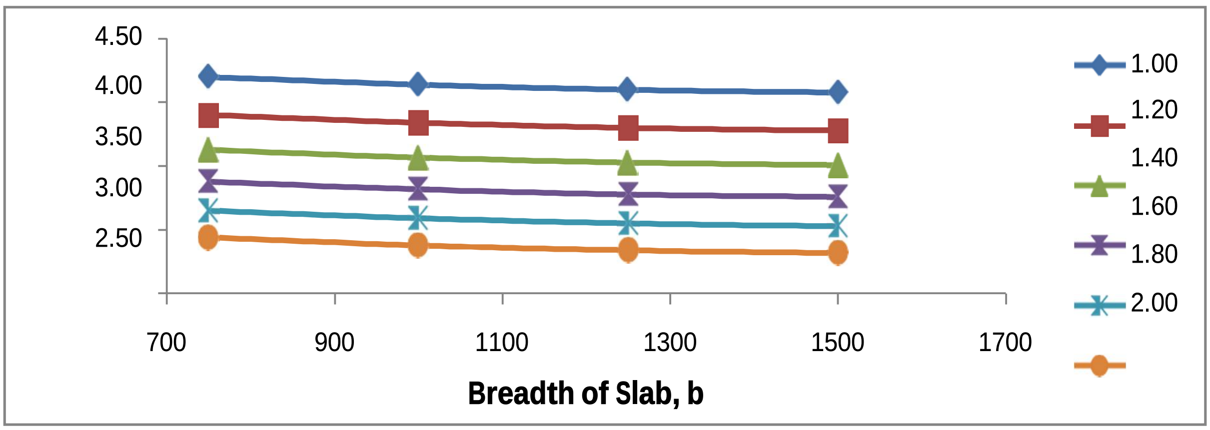

Figure 7: $f_{cu} = 40N/mm^2$

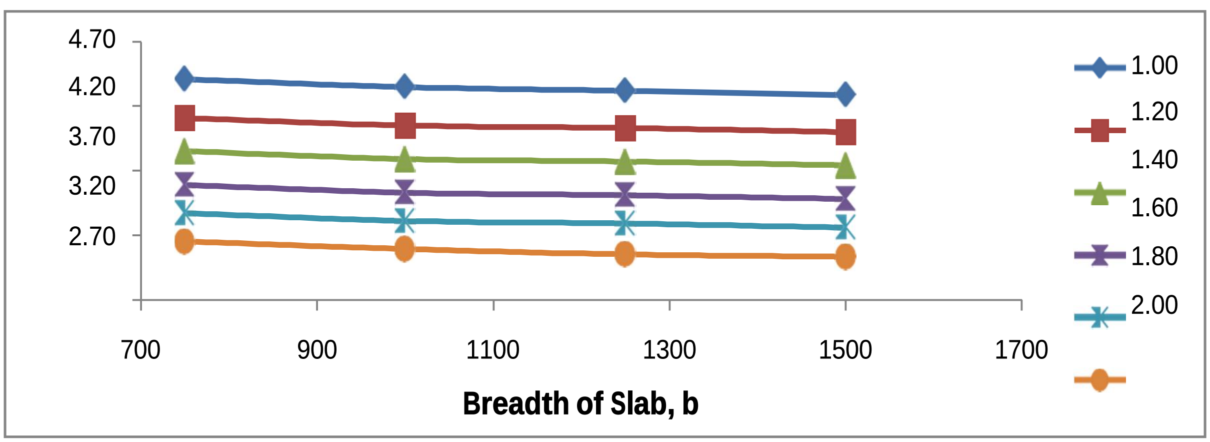

Figure 8: $f_{cu} = 50N/mm^2$

Figures 9 to 12 display the effects of varying the breadth of slab for different load ratios on the reliability analysis of sandwiched slab in deflection for 20m slab span. The safety index decreases as the breadth of slab increases for all the load ratio cases considered. The safety index also decreases with increase in load ratio. The safety index values generally increase with increasing concrete strength. Therefore, it can also be deduced that the deflection capacity of reinforced sandwiched concrete slabs is dependent on the concrete strengths.

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Figures 9 TO 12

Safety Index Against Breadth Of Slab For Slab In Deflection On 20 Meters Slab Span

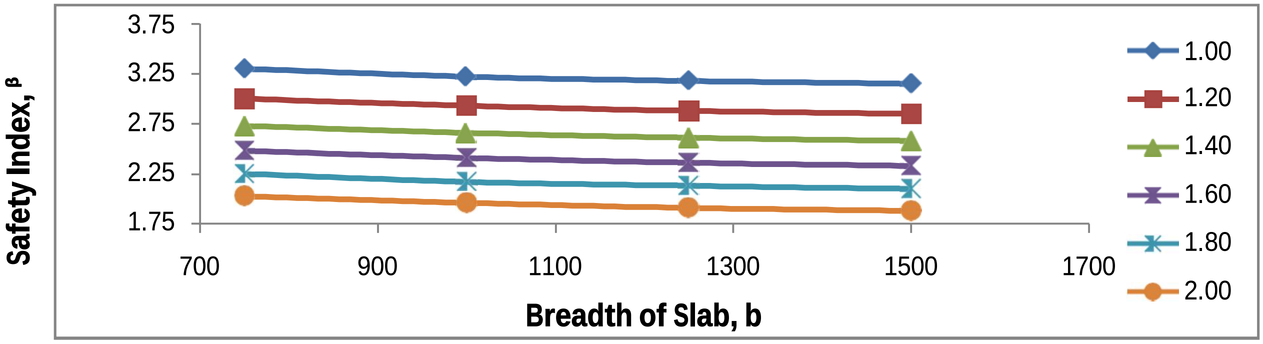

Figure 9: $fcu = 25N/mm^2$

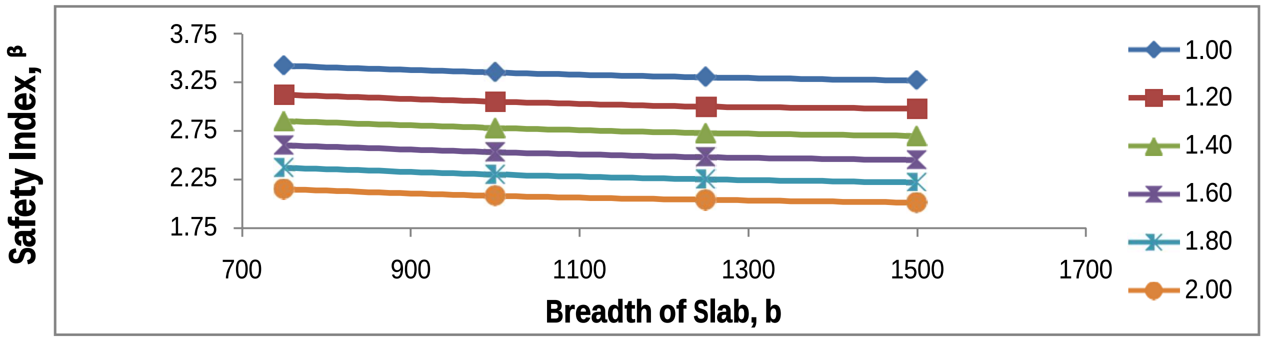

Figure 10: $fcu = 30N/mm^2$

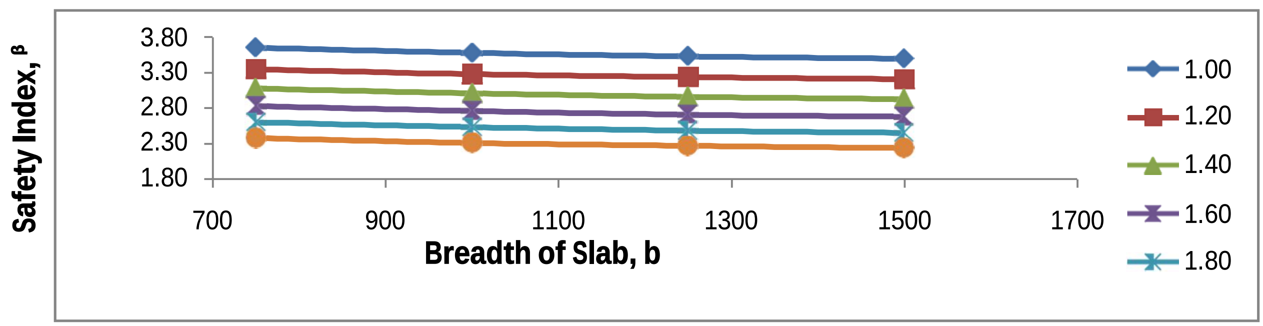

Figure 11: $fcu = 40N/mm^2$

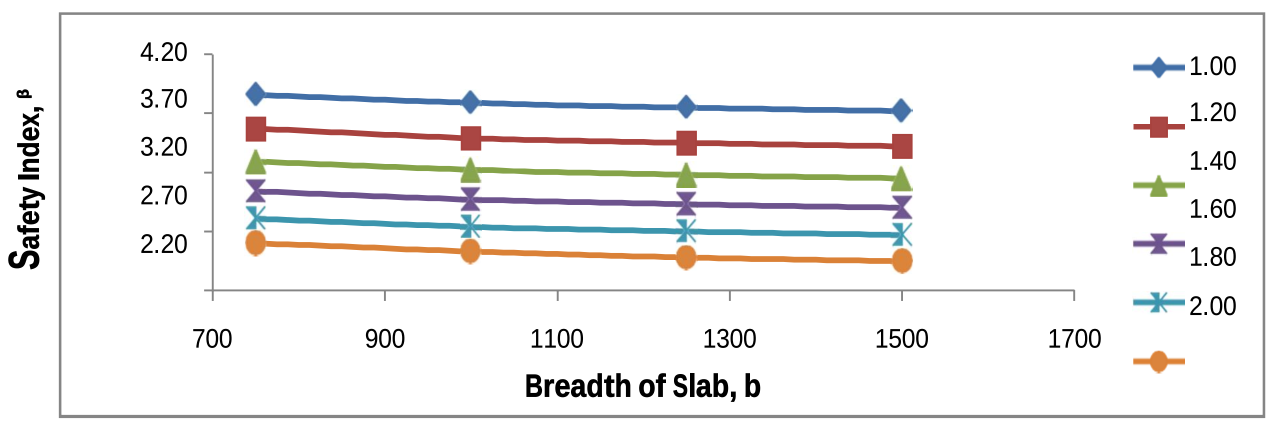

Figure 12: $fcu = 50N/mm^2$

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IV. CONCLUSION

The results show that the safety index of reinforced sandwiched concrete slab in deflection generally decreases as the load ratio and breadth of slab increase for each combination of concrete strength. It means that at low values of load ratio and breadth of slab, sandwiched slab is safer in deflection. It can also be deduced that deflection capacities are dependent on the concrete strength.

It is also evident that the safety index decreases as the slab span increases.

It is recommended that reinforced sandwiched concrete slabs are used in simple supports of between 10m and 29m spans and the breadth of slab should be taken as 1000mm and with about 60% voids within the slab. Also the concrete strength should not be less than 25N/mm^2.

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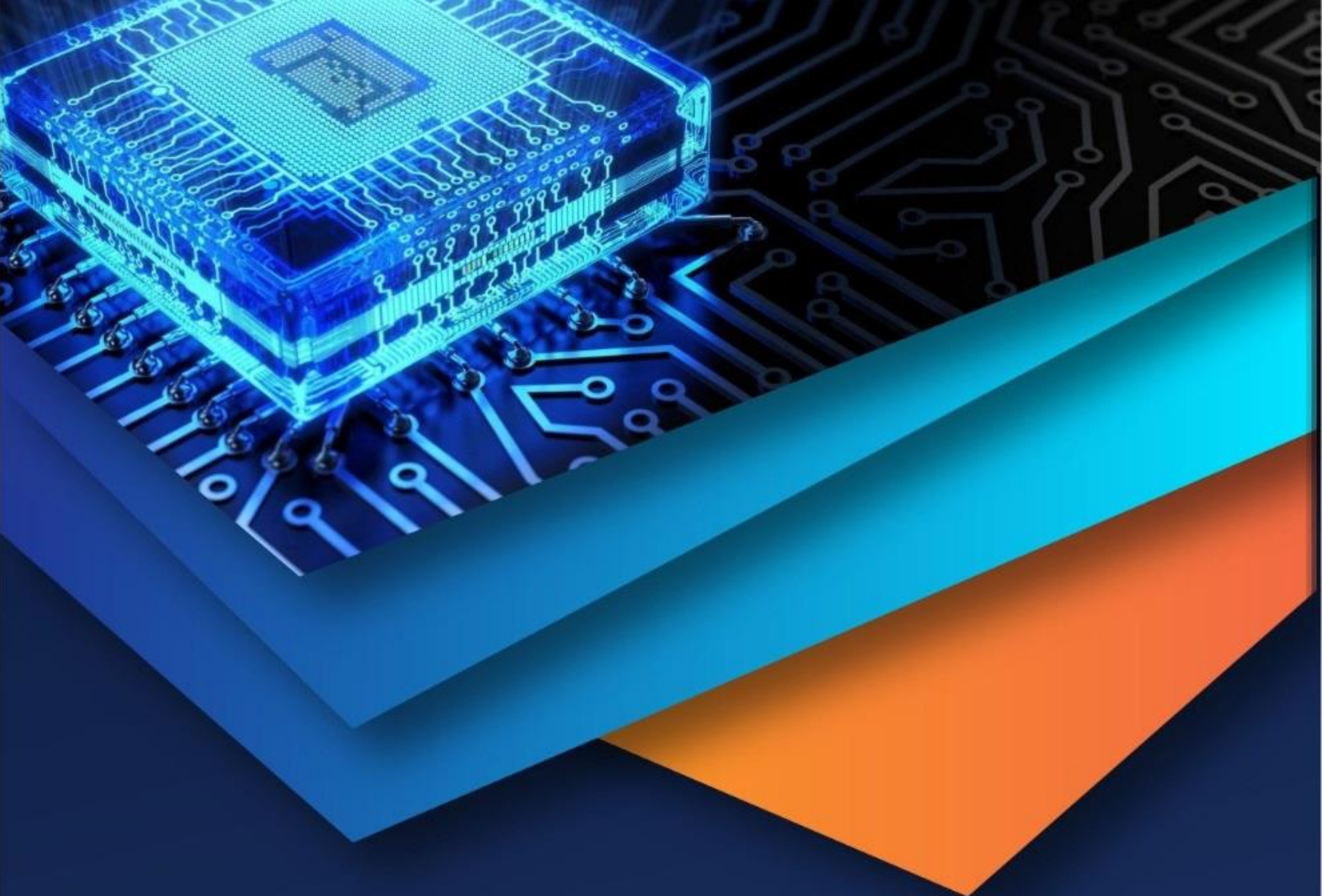

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