GAZİANTEP UNIVERSITY GRADUATE
SCHOOL OF NATURAL & APPLIED SCIENCES

SOFT COMPUTING MODELING OF RC BEAMS WITHOUT WEB REINFORCEMENT

M. Sc.THESIS
IN
CIVIL ENGINEERING

BY
ŞEFİK ÖZTÜRK
JULY 2008

Soft Computing Modeling of RC beams without web reinforcement

M.Sc.Thesis
in
Civil Engineering
University of Gaziantep

Supervisor
Assist. Prof. Dr. Abdulkadir ÇEVİK

by

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Prof. Dr. Ramazan KOÇ
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science/Doctor of Philosophy.

Assoc. Prof. Dr. Mustafa GÜNAL
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science/Doctor of Philosophy.

Assist Prof. Dr. Abdulkadir ÇEVİK
Supervisor

Examining Committee Members

Prof. Dr. Mustafa ÖZAKÇA ________________________

Prof. Dr. İbrahim GÜZELBEY ________________________

Assoc. Prof. Dr. Mustafa GÜNAL ________________________

Assist. Prof. Dr. Abdülkadir ÇEVİK ________________________

Assist Prof. Dr. Ahmet ERKLİĞ ________________________

ABSTRACT

Soft Computing Modeling of RC beams without web reinforcement

ÖZTÜRK, Şefik
M.Sc. in Civil Engineering
Supervisor: Assist. Prof. Dr. Abdulkadir ÇEVİK
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In this thesis, the availability of soft computing (SC) techniques (Neural Networks (NN), genetic programming (GP) and Neuro-Fuzzy (NF) for the prediction and formulation of shear strength of reinforced concrete (RC) beams without web reinforcement was investigated. Previous soft computing applications on shear strength of RC beams without web reinforcement have been surveyed firstly. It has been found that neural networks and genetic programming has been applied to modeling of shear strength of RC beams. Therefore the scope of the thesis is focused on neuro-fuzzy modeling which has not been studied so far. Literature survey on previous experimental studies has also been carried out regarding shear strength of RC beams without web reinforcement and a wide range of experimental database (664 tests) has been gathered from literature from 56 separate studies. The proposed neuro-fuzzy model is based on this wide range of experimental database. Various types of membership functions (MF) such as Gaussian, Gaussian combination, Generalized bell-shaped, Triangular-shaped and Trapezoidal-shaped membership functions are evaluated for varying number of membership functions to obtain the optimum NF model. The accuracy of the proposed NF model is compared with accuracies of current design codes and existing shear strength equations and found to be more accurate.

Key Words: RC beams, shear strength, Soft Computing, Neuro-Fuzzy, Modeling

ÖZET

ETRİYESİZ BETONARME KİRİŞLERİN ESNEK HESAPLAMA İLE MODELLENMESİ

ÖZTÜRK, Şefik
Yüksek Lisans Tezi, İnşaat Mühendisliği Bölümü
Tez Yöneticisi: Assist. Prof. Dr. Abdulkadir ÇEVİK
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Bu tezde etriyesiz betonarme kirişlerin kesme dayanımının esnek hesaplama teknikleri ile tahmini ve formulasyonu imkanı araştırılmıştır. Öncelikle, Etriyesiz betonarme kirişlerin kesme dayanımının esnek hesaplama teknikleri ile yapılan uygulamalara ilişkin literatür taraması yapılmış ve Yapay Sinir ağları ile genetik programlama tekniklerinin daha önce bu konuda uygulandığı görülmüştür. Bundan dolayı tezin kapsamı daha önce bu konuda çalışılmamış Bulanık sinir ağları üzerinde odaklanmıştır. Etriyesiz betonarme kirişlerin kesme dayanımıyla ilgili daha önce yapılan deneysel çalışmalara ilişkin literatür taraması yapılmış ve 56 farklı çalışmaya ait toplam çok geniş aralıklı bir deneysel veritabanı (664 deney) toplanmıştır. Önerile Bulanık sinir ağ modeli bu deneysel veritabanına dayanmaktadır. Optimum Bulanık sinir ağ modelini bulmak için farklı üyelik fonksiyonları (Gaussian, Gaussian kombinasyonu, Genel zil şekli, Üçgen ve Yamuk) değişen üyelik fonksiyonları sayıları ile değerlendirilmiştir. Daha sonra önerilen bulanık sinir ağ modeli mevcut tasarım kodları ve kesme dayanımı denklemleri ile karşılaştırılmış ve daha doğru olduğu görülmüştür.

Anahtar Kelimeler:Betonarme kirişler, kesme dayanımı, esnek hesaplama, bulanık sinir ağları, modelleme.

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LIST OF SYMBOLS

a/d	shear span to depth ratio
b_w	web width
d	effective depth
f_c	concrete compressive strength
ρ_l	longitudinal reinforcement ratio
fy	yield strength of steel

LIST OF ABBREVIATION

RC	Reinforced Concrete
SC	Soft Computing
NN	Neural Networks
GP	Genetic programming
GA	Genetic algorithm
MFs	Membership Functions
ANFIS	Adaptive Neuro Fuzzy Inference System
FIS	Fuzzy Inference System
GUI	Graphical User Interface
FIS	Fuzzy Inference System
COV	Coefficient of Variation

CHAPTER I

INTRODUCTION

1.1 General Information

The shear strength of RC beams without web reinforcement has been an important phenomenon in structural engineering and tremendous amount of research has been performed throughout the 20th century. Thus the knowledge of shear behavior and its failure mechanism has improved significantly. However, the subject still needs further study due to the complexity of the shear transfer mechanism and affecting parameters. For reinforced concrete beams without shear reinforcement, the provisions for shear design in current codes are based on empirical equations, due to the complex mechanism of shear transfer, various failure types and interdependent internal forces in beams. The use of these empirical equations to predict the shear strength is not satisfactory. Thus several models based on rational approach are proposed (Peng, 1999, Cevik & Öztürk, 2008).

1.2 Principle Objectives

This thesis aims to investigate the feasibility of soft computing techniques as an alternative tool for the empirical modeling for shear strength of RC beams without web web reinforcement. The study will be based on existing experimental studies available in the literature. Therefore an extensive literature survey on experimental studies will be performed. Among a wide range of soft computing (SC) techniques, Neural Networks, Genetic programming and Neuro-fuzzy approaches will be investigated. The general behavior of the proposed SC models will also be studied by means of a wide range of parametric studies. The accuracy of SC models will be evaluated with existing design codes and equations.

1.3 Layout of Thesis

The contents of each chapter are expressed as:

- Chapter 2 contains literature survey about Shear Strength of RC Beams without stirrups
- Chapter 3 includes overview of soft computing concept and soft main computing techniques that will be used in the thesis. Optimization process, definition of elements and design variables, structural optimization flowchart are presented
- Chapter 4 presents numerical application with results of proposed SC model, comparison with existing design codes and a wide range of parametric study.
- Chapter 5, emphasizes conclusions based on the findings of the thesis are and suggestions for future work.

CHAPTER II

LITERATURE SURVEY

2.1 Shear Strength of RC Beams without stirrups

The design of RC beam is in general based on axial load, bending moment, and shear actions. Among these actions, RC members' response to axial load and bending moment is well understood which is not the case for shear failure mechanism of RC members. For example shear failure mechanisms in RC beams without stirrups are quite complex and difficult to model analytically due to the complex stress redistributions that occur after cracking which are influenced by various components. This difficulty has led to extensive amount of experimental studies in this field which has been followed by numerous empirical formulations proposed by many researchers based on these experimental studies. Main Factors affecting shear strength of RC beams without stirrups can be summarized as (Kim, 2004): Concrete strength, size effect, shear span to depth ratio (a/d) and longitudinal reinforcement Ratio. To discuss this behavior, a simply supported beam with a rectangular cross-section, loaded by two symmetrically placed loads will be considered, Figure 2.1(a). The distance from the load to the reaction is called "shear span" and is designated as "a". About 30 years ago, researchers have observed that the dimension less shear span or a/d influenced the behavior and strength of reinforced concrete beams significantly. Therefore, the beam behavior will be discussed in relation to a/d (Cevik & Öztürk, 2008, Ersoy, 2000).

Kani (1964) conducted a very large experimental study on shear and reported relationships between the beam capacity and the a/*d* ratio. "Kani's Valley of Shear Failures" is presented in Figure 2.1 by McGregor (1988). Kani tested a large number of rectangular beams without shear reinforcement and having various a/*d ratios*, while the rest of the beam details remained the same, as shown in Figure 2.1(a). Then, the moment and shear at inclined cracking and failure were observed as presented in Figure 2.1(b). In the figure, the flexural capacity, M_n, is the horizontal line while the shaded area represents the reduction of strength due to shear. From this figure, beams can be classified into four groups by *a/d ratios*: very short, short, slender, and very slender beams. Figure 2.1(c) can be obtained by dividing the moment in Figure 2.1(b) by the shear span, "a", as the moment is $M = V xa$ for beams with two point loads. Kani also tested beams subjected to uniformly distributed load and used the *a/d* ratio as a quarter of the span length, i.e. *l*/4.

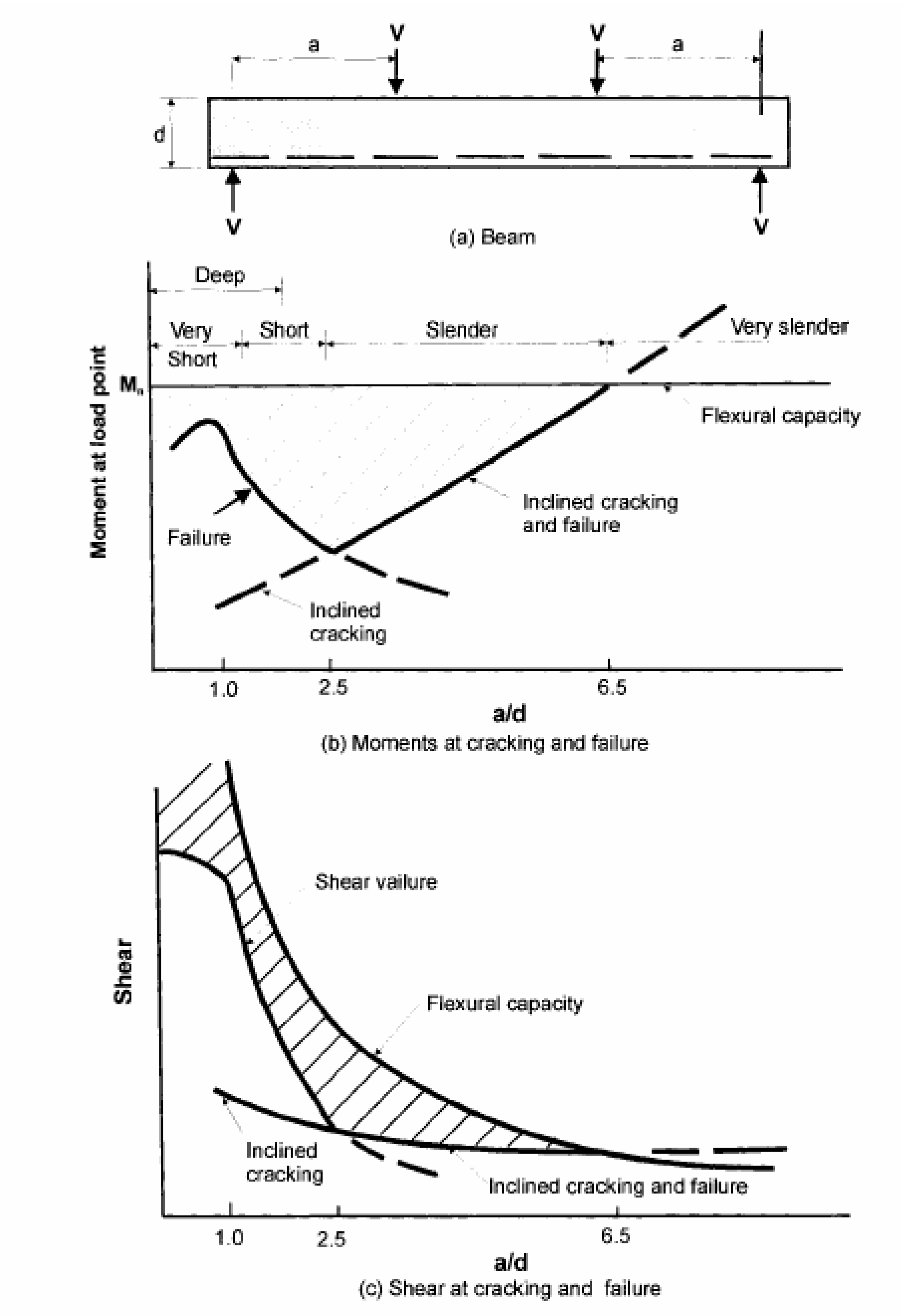


Figure 2.1 Effect of a/d on shear strength of beams without stirrups (McGregor, 1988)

The ASCE-ACI Committee 426 in 1973 has classified failure modes of simply supported rectangular beams without shear reinforcement based on a/d ratios given as follows (Kim, 2004):

i) Failure Mode I (a/d >6) which is the case of very slender beams where RC beams tend to fail in flexure even before the formation of inclined cracks.

ii) Failure Mode II (2.5<a/ d <6) which is the case of slender beams where some of the flexural cracks grow and may become flexure-shear cracks. The diagonal cracks may continue to propagate toward the top and bottom of the beam and cause yield of the tension steel. The beam may split into two pieces at failure. This is called as diagonal tension failure (Figure 2.2).

iii) Failure Mode III (a/d <2.5) which is the case in short beams where a diagonal crack may propagate along the tension steel causing splitting between the concrete and the longitudinal bars(Figure 2.3 (a)) which is called a shear-tension failure. The case where the diagonal crack results in crushing of the compression zone is called a shear-compression failure (Figure 2.3 (b))

iv) Failure Mode IV (a/d <1) which is the case in very short beams where following failure types can be observed: Anchorage failure of tension steel, Bearing failure, Flexural failure, Tension failure of “arch-rib and Compression strut failure (Figure 2.4) (Cevik & Öztürk, 2008).

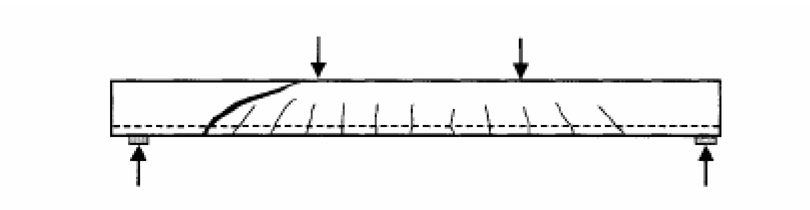


Figure 2.2 Diagonal Tension failure (ASCE-ACI 426, 1973)

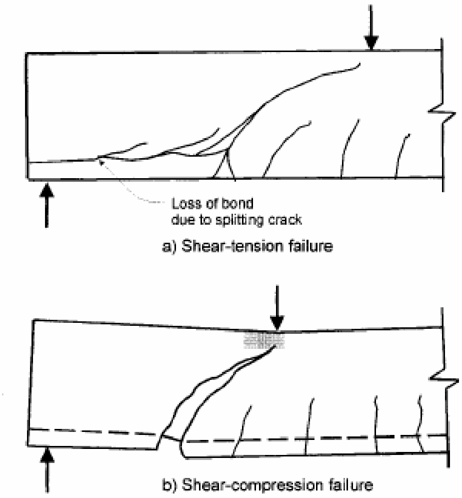


Figure 2.3 Modes of shear failures in short Beams (ASCE-ACI 426, 1973)

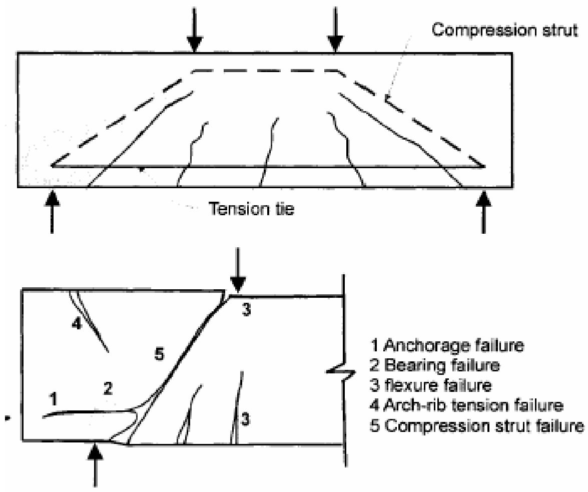


Figure 2.4 Modes of shear failures in deep Beams (ASCE-ACI 426, 1973)

2.2 Experimental studies

In this study an extensive literature survey on experimental studies related to shear strength of RC beams without web reinforcement has been carried out and an experimental database has been constructed. A total of 664 tests from 56 separate studies were included in the database with ranges of variables as shown in details in Table 2.1.

Table 2.1 Experimental Database and Range of Variables

Researcher	N*	d (mm)	bw (mm)	a/d	fc (Mpa)	fy (Mpa)	ρ_l (%)
Adebar & Collins (1996)	6	178 to 277	290 to 360	2.9 to 4.5	46.2 to 58.9	484 to 536	1 to 3.04
Ahmad & Lue (1987)	16	184 to 208	127	2.7 to 4	60.8 to 67	413.6	1.8 to 6.7
Ahmad et al. (1994)	2	215.9	127	3	40.3 to 89.1	420.5	1.04 to 2.07
Ahmad et al. (1995)	4	178	102.1	3.7	42.8 to 79.3	413	1.39
Ahmad et al. (1986)	18	184.1 to 208	127	2.7 to 4	63.3 to 68.6	413.6	1.77 to 6.64
Al-Alussi (1957)	21	127	76.2	2.5 to 7.4	25.1 to 31.7	365.4	1.47 to 4.09
Angelakos et al. (2001)	7	895 to 925	300	2.92 to 3.02	21 to 79.9	550.1	0.5 to 2.09
Aster & Koch (1974)	9	249.9 to 750	1000	3.65 to 5.50	19.9 to 31.1	535 to 553.6	0.42 to 0.91
Bazant & Kazemi (1991)	21	40.6 to 330.2	38.1	3	46.1 to 46.8	792.8	1.62 to 1.65
Bhal (1968)	8	300 to 1200	240.1	3	23.2 to 29.6	430.2 to 433.7	0.63 to 1.26
Bresler & Scordelis (1963)	3	461 to 466	305 to 310	3.8 to 6.8	22.6 to 37.6	551.5 to 555	1.8 to 2.73

Cederwall,et al. (1974)	1	260	135	3.08	29.6	882.4	0.97
Chana (1981)	3	356.1	203	3	32.8 to 38.9	477.8	1.74
Chang & Kesler (1958)	24	136.7	10.2	2.6 to 4.1	14.9 to 36.6	327.5	1.86 to 2.89
Collins & Kuchma (1999)	36	110 to 930.1	168.9 to 300	2.5 to 3	36 to 98.7	475 to 650	0.5 to 1.44
Cossio & Siess (1960)	7	254	151.9 to 152.4	3 to 6	19.4 to 31.5	319.9 to 459.1	0.98 to 3.33
Elzanaty et al. (1986)	13	273	177.8	4 to 6	20.7 to 79.2	434.3	0.6 to 3.3
Feldman & Siess (1955)	8	252.5	152.4	3.02 to 6.04	21.5 to 36.7	282.7 to 331	3.35
Ferguson & Thompson (1953)	24	114.3 to 209.6	101.6 to 177.8	3.4 to 6.22	17.5 to 45.3	275.8	2.5 to 4.8
Ferguson (1956)	1	189	100.9	3.23	29.3	310.2	2.1
Grimm (1997)	12	160 to 746	300	3.53 to 3.9	90 to 110.8	468.8 to 659.8	0.94 to 4.22
Hallgren (1994)	19	191 to 199	155 to 163	3.57 to 3.66	31 to 86.2	442.6 to 650.8	2.17 to 4.1
Hallgren (1996)	3	208 to 211	261.9 to 337	2.61 to 2.64	85 to 92.4	604 to 631.5	0.57 to 1.05
Hamadi & Regan (1980)	4	370 to 373.9	100	3.42 to 5.97	22.3 to 30.3	400 to 800	0.6 to 1.7
Hanson (1958)	21	266.7	152.4	2.48	20.6 to 73.6	333	2.5 to 5

Hanson (1961)	49	266.7	152.4	4.95	20.5 to 58	326 to 636	1.27 to 2.54
Islam et al. (1998)	19	203 to 207	150	2.9 to 3.94	26.6 to 83.2	319.9 to 553.6	2.02 to 3.22
Johnson & Ramirez (1989)	1	538.7	304.8	3.1	56.6	524.6	2.49
Kani (1967)	41	132 to 1097.2	152.1 to 612.1	2.41 to 8.03	20.3 to 30.7	335 to 391.6	2.59 to 2.87
Kim & Park (1994)	16	142 to 915	170 to 300	3 to 4.5	53.7	477	1.01 to 4.68
Krefeld & Thurston (1966)	64	237.8 to 482.6	152.4 to 254	2.9 to 9.6	11.2 to 38.4	365.4 to 393.6	1.31 to 5.08
Kulkarni & Shah (1998)	4	151.9	102	3.5 to 5	41.9 to 45	517.7	1.37
Küng (1985)	5	200	140	2.5	18.9 to 20.1	491.5	0.56 to 1.82
Lambotte & Taerwe (1990)	6	415	200	3.01	34 to 81.6	524	0.48 to 1.45
Laupa et al (1953)	9	261.9 to 272.3	152.4	4.48 to 4.81	14.8 to 32.3	284 to 409.5	0.93 to 4.11
Leonhardt & Walther (1962)	27	140 to 600	100	2.46 to 6	12.6 to 38.3	413 to 490	0.91 to 2.07
Marti et al. (1977)	1	162	400	3.95	29.6	541.2	1.38
Mathey & Watstein (1963)	9	402.8	203.2	2.84 to 3. 8	23.5 to 30.5	505.3 to 704.6	0.47 to 2.54
Moayer & Regan (1974)	1	279.4	150	3.55	44	641	1.92

Moody et al (1954)	28	261.6 to 274.3	152.4 to 177.8	2.92 to 3.41	6 to 41.2	302 to 310.2	0.8
Morrow & Viest (1957)	13	355.6 to 374.7	304.8 to 308.1	2.76 to 7.86	14.7 to 45.7	329.5 to 470.9	0.58 to 3.83
Mphonde & Frantz (1984)	14	298.5	152.4	2.5 to 3.6	22.4 to 101.8	413.7	2.32 to 3.36
Niwa et al. (1987)	3	1000 to 2000	300 to 600	3	24.6 to 27.1	1000	0.14 to 0.28
Rajagopalan & Ferguson (1968)	10	259.1 to 268	150.9 to 153.9	3.83 to 4.27	23.7 to 36.6	524 to 1778.6	0.25 to 1.73
Reineck et al. (1978)	3	225 to 226	500.1	2.5 to 3.5	24.6 to 25.8	440.5 to 500.5	0.79 to 1.39
Remmel (1991)	4	161.5 to 165.1	150.1	3.06 to 4	84.4 to 85	473.6 to 522.6	1.87 to 4.09
Ruesch et al (1962)	3	111 to 261.9	90 to 180	3.6 to 3.62	23 to 24.1	406.8 to 480.5	2.65
Salandra & Ahmad (1989)	4	171.5	101.6	2.59 to 3.63	52 to 69.4	413.6	1.45
Scholz (1994)	3	362 to 372.1	200	3 to 4	80.5 to 96.7	499.8	0.81 to 1.94
Taylor (1968)	7	369.8	203.2	2.47 to 3.02	28.8 to 33.2	350.2	1.03 to 1.55
Taylor (1972)	5	465 to 929.9	200 to 400	3	20.9to 27	420	1.35
Thorenfeldt (1990)	16	207to 442	150 to 300	3 to 4	54 to 97.7	450	1.82 to 3.23
Walraven (1978)	2	420.1 to 720	200	3	24.1 to 24.4	440	0.74 to 0.79

Xie et al (1994)	2	215.9	127	3	37. to 99	420.5	2.07
Yoon et al. (1996)	3	655	375	3.23	36 to 87	400	2.8
Yoshida (2000)	1	1890	300	2.86	33.6	455	0.74

N*: Number of test specimen

2.3 Soft Computing

The concept of soft computing -- which was introduced by Lotfi Zadeh in 1991 -- serves to highlight the emergence of computing methodologies in which the accent is on exploiting the tolerance for imprecision and uncertainty to achieve tractability, robustness and low solution cost. At this juncture, the principal constituents of soft computing are fuzzy logic, neurocomputing, evolutionary computing and probabilistic computing, with the later subsuming belief networks, chaotic systems and parts of learning theory. What is particularly important about soft computing is that it facilitates the use of fuzzy logic, neurocomputing, evolutionary computing and probabilistic computing in combination, leading to the concept of hybrid intelligent systems. Such systems are rapidly growing in importance and visibility (http://www.cs.berkeley.edu/~zadeh/acprco.html, Cevik et al., 2008).

Soft computing is an antithesis of hard computing: it provides algorithms that are able to value, to reason and to discriminate, rather than just to 'calculate'; these new structures of calculation arc based on logic with more values and inspired by natural processes like selection, aggregation and co-operation. The basic principle of soft computing is its combined use of these new computation techniques that allow u to achieve a higher tolerance level towards imprecision and approximation. The principal constituents of Soft Computing are Fuzzy Logic , Neural Computing , Evolutionary Computation, Machine Learning, Probabilistic Reasoning and chaos heory (Caponetto et al, 2001, Cevik et al., 2008).

2.4 Neural Networks

Neural networks are adaptive statistical models based on an analogy with the structure of the brain. They are adoptive in that they can learn to estimate the parameters of some population using a small number of exemplars (one or a few) at a time. They do not differ essentially from standard statistical models. Neural networks are used as statistical tools in a variety of fields in engineering (Abdi et al, 1998, Cevik et al., 2008).

Neural networks are quantitative models linking inputs and outputs adaptively in a teaming process analogous to that used by the human brain. The networks consist of elementary units, labeled neurons, joined by a set of rules and weights. The units code characteristics, and they appear in layers, the first being the input layer and the last being the output layer. The data under analysis are processed through different layers, with learning taking place through alteration of the weights connecting the units. At the final iteration, the association between the input and output patterns is established (Abdi et al, 1998, Cevik et al., 2008).

Figure 2.5 shows the structure of an abstract neuron with n inputs. The *primitive function f* computed in the body of the abstract neuron can be selected arbitrarily. Usually the input channels have an associated weight, which means that the incoming information which is the summation of inputs with corresponding weights and biases added is transformed by a transfer function. If we conceive of each node in an artificial neural network as a primitive function capable of transforming its input in a precisely defined output, then artificial neural networks are nothing but *artworks of primitive functions.* Different models of artificial neural networks differ mainly in the assumptions about the primitive functions used, the interconnection pattern, and the timing of the transmission of information (Rojas, 1996, Cevik et al., 2008).

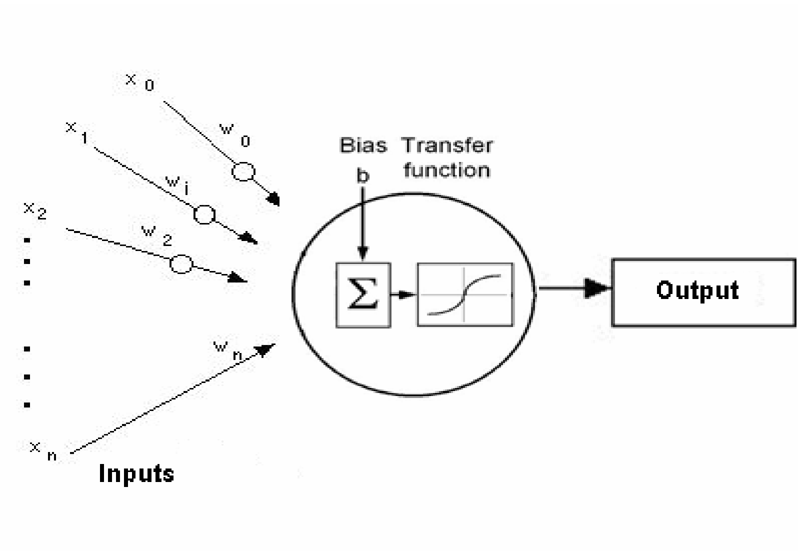


Figure 2.5. Artificial Neuron Model

2.5 Genetic Programming

Genetic algorithm (GA) is an optimization and search technique based on the principles of genetics and natural selection. A GA allows a population composed of many individuals to evolve under specified selection rules to a state that maximizes the "fitness" (i.e., minimizes the cost function). The method was developed by John Holland (Holland, 1975) and finally popularized by one of his students, David Goldberg (Goldberg, 1989), solved a difficult problem involving the control of gas-pipeline transmission for his dissertation (Haupt, 2004). The fitness of each individual in a genetic algorithm is the measure the individual has been adapted to the problem that is solved employing this individual. It means that fitness is the measure of optimality of the solution offered, as represented by an individual from the genetic algorithm. The basis of genetic algorithms is the selection of individuals in accordance with their fitness; thus, fitness is obviously a critical criterion for optimization (Chambers, 2001, Cevik, 2007).

Genetic programming (GP) is an extension to Genetic Algorithms proposed by Koza (Koza, 1992). Koza defines GP as a domain-independent problem-solving approach in which computer programs are evolved to solve, or approximately solve, problems based on the Darwinian principle of reproduction and survival of the fittest and analogs of naturally occurring genetic operations such as *crossover* (*sexual recombination*) and *mutation.* GP reproduces computer programs to solve problems by executing the following steps (Figure 2.6, Cevik, 2007):

1) Generate an initial population of random compositions of the functions and terminals of the problem (computer programs).

2) Execute each program in the population and assign it a fitness value according to how well it solves the problem.

3) Create a new population of computer programs.

i) Copy the best existing programs (Reproduction)

ii) Create new computer programs by mutation.

iii) Create new computer programs by crossover (sexual reproduction).

iv) Select an architecture-altering operation from the programs stored so far.

4) The best computer program that appeared in any generation, the best-so-far solution, is designated as the result of genetic programming (Koza, 1992, Cevik, 2007)

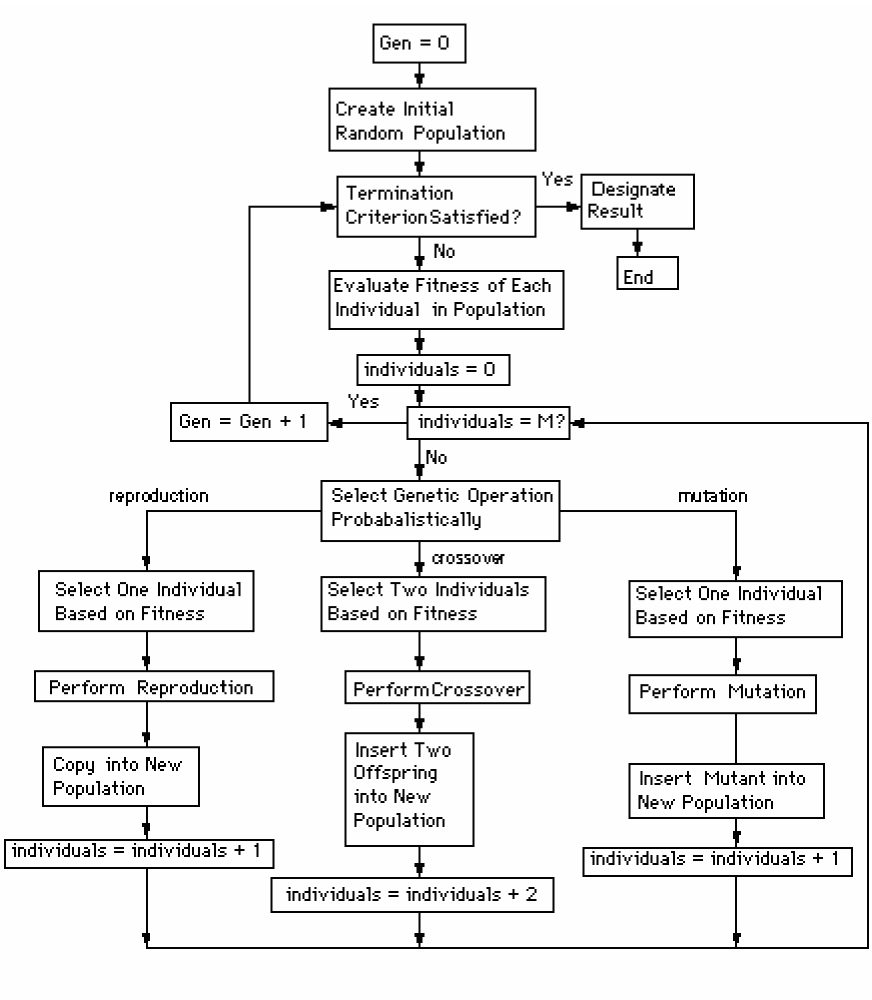


Figure 2.6 Genetic Programming Flowchart (Koza, 1992)

2.6 Neuro-Fuzzy Approach

The idea of fuzzy logic was invented by Professor L. A. Zadeh of the University of California at Berkeley in 1965 (Zadeh, 1965). This invention was not well recognized until Dr. E. H. Mamdani, who is a professor at London University, applied the fuzzy logic in a practical application to control an automatic steam engine in 1974, which is almost ten years after the fuzzy theory was invented. Then, in 1976, Blue Circle Cement and SIRA in Denmark developed an industrial application to control cement kilns. That system began to operation in 1982. More and more fuzzy implementations have been reported since the 1980s, including those applications in industrial manufacturing, automatic control, automobile production, banks, hospitals, libraries and academic education. Fuzzy logic techniques have been widely applied in all aspects in today's society (Bai et al, 2006, Cevik & Ozturk, 2008)

To implement fuzzy logic technique to a real application requires the following three steps:

1. Fuzzification – convert classical data or crisp data into fuzzy data or Membership Functions (MFs)

2. Fuzzy Inference Process – combine membership functions with the control rules to derive the fuzzy output

3. Defuzzification – use different methods to calculate each associated output and put them into a table: the lookup table. Pick up the output from the lookup table based on the current input during an application (Bai et al, 2006, Cevik & Ozturk, 2008).

Rules form the basis for the fuzzy logic to obtain the fuzzy output. The rule based system is different from the expert system in the manner that the rules comprising the rule-based system originate from sources other than that of human experts and hence are different from expert systems. The rule-based form uses linguistic variables as its antecedents and consequents. The antecedents express an inference or the inequality, which should be satisfied. The consequents are those, which we can infer, and is the output if the antecedent inequality is satisfied. The fuzzy rule-based system uses IF–THEN rule-based system, given by, IF antecedent, THEN consequent (Sivanandam, 2007, Cevik & Ozturk, 2008).

The operations in FL are performed in terms of fuzzy sets. In practice, the input data may also be in terms of fuzzy sets or a singleton (single element with a membership value of unity), which is infect a special type of fuzzy set. The input data needs to be assigned membership values of one or more fuzzy sets into which the UD has been partitioned. The membership values are found from the intersections of the data sets with the fuzzy sets of the UD. Figure 2.7 illustrates the graphical method of finding membership values in the case of a singleton (Figure 2.7(a)), and the more general fuzzy input (Figure 2.7(b)). For the singleton in Figure 2.7(a), there are two intercepts, i.e., at a and b, which determine the membership values. Whilst for the fuzzy input in Figure 2.7(b) there are four intercepts at c, d, e and f which determine the membership values (Haris, 2006, Cevik & Ozturk, 2008).

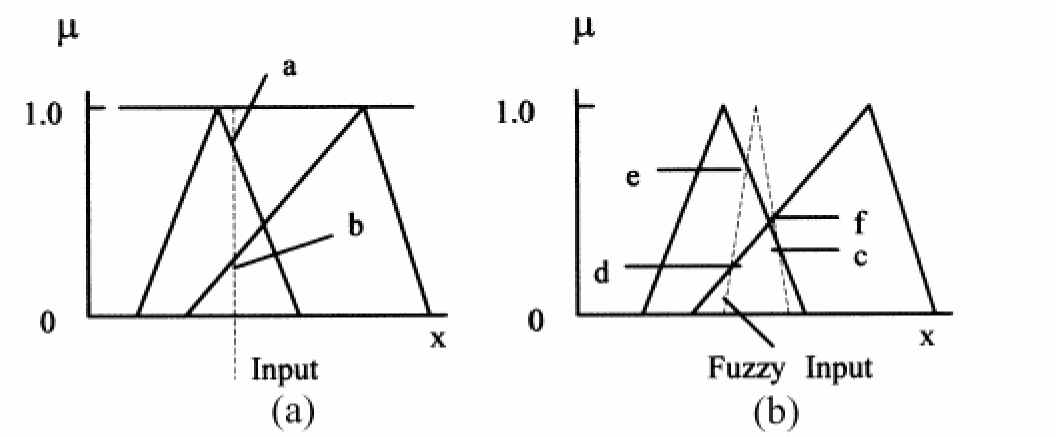


Figure 2.7 Input data Membership Values a) singleton b) More general fuzzy input (Haris, 2006)

Fuzzy systems can be combined with neural Networks to form neuro-fuzzy systems which exhibit advantages of neural networks and fuzzy systems. They combine the natural language description of fuzzy systems and the learning properties of neural networks. In literature, various neuro fuzzy systems have been developed that are known in literature under short names such as ANFIS which will be the scope of this thesis, ANNBFIS, DENFIS, NEFCLASS, and others. The most popular designs of neuro-fuzzy structures fall into one of the following categories, depending on the connective between the antecedent and the consequent in fuzzy rules (Rutkowski, 2004, Cevik & Ozturk, 2008):

- Takagi-Sugeno method – consequents are functions of inputs,
- Mamdani-type reasoning method – consequents and antecedents are related by the min operator or generally by a t-norm,
- Logical-type reasoning method - consequents and antecedents are related by fuzzy implications, e.g. binary,

A notable contribution of Neuro-Fuzzy and Soft Computing, is the exposition of ANFIS (Adaptive Neuro Fuzzy Inference System) — a system developed by the authors which is finding numerous applications in a variety of fields. Thus, neuro-fuzzy and soft computing, with their ability to incorporate human knowledge and to adapt their knowledge base via new optimization techniques, are likely to play increasingly important roles in the conception and design of hybrid intelligent systems. The quintessence of designing intelligent systems of this kind is neuro-fuzzy computing: neural networks that recognize patterns and adapt themselves to cope with changing environments; fuzzy inference systems that incorporate human knowledge and perform inference and decision making. The integration of these two complementary approaches, together with certain derivative-free optimization techniques, results in a novel discipline called neuro-fuzzy and soft computing.Thus, we incorporate neural network learning concepts in fuzzy inference systems, resulting in neuro-fuzzy modeling, a pivotal technique in soft computing. Neuro-fuzzy models allow prior knowledge to be embedded via fuzzy rules with appropriate linguistic labels, and they offer the possibility of understanding the resultant models after learning. On the other hand, black-box neural networks, particularly back propagation multilayer perceptions, do not have the same level of ability to do knowledge embedding and extraction (Jang, 1997, Cevik & Ozturk, 2008).

In this study the Sugeno FIS is used where each rule is defined as a linear combination of input variables. The corresponding final output of the fuzzy model is simply the weighted average of each rule's output. A Sugeno FIS consisting of two input variables *x and y,* for example, a one output variable *f* will lead to two fuzzy rules (Cevik & Öztürk, 2008):

Rule 1: If x is A_1, y is B_1 then $f_1 = p_1x + q_1y + r_1$

Rule 2: If x is A_2, y is B_2 then $f_2 = p_2x + q_2y + r_2$

where p_i, q_i, and r_i are the consequent parameters of i_{th} rule. A_i, B_i and C_i are the linguistic labels which are represented by fuzzy sets shown in Figure 2.8.

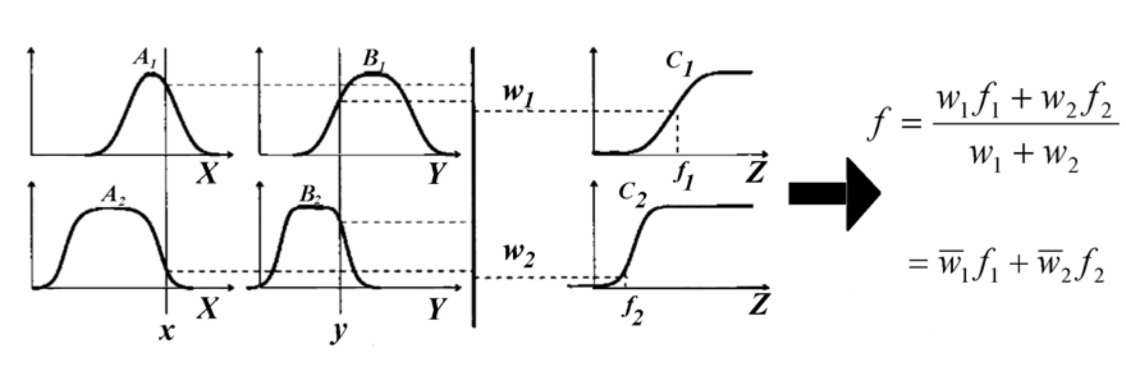


Figure 2.8. The Sugeno fuzzy model (Jang et al, 1997).

2.7 Soft Computing Applications of Shear Strength of RC beams

Although NNs have been widely applied to the prediction of shear strength of RC beams (Seleemah (2005), Adhikary (2004), Cladera (2004a, 2004b), Mansour (2004), Oreta (2004), Sanad (2001)), there is very limited research on GP applications for the prediction of shear strength of RC beams (Ashour, 2003). Fuzzy

Approach has no been applied to shear strength of RC beams so far which is the scope of this thesis.

CHAPTER III

NEURO-FUZZY MODELING OF RC BEAMS WITOUT STIRRUPS

3.1 Introduction

Modeling of Shear strength behavior of RC beams without stirrups has been the subject of a huge number of experimental and theoretical studies so far. Classical regression techniques have been widely used in general for modeling. On the other hand, there have been a few other attempts rather than classical regression techniques such as neural networks and genetic programming often called as soft computing approaches. However, fuzzy logic which is a robust branch of soft computing approaches has not been used for modeling of shear strength behavior of RC beams without stirrups in the literature so far. This thesis aims to investigate the availability Fuzzy logic in this field.

3.2 Problem Definition

The first step in soft computing modeling is the collection of experimental of numerical database on which the proposed soft computing model will be constructed. To achieve generalization capability, approximately % 80 of the whole dataset is used for training where the rest-% 20 is used for verification after the model has been constructed. Therefore an extensive literature survey has been carried out to collect all experimental studies regarding the shear strength behavior of RC beams without stirrups. A typical experimental set up used in the evaluation of shear strength behavior of RC beams without stirrups is given in Figure 3.1

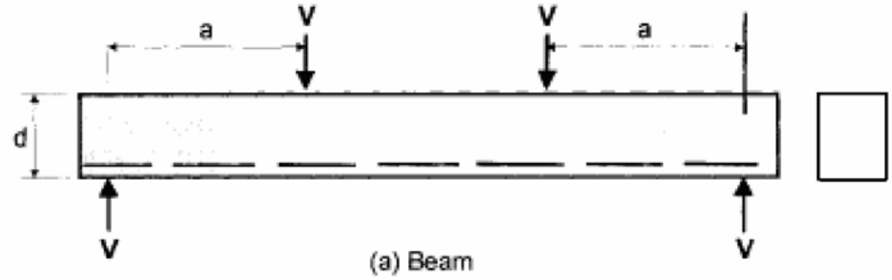


Figure 3.1 Typical experimental set up for shear strength of RC beams without stirrups.

The second step in SC studies is the determination of inputs and corresponding output to be modeled. In this thesis the inputs considered are shown in Figure 3.1 which are geometric (d, a/d) and material (concrete strength and longitudinal reinforcement) properties where the output will obviously be shear strength.

After these common steps, the soft computing technique to be used is selected which is neuro-fuzzy approach in this thesis. Another important topic is obviously the selection software that will be used for soft computing computations which MATLAB fuzzy logic toolbox in this thesis.

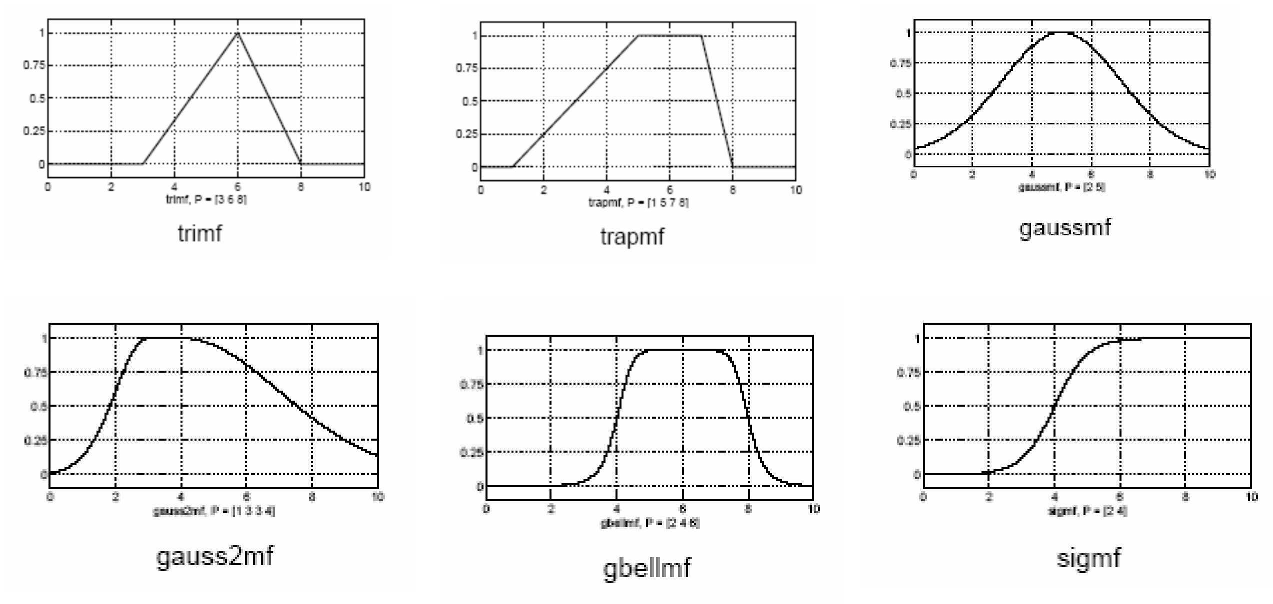
3.3 MATLAB Fuzzy Logic Toolbox

Fuzzy Logic Toolbox software is a collection of functions built on the MATLAB® technical computing environment. It provides tools for you to create and edit fuzzy inference systems within the framework of MATLAB. What makes the toolbox so powerful is the fact that most of human reasoning and concept formation is linked to the use of fuzzy rules. By providing a systematic framework for computing with fuzzy rules, the toolbox greatly amplifies the power of human reasoning (www.mathworks.com).

In some modeling situations, you cannot discern what the membership functions should look like simply from looking at data. Rather than choosing the parameters associated with a given membership function arbitrarily, these parameters could be chosen so as to tailor the membership functions to the input/output data in order to account for these types of variations in the data values. In such cases, you can use the Fuzzy Logic Toolbox *neuro-adaptive* learning techniques incorporated in the anfis command. The acronym ANFIS derives its name from *adaptive neuro-fuzzy inference system*. Using a given input/output data set, the toolbox function anfis constructs a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using either a back propagation algorithm alone or in combination with a least squares type of method. This adjustment allows your fuzzy systems to learn from the data they are modeling (www.mathworks.com).

The toolbox includes 11 built-in membership function types. These 11 functions are, in turn, built from several basic functions shown in Figure 3.2:

- Piecewise linear functions
- The Gaussian distribution function
- The sigmoid curve
- Quadratic and cubic polynomial curves



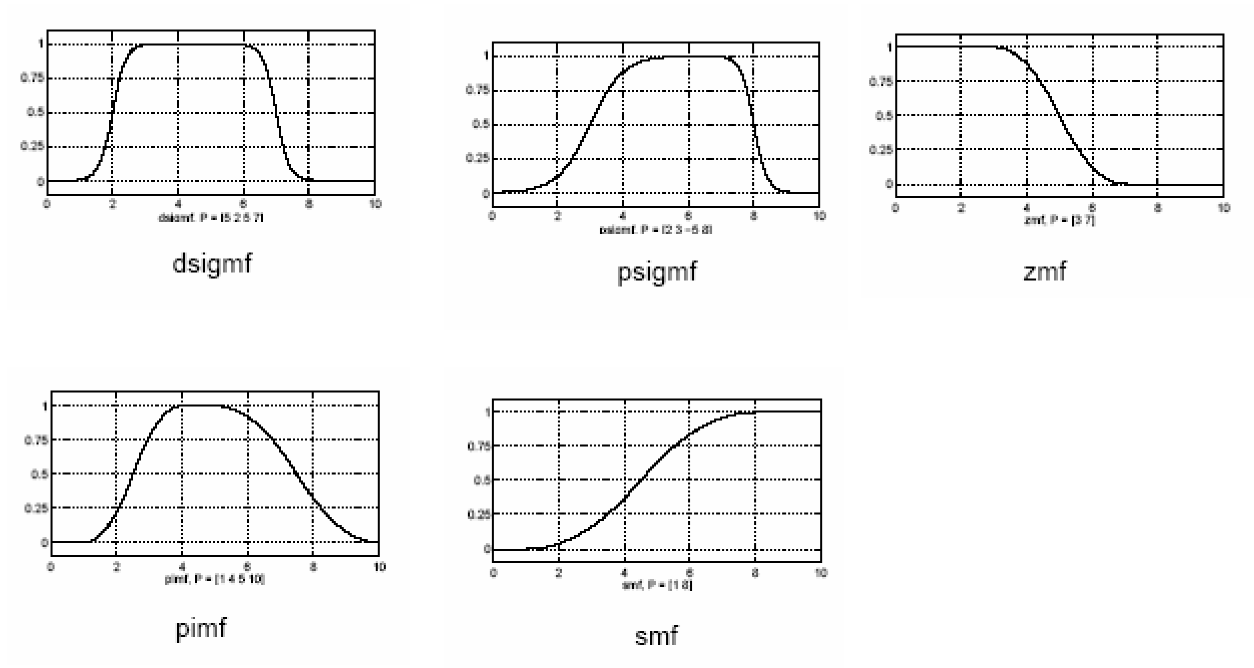


Figure 3.2 MF used in MATLAB Fuzzy Logic Toolbox

There are five primary GUI (graphical user interface) tools for building, editing, and observing fuzzy inference systems in the toolbox shown in Figure 3.3:

- Fuzzy Inference System (FIS) Editor
- Membership Function Editor
- Rule Editor
- Rule Viewer
- Surface Viewer

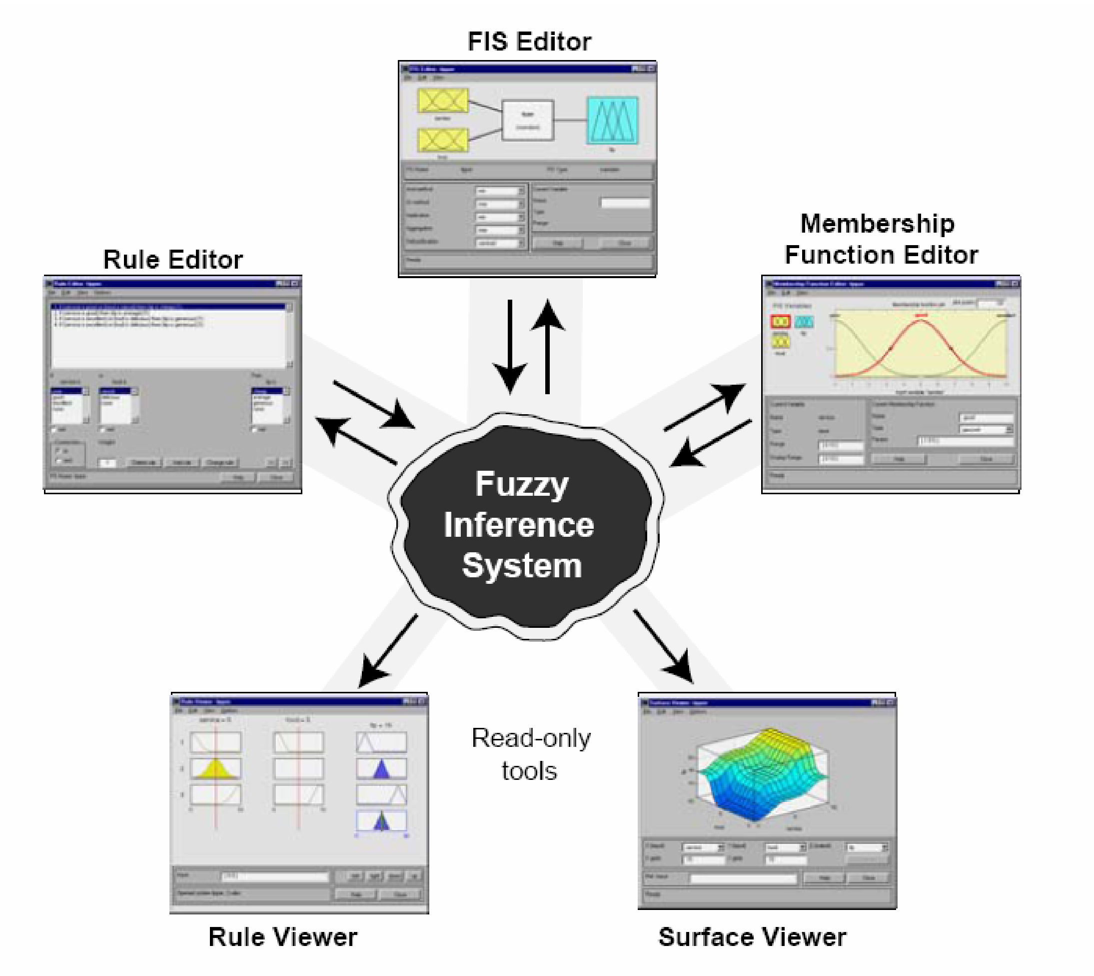


Figure 3.3 GUI (graphical user interface) tools of MATLAB Fuzzy Logic Toolbox (www.mathworks.com)

3.4 Solving a simple problem with ANFIS

To understand how ANFIS models for a simple function approximation problem, consider you are given to predict the simple equation given as follows:

$$y_i = a^3 + 3b \qquad (3.1)$$

where a and b are independent variables chosen over randomly points in the real interval [1, 9] and. Lets develop the ANFIS model fitting those values within Eqn 1 with 2 fuzzy rules only and the type of output membership function should be constant.

The inference diagram of the proposed ANFIS model is given in Figure 3.4 for input values of 9 and 5. If you want to compute the ANFIS output for 9 and 5. As a rule the minimum of the two fuzzy rules are considered which makes the first and second outputs to be zero. The third and fourth outputs of fuzzy rules are 0.5. Thus the final output will be: 732x0.5+756x0.5=744. The exact result for a=9 and b=5 from Eqn 3.1 will be y=9^3 + 3(5)=744 .

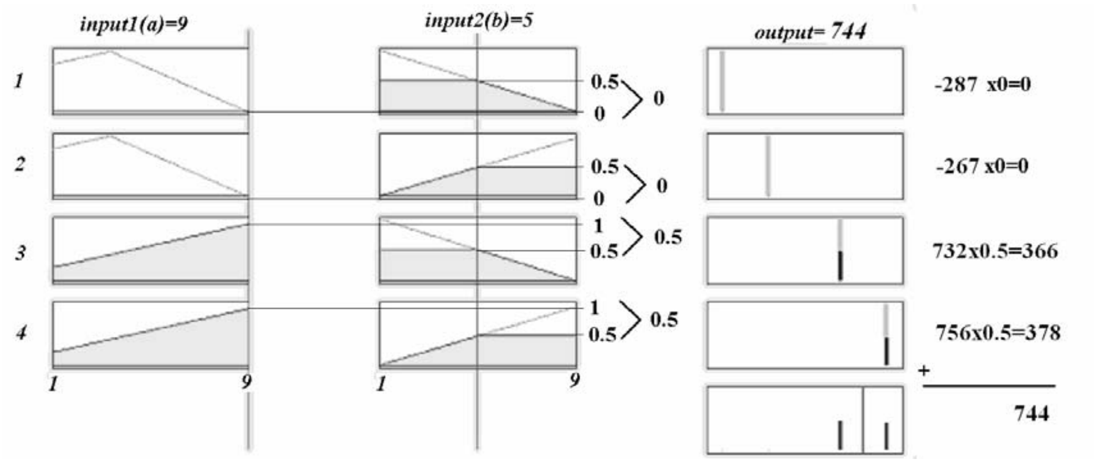


Figure 3.4. Fuzzy Inference Diagram

In this thesis, a computer program developed in Matlab by Dr. Abdulkadir Cevik which selects the optimum ANFIS model was used. The program tries various number of epochs for increasing number of membership functions (NUMMF) starting from 2 up to 5 and selects the best ANFIS model with the minimum COV (Coefficient of variation) of the testing set, as the training of the testing set is more critical. Moreover this selection process is performed for different membership functions such as Gaussian, Gaussian combination, generalized bell-shaped, Triangular-shaped, and Trapezoidal-shaped. The flowchart of the whole selection process is given in Figure 3.5(Cevik & Oztürk, 2008)

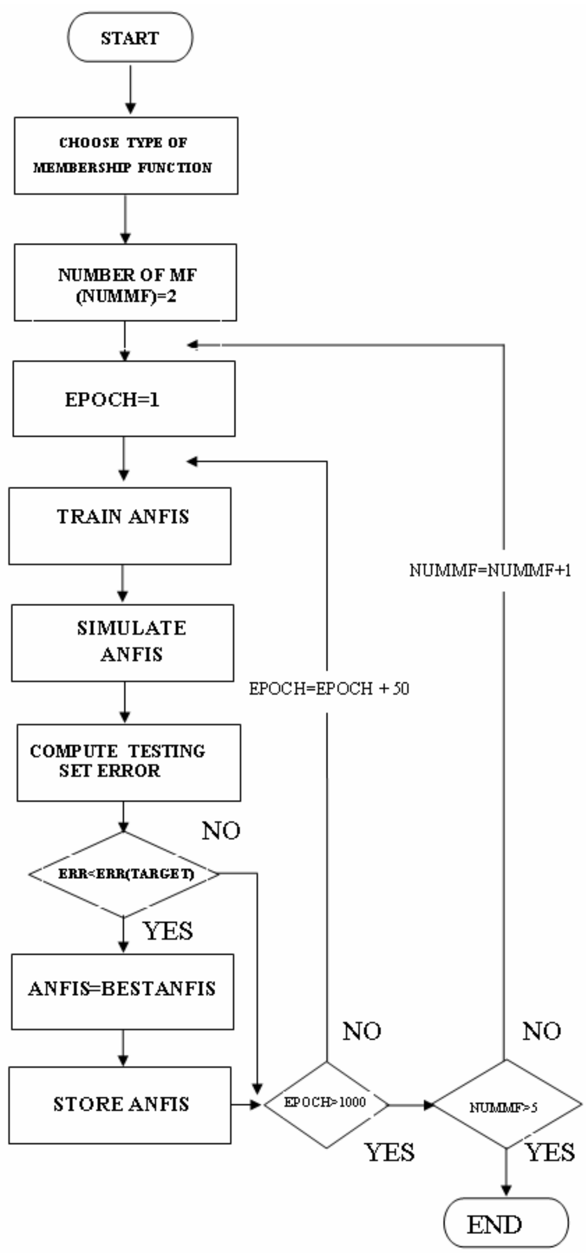


Figure 3.5 Flowchart for Optimum ANFIS Model Selection Process (Cevik & Oztürk, 2008)

CHAPTER IV

NUMERICAL APPLICATION

4.1 Introduction

Among the experimental database given in Table 2.1, 134 tests were used as test set and the remaining 530 test as training set for training. MATLAB Fuzzy Logic Toolbox is used for Neuro-Fuzzy modeling process. The computer program developed by Cevik (2007) has been used for modeling. The proposed ANFIS Model is based on the experimental database given in Table 2.1. The output membership function is chosen as the simplest one available which is a constant value. The fuzzy inference diagram of the proposed ANFIS model is shown in Figure 4.1. Statistical parameters of evaluated ANFIS models with respect to various types and number of membership functions for Test/Predicted results are presented in Table 4.1. As seen from Table 4.1, the optimum ANFIS model is found to be the one which has triangular input membership function with minimum number of membership functions of 2. The accuracies of Mean (Test/ANFIS) for training and test sets are presented in Figures 4.2(a) and 4.2(b). The initial and final membership functions for inputs are presented in Figures 4.3 and Figures 4.4 respectively. Features of the proposed ANFIS models are given in Table 4.2. It should be noted that the proposed ANFIS model will be valid for the range of variables given in Table 4.3 Output membership function values are presented in Table 4.4 (Cevik & Öztürk, 2008).

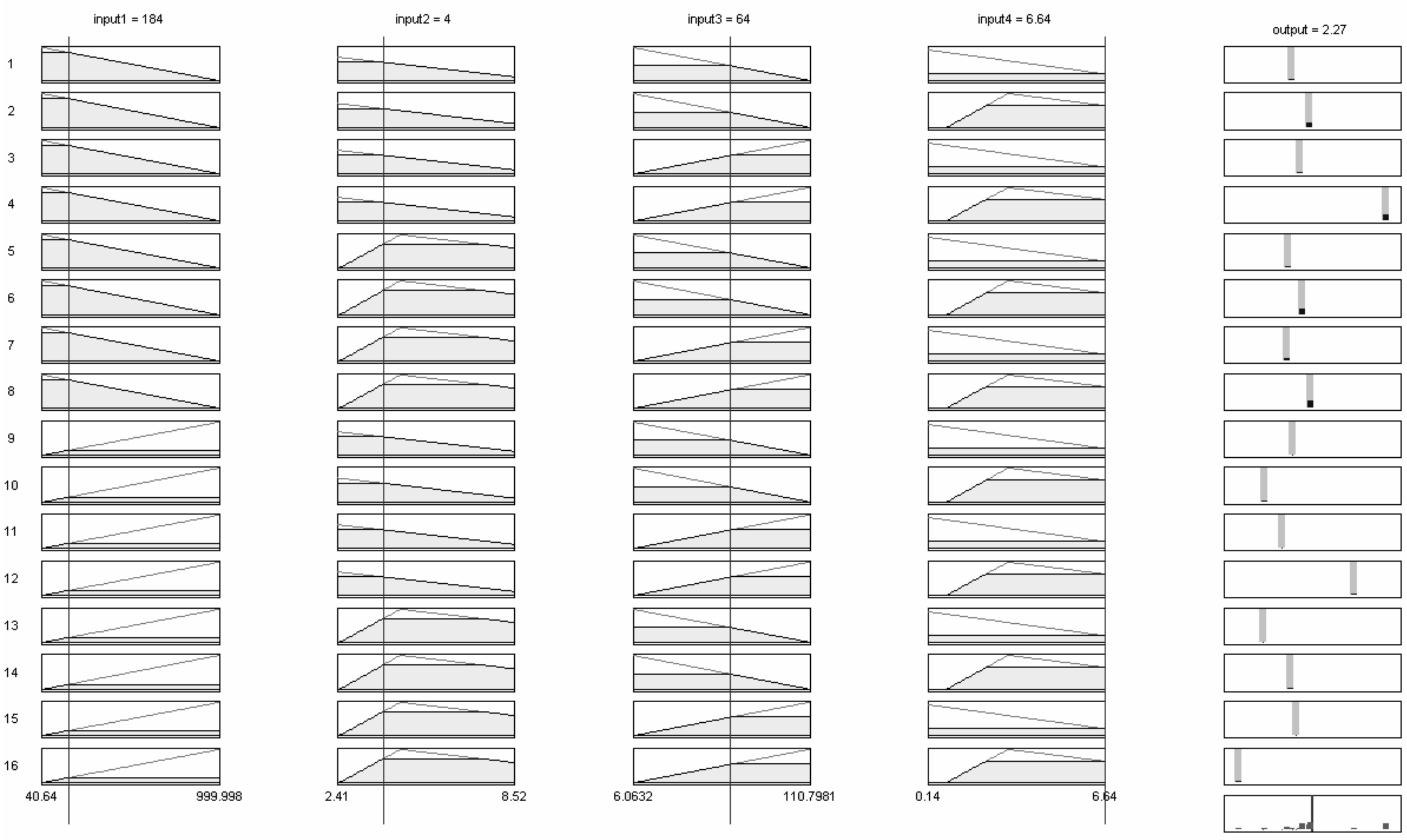


Figure 4.1 Fuzzy Inference Diagram of ANFIS Model

Table 4.1 Statistical parameters of evaluated ANFIS Models

Membership Function (matlab abbreviations)	Number of membership functions	R (Correlation Coeeficiet)	COV
Gaussian (gaussmf)	2	0.83	22.2
	3	0.84	20.3
	4	0.87	19.0
	5	0.62	0.47
Gaussian combination (gauss2mf)	2	0.84	21.6
	3	0.83	22.1
	4	0.8	25.2
	5	0.76	29.6
Generalized bell-shaped (gbellmf)	2	0.87	19.1
	3	0.88	18.1
	4	0.88	18.1
	5	0.77	28.1
Triangular-shaped (trimf)	**2**	**0.89**	**18.9**
	3	0.86	19.2
	4	0.85	20.6
	5	0.8	26.3
Trapezoidal-shaped (trapmf)	2	0.83	22.9
	3	0.86	19.1
	4	0.86	19.2
	5	0.75	30.3

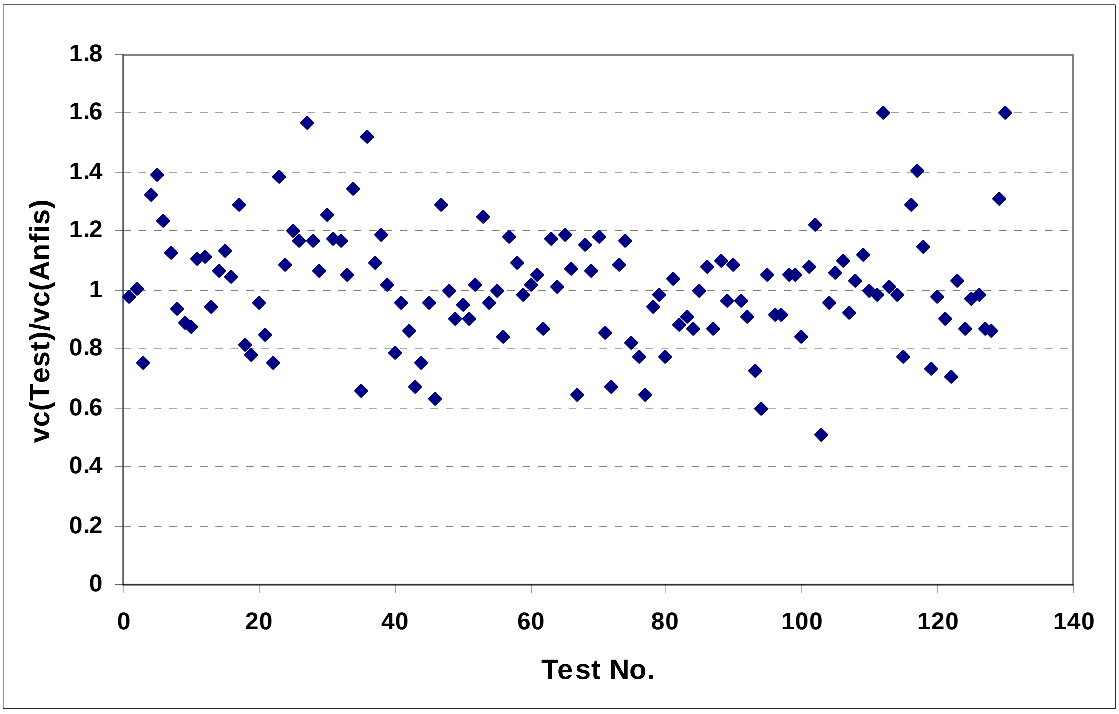


Figure 4.2(a) Mean of (Test/ANFIS) of Test Set

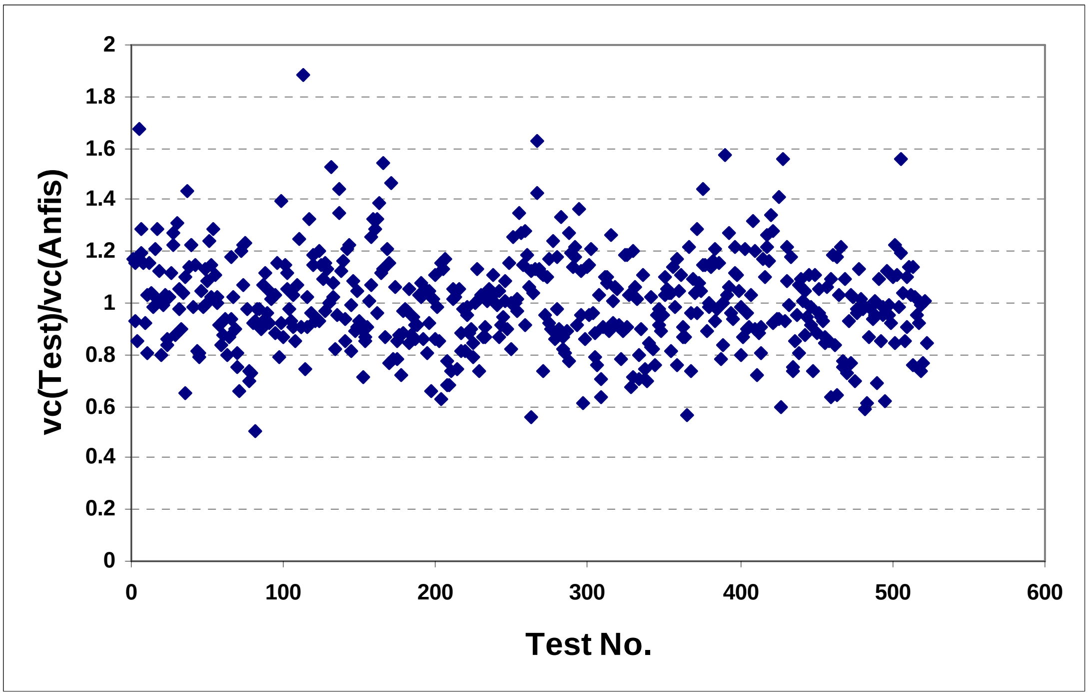


Figure 4.2(b) Mean of (Test/ANFIS) of Training Set

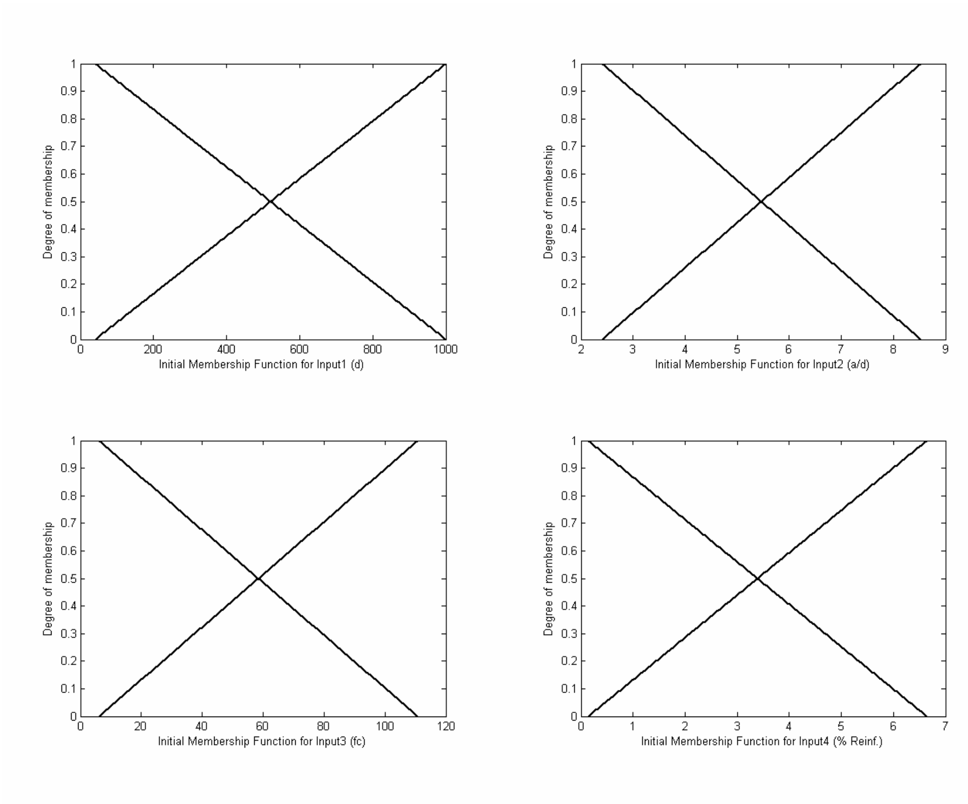


Figure 4.3 Initial Membership Functions of Inputs

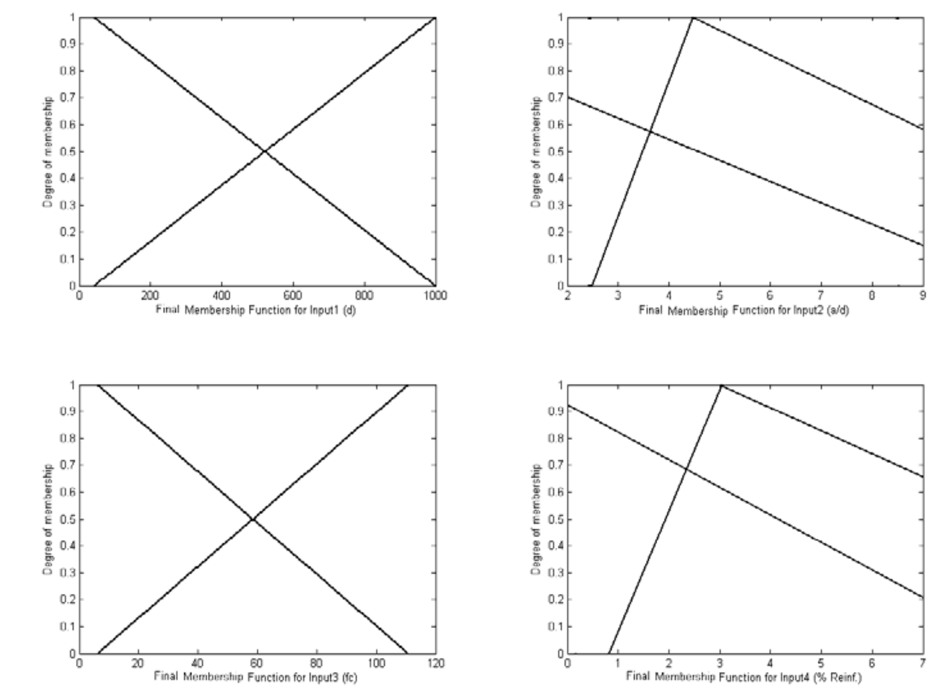


Figure 4.4 Final Membership Functions of Inputs

Table 4.2 Features of the evaluated ANFIS models

Type	SUGENO
Aggregation Method	Maximum
Defuzzification Method	Weighted Average
Input Membership Function Type	Gaussian (gaussmf) Gaussian combination (gauss2mf) Generalized bell-shaped (gbellmf) Triangular-shaped (trimf) Trapezoidal-shaped (trapmf)
Output Membership Function Type	Constant

Table 4.3 Range Of Variables Of ANFIS model

Variable	Depth (d) mm	a/d	fc (MPa)	% Reinf.	Output (vc) MPa
Range	40.64 - 1000	2.41- 8.52	6.063 - 110.8	0.14 - 6.64	0.34 - 4.523

Table 4.4 Output membership function Values of proposed ANFIS model (Constant)

mf1	mf2	mf3	mf4	mf5	mf6	mf7	mf8	mf9	mf10	mf11	mf12	mf13	mf14	mf15	mf16
0.96	2.075	1.507	6.68	0.77	1.6	0.68	2.1	1.1	-0.65	0.45	4.76	-0.7	0.93	1.27	-2.2

4.2 Comparison of Current Design Codes and Equations with ANFIS Model

The results of the proposed FL model are also compared with results of current design codes and existing equations summarized in Table 4.5. The overall comparison of COV (coefficient of variation) of the proposed ANFIS model, current design codes and existing equations of the experimental database used in the study are given in Table 4.5. As seen from the results, the overall accuracy of the proposed ANFIS model is satisfactory compared to design codes and existing equations.

Table 4.5 Comparison of Overall accuracy (Coefficient of Variation) of proposed ANFIS Model with Current Design Codes and Existing Equations

Name	Current Design Codes and Existing Equations	COV
ACI-318-02 (2002)	Vc= $\sqrt{f_c}/6$	**34.4**
ACI-318-02 (2002)	Vc= $\min((\sqrt{f_c}+120\rho_l \min(1, V_u d/M_u))/7; 0.3\sqrt{f_c})$	**30.7**
ASCE-ACI 445 (2003)	Vc= $6.85(f_c\rho/d)^{1/3}$	**23.8**
ASCE-ACI 445 (2003)	Vc= $3.66(\rho/d)^{1/3}\sqrt{f_c}$	**24.3**
ACI-446 (2005)	Vc= $\min(0.166\sqrt{f_c}; 2.1\sqrt{f_c/d})$	**29.3**
ASCE-ACI 445 (2003)	Vc= $0.026(f_c(100\rho)\frac{d}{a})^{1/3}(\frac{890}{d+250})^{1/2}$	**19.7**
CSA (2005)	Vc= $0.2\lambda\theta_c\sqrt{f_c}$ **or** Vc= $\max((\frac{260}{1000+d})\lambda\theta_c\sqrt{f_c}; 0.1\lambda\theta_c\sqrt{f_c})$	**30**

	$[\lambda = 1; \theta_c = 0.6]$	
Eurocode (1992)	Vu,cd= $\tau_{RD} k\beta(1.2+40\rho)$ where $k = 1.6 - d$ (d in m) or Vu,cd= $0.0525k(0.9 f_c)^{2/3}(1.2+40\rho)$	**20.4**
CEB-FIB (1997)	Vc= $150(1+\sqrt{\frac{0.2}{d}})(\frac{3d}{a})^{1/4}(100\rho)^{1/3} f_c^{1/3}$	**24.7**
British Standards (1997)	Vc= $\frac{790}{\gamma_m}(100\rho)^{1/3}(\frac{0.4}{d})^{1/4}(\frac{f_c}{25})^{1/3}$	**23.7**
Zsutty (1968)	Vc= $2.2(f_c\rho\frac{d}{a})^{1/3}$	**24.6**
ANFIS Model		**18.9**

4.3 Parametric Study

A wide range of parametric studies has been performed by using the NF model to investigate the interacting influence of each parameter on shear strength. Influence of a/d on the effect of % Reinforcement on shear strength for various fc and a/d values are shown in figures 4.5-4.7 with corresponding 3D response. Influence of d on the effect of % Reinf. On shear strength for various a/d and fc values are shown in figures 4.8-4.11 with corresponding 3D response. Influence of a/d on the effect of d on shear strength for various % Reinf. and fc values are shown in figures 4.12-4.15 with corresponding 3D response. Influence of fc on the effect of a/d on shear strength for various % Reinf. and d values are shown in figures 4.16-4.19 with corresponding 3D response. Influence of fc on the effect of d on shear strength for various % Reinf. and a/d values are shown in figures 4.20-4.24 with corresponding 3D response. As seen from figures, the relationship in most cases tends to be parabolic and is consistent with the findings in literature. This wide range of parametric studies also verifies the generalization capability and the accuracy of the proposed NF model.

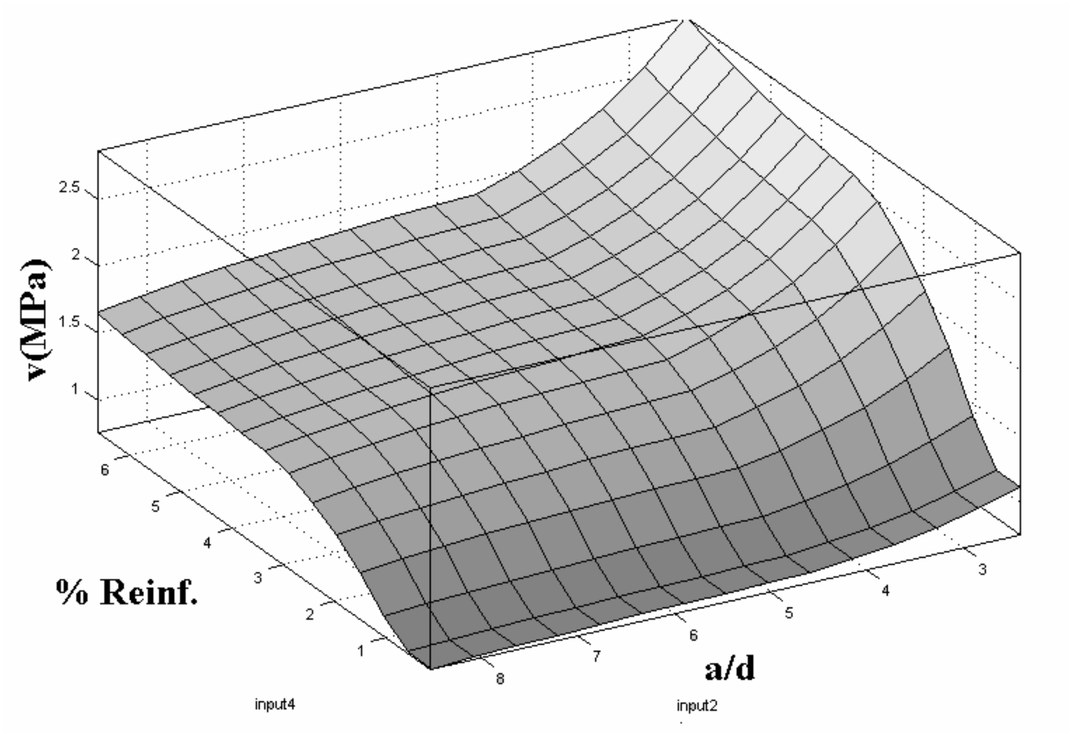


Figure 4.5 3D Response of Influence of a/d on the effect of % Reinf. on shear strength for d=100; fc=40MPa

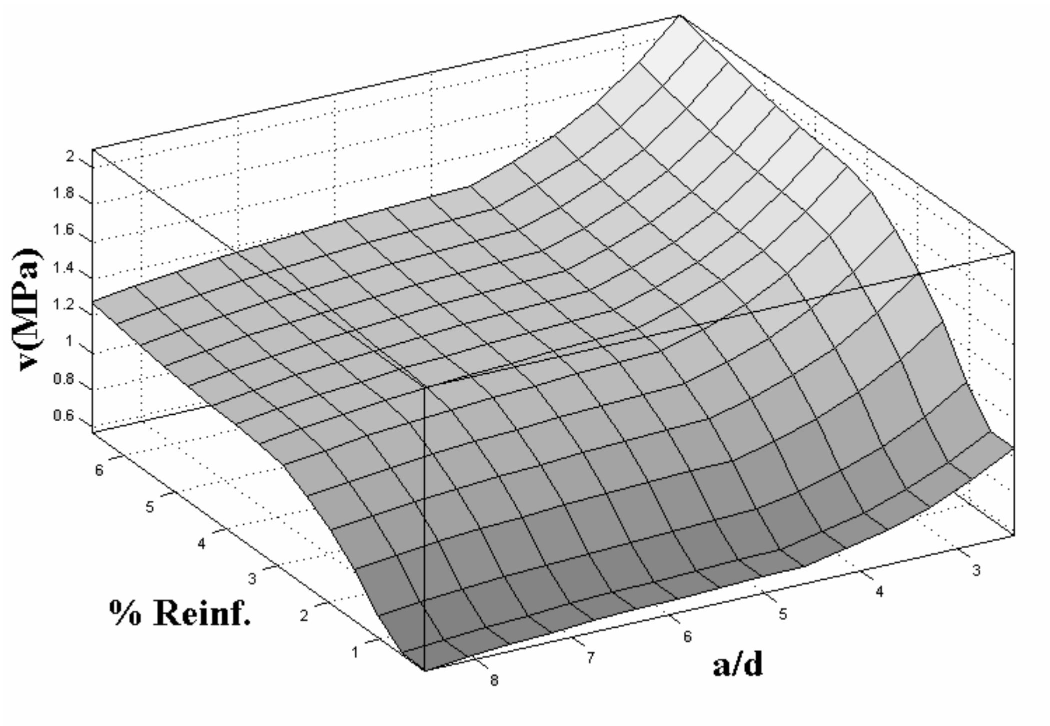


Figure 4.6 3D Response of Influence of a/d on the effect of % Reinf. on shear strength for d=300; fc=30MPa

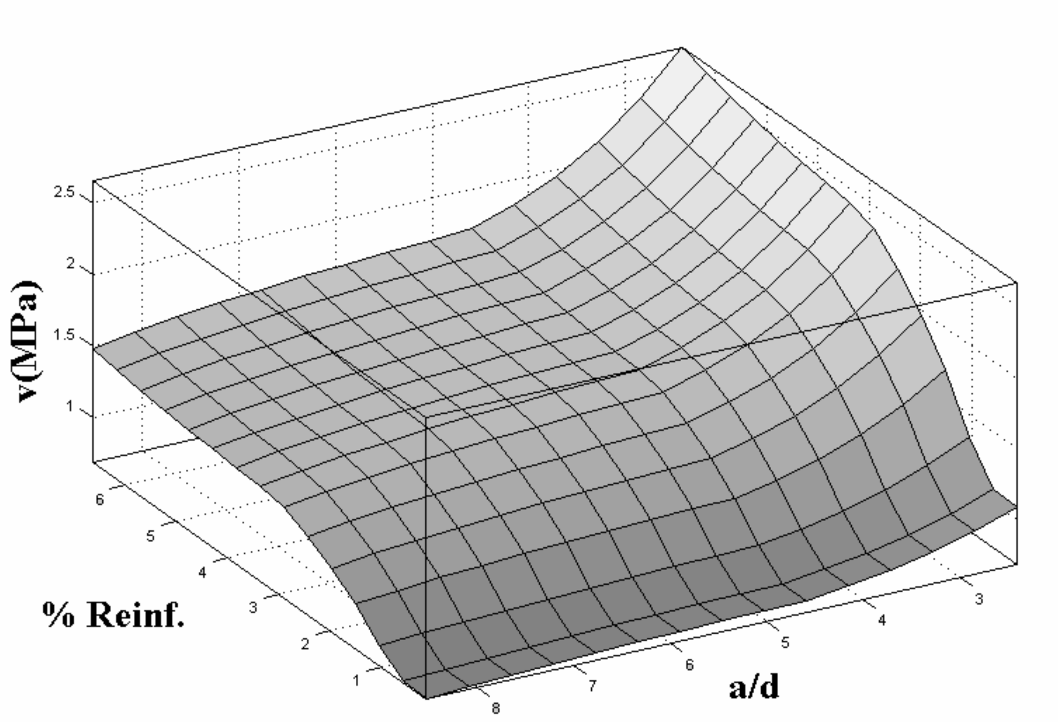


Figure 4.7 3D Response of Influence of a/d on the effect of % Reinf. on shear strength for d=200; fc=40MPa

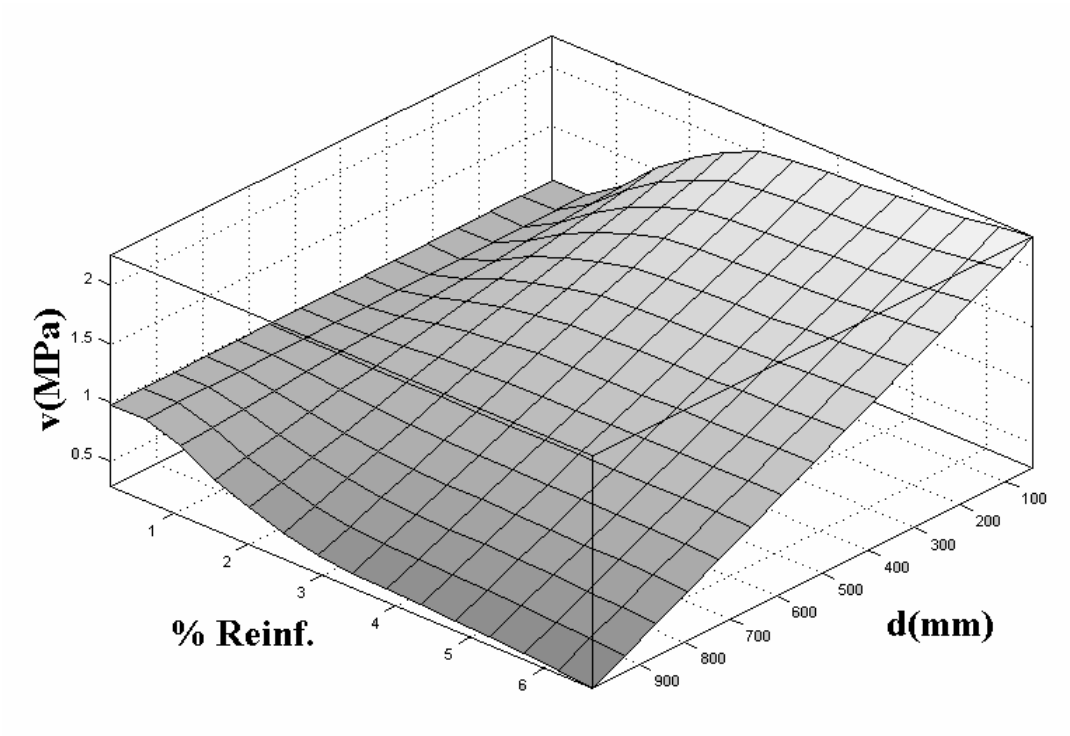


Figure 4.8 3D Response of Influence of d on the effect of % Reinf. on shear strength for a/d=2.5; fc=20MPa

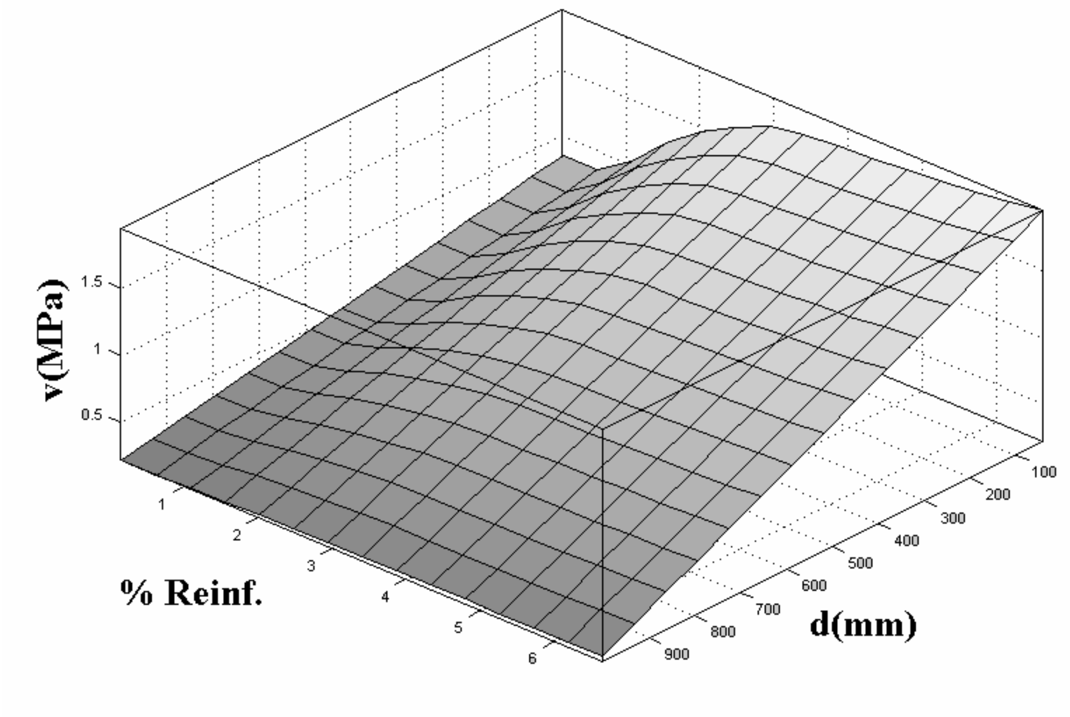


Figure 4.9 3D Response of Influence of d on the effect of % Reinf. on shear strength for a/d=6; fc=40MPa

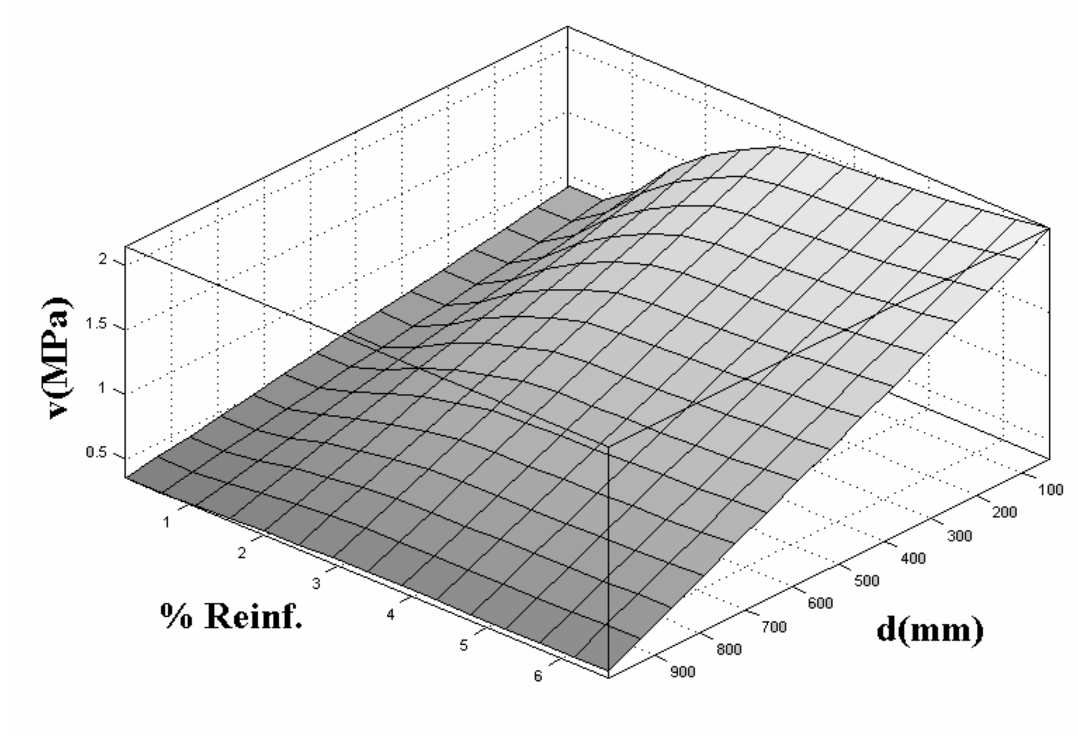


Figure 4.10 3D Response of Influence of d on the effect of % Reinf. on shear strength for a/d=4; fc=40MPa

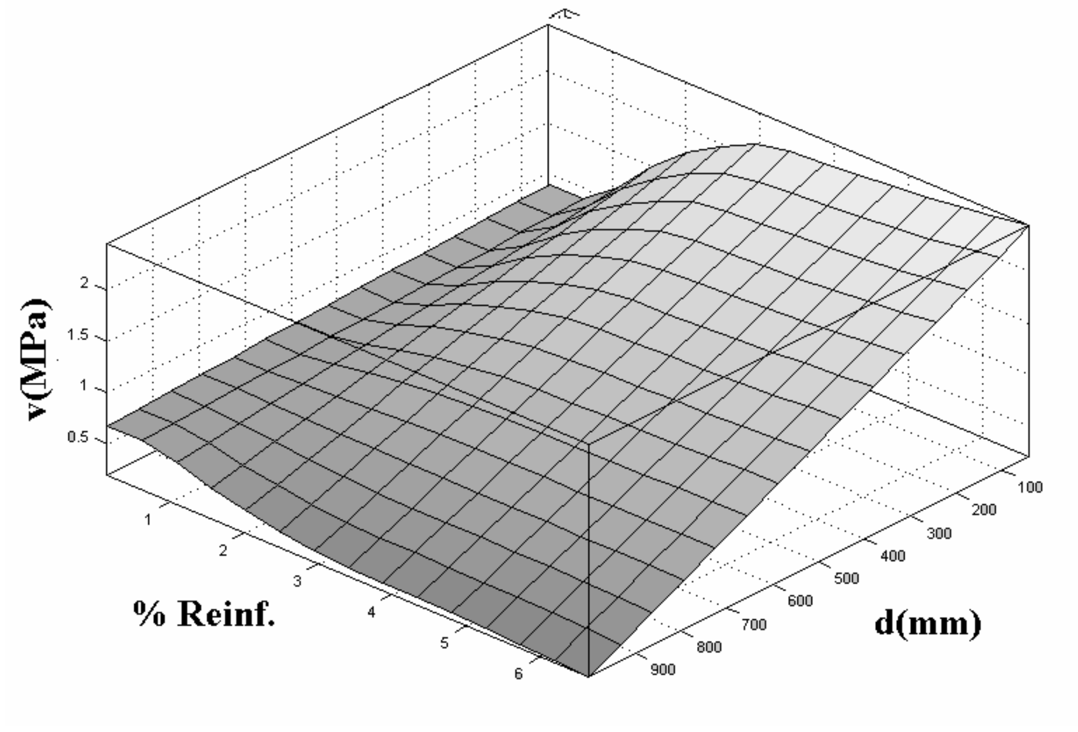


Figure 4.11 3D Response of Influence of d on the effect of % Reinf. on shear strength for a/d=6; fc=80MPa

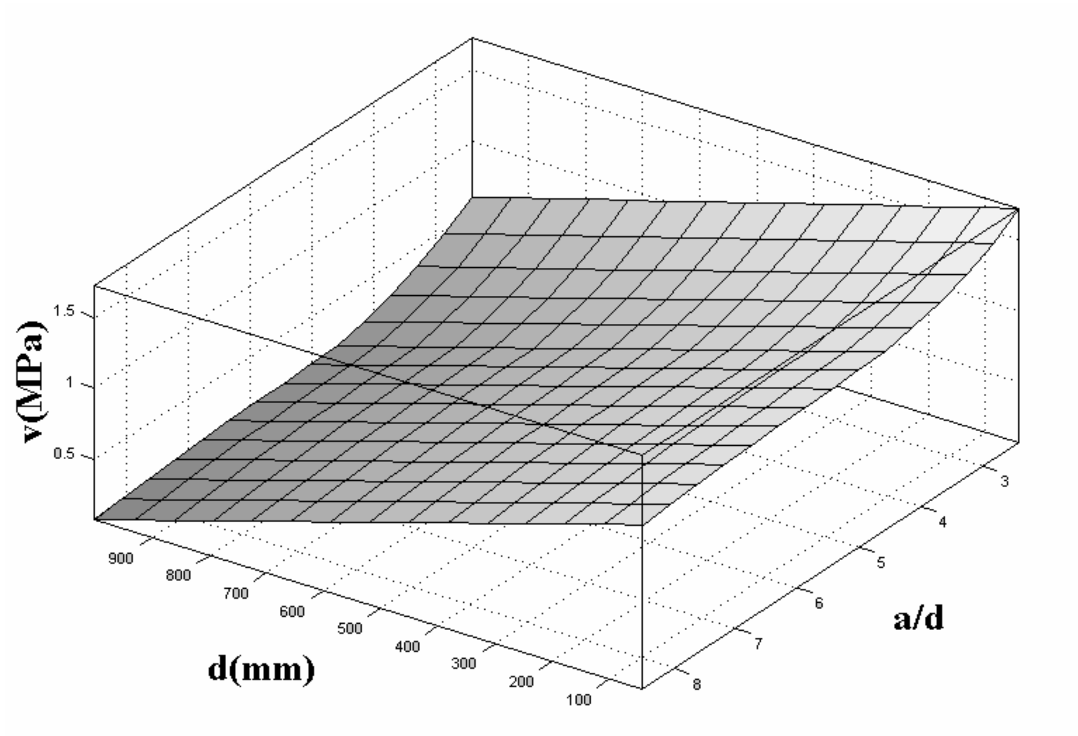


Figure 4.12 3D Response of Influence of d on the effect of a/d on shear strength for % Reinf.=2; fc=20MPa

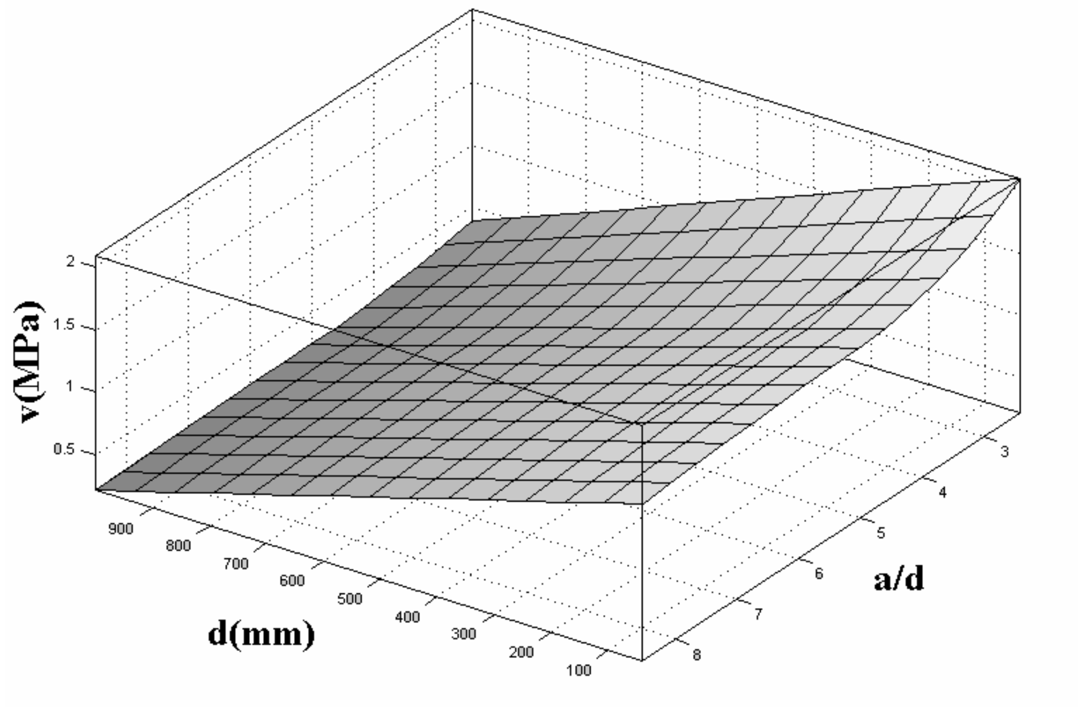


Figure 4.13 3D Response of Influence of d on the effect of a/d on shear strength for % Reinf.=4; fc=20MPa

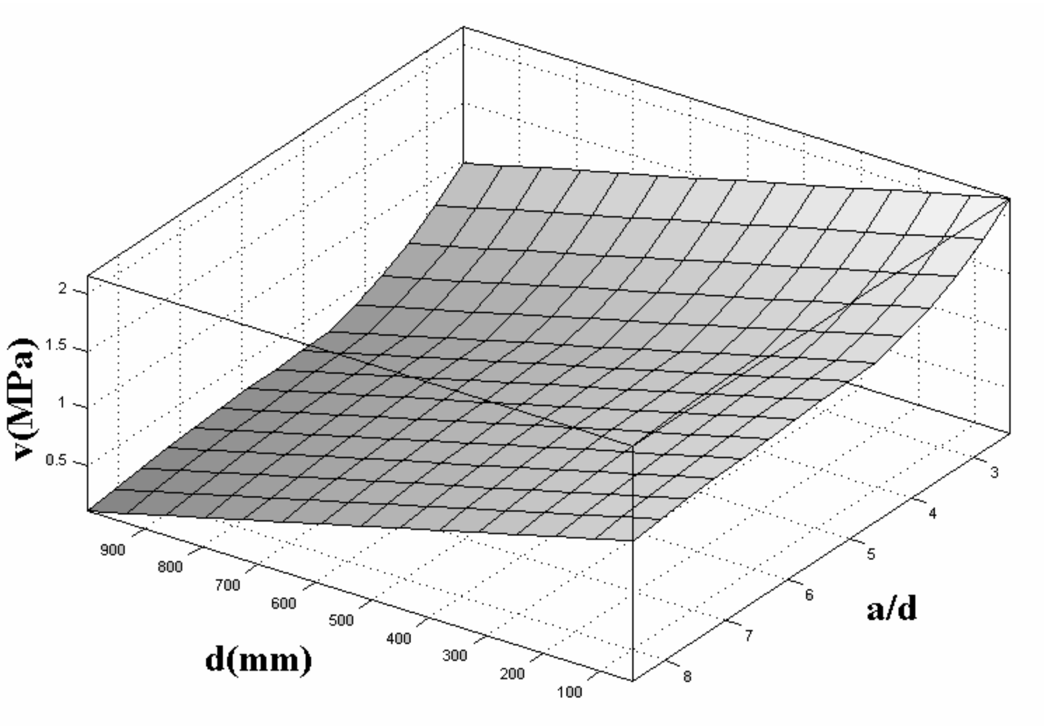


Figure 4.14 3D Response of Influence of d on the effect of a/d on shear strength for % Reinf.=2; fc=40MPa

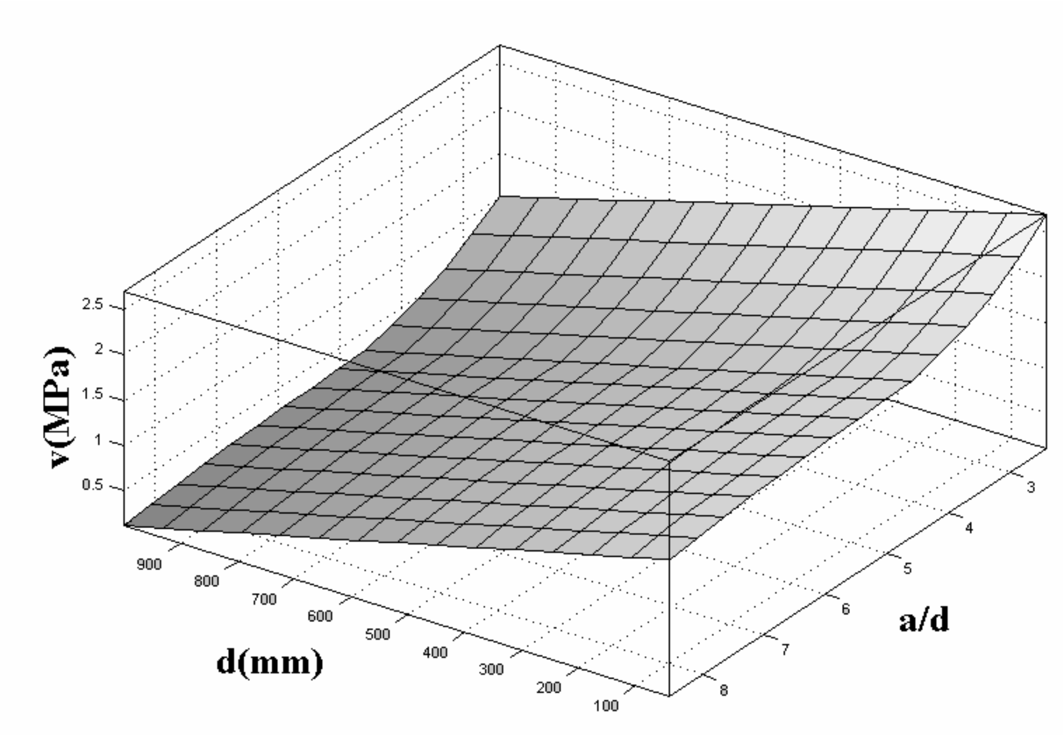


Figure 4.15 3D Response of Influence of d on the effect of a/d on shear strength for % Reinf.=4; fc=40MPa

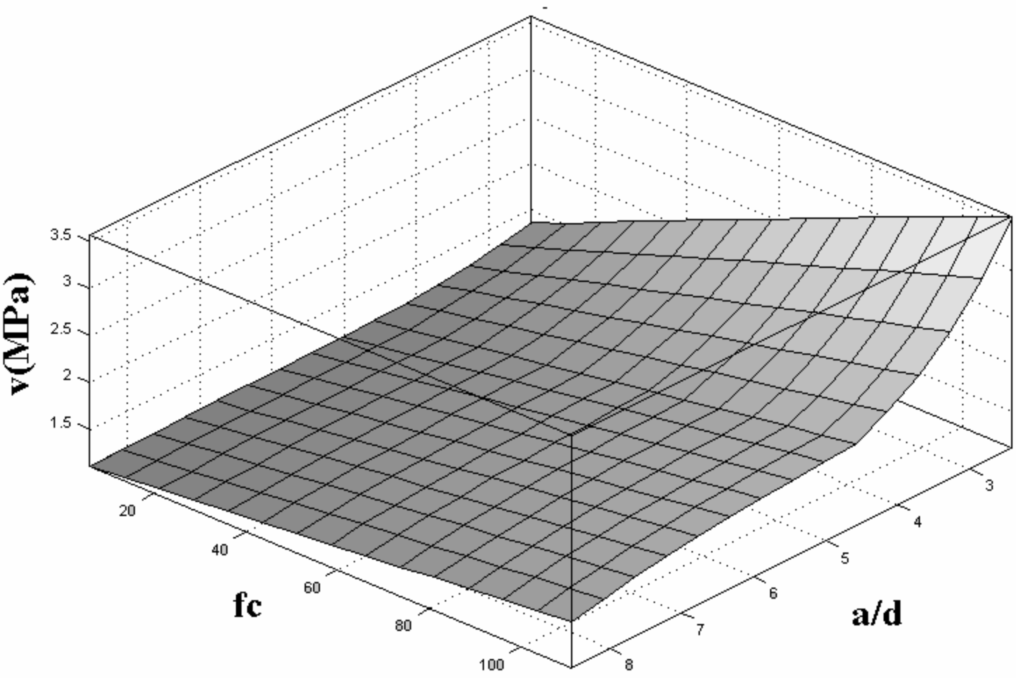


Figure 4.16 3D Response of Influence of fc on the effect of a/d on shear strength for d=100; % Reinf.=2

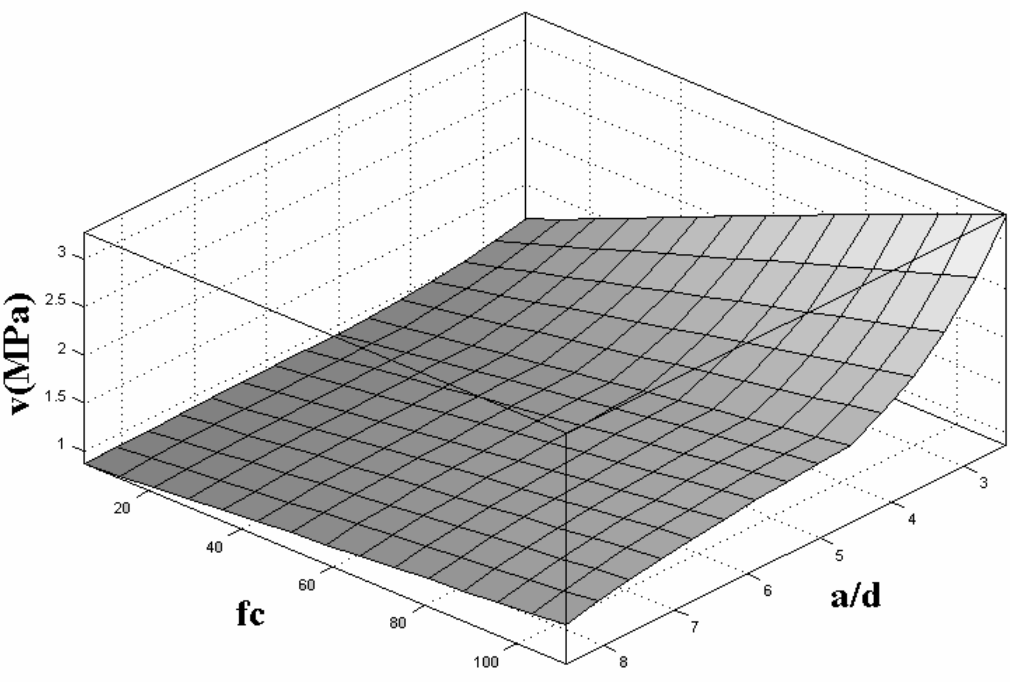


Figure 4.17 3D Response of Influence of fc on the effect of a/d on shear strength for d=300; % Reinf.=2

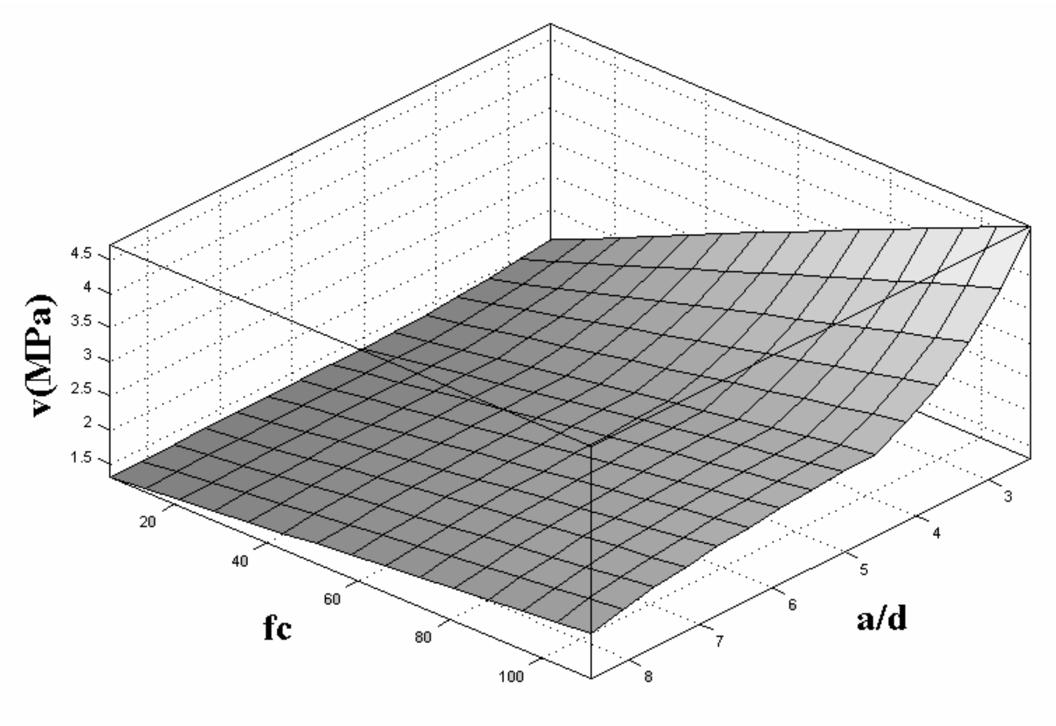


Figure 4.18 3D Response of Influence of fc on the effect of a/d on shear strength for d=100; % Reinf.=4

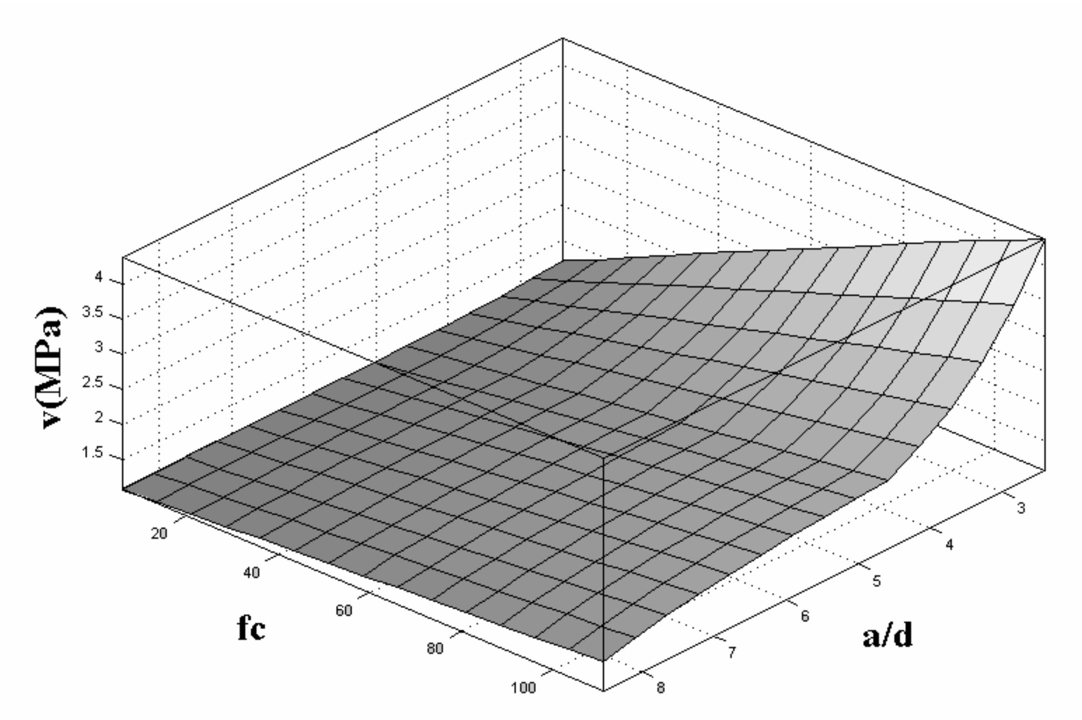


Figure 4.19 3D Response of Influence of fc on the effect of a/d on shear strength for d=300; % Reinf.=4

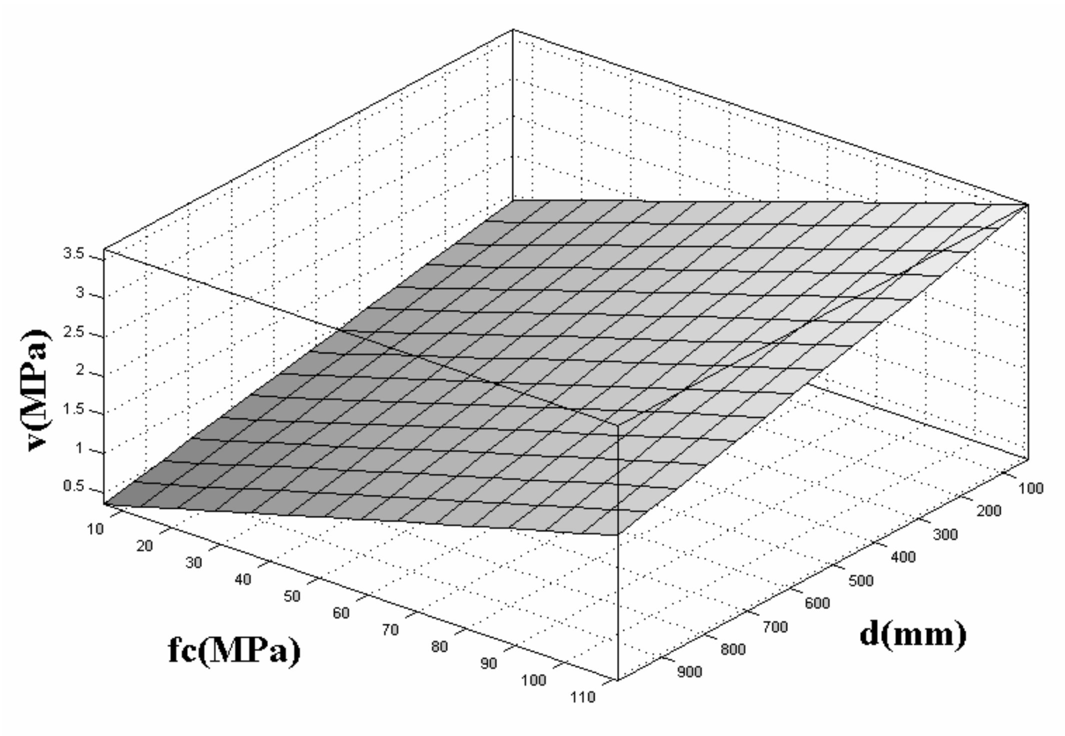


Figure 4.20 3D Response of Influence of fc on the effect of d on shear strength for a/d=2.5; % Reinf.=2

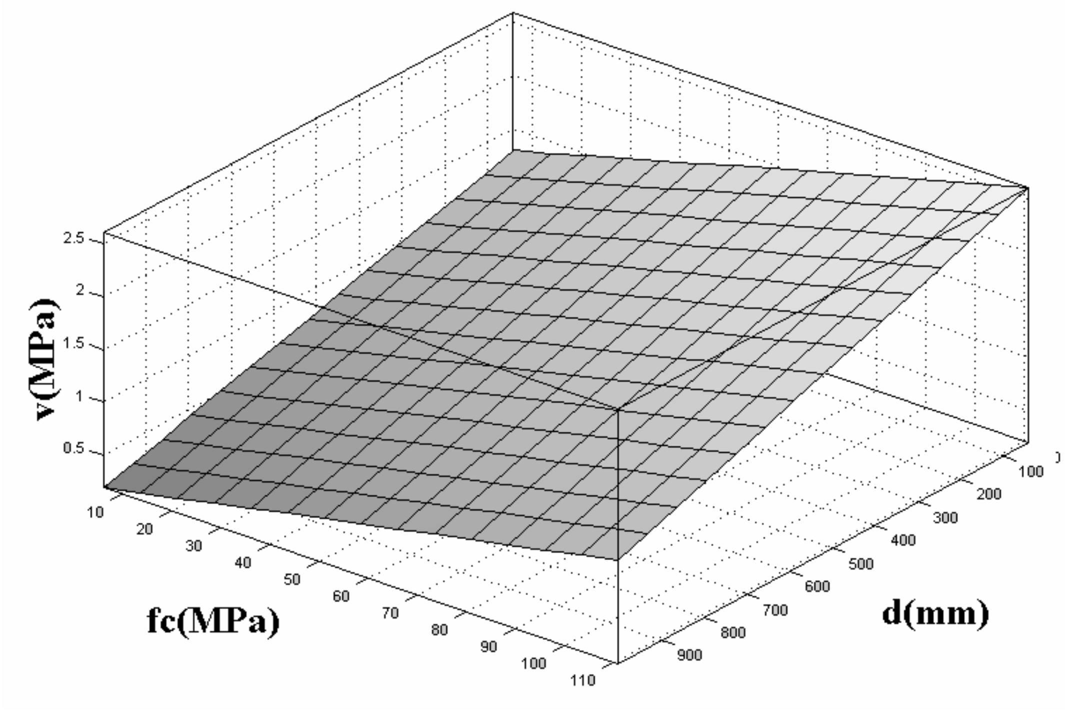


Figure 4.21 3D Response of Influence of fc on the effect of d on shear strength for a/d=3.5; % Reinf.=2

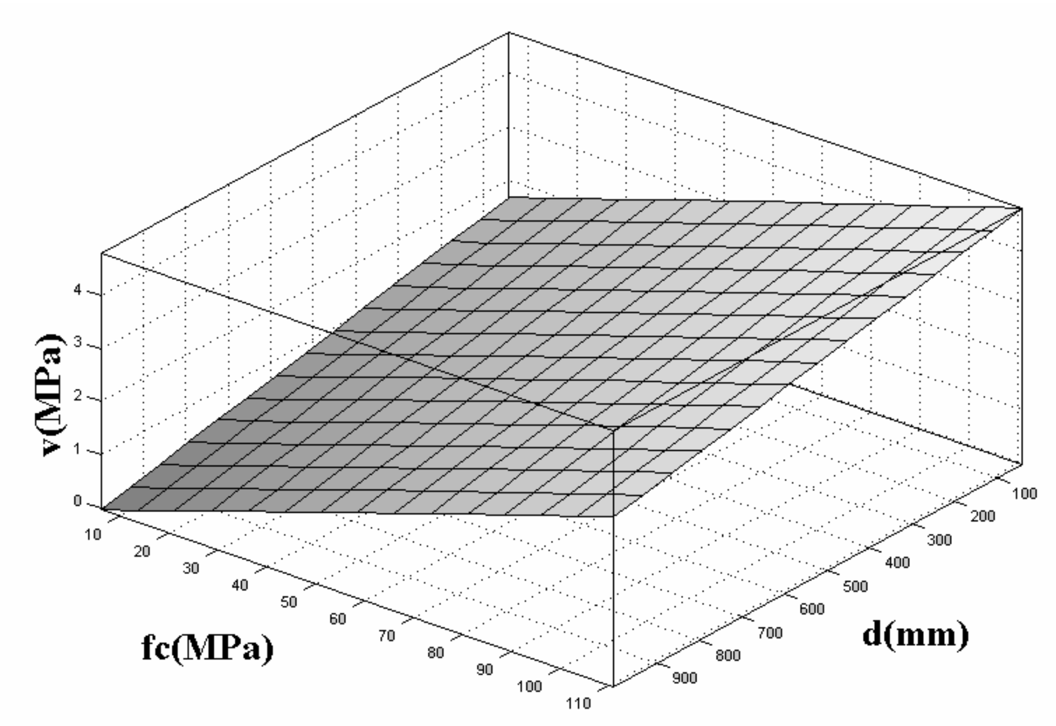


Figure 4.22 3D Response of Influence of fc on the effect of d on shear strength for a/d=2.5; % Reinf.=4

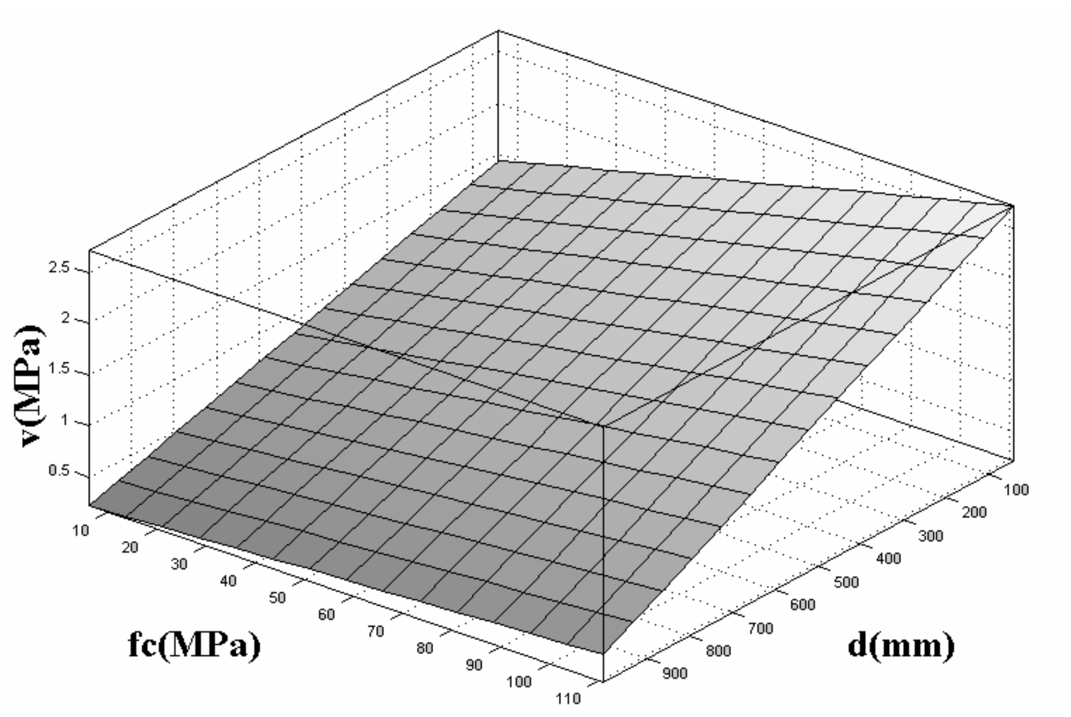


Figure 4.23 3D Response of Influence of fc on the effect of d on shear strength for a/d=4.5; % Reinf.=4

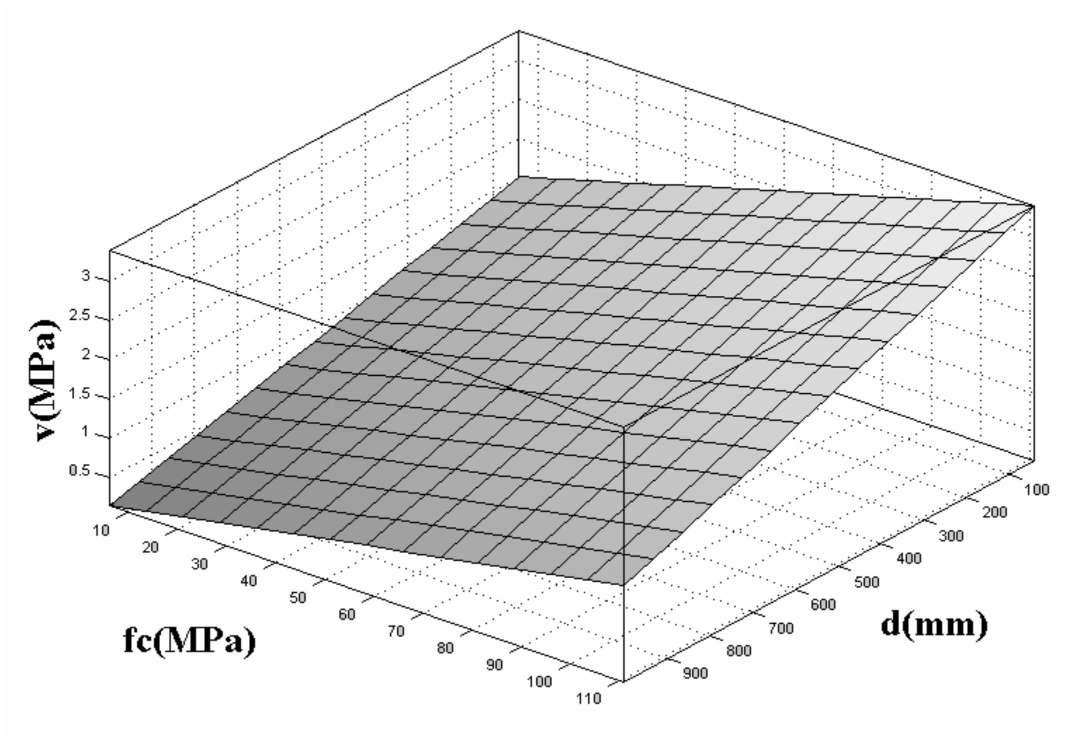


Figure 4.24 3D Response of Influence of fc on the effect of d on shear strength for a/d=4.5; % Reinf.=2

CHAPTER V

CONCLUSION

5.1 Introduction

This pioneer thesis presents Neuro-fuzzy (NF) approach as an alternative tool for the empirical modeling for shear strength of RC beams without web reinforcement. Although Fuzzy Logic techniques have been widely used in engineering applications since 1980s, they have not been applied for the modeling of shear strength of RC beams without web reinforcement so far. The proposed FL model in this paper is actually a realistic empirical model based on a wide range of experimental results collected from literature consisting of 664 test results belonging to 56 separate studies. The results are also compared with current design codes existing equations and are found to be more accurate (Cevik & Öztürk, 2008).

5.2 Conclusions

In this thesis, the computer developed in MATLAB Fuzzy Logic Toolbox developed by Cevik (2007) was used. As a result of this thesis, the following outcomes were achieved:

- Among widely used soft computing techniques such as neural networks, genetic programming and fuzzy approach, neural networks, genetic programming has been applied to shear strength of RC beams without stirrups. On the other hand Neuro-fuzzy approach has not been used so far. Therefore Neuro-Fuzzy approach has been used in this thesis.

- The simplest NF model which is the one with only 2 fuzzy rules has been used to construct the NF model to show the effectiveness of NF approach. The output has chosen to be of constant type.
- Various combinations of membership function type and numbers of Fuzzy rules have been evaluated and the optimum model among them has been obtained. The model wth triangular MFwith 2 fuzzy rule has been found to be the best model.
- The accuracy of proposed NF model is also compared with existing design codes and equations available in the literature. The NF model was seen to be more accurate.
- The NF model in this thesis is an empirical model based on collected test available in the literature. Thus it should be stated the NF model proposed in this thesis is valid for the ranges of variables of the experimental database.

FURTHER WORK

In this thesis, NF approach was used to model shear strength of RC beams without stirrups. On the other hand NF approach can also be applied to shear strength modeling of RC beams with stirrups, prestressed RC beams or torsional strength modeling of RC beams in further studies.

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