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Shear Strength of Slender Reinforced Concrete Beams without Web Reinforcement

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ABSTRACT
This paper attempt to predict the shear strength of high strength concrete beam with different shear span of depth ratio without web reinforcement. The large data base available has been clustered and a linear equation analysis has been performed . The prepared models are functions of compressive strength , percentage of flexural reinforcement and depth of beam. The proposed models have been validated with existence of popular models as well as with design code provisions.
Keywords - Shear strength, genetic programming, fuzzy rule, shear span to depth ratio (a/d).

I. INTRODUCTION

The shear strength in concrete beams without shear reinforcement has been undoubtedly. Numerous experimental efforts made on reinforced concrete(RC) beams under concreted loads showed that the shear strength decreased with increase in the beam depth . the reinforced concrete beams are classified into three types depending on the a/d ratio maintaining the compressive strength of concrete percentage of heretical reinforcement and depth of the beam constant as

(i) Deep beams with 0<a/d<1
(ii) Short beams with 1<a/d < 2.5
(iii) Normal beams with a/d > 2.5

For these are well – understood. Databank established by Renieck (1999) and checked by Hegger and Gortz was used to compare the empirical equation for members without transverses reinforcement.

The prime objective of shear design is to identity where shear force in required to prevent shear failure involve a breakdown of linkages and for members without stireups typically involved opening of major diagonal crack.The purpose of this paper is to review what is now know about the shear strength of reinforced concrete members without stirrups, by examine over 2000 available database and comparing these result to prediction from genetic algorithm, fuzzy rule.Thus this paper concludes with summery and description of future activities and request for reader's participation in this effort.

II. SHEAR BEHAVIOR OF FLEXURAL MEMBER

Shear failure of slender reinforced concrete beams without web reinforcement is usually caused by inclined diagonal tension cracking (Fig. 1). Once the diagonal tension cracks develop in the web of the beam, the beam without web reinforcement becomes unstable. ASCE-ACI Committee reported that for cracked beams the shear resistance is developed by several shear transfer mechanisms (Fig. 2). First, the intact un-cracked concrete in the compression zone is capable of transferring the shear force (Vcc). However, in a slender beam, the contribution of the shear force at the compression zone does not account for the major part of the total shear resistance. According to test results a large amount of shear force is transferred along the cracked surface via aggregate interlocking (Va). Usually, this shear transfer mechanism is known to be dependent on the aggregate size , the compressive strength of the concrete and the fracture mode of concrete whether occurring in the aggregate or the concrete transition zone. The contribution of the dowel action of the longitudinal reinforcement (Vd) to shear strength has been proven. When shear deformations occur in the cracked concrete, the tension reinforcement is subjected to a certain amount of shear stress.

According to existing test results, these shear resisting mechanisms are affected mainly by concrete strength, tension reinforcement ratio, effective depth, and shear span to depth ratio as shown in Fig. 3. The shear strength of slender beams vary according to the amount of tension reinforcement ratio as well as the compressive strength of the concrete.

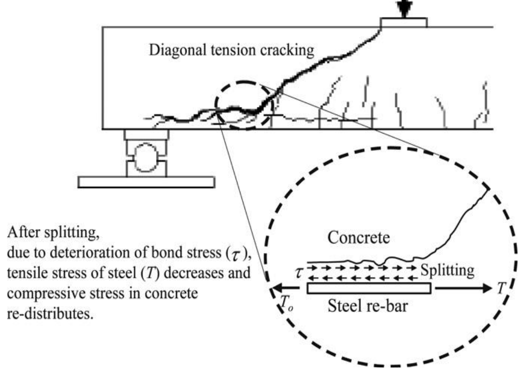

Fig.1. Shear failure mechanism of reinforced test beams without shear reinforcement.

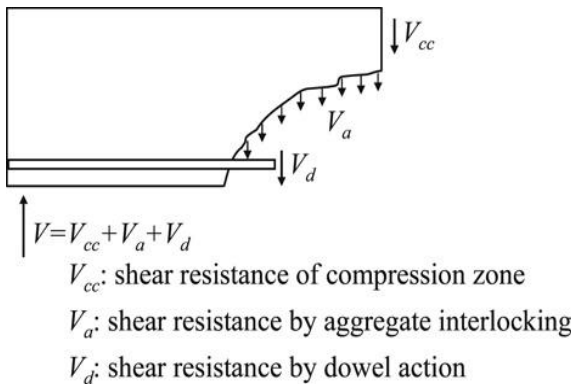

Fig.2. Several components of shear resistance.

The experimental studies showed that the shear strength of concrete beams decreases as the size of the beam increases, in spite of keeping cross-section geometry, material properties, and reinforcement ratios of the beams constant. To satisfy the condition of energy balance, the size effect must be addressed in the evaluation of shear strengths of brittle materials like concrete For deep beams and relatively short beams (a/d < 2:5), the shear resistance may be affected by shear span to depth ratio (a/d) because the applied shear force may be transmitted directly to the supports by arch action (compressive struts) of the concrete. Slender beams were therefore defined to be those beams with a/d > 2:5 However, it is known that in case of concrete beams without web reinforcement, dowel action becomes insignificant because the maximum shear developed in the longitudinal reinforcement is limited by the tensile strength of the concrete cover supporting this reinforcement.

III. DATABASE OF SHEAR FAILURE

The shear failure mechanism of the slender reinforced concrete beams without web reinforcement is a complex phenomenon that is difficult to analyze accurately. The shear failure may be suddenly developed by various local failures including crushing of concrete in the web or underneath the supports, anchorage failure, and splitting between the longitudinal reinforcement and concrete in the cracked section (Fig. 1). The shear strength may be also affected by various parameters (which are considered as minor parameters) such as maximum aggregate size, diameter of longitudinal bars, and spacing between the cracks. Due to such complexity, theoretical models usually do not show high accuracy in predicting shear strength. Most analytical models, such as the modified compression field theory , strut and tie , and truss models , include important semi-empirical expressions such as the expressions for concrete softening in stress-strain relationship or concrete cracking angle for truss models .

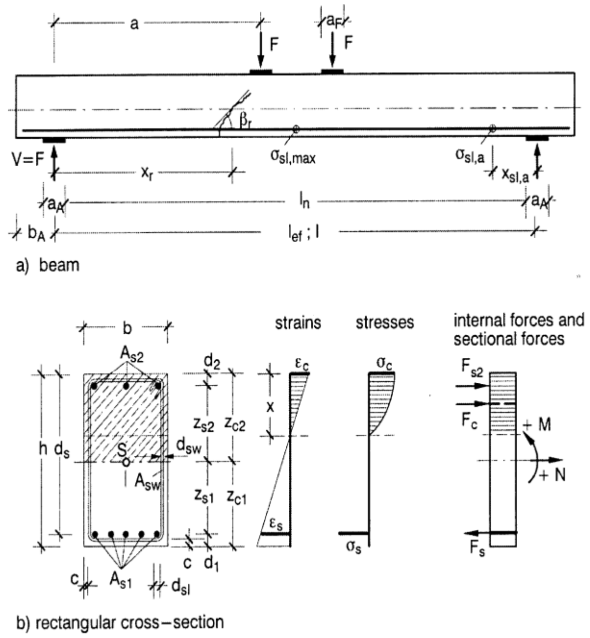

Fig: 3 - two-point load bending test

Further complexity is attributed to the fact that some modeling parameters are ambiguous (e.g. concrete cracking strength) and precise measurement of other parameters is hard to perform (e.g. cracking angle). As a consequence, considerable uncertainty in the modeling process exists and some of these uncertainties cannot be handled using the theory of probability as these errors cannot be classified as random errors that occur due to the inherent variability (randomness) in materials but due to the vagueness and ambiguity in modeling and definitions. Therefore, in design practice, complex theoretical models, are usually abandoned and replaced by simple design methods such as those used by European code: EC2,American code, IS code and the Canadian code. It becomes apparent that the complexity of the shear problem and the dependence of the shear strength on a number of interacting variables necessitate the use of an empirical modeling approach to estimate the shear strength. There has been considerable interest to incorporate probability theory in concrete modeling. However, most of these efforts were directed to reliability analysis for structural safety. It is important to realize that the theory of probability only addresses one type of uncertainty that is random uncertainty. Probability theory does not address information uncertainty. To the best of the authors' knowledge, all existing models for predicting shear strength of concrete beams have been based on deterministic mechanical assumptions with no consideration of uncertainty. This paper emphasizes the importance of considering uncertainty in structural modeling. We introduce a methodology to incorporate and epistemic uncertainties for robust modeling of shear of slender reinforced concrete beams. The present study suggests an alternative approach to model shear strength of slender reinforced concrete beams without web reinforcement using fuzzy set theory and principles of learning from example datasets.

IV. OVERVIEW OF GENETIC PROGRAMMING METHODOLOGY

GA is an optimization algorithm and is advantageous relative to traditional gradient based algorithm due to its ability to locate global minima and also operate with discrete or integer design variables. Curve fitting is the process of approximating a closed form function from a given data set . To express the data in closed form equation is particularly useful for analysis and interpretation of observed data. Curve fitting is a preliminary activity to many techniques used to model and solve production problems ,such as simulation , predictive modeling , and statistical inference . Although there are many ways to approach curve fitting, and there are methods that work well on data with few variables , there are few general techniques for complex functions with no derivatives information and /or non linear forms. An optimization problem is defined as finding values of the variables that minimize or maximize the objective function while satisfying the constraints.

$$v = mf_{ck} + nd + o\rho + z$$

where f_{ck} = compressive strength
d = effective depth
ρ = percentage of steel
and m, n, o, z are constant
The optimization problem solved using Genetic Algorithm for curve fit is as given below

$$J = \sum_{i=1}^{n} \left(V_{pred\,.} - V_{db} \right)$$

$$m_{min} < m \leq m_{max}$$
$$n_{min} < n \leq n_{max}$$
$$o_{min} < o \leq o_{max}$$
$$z_{min} < z \leq z_{max}$$

These curve fit equations are obtained for different ranges of d and f_{ck}. In GA design, there must be a balance between the generation numbers and population size. Population size has another effect in GA. Population size reduces the effect of the highest fitness valued chromosomes. Evaluation of chromosomes and fitness calculations are the most time consuming parts of on GA. If the evaluation operation is reduced, GA process will work faster and this can be achieved by reducing the population size and number of generations needed to reach a solution. GAs mimic the survival of the fittest principle of nature to make a search process. Therefore, GAs are naturally suitable for solving maximization problems. Minimization problems are usually transformed to maximization problems by some suitable transformation.

V. FUZZY RULE

It is interesting to utilize the modified database with the increased number of samples to get further accuracy in shear strength prediction model. Over the period, there is progress in development of regression and empirical modeling techniques. Fuzzy logic is a powerful tool available for extracting precision information from the vague and slightly imprecise experimental data. Further the genetic algorithm can be combined get advanced logic model to extract the empirical formulas through huge database of the shear strength experiment. The process of development of empirical models using this algorithm will be initially started using subgroup of the database with closer cluster. Further, as the success will be achieved with smaller database finally fuzzy rules will be developed for complete database.
The genetic algorithm will be utilized to automatically extract the rules from the database based on the error minimization technique. Fuzzy set theory is used here to model the shear strength of slender beams without shear reinforcement as a complex engineering phenomenon that shall be modeled with some tolerance for imprecision/uncertainty. It was suggested that the use of fuzzy set theory allows accounting for probabilistically unqualified data as well as for vaguely understood failure modes .The modeling process starts by defining a number of fuzzy sets over the modeling domains and describing the complex phenomenon of interest using a fuzzy rule-base that relates a number of input parameters to the output parameter (shear strength) while considering uncertainty bounds in the input parameters.

The fuzzy rule-base replaces the classical simplified regression equations and is designed to describe all complex relationships between the system parameters . The fuzzy rules can be initiated arbitrarily and can then be modified by learning algorithms such that the fuzzy-based model prediction meets a pre-specified level of accuracy . One of the common challenges in establishing a fuzzy-based model of complex system is the choice of the input parameters that will be used to describe the phenomenon. In the current analysis, possible parameters included concrete compressive strength, effective depth of beams, span length, shear span to depth ratio, beam size, and compression and tension reinforcement ratios. The most significant parameters that affect the shear strength are: concrete compressive strength (f_{ck}), effective depth (d), and tension reinforcement ratio The in significance of the (a/d) ratio on shear strength of slender reinforced concrete beams with a/d > 2:5 . Here after, these three parameters were used as input parameters for the fuzzy based model for predicting the shear strength of slender beams without shear reinforcement. Other parameters that might be thought to be important such as the cracking/tensile strength of concrete was not included in the analysis due to its absence in the databases used to perform the analysis. However, it is also evident that these three parameters always represented the major criteria in shear modeling as proposed by many other researchers.

These include shear strength and cracking capacity conventionally represented by the cubical or square root of the compressive strength , size effect related to effective depth. The fuzzy-based model is established by first defining a number of fuzzy sets over the input parameter domains. The initial definition of the fuzzy sets is provided by using k-means clustering followed by automated update of the fuzzy sets during the learning process. The second step is establishing the fuzzy rule base which describes the relationship between the fuzzy sets defined over the input domains and the shear strength using a group of linear equations. An exemplar rule in the fuzzy rule-base can be defined as, If $f_{ck} \in A_f^k$, $d \in A_d^k$, and $\rho \in A_p^k$.

where, A_f^k , A_d^k and A_p^k are the K^{th} fuzzy set ($k = 1,2,3\ldots\ldots N_j$) defined on the fuzzy domains of compressive strength F_{ck} , effective depth d, and tension reinforcement ratio ϱ, respectively. N_j is the total number of fuzzy sets defined over the j^{th} input domain with T being the total number of input parameters.

$$v_i = m_i f_{ck} + n_i d + o_i \rho + z_i$$

Above equation represents the i^{th} rule in the fuzzy rule-base (i= 1,2,3,…R) with R being the total number of fuzzy rules in the knowledge rule-base m_i , n_i , p_i, and z_i are the consequent coefficients that define the output of the i^{th} rule in the fuzzy knowledge rule-base. Following data gives the fuzzy based models for rule fourteen.

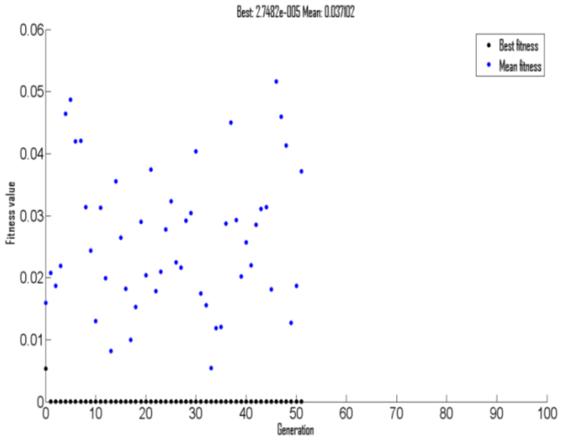

Fig.4 a) Training Curve

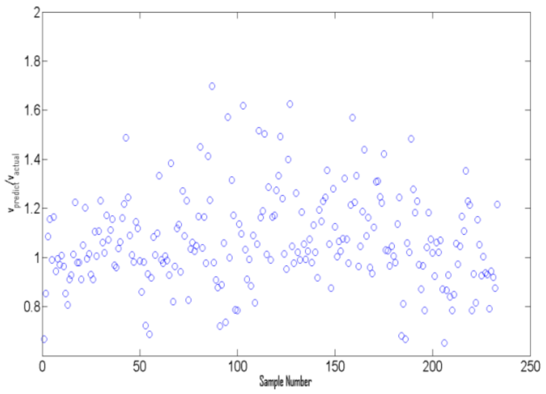

Fig.4 b) Performance Curve Fit

The figure 4 Shows the training curve along with curve fit performance for the fuzzy rule fourteen. The best value and mean value for error are 2.7482 $\times 10^{-5}$ and 0.037 respectively. The ratio of predicted and actual shear strength is 0.6 to 1.6 for 250 samples and few samples are nearer to it.

Fuzzy rule formation for rule 14

$v\,1 = -1.306fck + 1.012d + 0.7388p + 1.516$

$v\,2 = 1.895fck + 1.245d + 2.620p + 2.154$

$v\,3 = 1.742fck + 1.249d + 2.073p + 0.102$

$v\,4 = 0.744fck - 0.444d + 1.070p + 1.971$

$v\,5 = -0.714fck + 0.127d + 1.868p + -0.477$

$v\,6 = 1.044fck + 2.626d + 2.297p - 0.592$

$v\,7 = 1.167fck + 1.393d - 0.061p + 0.214$

$v\,8 = 0.538fck + 3.744d + -1.196p + 1.827$

$v\,9 = 1.630fck + 0.113d + 1.251p + 1.688$

$v\,10 = 0.783fck + 0.813d + 0.326p - 0.818$

$v\,11 = 0.702fck - 0.732d + 0.205p + 0.200$

$v\,12 = -0.979fck + 0.941d - 0.405p - 0.684$

$v\,13 = 0.370fck + 0.731d + 1.348p + 0.446$

$v\,14 = 1.195fck + -0.941d + 1.785p + 0.689$

The fuzzy rule-base that achieved the lowest root mean square error during learning was used for verification of the model capability to predict shear strength of concrete beams. It was found that optimal learning was achieved using two fuzzy sets to represent the compressive strength, two fuzzy sets to represent the tension reinforcement ratio and three fuzzy sets to represent the effective depth respectively.

VI. SHEAR DESIGN BY CODE

❖ ACI code Equation

According to ACI Building Code, the shear strength of concrete members without transverse reinforcement subjected to shear and flexure is given by following equation.

$$V = 0.167\sqrt{f'_c}$$

Where f_{ck} = compressive strength.

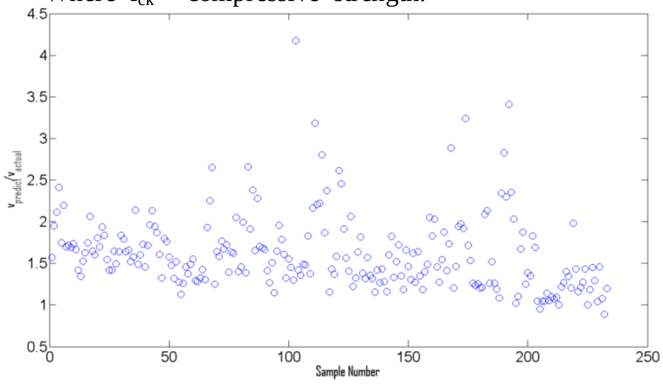

Fig 5.performance curve fit for ACI code Equation

Fig. 5 shows the performance curve fit for ACI code which gives the ratio of predicted and actual shear strength 1 to 2.5 by taking 250 samples.

❖ EC2 Building Code Equation

According to EC2 Building Code, the shear strength of concrete members without transverse reinforcement subjected to shear and flexure is given by following equation.

$v = 0.18K(100\rho f'c)^{1}$

where,

$K = 1 + \sqrt{200}/d$ ($K \leq 2$)

Fig. 6 shows the performance curve fit for EC2 building code which gives the ratio of predicted and actual shear strength 0.1 to 0.16 by taking 250 samples.

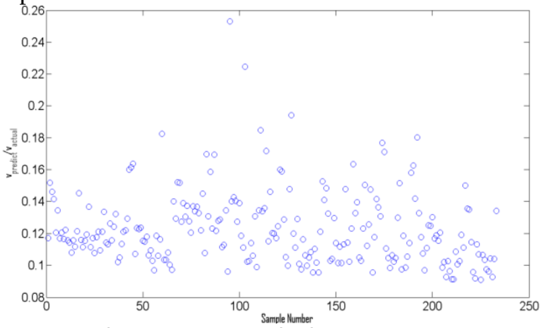

Fig 6 Performance curve fit for EC2 building code Equation

- **Indian Standard Building Code Equation**

According to Indian Standard Building Code, the shear strength of concrete members without transverse reinforcement subjected to shear and flexure is given by following equation.

$$\tau c = 0.85\sqrt{0.85f'c}\ \left(\frac{\sqrt{1+5\beta}-1}{6\beta}\right)$$

Where, $\beta = \frac{(0.8f'c)}{(6.89\rho)}$

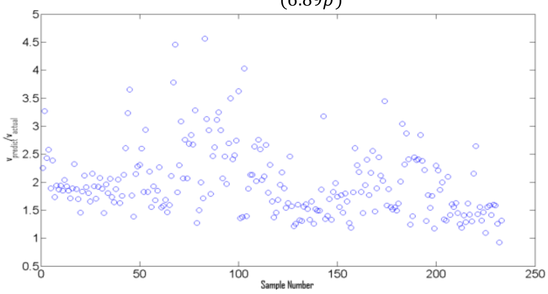

Fig 7 performance curve fit for Indian Standard Building Code Equation

Fig. 7 shows the performance curve fit for Indian Standard building code which gives the ratio of predicted and actual shear strength 1.5 to 2.5 by taking 250 samples.

- **Canadian Code Equation**

According to Canadian Standard , the shear strength of concrete members is given by following equation

$$V = 0.2\sqrt{f'_c}\ \ b\ d$$

The Canadian standard in Eq (2) has not considered the effect of shear span to depth ratio and longitudinal tension reinforcement effect on shear strength of concrete.

Fig. 8 shows the performance curve fit for Canadian building code which gives the ratio of predicted and actual shear strength 1.5 to 2.5 by taking 250 samples.

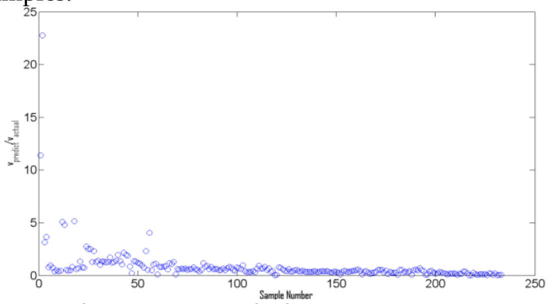

Fig 8 performance curve fit for candian curve equation

VII. RESULT

A new alternative method for predicting the shear strength of slender reinforced concrete beams without web reinforcement based on fuzzy set theory is proposed. The new model can accurately predict the shear strength of simply supported slender concrete beams (a/d > 2:5) without shear reinforcement. The learning and verification datasets cover a wide range of the material and geometric properties. The verification dataset was not used in the learning process. Investigations for developing a model with good accuracy showed that concrete compressive strength, effective depth, and tension reinforcement ratio are the primary parameters that dominate the shear behavior of slender concrete beams. This finding is limited to slender reinforced concrete beams without shear reinforcement with shear span to depth ratio (a=d) ranging between 2.6 and 9.0, effective depth (d) ranging between 60 mm and 2000 mm, and compressive strength ranging between 11 and 100 MPa. It is evident that the fuzzy-based model which considers random and information uncertainty in modeling shear of reinforced concrete beams can yield higher prediction accuracy compared with current design codes such as EC2, ACI, Canada and IS in predicting the shear strength of slender concrete beams without web reinforcement. The proposed model while addressing uncertainty and interactions between modeling parameters was shown to respect the fundamental mechanics of shear failure in reinforced concrete beams as described by many researchers.

VIII. CONCLUSION

The main aim of this effort is to establish a unique database for shear tests that are critically reviewed and selected under agreed criteria so that the manifold available formulae for the shear strength of member without shear reinforcement can be checked against these all data. To demonstrate the potential of such a unique database for comparison with many prediction of the shear strength of member without shear reinforcement. By training and performance of curve fit. The ratio of $V_{act.}/ V_{pred.}$ was calculated. A genetic programming , algorithm valid for adjustment as well as fuzzy rule for the shear formulation for element without shear reinforcement .

An experimental model to predict the shear strength of RC deep beams has been obtained by genetic programming . experimental result are used to build and validate the model, Good agreement between the model prediction's and experiments has been achieved. As per more experimental results and knowledge of the shear behavior of deep beams becomes available the Genetic programming prediction could be used. The future activities comprise the comparisons of the tests of this ESDB (Evaluation shear database) with other imperial formulae and extend the database to pre- stressed members as well as to reinforced concrete beams.

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