EVALUATION OF WIND LOADS ON BUILDINGS USING GENETIC PROGRAMMING

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IN

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Submitted By

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DECLARATION

The author hereby declares that this thesis entitled **"Evaluation of Wind Loads on Buildings Using Genetic Programming"**, in whole or part, has not been used to obtain any degree in this, or any other, institute. Except where references have been given in text, it is entirely the authors own work.

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Wind loading on low building has been an area of active investigation due to increasing public concern towards severe damage caused by windstorms in recent years. Design wind loading is mainly obtained from different codes, wherein the major source of information on which specifications are based is wind tunnel testing of scaled rigid models under simulated flow. The study reported in this thesis is an effort to examine the efficiency of Genetic Programming (GP) to predict the wind induced pressures on the basis of the data obtained from the wind tunnel testing done by Kwatra et al. (2002).

Any Tall building can vibrate in both the directions of Along wind and Across wind caused by the flow of wind. Modern Tall buildings designed to satisfy lateral drift requirements, still may oscillate excessively during wind storm. These oscillations can cause some threats to the Tall building as buildings with more and more height becomes more vulnerable to oscillate at high speed winds. Sometimes these oscillations may even cause discomfort to the occupants even if it is not in a threatening position for the structural damage. So an accurate assessment of building motion is an essential prerequisite for serviceability. Therefore, Genetic Programming has been used for the estimation of the Gust Factor and Base Moment for tall buildings in the along wind direction for Long After Body and Short After Body.

In the first phase of the study, the data obtained from the experimental study carried out by Kwatra et al. (2002) is used to develop the database for the gable roof building. The angle of wind incidence, roof slope and pressure coefficient for various zones has been used as the parameters for the development of the equations for the estimation of wind induced pressure on gable roof building. The pressure coefficients thus obtained are compared with the experimental values. Also, equations have been developed for all azimuths for various zones and compared with the experimental values. The wind induced pressure coefficients obtained from Genetic Programming are also compared with the codal values as mentioned in IS875-1987, Part-3.

In the second phase of the study, Genetic Programming has been used for the estimation of Gust Factor and Base Moment on tall buildings for the along wind orientation. The database has been developed using the analytical approach as given by A.G. Davenport mentioned in IS875-1987, Part-3. The building height, plan dimensions, design wind speed, gust factor and base moment have been used as the parameters for the development of the equations. The Gust Factor and Base Moment thus obtained from Genetic Programming have been thus compared with the analytical values.

The results for the Gable Roof Building and Tall Building are presented in the form of various plots and tables showing the comparison made in the study.

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CHAPTER – 1

INTRODUCTION

1.1 GENERAL

In recent years, wind loading on buildings has been an area of active investigation due to increasing public concern towards severe damage caused by windstorms. Low-rise residential and light commercial structures continue to be the most vulnerable to damage in severe wind. A gable building is the most common among low buildings of all type and so this has been the focus in many studies in the last few years. Surface pressure, both the mean and fluctuating components, on the roof of a building are not only strongly influenced by building geometry and wind incidence angle, but also depend on surroundings and wind flow characteristics. These are also influenced by features at roof edges. Wind loads on low buildings are mainly obtained from different codes, wherein the major source of data on which specifications are based is wind tunnel testing of scaled rigid models under simulated flow. The measured pressures are reduced to dimensionless coefficients based on such information, usually a statistical reduction of averaged peak pressure.

Various full-scale studies have been conducted on low buildings. Full-scale experiments are necessary to validate wind tunnel and computational models and to study phenomena not easily studied in the conventional wind tunnels. Issues of flow simulations and measurement techniques for wind tunnel tests have been brought out from various studies on full-scale/ model-scale comparisons with greater clarity. In view of the recent findings from these studies, there is need to examine the suitability of the current design wind pressure coefficients for gable roof buildings, specified in the different codes and standards and to explore ways of predicting wind loads from a comparatively reduced test programme.

A structure that, because of its height, is affected by lateral forces due to wind or earthquake to the extent that the forces constitute an important element in structural design is known as high-rise or tall building. Tall buildings are flexible structures which tend to oscillate due to dynamic effects of wind. The wind on earth's surface is turbulent in nature that gives rise to randomly varying wind pressures about a certain value associated with the mean wind speed. The dynamic part of the wind pressures would set up oscillations in a flexible structure, which may be defined as one having the fundamental time period of vibration more than 1.0 second. Oscillations will thus be caused in the along - wind direction. The IS: 875 (Part 3) - 1987 Code which gives procedure to determine along wind response of a flexible structure given by A.G. Davenport, is only applicable to a regular shape building but for an irregular shaped building behaviour under the high wind speeds is provided from a prototype measurements in a wind tunnel. A simulated wind tunnel experiment on an appropriate model of the building yields results which give a deeper insight into the phenomenon and provides more precise information, overcomes the shortcomings of the analytical formulation. In the wind tunnel testing there are two approaches used for determining the response of any Tall building with an irregular or regular shape under the high wind speeds, one is the Dynamic Analysis method used to determine the wind loads on the buildings in which Base Forces can be economically obtained from HFFB test while the other one is Pressure measurement studies which are used for the safe designs of Individual structural elements as roofs and walls, and Individual cladding units including glazing and their fixing.

In recent years, the problems of wind loading and structural response have been subjected to detailed analysis and discussion. The acceleration caused in tall buildings due to wind, poses important design criteria. Many of the tall buildings have been found to become unserviceable due to acceleration during wind storms.

Keeping all this in view, in the present work an attempt has been made to study the use of Genetic programming to get equations for the design pressure coefficients for various zones on a low gable building in a stand-alone situation. Further, Genetic Programming has been applied to find the gust factor and base bending moment on tall buildings in along-wind direction for Long After Body (LAB) and Short After Body (SAB). The ability of Genetic programming to develop relationships between the input and output parameters makes it an attractive proposition for knowledge acquisition for problems where there is no acceptable theory or empirical generalisation at present.

Data used for obtaining equations for the design pressure coefficients for various zones on a low gable building using genetic programming is obtained from wind tunnel tests carried out by Kwatra et al. (2002) on building models. Subsequently the suitability of the developed equations has been checked by using relevant values from IS 875, 1987 part III.

The mean response of the wind on tall buildings is influenced by various important parameters which include the geometry of the building as well as the velocity of the wind. Therefore, these parameters have been used as the input parameters for obtaining the Gust Factor and the Base Moment which are used as output parameters to develop equations for along-wind direction for LAB and SAB using GP. However, the gust factor and base moment which have been used for developing the equations have been analytically obtained as per IS: 875 Part III by taking into consideration important factors such as turbulence effect, geometry of the building, velocity of wind, terrain conditions and the natural period of the building.

1.2 OBJECTIVES

Following are the main objectives of the work.

1. Application of Genetic Programming for predicting wind induced pressure coefficients for varying angle of wind incidence and roof slopes on the gable roof building for various zones.

2. Application of Genetic Programming for predicting wind induced pressure coefficients on the gable roof building for all azimuths for various zones.

3. Application of Genetic Programming for the prediction of Gust Factor and Base Moment caused by the along-wind direction on tall buildings for Long After Body (LAB) and Short After Body (SAB).

1.3 SCOPE OF THE WORK

In the first phase of the study, Genetic Programming has been used for the prediction of wind induced pressure coefficients for varying angle of wind incidence and roof slopes by developing equations for various zones. The angle of wind incidence and the roof slope have been taken as input parameters and the wind pressure coefficient has been taken as the output parameter. The program has been run for various combinations of crossover rate, population size, number of generations which are randomly selected until the best fitted result is obtained. These results have been then compared with the experimental results taken from the studies carried out by Kwatra et al. (2002). Thereafter, the results obtained by Genetic Programming have also been compared with the codal values of the Indian Standard Code as per IS 875, 1987 part III.

In the second phase of the study, Genetic Programming has been used to develop equations for the estimation of Gust Factor and Base Moment for the along-wind direction for

LAB and SAB. Thereafter, these results have been compared with the analytical values obtained using the Davenport approach as mentioned in IS: 875, 1987 part III.

1.4 ORGANISATION OF THESIS

The thesis has been divided into six chapters. Chapter-2 presents the review of the work carried out in various fields using Genetic Programming approach. Chapter-3 presents the explanation of Genetic programming and the algorithm used in genetic programming. It also includes the advantages of using genetic programming for various studies. Chapter-4 presents the detailed discussion of the experimental data used and the results obtained using genetic programming on gable roof buildings for various zones and there comparison with the experimental results as well as the codal values as mentioned in IS875-1987, Part-3. Chapter-5 presents the analytical approach adopted for the development of the database and the results obtained using genetic programming on tall buildings and there comparison with the analytical results. Conclusions of the study are summarised in chapter-6. A list of references, directly referred in the work is alphabetically arranged after chapter-6.

CHAPTER – 2

REVIEW OF LITERATURE

2.1 GENERAL

This chapter presents a review of the relevant literature to bring out the background for the study undertaken in this thesis. However, no such work has been carried out in the field of wind engineering using Genetic Programming, although it has been widely used in the other fields of civil engineering. Therefore, a brief review of the historical background relating to the work being carried out in other areas of civil engineering is presented.

2.2 HISTORICAL BACKGROUND

Johari et al. (2006) employed Genetic Programming approach to predict the soil-water characteristic curve (SWCC) of soils. The input set consisted of initial void ratio, initial gravimetric water content, logarithm of suction normalised with respect to atmospheric air pressure, clay content and silt content. The output set consisted of the gravimetric water content corresponding to the assigned input suction. Results from pressure plate tests carried on clay, silty clay, sandy loam and loam compiled in the Soil Vision software, were adopted as a database for developing and validating the GP model. GP software (GPLAB) provided by MATLAB was employed for analysis. GP simulations were compared with the experimental results as well as the models proposed by other investigators. The comparison indicated superior performance of the proposed model for predicting SWCC.

Heshmati et al. (2008) proposed new formulations for soil classification using Linear Genetic Programming (LGP). Properties of soil, namely liquid limit, plastic limit, colour of soil, percentage of gravel, sand and fine grained particles are used as input variables. The database used for the study was obtained from the previous published literature. The results of the proposed formulations were compared with the existing models found in the literature. From the comparisons it was observed that the LGP based formulations predicted the targeted values with higher degree of accuracy.

Kermani et al. (2009) presented the use of genetic programming for predicting the equations for the ratio of maximum velocity to maximum acceleration (v_{max}/a_{max}) of strong ground motions. The predictive equations were established using a reliable database released by Pacific Earthquake Engineering Research Center (PEER) for three types of faulting mechanisms including strike slip, normal and reverse. The proposed models provided reasonable accuracy to estimate the frequency content of site ground motions in practical projects.

Nitsure et al. (2009) used Genetic Programming to estimate an important oceanic parameter i.e. Significant Wave Height (SWH) using the wind information. Wave and wind measurements taken by moored ocean buoys were used to develop the GP models. The GP based estimations were found to have a reasonable accuracy in estimation of significant wave heights as evident from wave plots and accompanying high values of correlation coefficient.

Gandomi et al. (2010) proposed the formulation of compressive strength of carbon fibre reinforced plastic (CFRP) confined cylinders using Linear Genetic Programming (LGP). The LGP-based models were constructed using two different sets of input data. The first set of inputs comprised of diameter of concrete cylinder, unconfined concrete strength, tensile strength of CFRP laminate and total thickness of utilized CFRP layers. The second set included unconfined concrete strength and ultimate confinement pressure which were the most widely used parameters in the CFRP confinement existing models. The models were developed based on experimental results collected from the available literature. The results demonstrated that the LGP-based formulas predicted the ultimate compressive strength of concrete cylinders with an acceptable level of accuracy. The LGP results were also compared with several CFRP confinement models presented in the literature and found to be more accurate in nearly all of the cases.

Saridemir (2010) developed two models in gene expression programming (GEP) approach for predicting compressive strength of concretes containing rice husk ash at the age of 1, 3, 7, 14, 28, 56 and 90days. For purpose of building the models, experimental results for 188 specimens produced with 41 different mixture proportions were obtained from the literature. According to these experimental results, the models were arranged by using seven different input variables in GEP approach. In according to these input variables, the compressive strength values from mechanical properties of concretes containing rice husk ash were predicted in GEP approach models. The results of training, testing and validation sets of the models were compared with experimental results. All of the results showed that GEP is a strong technique for the prediction of compressive strength values of concretes containing rice husk ash.

Muduli et al. (2013) examined the potential of multi-gene genetic programming (MGGP) based classification approach to evaluate liquefaction potential of soil in terms liquefaction index (*LI*) using a large database from post liquefaction cone penetration test (CPT) measurements and field manifestations. The database consisted of CPT measurements; cone tip resistance (q_c), friction ratio (R_f), vertical total stress (σ_v) and vertical effective stress of soil (σ_v'), seismic parameters; peak horizontal ground surface acceleration (a_{max}) and earthquake moment magnitude (M_w), and the depth under consideration (z). The MGGP models were developed for predicting occurrence and non-occurrence of liquefaction on basis of combination of above input parameters. The performance of the models was found to be more efficient compared to available artificial neural network models.

CHAPTER – 3

GENETIC PROGRAMMING

3.1 GENERAL

Genetic Programming (GP) is a domain independent, problem-solving approach in which computer programs (which in general are the equations) are evolved to find solutions to the problems. The solution technique is based on the Darwinian principle of 'survival of the fittest'. Genetic Programming (GP) is similar to genetic algorithm (GA) but unlike the latter its solution is a computer program or an equation as against a set of numbers in the GA. (Gaur and Deo, 2008).

Genetic programming is a search technique that explores the space of computer programs. The search for solutions to a problem starts from a group of points (random programs) in the search space. Those points that are of above average quality are then used to generate a new generation of points through crossover, mutation, reproduction and possibly other genetic operations. This process is repeated over and over again until a termination criterion is satisfied. Because genetic programming is a stochastic search technique, in different runs different trajectories are observed.

Therefore, many real runs are performed and variations of certain numerical descriptors (like the average fitness or the average size of the programs in the population at each generation, the average difference between parent and offspring fitness, etc) are recorded. The result which is finally compatible with the empirical observation is considered.

This exercise is very error prone, though, because a genetic programming system is a complex adaptive system with zillions of degrees of freedom. So, any small number of statistical descriptors is likely to be able to capture only a tiny fraction of the complexities of such a system.

3.2 PRIMITIVES OF GENETIC PROGRAMMING

Every solution evolved by GP is assembled from two sets of primitive nodes; terminals and functions. The terminal set contains nodes that provide an input to the GP system. The terminal set contains the arguments for the function and consists of variables or numerical constants. The function set contains nodes that process values already in the system which may be arithmetical operations such as +, -, mathematical operations such as log, exponential, sin, cos etc. Constants may also be used in GP by including them in the terminal set. The primitives of GP, the function and terminal nodes, are then assembled into a structure before they are executed.

3.3 ALGORITHM OF GENETIC PROGRAMMING

The genetic programming paradigm breeds computer programs to solve problems by executing the following three steps:

1. An initial population of individual computer programs is randomly created composing the available functions and terminals.

2. The initial population is now tested for its fitness. The best fitted individual program is then selected for participating in the genetic operations to be conducted to form a new population. Fitness may be measured in many different ways such as coefficient of determination (COD), root mean square error (RMS), Unit Error (deviation from dimensional error) and fitness per node (measurement of the simplicity of the expression of the individuals). The population can be tested by some or all the fitness parameters mentioned above.

3. Various genetic operators are now applied to the best fitted individual program to form a new individual program(s) for the new population. There are three major evolutionary operators within a GP system:

Reproduction: selects an individual from within the current population to be copied exactly into the next generation. In fig.3.1 individual (a) of the current population is as such copied into the new population as the individual (a) in fig.3.2.

Crossover: mimics sexual recombination in nature, where two parent solutions are chosen and parts of their sub tree are swapped. In fig. 3.1 individuals (a) and (b) are the two parents chosen for the crossover operation. The + function of parent (a) and leftmost terminal x of parent (b) are swapped to form individuals (c) and (d) of the new population in fig.3.2.

Mutation: causes random changes in an individual before it is introduced into the subsequent population. Unlike crossover, mutation is asexual and thus only operates on one individual. During mutation, either all functions and terminals are removed beneath an arbitrarily determined node and a new branch is randomly created, or a single node is swapped for another. In fig 3.1 individual (c) is muted wherein terminal 2 is picked as the mutation site and a subtree is inserted in its place which again is randomly created to form a individual (b) of the new population in fig.3.2.

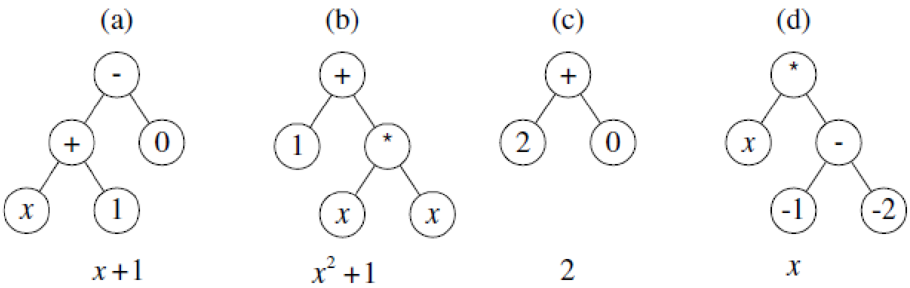


Fig.3.1 Initial population of four randomly created individuals

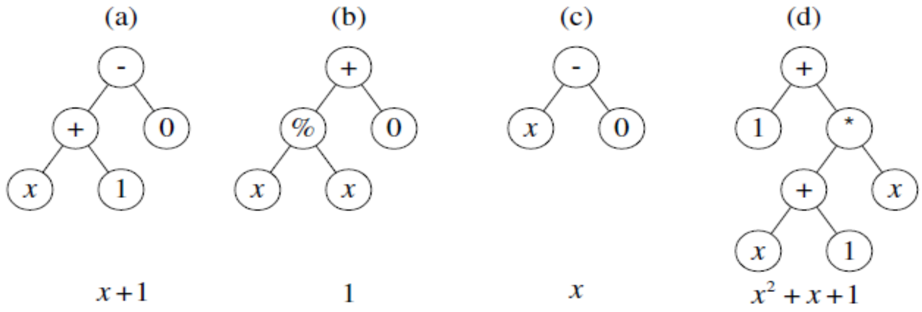


Fig.3.2 New population ((a)after reproduction, (b) after mutation and (c),(d) after crossover operation)

After the above mentioned operations are performed on the current population, the population of offspring (i.e., the new generation) replaces the old population (i.e., the old generation).Each individual in the new population of computer programs is then again measured for fitness, and the process is repeated for many generations. However, the genetic programming is a never ending process and therefore it is required to define some control parameters. Some of the control parameters that are required to be set are as follows:-

1. Population size: A larger population allows a greater exploration of the problem at each generation and increases the chance of evolving a solution.

2. Maximum number of generations: The greater the maximum number of generations the greater the chance of evolving a solution. However, even if after the evolution of a population, a solution is not found then it is better to start again with a different initial population. However if, after a user-defined number of generations, a sufficiently successful individual has not evolved then the process should stop.

3. Probability of crossover is the proportion of the population that will undergo crossover before entering the new population. If the probability of crossover is 0.90 it means that the crossover is performed on 90% of the population for each generation.

4. Probability of reproduction is the proportion of individuals in a population that will undergo reproduction.

Flowchart for the genetic programming paradigm has been presented in figure 3.3. (Koza, 1992)

3.4 ADVANTAGES OF GENETIC PROGRAMMING

A key advantage of GP when compared to traditional modelling approaches is that it does not assume a prior functional form of the solution. For instance, in a typical regression method, the model structure is specified in advance (which is in general difficult to do) and the model coefficients are determined. For neural networks, the time consuming task of initially defining the network structure has to be undertaken and then the coefficients (weights) are found by the learning algorithm. On the other hand, in GP, the building blocks (the input and target variables and the function set) are defined initially, and the learning method subsequently finds both the optimal structure of the model and its coefficients. Moreover, since GP evolves an equation or formula relating to the input and output variables, a major advantage of the GP approach is its automatic ability to select input variables that contribute beneficially to the model and disregard those that do not. GP can thus reduce substantially the dimensionality of the input variables. However, a common limitation of GP is that it cannot handle more numbers of constants. In GP, as in any data-driven prediction model, the selection of appropriate model input is extremely important. Inclusion of irrelevant input parameters leads to poor model accuracy and creation of complex models, which are more difficult to interpret as compared to simpler ones.

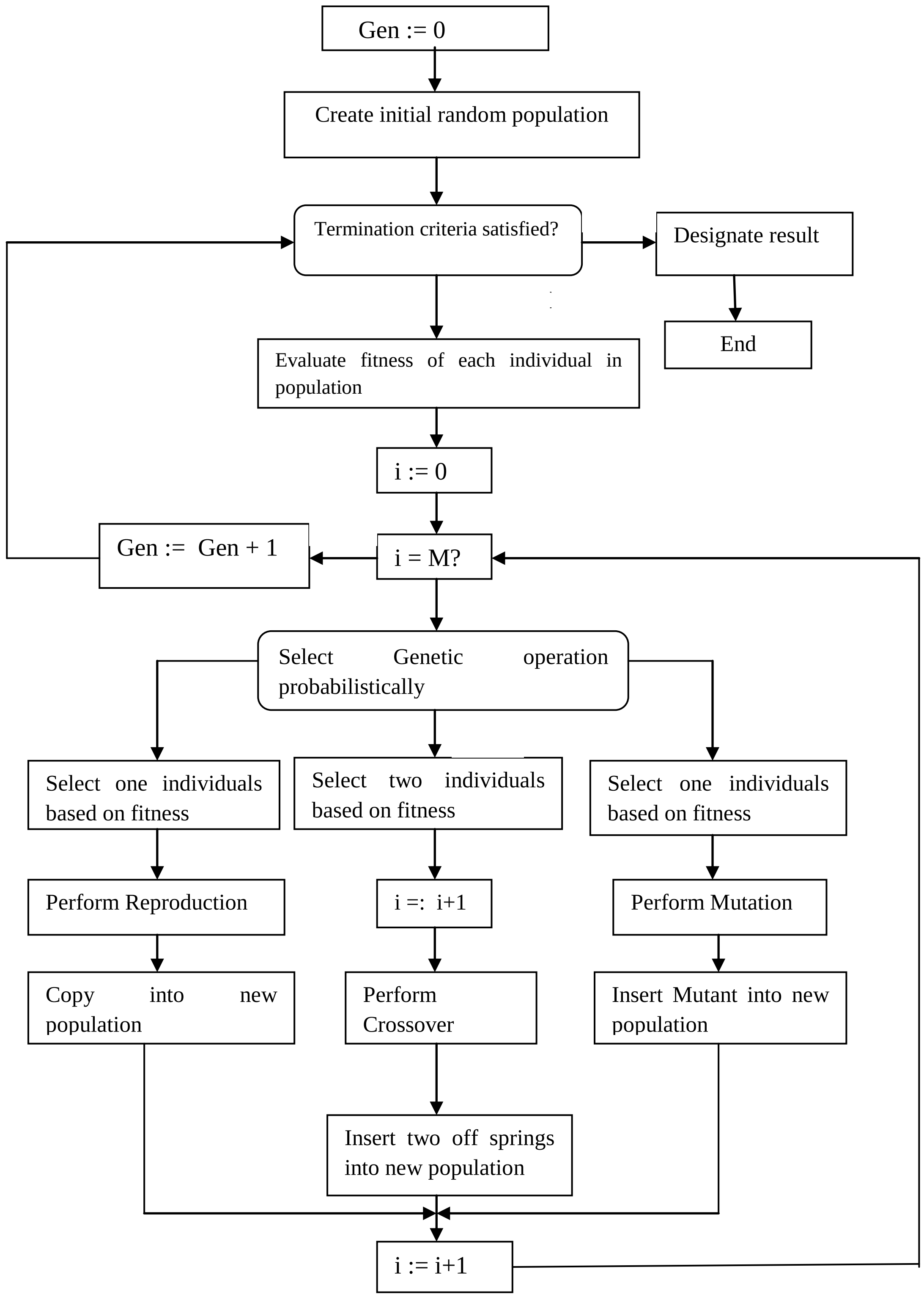


Fig. 3.3 Flowchart of Genetic Programming

CHAPTER – 4

STUDY ON GABLE ROOF BUILDINGS

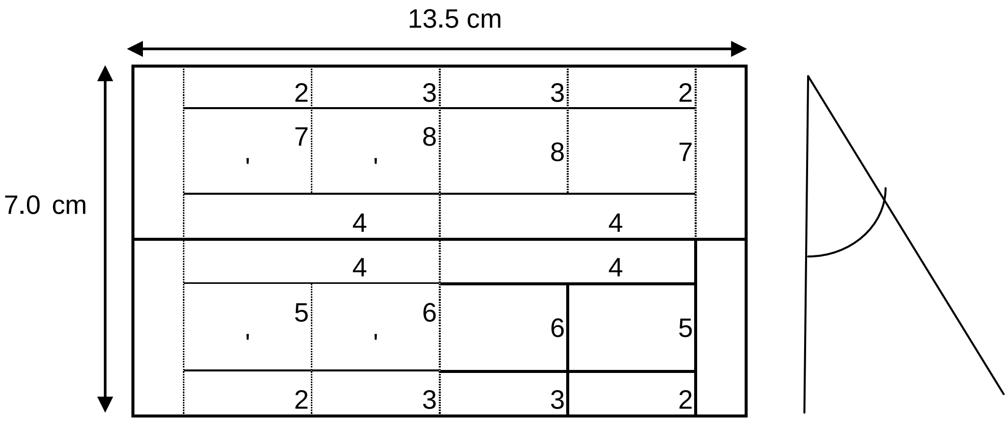
4.1 General

IS code uses wind incidence angle of 0° and 90° for evaluation of wind pressure coefficients. However, it is worth mentioning that oblique wind is also critical for various zones. It has been observed from the studies of Stathopoulos (1984), Eaton et al. (1975), Kumar (1987), Holmes (1983), Stathopoulos & Saathoff (1991) and Ginger & Letchford (1992), that angle of wind incidence has significant effect on the magnitude and distribution of wind pressure on low buildings. Therefore, in the present study wind pressure coefficients for varying angle of wind incidence have been obtained using genetic programming.

4.2 Experimental Data used for the study

Kwatra et al. (2002) carried out wind tunnel tests on a gable roof building (13.5 X 7 X 5 m) with the roof slope varying from 10˚ to 35˚ (with increments of 5˚). Models have been made on a geometric scale of 1:100. The tubing system to measure the surface pressures and the pressure sensor have been appropriately chosen to capture the fluctuating pressures. The roof area has been divided into different zones as per the Indian Standard Code (IS875-1987, Part-3), (refer fig.4.1) with the purpose of making a direct comparison of codal values with those predicted experimentally. Zones 1, 2, 3 and 4 are defined as local pressure zones and zones 5,6,7 and 8 are defined as field zones. For local pressure zones worst pressures emerging from all wind direction from all four quadrants have been considered to be critical. For field zones 5-5′, 6-6′, 7-7′ and 8-8′ worst pressures emerging from all wind directions have been considered to be critical. Tests in the wind tunnel were performed under duly simulated flow conditions for the angle of wind incidence of 0° to 90° with increments of 15°.

Atmospheric surface layer has been developed in the wind tunnel over the building models by controlling the longitudinal turbulence intensity and its small scale turbulence content by using the combination of vortex generators, barrier wall and roughening blocks. The target values for these flow parameters have been fixed on the basis of the findings of Cermak& Cochran (1992) and Tieleman et al. (1997).



θ=Angle of wind incidence, changes from 0° - 90° at increment of 15°
Fig. 4.1 Location of various Zones on the roof building model

The mean velocity and longitudinal turbulence intensity at the eaves height of model have been found to be 8.9 m/s and 19% respectively with the velocity profile index being 0.136. The longitudinal integral scale at the same height has been found to be 0.436m. The value for the small scale turbulence content (Tieleman et al. 1997) has been obtained to be 73. Tieleman et al. (1999) have reported values of the same order for small scale turbulence content in their wind tunnel studies and have reported good correlation between full scale and wind tunnel model results for mean and peak pressure coefficients.

4.3 Application of Genetic Programming for predicting wind pressure coefficients on buildings with varying angle of incidence and roof slopes

The roof slope of the building and angle of wind incidence have been used as the input parameters and the design wind pressure coefficients as the output parameter. The database for various zones has been presented in table 4.1 to 4.8. The equations for design pressure coefficients have been developed using the values of input and output parameters for various combinations of crossover rate, number of generations, population size and number of children to produce. This process is continued until the most accurate equations are obtained by reaching the maximum number of generations. The statistic measures used to assess the accuracy of these equations are Coefficient of Determination (COD) and Root Mean Square (RMS) wherein the objective is to have COD nearly equal to 1 and RMS nearly equal to 0. The actual values of COD and RMS that have been achieved in the development of the equations vary from 0.85 to 0.9 for COD and 0.2 to 0.28 for RMS.

Table-4.1 Table showing the database for Zone 1

theta	i	Cpmin
10	0	-2.4
10	15	-2.25
10	30	-3
10	45	-3.5
10	60	-4
10	75	-3.75
10	90	-3
15	0	-2.15
15	15	-2.25
15	30	-2.75
15	45	-3
15	60	-4
15	75	-3.5
15	90	-3.45
20	0	-1.55
20	15	-1.5
20	30	-2.85
20	45	-2.75
20	60	-2.8
20	75	-3.2
20	90	-3.25
25	0	-1.25
25	15	-1.6
25	30	-1.75
25	45	-2
25	60	-2.75
25	75	-2.8
25	90	-2.75
30	0	-1.5
30	15	-1.5
30	30	-2
30	45	-2.6
30	60	-2.5
30	75	-2.8
30	90	-2.75
35	0	-1.5
35	15	-1.6
35	30	-2
35	45	-2.4
35	60	-2.75
35	75	-2.8
35	90	-2.85

Table-4.2 Table showing the database for Zone - 2

theta	i	Cpmin
10	0	-3.95
10	15	-4.2
10	30	-3.45
10	45	-2.75
10	60	-3
10	75	-3.75
10	90	-2.5
15	0	-3.5
15	15	-3.75
15	30	-3.25
15	45	-2.75
15	60	-3.45
15	75	-2.75
15	90	-2.7
20	0	-2.65
20	15	-2.85
20	30	-2.48
20	45	-2.45
20	60	-2.42
20	75	-2.4
20	90	-2.65
25	0	-1.98
25	15	-1.95
25	30	-1.75
25	45	-2.15
25	60	-2.1
25	75	-2.5
25	90	-2.8
30	0	-1.49
30	15	-1.75
30	30	-1.7
30	45	-1.95
30	60	-2.49
30	75	-2.25
30	90	-3
35	0	-1.5
35	15	-1.65
35	30	-1.9
35	45	-1.75
35	60	-2.25
35	75	-2.5
35	90	-3

Table-4.3 Table showing the database for Zone - 3

theta	i	Cpmin
10	0	-4.5
10	15	-4
10	30	-3
10	45	-2.9
10	60	-2.5
10	75	-1.85
10	90	-1.75
15	0	-3.65
15	15	-3.5
15	30	-3.55
15	45	-2.75
15	60	-2.8
15	75	-1.75
15	90	-1.65
20	0	-2.7
20	15	-2.8
20	30	-2.75
20	45	-2.5
20	60	-2.35
20	75	-1.75
20	90	-1.85
25	0	-1.95
25	15	-1.9
25	30	-1.75
25	45	-1.95
25	60	-2.3
25	75	-2
25	90	-2
30	0	-1.5
30	15	-1.5
30	30	-1.65
30	45	-1.95
30	60	-2.75
30	75	-2.1
30	90	-2.75
35	0	-1.4
35	15	-1.7
35	30	-2.15
35	45	-1.95
35	60	-2.15
35	75	-2.15
35	90	-2.2

Table -4.4 Table showing the database for Zone-4

theta	i	Cpmin
10	0	-2
10	15	-2
10	30	-2.4
10	45	-3.3
10	60	-2.75
10	75	-2.8
10	90	-2.25
15	0	-2.1
15	15	-2.7
15	30	-2.8
15	45	-3.2
15	60	-2.35
15	75	-2.25
15	90	-2.3
20	0	-1.2
20	15	-1.65
20	30	-2.65
20	45	-2.75
20	60	-2.45
20	75	-2.4
20	90	-2.35
25	0	-1.45
25	15	-1.5
25	30	-1.85
25	45	-2.3
25	60	-2.35
25	75	-2.85
25	90	-2.35
30	0	-1.25
30	15	-1.4
30	30	-1.95
30	45	-2.45
30	60	-3
30	75	-2.85
30	90	-2.75
35	0	-1.3
35	15	-1.4
35	30	-1.95
35	45	-2.45
35	60	-2.75
35	75	-2.65
35	90	-2.5

Table -4.5 Table showing the database for Zone-5

theta	i	Cpmin
10	0	-3
10	15	-2.95
10	30	-2.9
10	45	-2.2
10	60	-1.75
10	75	-1.95
10	90	-2.5
15	0	-2.22
15	15	-2.25
15	30	-2.22
15	45	-1.8
15	60	-1.75
15	75	-1.85
15	90	-2.45
20	0	-1.35
20	15	-1.3
20	30	-1.5
20	45	-1.45
20	60	-1.25
20	75	-1.75
20	90	-2.25
25	0	-0.9
25	15	-0.75
25	30	-0.8
25	45	-0.9
25	60	-1
25	75	-2
25	90	-2.25
30	0	-0.7
30	15	-0.75
30	30	-0.9
30	45	-0.85
30	60	-1.7
30	75	-2.2
30	90	-2.45
35	0	-0.5
35	15	-0.7
35	30	-0.75
35	45	-0.8
35	60	-0.95
35	75	-1.95
35	90	-2.3

Table – 4.6 Table showing the database for Zone-6

theta	i	Cpmin
10	0	-3
10	15	-3.25
10	30	-2.75
10	45	-2.5
10	60	-2.2
10	75	-1.35
10	90	-1.5
15	0	-2.5
15	15	-2.9
15	30	-2.7
15	45	-2.5
15	60	-1.95
15	75	-1.2
15	90	-1.5
20	0	-1.6
20	15	-1.85
20	30	-1.8
20	45	-1.75
20	60	-1.7
20	75	-1.2
20	90	-1.8
25	0	-0.8
25	15	-0.7
25	30	-1
25	45	-0.95
25	60	-0.9
25	75	-1.2
25	90	-1.65
30	0	-0.7
30	15	-0.8
30	30	-0.75
30	45	-0.9
30	60	-0.95
30	75	-1.2
30	90	-1.45
35	0	-0.45
35	15	-0.5
35	30	-0.55
35	45	-0.6
35	60	-0.7
35	75	-0.95
35	90	-1.45

Table – 4.7 Table showing the database for Zone - 7

theta	i	Cpmin
10	0	-1.45
10	15	-1.55
10	30	-1.45
10	45	-1.4
10	60	-1.75
10	75	-1.95
10	90	-2
15	0	-1.7
15	15	-1.75
15	30	-1.8
15	45	-1.85
15	60	-1.9
15	75	-2
15	90	-2.3
20	0	-1.65
20	15	-1.5
20	30	-2.2
20	45	-2.35
20	60	-2.3
20	75	-2.1
20	90	-2.45
25	0	-1.2
25	15	-1.65
25	30	-2
25	45	-2.45
25	60	-2.4
25	75	-2.55
25	90	-2.3
30	0	-0.7
30	15	-0.75
30	30	-0.95
30	45	-0.9
30	60	-1.65
30	75	-2.2
30	90	-2.5
35	0	-1.2
35	15	-1.3
35	30	-1.7
35	45	-2.2
35	60	-2
35	75	-2.2
35	90	-2.5

Table-4.8 Table showing the database for Zone-8

theta	i	Cpmin
10	0	-1.7
10	15	-1.75
10	30	-1.5
10	45	-1.25
10	60	-1.4
10	75	-1.25
10	90	-1.45
15	0	-1.75
15	15	-1.75
15	30	-1.65
15	45	-1.8
15	60	-1.6
15	75	-1.55
15	90	-1.5
20	0	-1.25
20	15	-1.55
20	30	-2.2
20	45	-2.5
20	60	-2.25
20	75	-1.9
20	90	-1.75
25	0	-1.45
25	15	-1.2
25	30	-1.7
25	45	-2.25
25	60	-2.75
25	75	-2.3
25	90	-1.55
30	0	-1.3
30	15	-1.3
30	30	-1.7
30	45	-1.95
30	60	-2.7
30	75	-2.5
30	90	-1.75
35	0	-1.15
35	15	-1.55
35	30	-1.45
35	45	-1.85
35	60	-2.2
35	75	-2.3
35	90	-1.65

4.3.1 Comparison of GP results and experimental results

The equations for design pressure coefficients obtained by GP for various zones are presented in Table 4.9.The values of pressure coefficient obtained from these equations are compared with the experimental values for various zones. Typical plots for various zones and for various roof slopes showing the comparison of the design pressure coefficients obtained by GP and the experimental values are presented in fig. 4.2 to 4.9. It can be observed from these plots that the predicted values are more or less matching with the corresponding experimental values. From the comparisons, the maximum error for any angle of incidence and roof slope is observed to be 15%.

Table-4.9 Equations for the pressure coefficients obtained by GP for various Zones

ZONES	EQUATION OBTAINED BY GP
Zone- 1	$C_{pmin} = -\frac{\left[\left(\frac{17.8}{0.5+i}\right)+(3.9+1.44\theta+4.4i)\right]}{i+2\theta}$
Zone- 2	$C_{pmin} = -\frac{\left\{\left(\frac{185.19+2i}{\theta}\right)-\left[\left(\frac{\theta^{3}*i^{2}}{6.6*10^{2}}\right)+61.33\right]\right\}}{\theta}$
Zone- 3	$C_{pmin} = -\frac{\left\{\left[\frac{(\theta^{4}+24.5\theta^{3})i}{649(33.9+\theta)(2\theta+i)}\right]+58.6\right\}}{\left(\frac{2i+24.5+\theta}{\theta}\right)+\theta}$
Zone- 4	$C_{pmin} = -\frac{\left\{\left[\frac{(5.6i+\theta+32.4)(29.4i+\theta*i)}{i^{2}+63.7\theta+1008.42}\right]+10+\theta\right\}}{\theta+i}$
Zone- 5	$C_{pmin} = -\left\{\left[\frac{10(16-\theta)}{i+17.5+\left(\frac{41i^{2}}{800\theta}\right)}\right]+\frac{\theta}{9}\right\}$
Zone- 6	$C_{pmin} = \frac{\left\{-85-\left[\frac{(2i+\theta+9)\theta}{174.24}\right]+2\theta+\frac{6i}{\theta}\right\}}{\theta+9}$
Zone- 7	$C_{pmin} = -\left\{\left[i\left(\frac{60\theta}{3782}\right)\right]+\left[\frac{(2\theta^{2}-57\theta+52)(1+\theta)}{(2\theta-57)[(i-2\theta)(\theta+\theta^{2})]}\right]\right\}$

Zone- 8	$C_{pmin} = \left\{ \left[3 - \frac{\theta}{\left(\frac{10\theta + 30.6}{4.6(2\theta + 5.2)}\right) + 17.7 + i} \right] \left[\frac{4.6}{\theta + 5.2} - 0.9 \right] \right\}$

** i- angle of wind incidence, θ- roof slope, Cpmin – design pressure coefficient

Zone-1

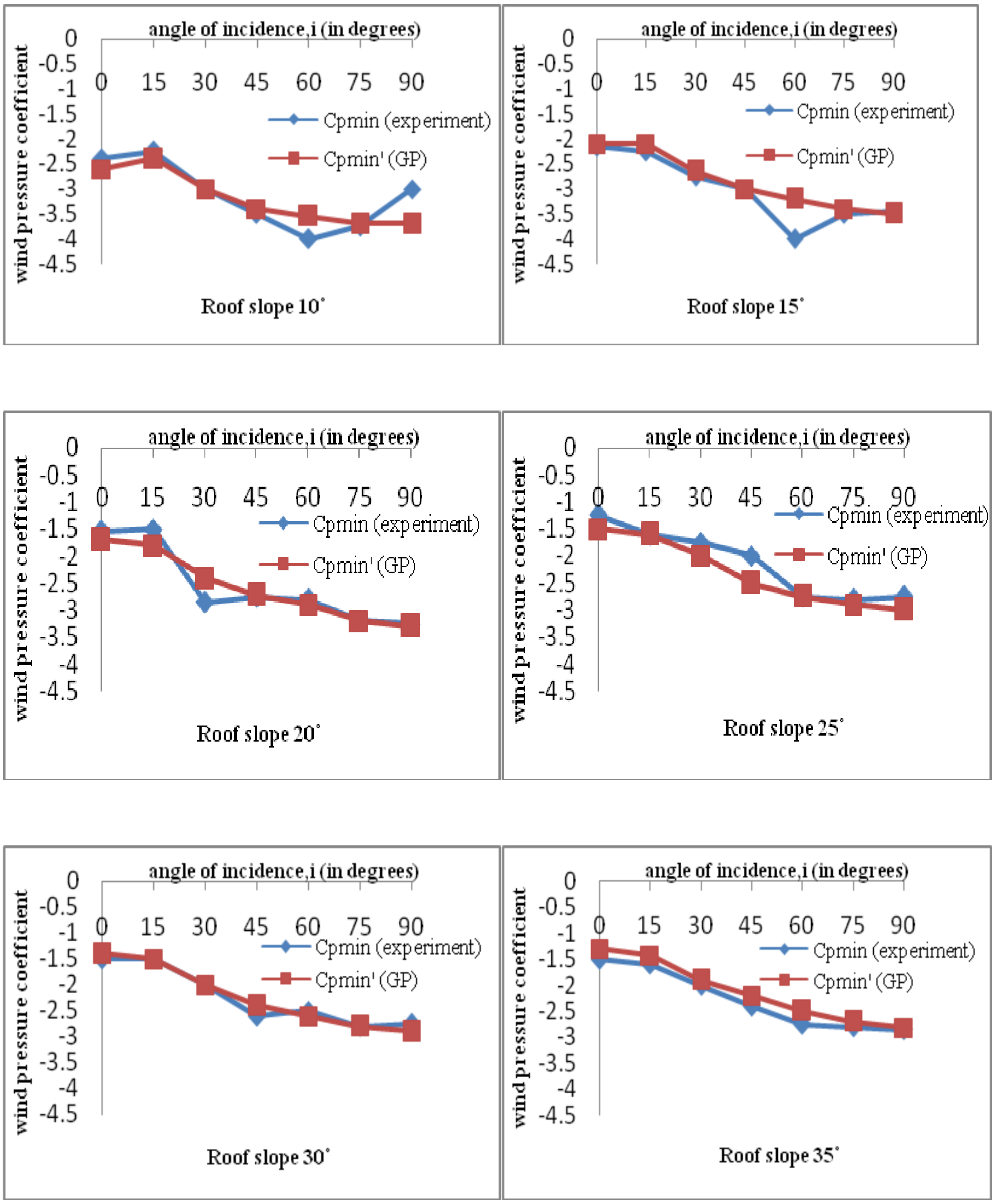


Fig.4.2 Comparison of Cpmin obtained by experiment and predicted by GP for varying angle of incidence and roof slopes

Zone -2

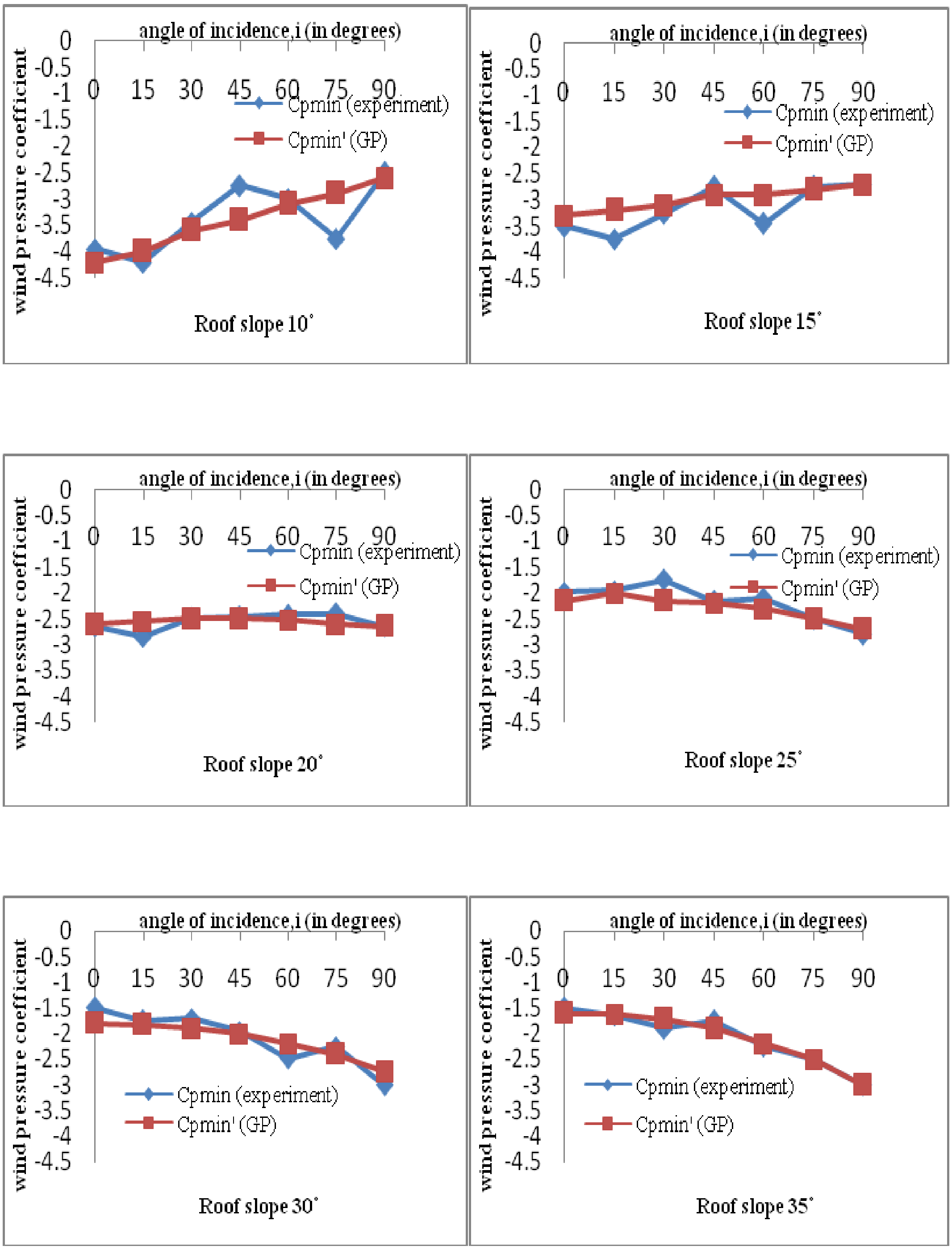


Fig.4.3 Comparison of Cpmin obtained by experiment and predicted by GP for varying angle of incidence and roof slopes

Zone-3

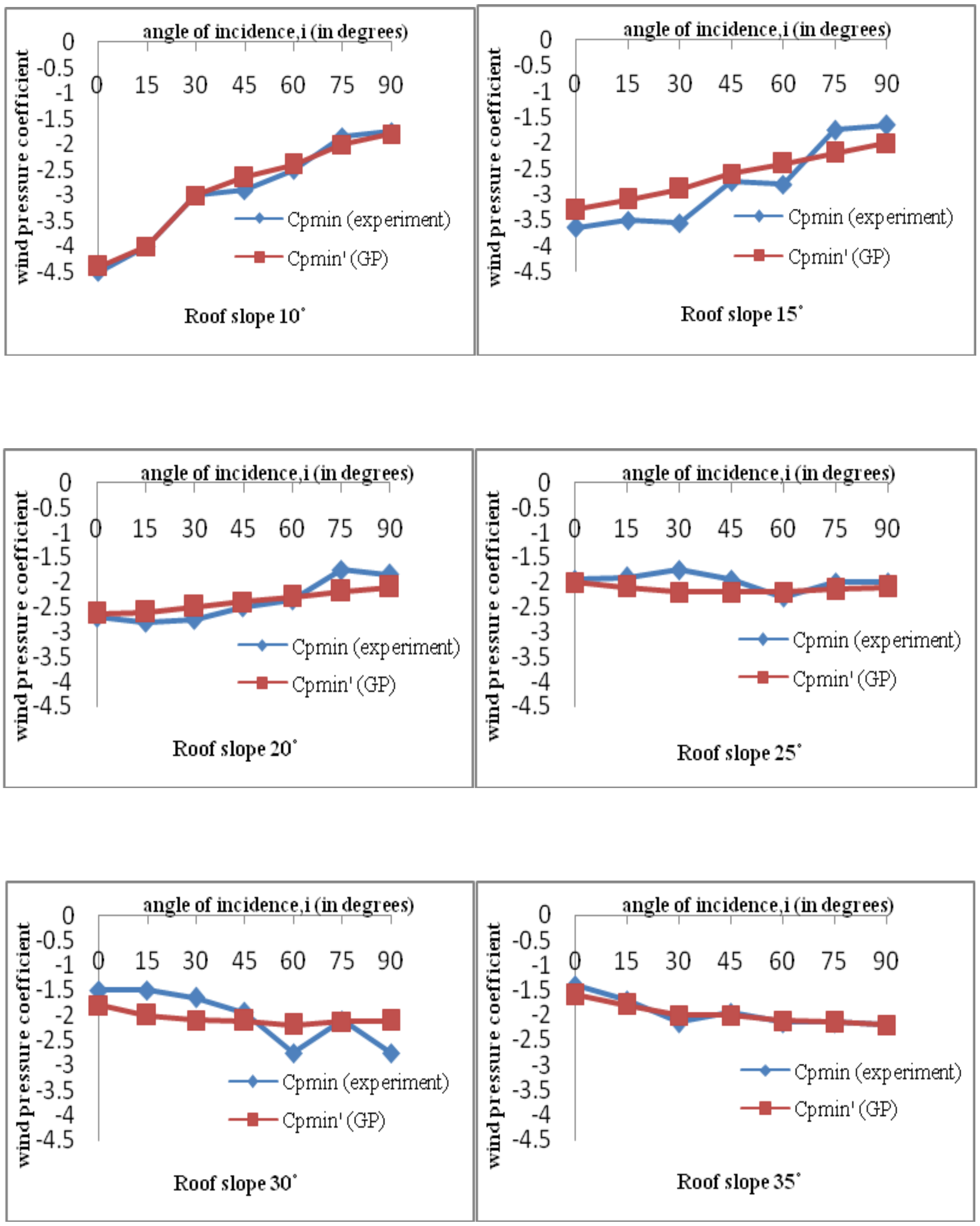


Fig.4.4 Comparison of Cpmin obtained by experiment and predicted by GP for varying angle of incidence and roof slopes

Zone – 4

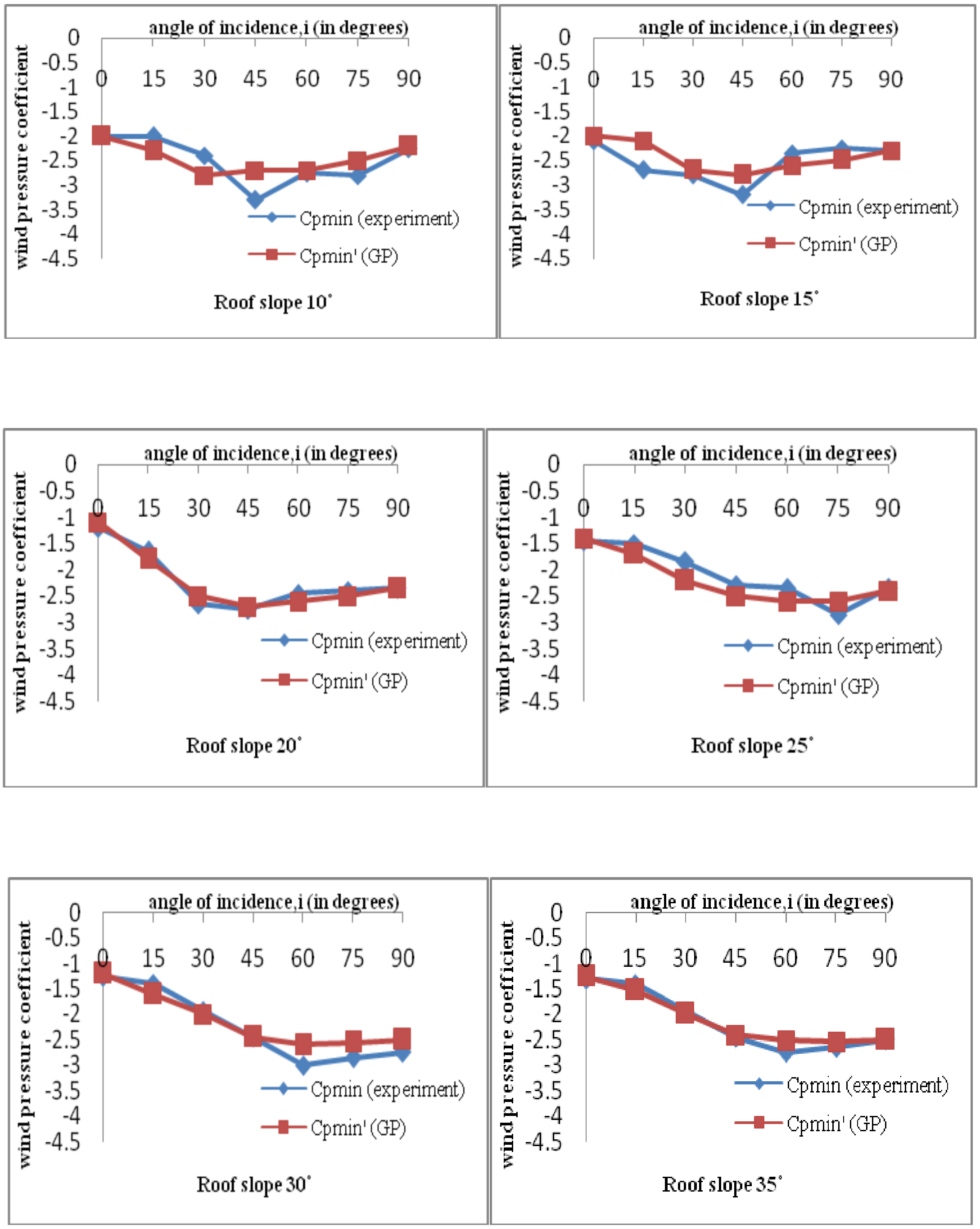


Fig.4.5 Comparison of Cpmin obtained by experiment and predicted by GP for varying angle of incidence and roof slopes

Zone – 5

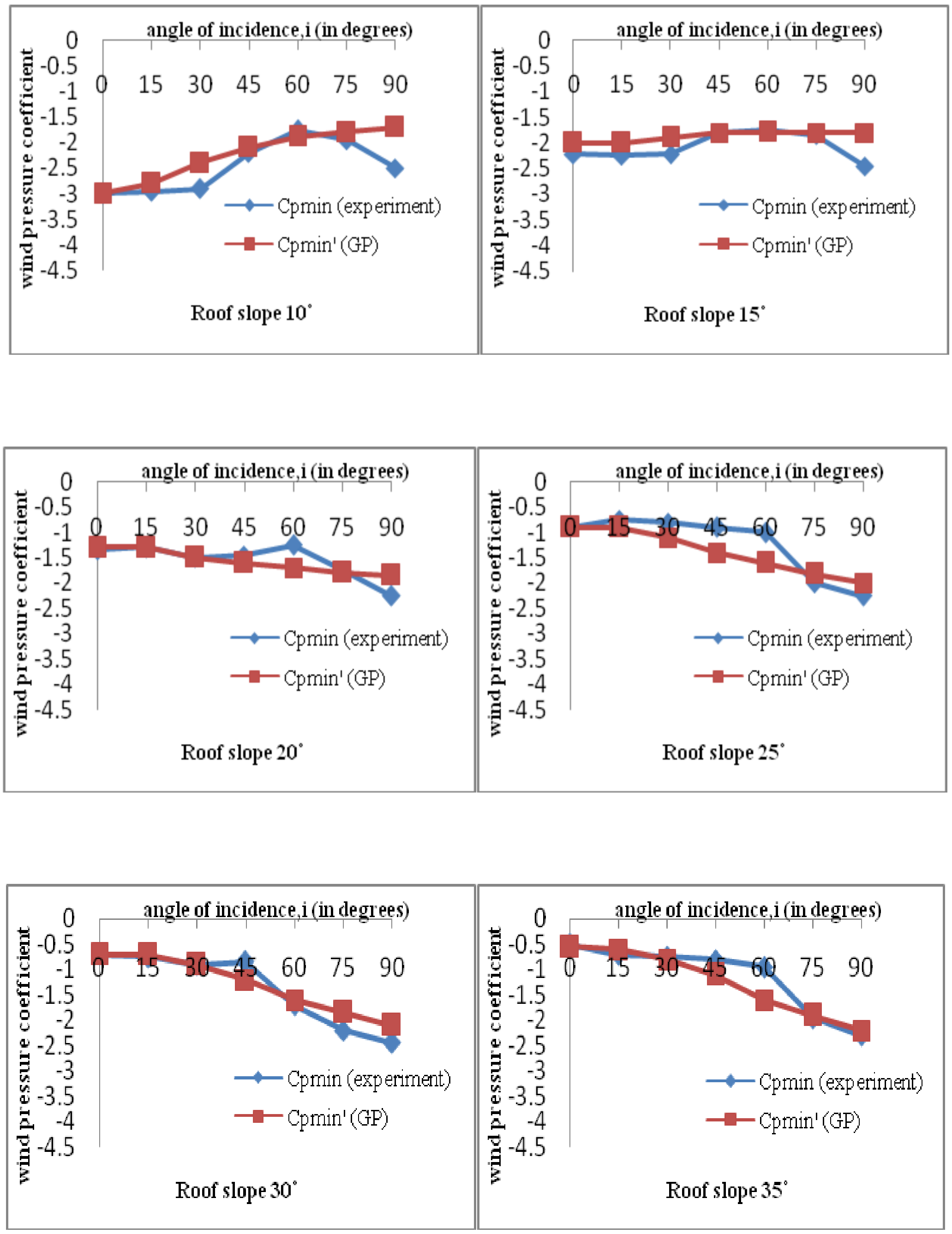


Fig.4.6 Comparison of Cpmin obtained by experiment and predicted by GP for varying angle of incidence and roof slopes

Zone – 6

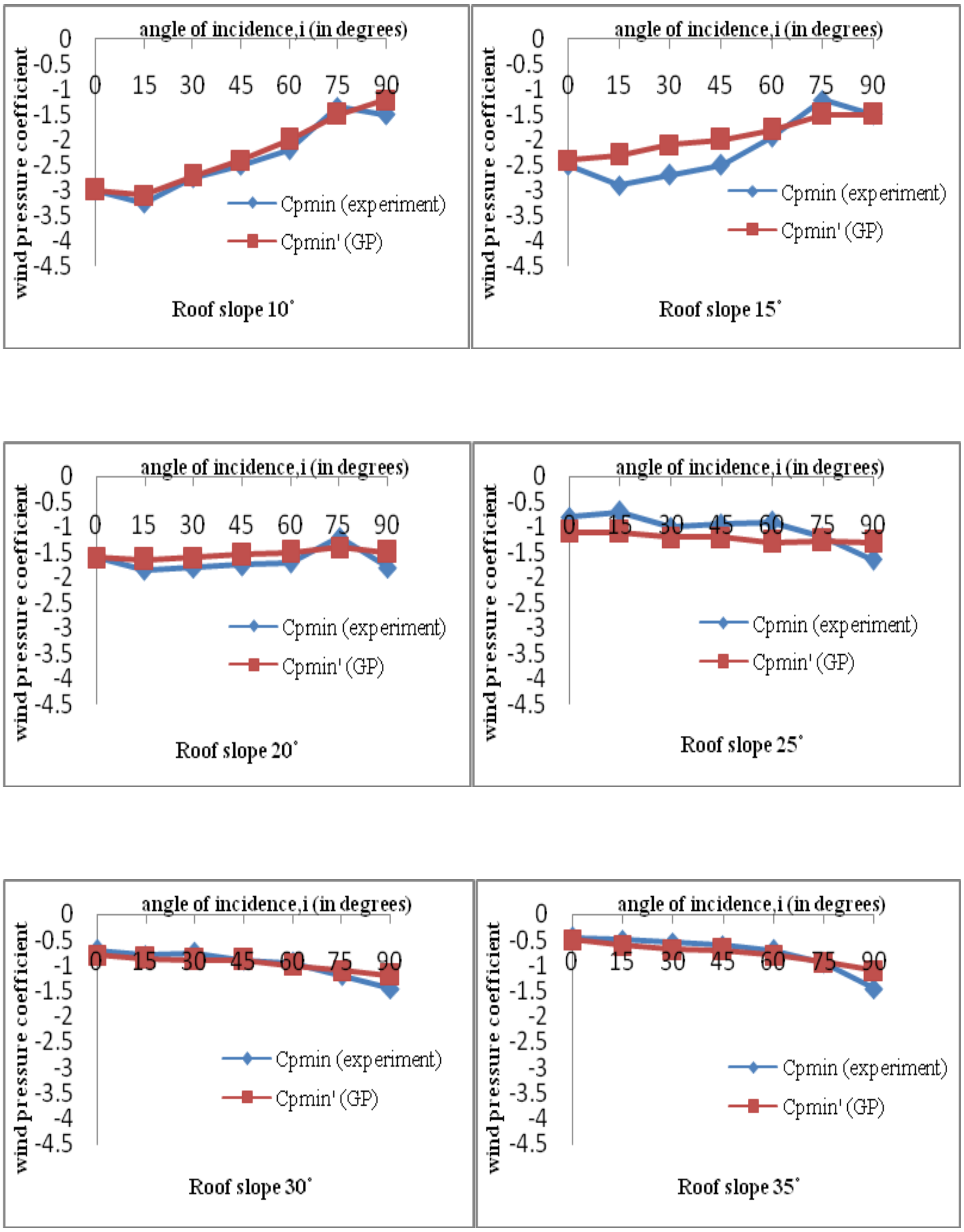


Fig.4.7 Comparison of Cpmin obtained by experiment and predicted by GP for varying angle of incidence and roof slopes

Zone-7

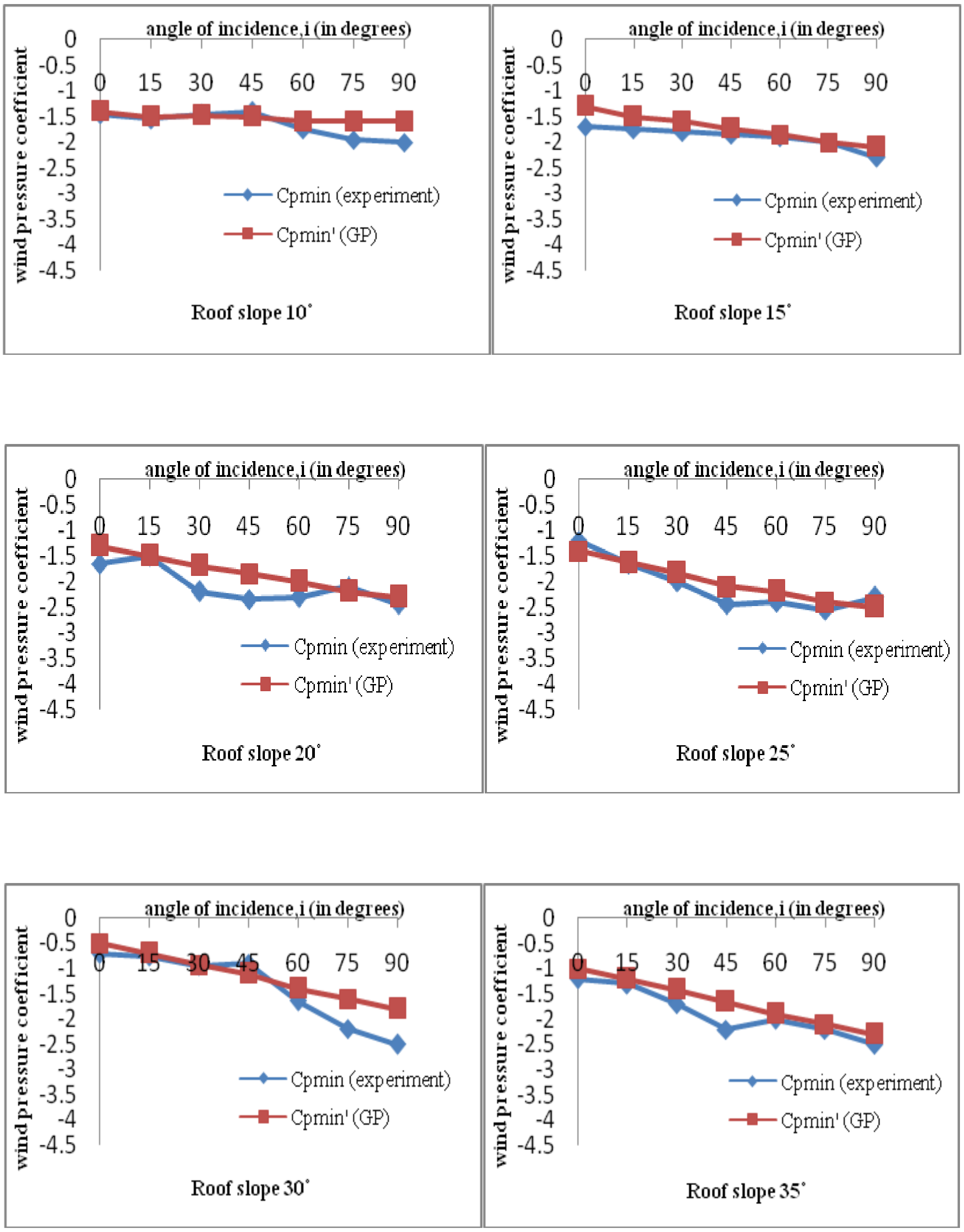


Fig.4.8 Comparison of Cpmin obtained by experiment and predicted by GP for varying angle of incidence and roof slopes

Zone – 8

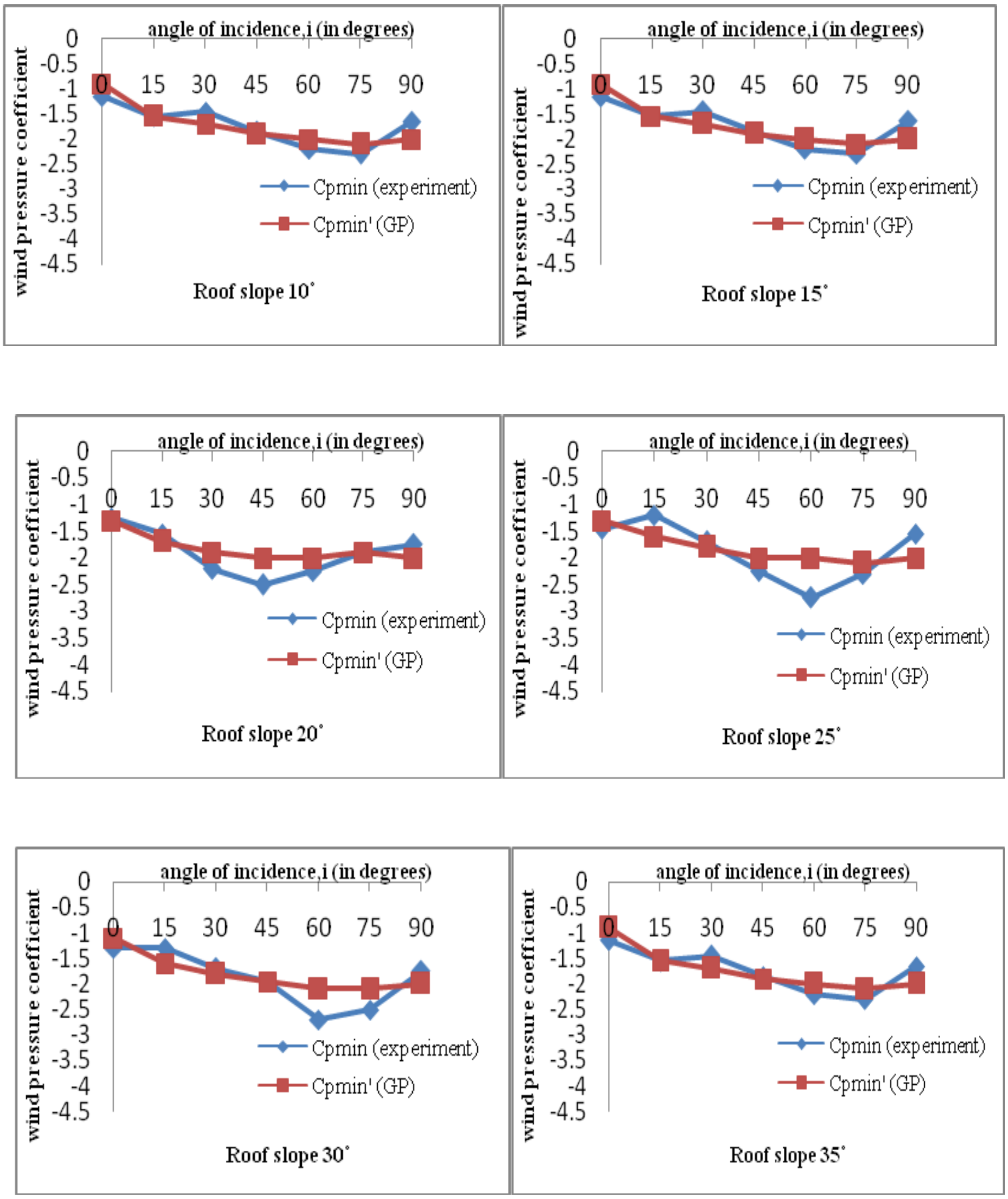


Fig.4.9 Comparison of Cpmin obtained by experiment and predicted by GP for varying angle of incidence and roof slopes

4.4 Application of Genetic Programming for predicting wind pressure coefficients on buildings for all azimuths

The roof slope of the building is used as the input parameter and the design wind pressure coefficients as the output parameter. The database for various zones has been presented in table 4.10 to 4.17. The equations for design pressure coefficients for all azimuths have been developed using the values of input and output parameters for various combinations of crossover rate, number of generations, population size and number of children to produce. This process is continued until the most accurate equations are obtained by reaching the maximum number of generations. The statistic measures used to assess the accuracy of these equations are Coefficient of Determination (COD) and Root Mean Square (RMS) wherein the objective is to have COD nearly equal to 1 and RMS nearly equal to 0. The actual values of COD and RMS that have been achieved in the development of the equations vary from 0.9 to 0.99 for COD and 0.01 to 0.02 for RMS.

Table – 4.10 Table showing the database for Zone-1 for all azimuths

theta	Cpmin
10	-3.75
15	-4
20	-3.25
30	-2.8

Table – 4.11 Table showing the database for Zone -2 for all azimuths

theta	Cpmin
10	-4.2
15	-3.75
20	-2.85
30	-3

Table – 4.12 Table showing the database for Zone -3 for all azimuths

theta	Cpmin
10	-4.5
15	-3.65
20	-2.8
30	-2.75

Table – 4.13 Table showing the database for Zone -4 for all azimuths

theta	Cpmin
10	-3.3
15	-3.2
20	-2.75
30	-3

Table – 4.14 Table showing the database for Zone -5 for all azimuths

theta	Cpmin
10	-3
15	-2.45
20	-2.25
30	-2.45

Table – 4.15 Table showing the database for Zone -6 for all azimuths

theta	Cpmin
10	-3.25
15	-2.9
20	-1.85
30	-1.45

Table – 4.16 Table showing the database for Zone -7 for all azimuths

theta	Cpmin
10	-2
15	-2.3
20	-2.45
30	-2.5

Table – 4.17 Table showing the database for Zone -8 for all azimuths

theta	Cpmin
10	-1.75
15	-1.8
20	-2.5
30	-2.7

4.4.1 Comparison of GP results and experimental results

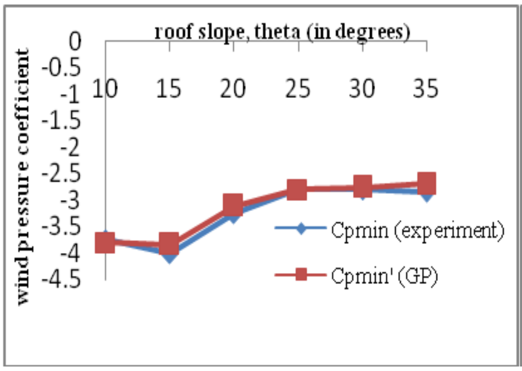
The equations obtained by GP for all azimuths for various zones are presented in Table 4.18. The values obtained by these equations are also compared with the experimental values for various zones and are presented in fig.4.10. From these comparisons it is observed that the values of Cpmin for all zones for the roof slopes 10˚, 15˚, 20˚ and 30˚ match perfectly with the experimental values as they were being used by the programme. However the predicted values of Cpmin for all the zones for the roof slopes 25˚ and 35˚ are also observed to be in close agreement with the experimental values. The maximum error found for the predicted values of Cpmin for roof slopes 25˚ and 35˚ is around 8% for all zones.

Table-4.18 Equations for the pressure coefficients obtained by GP for various Zones for all azimuths

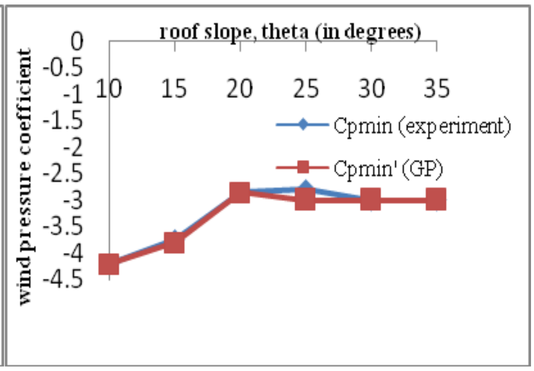
ZONES	EQUATION OBTAINED BY GP
Zone- 1	$C_{pmin} = -3.5 + \left\{\frac{\theta^2 - 26\theta + 156}{\theta^2 - 22\theta + 132}\right\}$
Zone- 2	$C_{pmin} = \left\{\left[\frac{\theta^2 - 2.03\theta}{-\theta^2 + 0.03\theta + 4}\right] - 1.78\right\}\left(\frac{\theta}{\theta - 3.42}\right)$
Zone- 3	$C_{pmin} = -\frac{\left\{\left[\left(\frac{6\theta}{36-\theta}\right) + \left(\frac{-405\theta^2 + 3736\theta - 90}{81\theta - 9\theta^2}\right)\right] + 6\right\}}{\theta}$
Zone- 4	$C_{pmin} = \left[\left(\frac{2\theta^2 - 101\theta - 38}{38\theta^2}\right) - \left(\frac{\theta - 25}{2\theta^2 - 38\theta}\right)\right] - 3$
Zone- 5	$C_{pmin} = -\left[\frac{(26\theta^2 - 162\theta + 1782)(198 - 9\theta)}{9\theta(-9\theta^2 + 199\theta)}\right]$

Zone- 6	$C_{pmin} = \dfrac{\left\{\dfrac{-\left[\left(22-\dfrac{15}{\theta-16}\right)(20-\theta)\right]}{35+\theta}-\theta-17\right\}}{\theta}$
Zone- 7	$C_{pmin} = \left[\dfrac{4\theta^2+26\theta+1.5}{\theta^3}\right]-2.667$
Zone- 8	$C_{pmin} = \left\{\left[\dfrac{(-2.8\theta^2+0.173\theta^3)(0.12\theta^2-0.12\theta-0.24)}{(0.0571\theta^2-0.794\theta-2.5)(-0.12\theta^3-2.48\theta^2+0.24}\right.\right.$

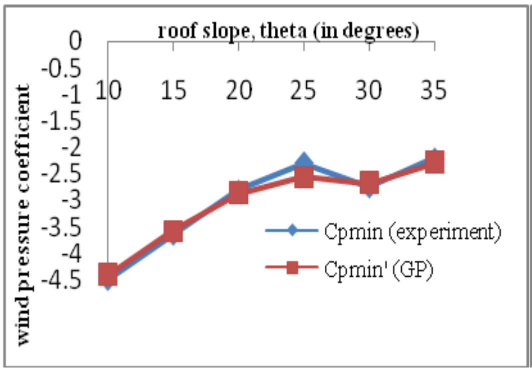
** θ- roof slope, Cpmin – design pressure coefficient



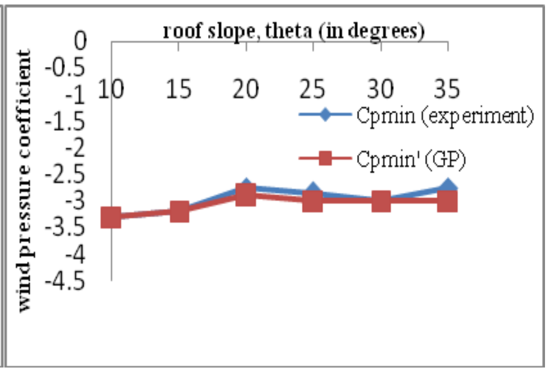
Zone-1



Zone-2



Zone-3



Zone-4

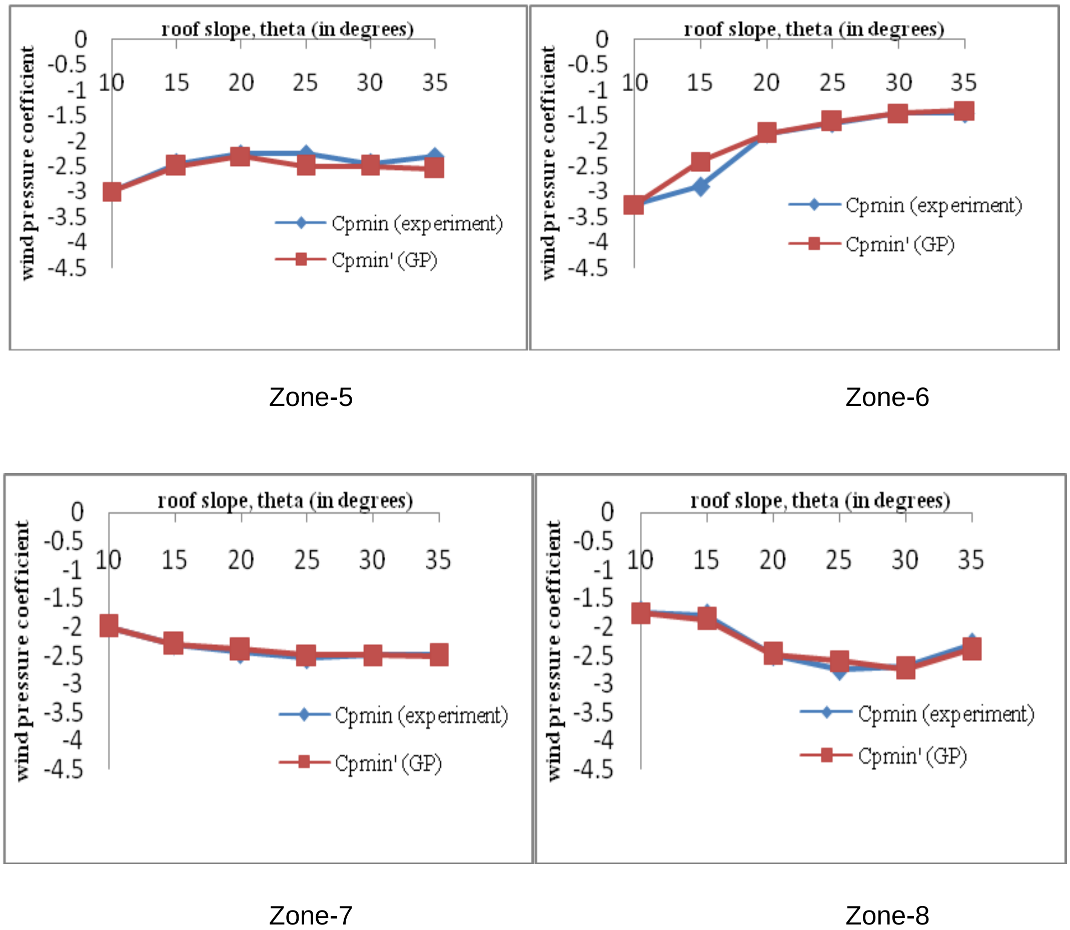


Fig.4.10 Comparison of Cpmin obtained by experiment and predicted by GP for all azimuths

4.5 Comparison of Values of Wind Pressures Coefficients Obtained by Genetic Programming with IS Code (IS 875- Part 3, 1987)

In this study the values of minimum pressure coefficients (Cpmin) for different zones of the building roof obtained by equations generated by genetic programming are compared with the corresponding values given in the Indian Standard Code (IS 875- Part 3, 1987). The values of design pressure coefficients in the Indian Standard Code are referred to as the dynamic velocity pressure corresponding to 3-second gust speed. The values of pressure coefficients obtained from the experiment which are used to obtain the values using GP are based on mean hourly wind speed. The 3-second gust speed has been taken as 1.5 times the mean hourly wind speed, based on IS 875- part 3, 1987. Therefore, the pressure coefficients obtained by GP are divided by a factor 2.25 ($=1.5^2$) so that they correspond to 3-second gust speed, in order to permit a direct comparison with the codal values.

In the Indian Code, the roof of the gable building is divided into eight different zones. Zone 1,2,3 and 4 are referred as zone of local pressure where as zone 5,6,7 and 8 are referred as zones of other than local pressure. For local pressure zones all azimuth values of Cpmin emerging have been considered for comparison as Indian Code does not specify any critical wind direction for these zones. Whereas for other than local pressure zones, pressure coefficients corresponding to wind directions perpendicular to ridge and parallel to ridge have been considered for comparison as these wind directions are considered critical for these zones in the Indian Code.

4.5.1 Comparison for Local Pressure Zones

Comparison of values of Cpmin obtained by GP with the values specified in the Indian Code for local pressure zones are presented below:

(a) Zone-1

It can be seen from fig. 4.11(a) that the values of Cpmin obtained by GP are almost similar to the codal values. However, for roof slope 10˚ the value obtained by GP is lower than the codal value with an error of 10%.

(b) Zone-2

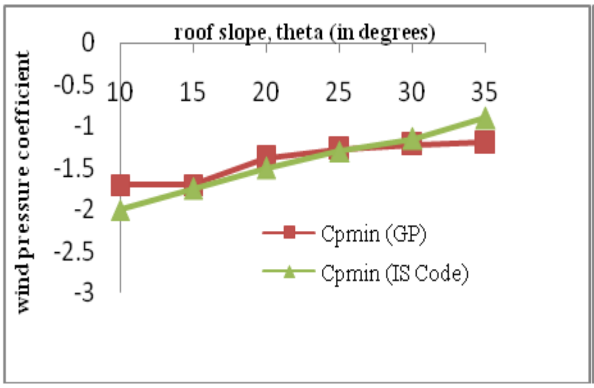
It can be seen from fig. 4.11(b) that the values of Cpmin obtained by GP are found to be lower for roof slope 20˚ with an error of 10% and for roof slopes 30˚ and 35˚ the values obtained by GP are larger than the codal values with a maximum error of 25%, whereas for roof slopes 10˚, 15˚ and 25˚ the values of GP match perfectly with the codal values.

(c) Zone-3

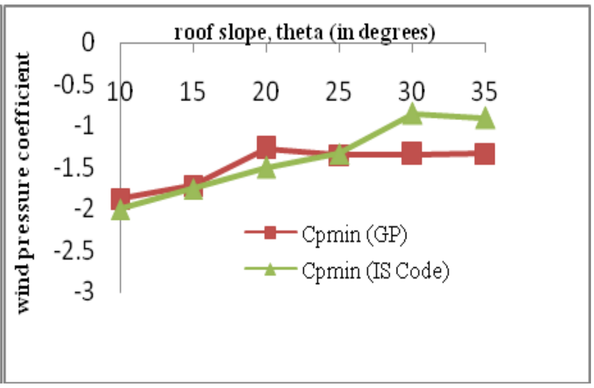
From fig. 4.11(c) it is evident that the values of Cpmin obtained by GP are larger than the codal values by a maximum error of 25% except for roof slope 20˚ where it is observed that the value of Cpmin by GP is lower than the codal value with an error of 15%.

(d) Zone-4

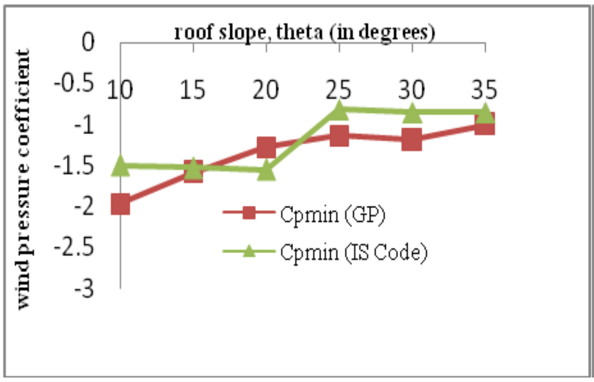
It is observed from fig. 4.11(d) that for all roof slopes the values of Cpmin obtained by GP are of the same order but larger than the codal values with a maximum error of 25%.



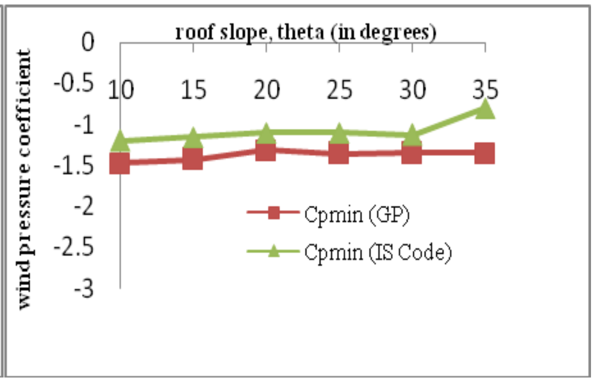
(a) Zone-1



(b) Zone-2



(c) Zone-3



(d) Zone-4

Fig. 4.11 Comparison of Cpmin for different zones of Local Pressure with Indian Standard Code (IS 875- part 3, 1987)

4.5.2 Comparison for other than Local Pressure Zones

In the Indian Code contrary to local pressure zones, wind approaching prependicular to ridge (angle of wind incidence 0˚) has been considered critical for zone 5,6 (windward side) and zone 7,8 (leeward side), whereas wind approaching parallel to the ridge (angle of wind incidence 90˚) has been considered critical for zone 5,7 and for zone 6,8. For both the cases values of minimum pressure coefficient (Cpmin) for the corresponding angle of wind incidence has been considered for comparison with the values of Indian Code. Comparison of values of Cpmin obtained by GP with the values specified in the Indian Code for other pressure zones for wind approaching prependicular to ridge and parallel to ridge are presented below:

4.5.2.1 Wind Approaching Prependicular to Ridge

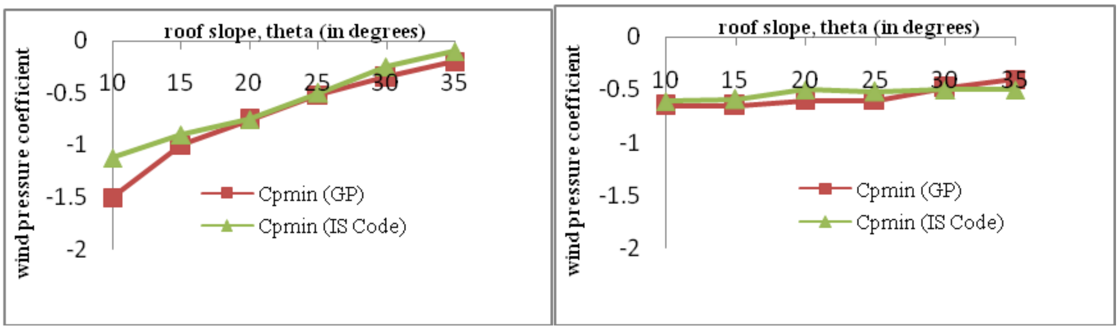
It can be seen from fig. 4.12 (a) that for zone-5 and zone-6, the values of Cpmin obtained by GP are almost similar to the codal values for all roof slopes except for roof slope 10˚ for which the value of Cpmin by GP is larger than the codal value with an error of 20%.

Also it can be observed from fig. 4.12 (b) that for the zone-7 and zone-8, the values of Cpmin obtained by GP are same as that of the codal values for all roof slopes.

4.5.2.2 Wind Approaching Parallel to Ridge

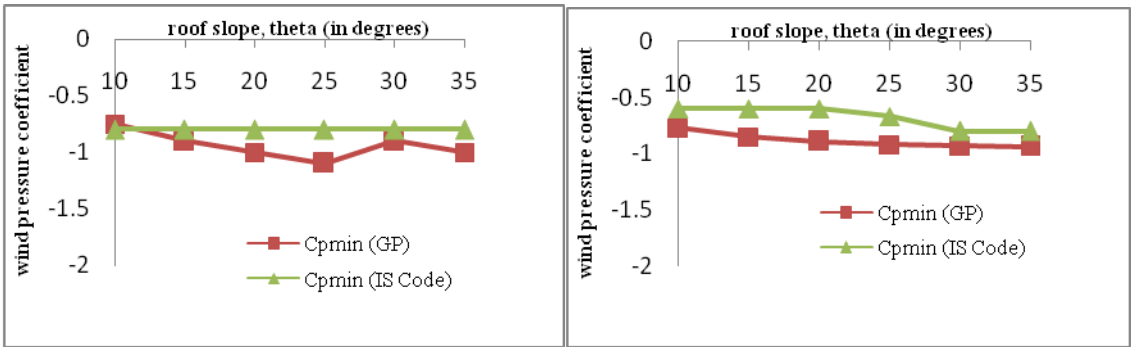
It can be observed from fig.4.13 (a) that for zone-5 and zone-7, the values obtained by GP are approximately similar to the codal values for roof slopes upto 10˚, 15˚, 30˚ and 35˚. For roof slopes 20˚ and 25˚ the values of Cpmin by GP are higher than the codal values with a maximum error of 20%.

It is also observed from fig. 4.13 (b) that for zone-6 and zone-8, the values of Cpmin are approximately similar to the codal values for roof slopes upto 10˚, 30˚ and 35˚. However, for roof slopes 15˚, 20˚ and 25˚ the values of Cpmin by GP are higher than the codal values with a maximum error of 30%.



(a) Zone-5,6 (b) Zone-7,8

Fig.4.12 Comparison of Cpmin for different zones of (Other than Local Pressure) with Indian Standard Code (IS 875- part 3, 1987) for angle of wind incidence = 0˚



(a) Zone-5,7 (b) Zone-6,8

Fig.4.13 Comparison of Cpmin for different zones of (Other than Local Pressure) with Indian Standard Code (IS 875- part 3, 1987) for angle of wind incidence = 90˚

CHAPTER – 5

STUDY ON TALL BUILDINGS

5.1 General

Researchers have laid down several analytical procedures for the evaluation of wind loads on tall buildings. Also, a simulated wind tunnel experiment on an appropriate model of the building yields results which give a deeper insight into the phenomenon and provides more precise information, overcomes the shortcomings of the analytical formulation. However, in the present study an attempt has been made using Genetic Programming to minimise the effort involved in the analytical analysis as well as the wind tunnel testing for evaluation of wind loads. The analytical approach given by A.G. Davenport as mentioned in IS875-1987, Part-3 has been used for the development of the database for the estimation of Gust Factor and Base Moment caused due to the along wind direction on tall buildings and has been discussed in detail.

5.2 Analytical Data used in the Study

The data used for the development of equations using GP consists of the plan dimensions of the building, height of the building, design wind speed (Vz), gust factor and the base moment. The plan dimensions considered are (30 X 30)m, (40 X 40)m and (50 X 40)m for various heights such as 180m, 200m, 230m and 250m. The design wind speeds used have been calculated for the various basic wind speeds for terrain conditions for category 2 & 3 as mentioned in IS875-1987, Part-3. Subsequently, gust factor and base moments have been calculated as per the analytical approach mentioned in IS875-1987, Part-3 given by A.G. Davenport which has been discussed below. Table 5.1 is an example of the excel sheet used for the estimation of gust factor and base moment of a 200m tall building for long after body orientation.

5.2.1 DAVENPORT'S GUST FACTOR APPROACH

Let us consider a tall slender building of height 'h', being exposed to mean wind speed V_h at top. Then the mean wind pressure near the top of building is given by:

$$P_H = \frac{1}{2}\rho_a C_D V_H^2$$

Where,

ρ_a =The air density is affected by altitude and depends on the temperature and pressure to be expected in the region during wind storms. Unless otherwise specified, the value of ρ_a shall be 1.208 kg/m3.

C_D= is Drag or force co-efficient of structure, depending up on the shape and size (Aspect ratio) of building.

The mean wind velocity variation with height is assumed to follow a Power law, as given by equation:

$$Vz / V_G = (Z / Z_G)^{\alpha}$$

Where,

V_z is the means wind velocity at height Z,

V_G is the mean velocity at the gradient height,

α is power law coefficient

Here coefficient α depends up on the roughness of the upstream terrain to which the building is exposed.

It follows from the nature of the wind that a structure exposed to wind will experience a steady wind load associated with the mean wind velocity and a fluctuating component associated with the gust and turbulence.

An empirical expression obtained from measurements suggested by Davenport (1961a) has the non dimensional form:

$$\frac{fS_u(f)}{\bar{V}_{10}} = \frac{4.0kX^2}{\left[1+X^2\right]^{4/3}}$$

where,

$$X = \left(\frac{n_o L}{\bar{V}_h}\right)$$

In which $S_u(f)$ is the power spectral density of wind fluctuations at frequency n_o, V_{10} is a reference wind velocity taken at 10m height, L is a length scale which is approx. 1200m, and 'k' is the Drag co-efficient of terrain defined in Davenport(1961a&b)

Davenport showed that the average largest response during a period 'T' is given by:

$$X_{max} = \bar{X} + g_f \sigma_x$$

where,

$\bar{X}$ is the response to mean wind load, and

g_f is the peak factor

$$g_f = \sqrt{2\log_e vT} + \frac{0.577}{\sqrt{2\log_e vT}}$$

Where ν is the number of times the mean value is crossed per unit time. For a lightly damped system ν = n_o, the natural frequency of the system. Davenport has suggested 600secs to 3600secs as the appropriate averaging period 'T', considering the spectral gap in the wind spectrum. Now the important parameters to be evaluated are the mean response ($\bar{X}$), RMS response (σ_x), and the peak factor (g_f). From the above equations

$$\frac{X_{max}}{\bar{X}} = 1 + g_f \frac{\sigma_x}{\bar{X}}$$

This gives,

$$G = 1 + g_f \frac{\sigma_x}{\bar{X}}$$

Where G, called 'Gust Factor', is the ratio of expected maximum response to the mean response.

Now,

$$F_h = G\ A_e\ C_f\ P_z$$

Where, F_h is Force, A_e is effective frontal area at ht 'z'.

Therefore, Base Moment, M is given as

$$M = F_h\ z$$

5.2.2 Based upon the above Analytical Analysis the Analytical Response of a Building using Davenport's Gust factor method and Codal procedure is given below

Given:-

α	=	0.14	
z (ref)	=	10	m
Plan length	=	40	m
Plan width	=	40	m
Height of building	=	200	m
Bulk density	=	400	Kg/m^3
Face width	=	40	m
Face depth	=	40	m
Interval	=	10	m

Natural period = 3.37 sec

Critical damping = 0.035

Calculation:-

From code V_b = 55 m/sec

K_1 = 1

K_2 = 0.67 (At 10m from Table-33)

K_3 = 1

V_{ref} (at 10m) = $V_b * K_1 * K_2 * K_3$

= 55*1*0.67*1

= 36.85 m/sec

At top of building

K_1 = 1

K_2 = 1 (At 200m from Table-33)

K_3 = 1

V_z = 55*1*1*1

V_z = 55 m/sec

V_z / V_G = $(Z / Z_G)^{\alpha}$

Vz = $V_G (Z / Z_G)^{\alpha}$

= $36.85\ (150/10)^{0.14}$

= 56.1 m/sec

Pz = $0.6(V_z)^2$

= $0.6*(56.1)^2$

= 1885.01 N/m^2

Calculation for Gust Factor, (G)

T	=	3600	sec
Building frequency n_0	=	1/Natural period	
	=	1/3.37	
	=	0.296	Hz
m_0	=	building mass/m height	
	=	ρ_b*B*D	
	=	400*40*40	
	=	640000	Kg/m
M_0	=	Generalized mass in 1^{st} mode	
	=	1/3 m_0 H	
	=	1/3*640000*200	
	=	$4.2*10^7$	Kg
g_f	=	is the peak factor, given by	
g_f	=	$\sqrt{2\log_e vT} + \frac{0.577}{\sqrt{2\log_e vT}}$	
gf	=	(2*logn n_0T)0.5+0.577/(2*logn n_0T)0.5	
gf	=	3.889	
C_f from graph	=	1.45	
K_0	=	Generalized stiffness in 1^{st} mode	
K_o	=	$4\pi^2$ Mo n_o^2	
	=	$4*3.14^2*4.2*10^7*0.296^2$	

	=	148165879 N/m
L_h	=	From graph (IS-Code)
	=	2200
X	=	$\left(\frac{n_o L_h}{\bar{V}_h}\right)$
X	=	0.296*2200/56.1
X	=	11.60
Gust energy ratio	=	$E = \frac{(X)^2}{\{1+(X)^2\}^{\frac{4}{3}}}$
E	=	$11.60^2/ (1+11.60^2)^{4/3}$
E	=	0.193
ξ_0	=	reduced frequency,
ξ_0	=	$\frac{hn_o}{\bar{V}}$
ξ_0	=	200*0.296/56.1
	=	1.055
S	=	is size reduction factor,
S	=	$\frac{\pi}{3}\frac{1}{\left(1+\frac{8\xi_0}{3}\right)}\frac{1}{\left(1+\frac{10\xi_0 b}{h}\right)}$
S	=	(3.14/3)*(1/ (1+8*1.055/3))*(1/ (1+10*1.055*40/200))
S	=	0.088
R	=	is resonant response excitation,
R	=	$\frac{SE}{\varsigma}$

R = 0.088*0.193/0.035

R = 0.484

B = is background turbulence excitation,

$$B = 2\left[1 - \frac{1}{\left\{1 + \left(\frac{457}{h}\right)^2\right\}^{\frac{1}{3}}}\right]$$

B = $2*(1-1/ (1+ (457/200)^{2})^{1/3})$

B = 0.913

k = 0.011 (by Simiu Scalan)

r = is roughness factor,

$$r = 4.0\sqrt{k}\left(\frac{10}{h}\right)^{\alpha}$$

r = $4*(0.011)^{0.5}(10/200)^{0.18}$

r = 0.276

$$F = \frac{C_d\, P_h\, b\, h}{2(1+\alpha)}$$

F = (1.45*1885.01*49*200)/ (2(1+0.14))

F = 9590423.3 N

$\bar{X}$ = The mean response of the first mode at the building ht.

$$\bar{X} = \frac{Mean\ Generalised\ force\ in\ first\ \mathrm{mod}\,e}{Generalised\ stiffness\ in\ first\ \mathrm{mod}\,e}$$

$$\bar{X} = \frac{F}{K_o}$$

$\bar{X}$ = 9590423.3/148165879

$\bar{X}$	=	0.0647
G	=	$1 + g_f r \sqrt{(B + R)}$
G	=	1+3.889*0.276*(0.913+0.484)$^{1/2}$
G	=	2.267

Calculation for Force, (F)

Ae	=	effective frontal area at ht 'z'	
	=	width*interval	
	=	40*10	
	=	400	m^2
Ae	=	effective frontal area at ht. z for top level	
	=	width*interval/2	
	=	40*5	
	=	200	m^2
F_h	=	$G\ A_e\ C_f\ P_z$	
F_h	=	2.267*400*1.45*1885.01/1000	
F_h	=	1239.5	kN
M	=	$F_h\ z$	
	=	2892076	kN-m

Table-5.1 Analytical Response of 200m Tall Building (Long After Body Orientation)

ANALYSIS OF 200M TALL BUILDING Long Afterbody Orientation										
α	0.14		Building Parameters					G, Gust Factor Calculations		
Zref	10	m	Ae=effective frontal area at ht 'z'			400	m2	T sec.	3600	sec
Plan Length	40	m	Ae=effective frontal area at ht. z fo			200	m2	Bldg Nat frequency n1	0.297	Hz
Plan breadth	40	m	Cf= from graph			1.45		gf=	3.889	
Story height	3	m	G=gust factor			2.27		Cd or Cf	1.45	
k1	1		ρa=			1.2	Kg/m3	Ph	1885.0142	N/m2
k3	1		Natural Period used			3.37	Sec	Ko=	148165879	N/m
Vb (fig.1)	55	m/s	Frequency used, Hz			0.297	Hz	F=	9590423.3	N
Density=	400	Kg/m3	Critical damping Coeff, ξ =			0.035		X mean=	0.065	m
Height of Building, h	200	m	bldg mass/m height, mo=			640000	Kg/m	k=surface drag coeffic	0.011	
face width	40	m	Generalised mass M1*=M0			42666667	Kg	r= Roughness factor	0.276	
depth	40	m	Natural period of building			Secs	Frequency Hz	B=	0.913	
Interval	10	m	Emperical @ weaker axis			3.77	0.265	Red freq n' =	1.059	
Vz at top=	56.1	m/s	Emperical @ stronger axis			2.94	0.340	S=	0.088	
Pz at top=	1885.01	N/m2	IS875 pt3 1987: RC frame only			6.67	0.150	Lh from IS875 pt3 Fig.8	2200	
K2 at 10m Table 33	0.67		IS875pt3:SMRF or Wall (LAB)			2.85	0.351	XE, for GER	11.647	
Vref at 10m	36.85	m/s	IS875pt3:SMRF or Wall (SAB)			2.85	0.351	E=gust energy ratio	0.193	
			Software modelling(LAB)			3.37	0.297	R=	0.484	
			Software modelling(SAB)			4.75	0.211	G=Gust factor	2.267	
height	K2 from table 33	Vz(k2)	Vz(α)	Z/Zref	V/Vref	Pz(N/m2)	Fz(kN)	Acceleration at top in alongwind		
0	0	0.0	0	0.000	0.000	0	0	0.111487722	m/s2	
10	0.67	36.9	36.9	0.077	0.698	814.75	1071.5	0.011364702	g	
20	0.75	41.3	40.6	0.154	0.769	989.27	1301.0	1.136470155	%g	
30	0.79	43.5	43.0	0.231	0.814	1108.21	1457.4	BASE BENDING MOMENT		
40	0.82	45.1	44.7	0.308	0.848	1201.17	1579.7	Base Moment =	2892076	kN-m
50	0.85	46.8	46.2	0.385	0.875	1278.61	1681.5		2892.076	MN-m
60	0.864	47.5	47.4	0.462	0.897	1345.58	1769.6		294808938	Kg-m
70	0.878	48.3	48.4	0.538	0.917	1404.93	1847.6	IMPORTANT		
80	0.892	49.1	49.3	0.615	0.934	1458.45	1918.0			
90	0.906	49.8	50.1	0.692	0.950	1507.35	1982.3	Enter data here only		
100	0.92	50.6	50.9	0.769	0.964	1552.48	2041.7			
110	0.928	51.0	51.6	0.846	0.977	1594.47	2096.9	Read Results here		
120	0.936	51.5	52.2	0.923	0.989	1633.79	2148.6			
130	0.946	52.0	52.8	1.000	1.000	1670.82	1098.7	Do not alter these		
140	0.952	52.4	53.3	1.077	1.010	1705.85	1121.7			
150	0.96	52.8	53.8	1.154	1.020	1739.13	1143.6			
160	0.968	53.2	54.3	1.231	1.029	1770.84	1164.4			
170	0.976	53.7	54.8	1.308	1.038	1801.16	1184.4			
180	0.984	54.1	55.2	1.385	1.047	1830.22	1203.5			
190	0.992	54.6	55.6	1.462	1.055	1858.13	1221.8			
200	1	55.0	56.1	1.538	1.062	1885.01	1239.5			
						Sum	30273	kN		

5.3 Application of Genetic Programming for predicting Gust Factor on Tall Buildings

Gust factor on tall buildings has been estimated for along wind direction for Long After Body (LAB) and Short After Body (SAB). The building height, design wind speed and aspect ratio have been used as the input parameters and gust factor as the output parameter. The database used for the development of the equations has been presented in table 5.2-5.3. The equation for gust factor has been developed using the values of input and output parameters for various combinations of crossover rate, number of generations, population size and number of children to produce. This process is continued until the most accurate equations are obtained by reaching the maximum number of generations. The statistic measures used to assess the accuracy of these equations are Coefficient of Determination (COD) and Root Mean Square (RMS) wherein the objective is to have COD nearly equal to 1 and RMS nearly equal to 0. The actual values of COD and RMS that have been achieved in the development of the equations vary from 0.84 to 0.88 for COD and 0.03 to 0.05 for RMS.

Table-5.2 Table showing the database for estimation of gust factor for LAB

A	H	v	G
1	180	32.5	2.188
1	180	38.4	2.234
1	180	43.3	2.277
1	180	46.2	2.304
1	180	49.2	2.331
1	180	54.1	2.379
1	200	33	2.131
1	200	39	2.174
1	200	44	2.214
1	200	47	2.24
1	200	50	2.266
1	200	55	2.312
1	230	33.4	2.052
1	230	39.5	2.092
1	230	44.5	2.129

1	230	47.6	2.152
1	230	50.6	2.176
1	230	55.7	2.218
1	250	33.7	2.006
1	250	39.8	2.044
1	250	44.9	2.079
1	250	47.9	2.102
1	250	51	2.125
1	250	56.1	2.165
1	180	32.5	2.167
1	180	38.4	2.206
1	180	43.3	2.242
1	180	46.2	2.266
1	180	49.2	2.29
1	180	54.1	2.332
1	200	33	2.111
1	200	39	2.148
1	200	44	2.182
1	200	47	2.204
1	200	50	2.227
1	200	55	2.267
1	230	33.4	2.034
1	230	39.5	2.068
1	230	44.5	2.1
1	230	47.6	2.12
1	230	50.6	2.141
1	230	55.7	2.178
1	250	33.7	1.989
1	250	39.8	2.021
1	250	44.9	2.051
1	250	47.9	2.071
1	250	51	2.091
1	250	56.1	2.127
1.25	180	32.5	2.167
1.25	180	38.4	2.206
1.25	180	43.3	2.242
1.25	180	46.2	2.266
1.25	180	49.2	2.29
1.25	180	54.1	2.332
1.25	200	33	2.111
1.25	200	39	2.148
1.25	200	44	2.182
1.25	200	47	2.204
1.25	200	50	2.227
1.25	200	55	2.267
1.25	230	33.4	2.034

1.25	230	39.5	2.068
1.25	230	44.5	2.1
1.25	230	47.6	2.12
1.25	230	50.6	2.141
1.25	230	55.7	2.178
1.25	250	33.7	1.989
1.25	250	39.8	2.021
1.25	250	44.9	2.051
1.25	250	47.9	2.071
1.25	250	51	2.091
1.25	250	56.1	2.127
1	180	28.5	2.2
1	180	33.7	2.25
1	180	38	2.296
1	180	40.6	2.325
1	180	43.2	2.355
1	180	47.5	2.407
1	200	29	2.141
1	200	34.3	2.188
1	200	38.7	2.232
1	200	41.4	2.259
1	200	44	2.288
1	200	48.4	2.337
1	230	29.6	2.064
1	230	35	2.108
1	230	39.5	2.149
1	230	42.2	2.174
1	230	44.9	2.201
1	230	49.4	2.247
1	250	30	2.016
1	250	35.5	2.058
1	250	40	2.097
1	250	42.8	2.122
1	250	45.5	2.148
1	250	50.1	2.192
1	180	28.5	2.176
1	180	33.7	2.219
1	180	38	2.259
1	180	40.6	2.284
1	180	43.2	2.311
1	180	47.5	2.356
1	200	29	2.119
1	200	34.3	2.159
1	200	38.7	2.197
1	200	41.4	2.221
1	200	44	2.246

1	200	48.4	2.289
1	230	29.6	2.044
1	230	35	2.081
1	230	39.5	2.116
1	230	42.2	2.139
1	230	44.9	2.162
1	230	49.4	2.203
1	250	30	1.998
1	250	35.5	2.033
1	250	40	2.067
1	250	42.8	2.088
1	250	45.5	2.111
1	250	50.1	2.15
1.25	180	28.5	2.176
1.25	180	33.7	2.219
1.25	180	38	2.259
1.25	180	40.6	2.284
1.25	180	43.2	2.311
1.25	180	47.5	2.356
1.25	200	29	2.119
1.25	200	34.3	2.159
1.25	200	38.7	2.197
1.25	200	41.4	2.221
1.25	200	44	2.246
1.25	200	48.4	2.289
1.25	230	29.6	2.044
1.25	230	35	2.081
1.25	230	39.5	2.116
1.25	230	42.2	2.139
1.25	230	44.9	2.162
1.25	230	49.4	2.203
1.25	250	30	1.998
1.25	250	35.5	2.033
1.25	250	40	2.067
1.25	250	42.8	2.088
1.25	250	45.5	2.111
1.25	250	50.1	2.15

Table-5.3 Table showing the database for estimation of gust factor for SAB

A	H	v	G
1	180	32.5	2.269
1	180	38.4	2.347
1	180	43.3	2.416
1	180	46.2	2.458
1	180	49.2	2.5
1	180	54.1	2.571
1	200	33	2.207
1	200	39	2.281
1	200	44	2.346
1	200	47	2.387
1	200	50	2.427
1	200	55	2.496
1	230	33.4	2.122
1	230	39.5	2.19
1	230	44.5	2.251
1	230	47.6	2.288
1	230	50.6	2.326
1	230	55.7	2.39
1	250	33.7	2.073
1	250	39.8	2.138
1	250	44.9	2.197
1	250	47.9	2.233
1	250	51	2.269
1	250	56.1	2.331
1	180	32.5	2.233
1	180	38.4	2.302
1	180	43.3	2.363
1	180	46.2	2.401
1	180	49.2	2.439
1	180	54.1	2.504
1	200	33	2.173
1	200	39	2.238
1	200	44	2.296
1	200	47	2.333
1	200	50	2.37
1	200	55	2.432
1	230	33.4	2.091
1	230	39.5	2.151
1	230	44.5	2.205

1	230	47.6	2.239
1	230	50.6	2.273
1	230	55.7	2.332
1	250	33.7	2.043
1	250	39.8	2.101
1	250	44.9	2.153
1	250	47.9	2.186
1	250	51	2.219
1	250	56.1	2.275
1.25	180	32.5	2.207
1.25	180	38.4	2.268
1.25	180	43.3	2.323
1.25	180	46.2	2.358
1.25	180	49.2	2.393
1.25	180	54.1	2.453
1.25	200	33	2.149
1.25	200	39	2.207
1.25	200	44	2.259
1.25	200	47	2.292
1.25	200	50	2.326
1.25	200	55	2.384
1.25	230	33.4	2.069
1.25	230	39.5	2.122
1.25	230	44.5	2.171
1.25	230	47.6	2.202
1.25	230	50.6	2.233
1.25	230	55.7	2.287
1.25	250	33.7	2.022
1.25	250	39.8	2.074
1.25	250	44.9	2.121
1.25	250	47.9	2.15
1.25	250	51	2.181
1.25	250	56.1	2.233
1	180	28.5	2.29
1	180	33.7	2.375
1	180	38	2.448
1	180	40.6	2.493
1	180	43.2	2.539
1	180	47.5	2.614
1	200	29	2.226
1	200	34.3	2.306
1	200	38.7	2.376

1	200	41.4	2.419
1	200	44	2.462
1	200	48.4	2.534
1	230	29.6	2.143
1	230	35	2.219
1	230	39.5	2.285
1	230	42.2	2.325
1	230	44.9	2.366
1	230	49.4	2.435
1	250	30	2.092
1	250	35.5	2.164
1	250	40	2.227
1	250	42.8	2.266
1	250	45.5	2.306
1	250	50.1	2.372
1	180	28.5	2.251
1	180	33.7	2.325
1	180	38	2.391
1	180	40.6	2.432
1	180	43.2	2.473
1	180	47.5	2.543
1	200	29	2.189
1	200	34.3	2.259
1	200	38.7	2.322
1	200	41.4	2.361
1	200	44	2.4
1	200	48.4	2.467
1	230	29.6	2.109
1	230	35	2.175
1	230	39.5	2.235
1	230	42.2	2.271
1	230	44.9	2.309
1	230	49.4	2.372
1	250	30	2.06
1	250	35.5	2.123
1	250	40	2.18
1	250	42.8	2.215
1	250	45.5	2.251
1	250	50.1	2.312
1.25	180	28.5	2.222
1.25	180	33.7	2.289
1.25	180	38	2.348

1.25	180	40.6	2.385
1.25	180	43.2	2.423
1.25	180	47.5	2.487
1.25	200	29	2.162
1.25	200	34.3	2.225
1.25	200	38.7	2.282
1.25	200	41.4	2.317
1.25	200	44	2.353
1.25	200	48.4	2.415
1.25	230	29.6	2.085
1.25	230	35	2.144
1.25	230	39.5	2.197
1.25	230	42.2	2.231
1.25	230	44.9	2.265
1.25	230	49.4	2.324
1.25	250	30	2.037
1.25	250	35.5	2.093
1.25	250	40	2.145
1.25	250	42.8	2.177
1.25	250	45.5	2.21
1.25	250	50.1	2.266

5.3.1 Comparison of GP Results and Analytical Results

The equation obtained for Gust Factor for LAB and SAB obtained by GP is presented in Table 5.4. The value of Gust Factor obtained from these equations for LAB and SAB has been compared with the analytical values. Typical plots for Gust Factor for LAB and SAB showing the comparisons of values obtained by GP and analytical values are presented in figure 5.1. It can be observed from these plots that the predicted values are more or less matching with the analytical values. From the comparison the maximum error to be observed is 5%.

Table -5.4 Equation for the Gust Factor for LAB and SAB

	EQUATION OBTAINED BY GP
LAB	$G = \left[\dfrac{-1.57(Hv+v^2)}{24v - 0.1A + H - vH}\right]$
SAB	$G = \left[\dfrac{\left(1.2H + 0.2v + \frac{v}{A}\right)}{0.7H - 12.5}\right]$

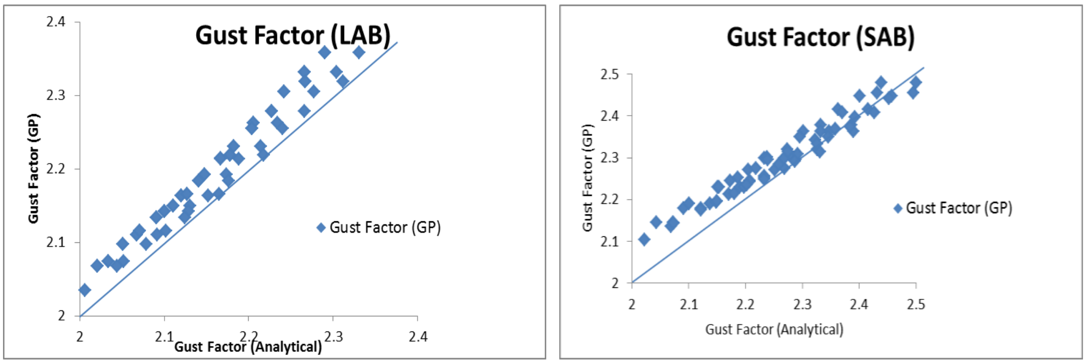


Fig. 5.1 Comparison of Gust Factor obtained analytically and predicted by GP

5.4 Application of Genetic Programming for predicting Base Moment on Tall Buildings

Base Moment on tall buildings has been estimated for along wind direction for Long After Body (LAB) and Short After Body (SAB). The building height, design wind speed and base dimensions have been used as the input parameters and base moment that is acting on the building due to the action of wind, as the output parameter. The database used for the development of equations has been presented in table 5.5 - 5.6. The equation for base moment has been developed using the values of input and output parameters for various combinations of crossover rate, number of generations, population size and number of children to produce. This process is continued until the most accurate equations are obtained by reaching the maximum number of generations. The statistic measures used to assess the accuracy of these equations are Coefficient of Determination (COD) and Root Mean Square (RMS) wherein the objective is to have COD nearly equal to 1 and RMS nearly equal to 0. The actual values of COD and RMS that have been achieved in the development of the equations vary from 0.89 to 0.91 for COD and 0.03 to 0.04 for RMS.

Table-5.5 Table showing the database for estimation of base moment for LAB

B	D	H	v	Moment
30	30	180	32.5	0.0631726
30	30	180	38.4	0.0900894
30	30	180	43.3	0.1168454
30	30	180	46.2	0.134895
30	30	180	49.2	0.1545045
30	30	180	54.1	0.1907907
30	30	200	33	0.0759026
30	30	200	39	0.1081759
30	30	200	44	0.1402329
30	30	200	47	0.1618485
30	30	200	50	0.1853251
30	30	200	55	0.2287518
30	30	230	33.4	0.0969961
30	30	230	39.5	0.1380986
30	30	230	44.5	0.1788736
30	30	230	47.6	0.206345
30	30	230	50.6	0.2361647
30	30	230	55.7	0.2912878
30	30	250	33.7	0.1144708
30	30	250	39.8	0.162908
30	30	250	44.9	0.2109333
30	30	250	47.9	0.2432778
30	30	250	51	0.2783788
30	30	250	56.1	0.343246
40	40	180	32.5	0.0805374
40	40	180	38.4	0.114509
40	40	180	43.3	0.1481587
40	40	180	46.2	0.1708085

40	40	180	49.2	0.1953798
40	40	180	54.1	0.2407708
40	40	200	33	0.0969196
40	40	200	39	0.1377281
40	40	200	44	0.1781227
40	40	200	47	0.2053008
40	40	200	50	0.2347761
40	40	200	55	0.2892076
40	40	230	33.4	0.1240645
40	40	230	39.5	0.1761498
40	40	230	44.5	0.2276469
40	40	230	47.6	0.2622681
40	40	230	50.6	0.2997953
40	40	230	55.7	0.3690511
40	40	250	33.7	0.1466064
40	40	250	39.8	0.2080795
40	40	250	44.9	0.2688286
40	40	250	47.9	0.3096565
40	40	250	51	0.3539017
40	40	250	56.1	0.4355331
50	40	180	32.5	0.0747847
50	40	180	38.4	0.1063298
50	40	180	43.3	0.1375759
50	40	180	46.2	0.1586079
50	40	180	49.2	0.1814241
50	40	180	54.1	0.2235728
50	40	200	33	0.0902355
50	40	200	39	0.1282296
50	40	200	44	0.1658384
50	40	200	47	0.1911421
50	40	200	50	0.2185847
50	40	200	55	0.2692622
50	40	230	33.4	0.1157935
50	40	230	39.5	0.1644065
50	40	230	44.5	0.2124705
50	40	230	47.6	0.2447835
50	40	230	50.6	0.279809
50	40	230	55.7	0.3444477
50	40	250	33.7	0.1371479
50	40	250	39.8	0.194655
50	40	250	44.9	0.2514848
50	40	250	47.9	0.2896787

50	40	250	51	0.3310693
50	40	250	56.1	0.4074342
30	30	180	28.5	0.0635025
30	30	180	33.7	0.0907219
30	30	180	38	0.1178428
30	30	180	40.6	0.1361672
30	30	180	43.2	0.1560971
30	30	180	47.5	0.193025
30	30	200	29	0.0762653
30	30	200	34.3	0.1088732
30	30	200	38.7	0.1413348
30	30	200	41.4	0.1632559
30	30	200	44	0.1870891
30	30	200	48.4	0.2312314
30	30	230	29.6	0.0975454
30	30	230	35	0.1391582
30	30	230	39.5	0.1805524
30	30	230	42.2	0.2084922
30	30	230	44.9	0.2388597
30	30	230	49.4	0.295085
30	30	250	30	0.1150732
30	30	250	35.5	0.1640719
30	30	250	40	0.2127798
30	30	250	42.8	0.2456415
30	30	250	45.5	0.281348
30	30	250	50.1	0.347435
40	40	180	28.5	0.0808855
40	40	180	33.7	0.1151863
40	40	180	38	0.1492388
40	40	180	40.6	0.1721949
40	40	180	43.2	0.1971258
40	40	180	47.5	0.2432432
40	40	200	29	0.097303
40	40	200	34.3	0.138476
40	40	200	38.7	0.179318
40	40	200	41.4	0.2068371
40	40	200	44	0.2367132
40	40	200	48.4	0.291956
40	40	230	29.6	0.1246463
40	40	230	35	0.1772885
40	40	230	39.5	0.2294713
40	40	230	42.2	0.2646164

40	40	230	44.9	0.3027606
40	40	230	49.4	0.3732683
40	40	250	30	0.1472452
40	40	250	35.5	0.2093321
40	40	250	40	0.2708384
40	40	250	42.8	0.3122457
40	40	250	45.5	0.3571737
40	40	250	50.1	0.4401928
50	40	180	28.5	0.075108
50	40	180	33.7	0.1069588
50	40	180	38	0.1385789
50	40	180	40.6	0.1598953
50	40	180	43.2	0.1830454
50	40	180	47.5	0.2258687
50	40	200	29	0.0905924
50	40	200	34.3	0.128926
50	40	200	38.7	0.1669513
50	40	200	41.4	0.1925725
50	40	200	44	0.2203882
50	40	200	48.4	0.2718211
50	40	230	29.6	0.1163365
50	40	230	35	0.1654693
50	40	230	39.5	0.2141732
50	40	230	42.2	0.2469753
50	40	230	44.9	0.2825765
50	40	230	49.4	0.3483837
50	40	250	30	0.1377455
50	40	250	35.5	0.1958268
50	40	250	40	0.253365
50	40	250	42.8	0.2921008
50	40	250	45.5	0.3341303
50	40	250	50.1	0.4117932

Table-5.6 Table showing the database for estimation of base moment for SAB

B	D	H	v	Moment
30	30	180	32.5	0.0655139
30	30	180	38.4	0.0946458
30	30	180	43.3	0.1239822
30	30	180	46.2	0.1439255
30	30	180	49.2	0.1656986
30	30	180	54.1	0.2062066
30	30	200	33	0.0786306
30	30	200	39	0.1135099
30	30	200	44	0.1486143
30	30	200	47	0.1724719
30	30	200	50	0.1985147
30	30	200	55	0.2469603
30	30	230	33.4	0.1002983
30	30	230	39.5	0.1446026
30	30	230	44.5	0.1891433
30	30	230	47.6	0.2193956
30	30	230	50.6	0.252407
30	30	230	55.7	0.3137941
30	30	250	33.7	0.1182849
30	30	250	39.8	0.1704401
30	30	250	44.9	0.2228486
30	30	250	47.9	0.2584355
30	30	250	51	0.2972621
30	30	250	56.1	0.3694528
40	40	180	32.5	0.0859519
40	40	180	38.4	0.1237309
40	40	180	43.3	0.1616733
40	40	180	46.2	0.1874318
40	40	180	49.2	0.2155323
40	40	180	54.1	0.2677758
40	40	200	33	0.1032196
40	40	200	39	0.1484882
40	40	200	44	0.1939273
40	40	200	47	0.224766
40	40	200	50	0.2584034
40	40	200	55	0.3209319
40	40	230	33.4	0.1317789
40	40	230	39.5	0.1893518
40	40	230	44.5	0.247078

40	40	230	47.6	0.2862314
40	40	230	50.6	0.328922
40	40	230	55.7	0.4082489
40	40	250	33.7	0.1554725
40	40	250	39.8	0.2232873
40	40	250	44.9	0.2912515
40	40	250	47.9	0.3373371
40	40	250	51	0.3875784
40	40	250	56.1	0.4809217
50	40	180	32.5	0.1061911
50	40	180	38.4	0.1524146
50	40	180	43.3	0.1987144
50	40	180	46.2	0.2300995
50	40	180	49.2	0.2643078
50	40	180	54.1	0.3278473
50	40	200	33	0.1275767
50	40	200	39	0.1829974
50	40	200	44	0.2384795
50	40	200	47	0.2760781
50	40	200	50	0.3170519
50	40	200	55	0.3931466
50	40	230	33.4	0.1629777
50	40	230	39.5	0.2335295
50	40	230	44.5	0.304084
50	40	230	47.6	0.3518671
50	40	230	50.6	0.4039199
50	40	230	55.7	0.5005513
50	40	250	33.7	0.1923345
50	40	250	39.8	0.2754736
50	40	250	44.9	0.3585797
50	40	250	47.9	0.4148494
50	40	250	51	0.4761379
50	40	250	56.1	0.5898968
30	30	180	28.5	0.0661162
30	30	180	33.7	0.0957426
30	30	180	38	0.1256438
30	30	180	40.6	0.1459974
30	30	180	43.2	0.1682364
30	30	180	47.5	0.2096466
30	30	200	29	0.0792967
30	30	200	34.3	0.1147271
30	30	200	38.7	0.1504631

30	30	200	41.4	0.1747809
30	30	200	44	0.2013471
30	30	200	48.4	0.2508091
30	30	230	29.6	0.1013144
30	30	230	35	0.1464666
30	30	230	39.5	0.1919835
30	30	230	42.2	0.2229492
30	30	230	44.9	0.2567738
30	30	230	49.4	0.3197457
30	30	250	30	0.1194033
30	30	250	35.5	0.1724964
30	30	250	40	0.2259874
30	30	250	42.8	0.2623668
30	30	250	45.5	0.3020983
30	30	250	50.1	0.3760553
40	40	180	28.5	0.086631
40	40	180	33.7	0.1249878
40	40	180	38	0.1635999
40	40	180	40.6	0.1898492
40	40	180	43.2	0.2185103
40	40	180	47.5	0.2718475
40	40	200	29	0.1039711
40	40	200	34.3	0.1498838
40	40	200	38.7	0.1960721
40	40	200	41.4	0.2274615
40	40	200	44	0.2617291
40	40	200	48.4	0.3254903
40	40	230	29.6	0.132926
40	40	230	35	0.1914908
40	40	230	39.5	0.2503758
40	40	230	42.2	0.2903835
40	40	230	44.9	0.3340542
40	40	230	49.4	0.4153045
40	40	250	30	0.1567358
40	40	250	35.5	0.2256483
40	40	250	40	0.2948982
40	40	250	42.8	0.3419333
40	40	250	45.5	0.3932656
40	40	250	50.1	0.4887539
50	40	180	28.5	0.106927
50	40	180	33.7	0.1537934
50	40	180	38	0.200847

50	40	180	40.6	0.2327888
50	40	180	43.2	0.267636
50	40	180	47.5	0.3324297
50	40	200	29	0.1283912
50	40	200	34.3	0.1845289
50	40	200	38.7	0.2408547
50	40	200	41.4	0.279078
50	40	200	44	0.3207704
50	40	200	48.4	0.3982792
50	40	230	29.6	0.1642217
50	40	230	35	0.2358781
50	40	230	39.5	0.3077383
50	40	230	42.2	0.3564913
50	40	230	44.9	0.4096623
50	40	230	49.4	0.5085015
50	40	250	30	0.193705
50	40	250	35.5	0.278067
50	40	250	40	0.3626224
50	40	250	42.8	0.4199705
50	40	250	45.5	0.4825042
50	40	250	50.1	0.5987265

5.4.1 Comparison of GP Results and Analytical Results

The equation obtained for Gust Factor for LAB and SAB obtained by GP is presented in Table 5.7. The value of Gust Factor obtained from these equations for LAB and SAB has been compared with the analytical values. Typical plots for Gust Factor for LAB and SAB showing the comparisons of values obtained by GP and analytical values are presented in figure 5.2. It can be observed from these plots that the predicted values are more or less matching with the analytical values. From the comparison the maximum error to be observed is 10%.

Table -5.7 Equation for the Base Moment for LAB and SAB

	EQUATION OBTAINED BY GP
LAB	$M = 15.2 \times \frac{Dv^2}{H}\left[\frac{(2H^2 - 3BH + B^2)}{(v+109)}\right]$
SAB	$M = 0.23\ X\ Bv^2(H - v - D)$

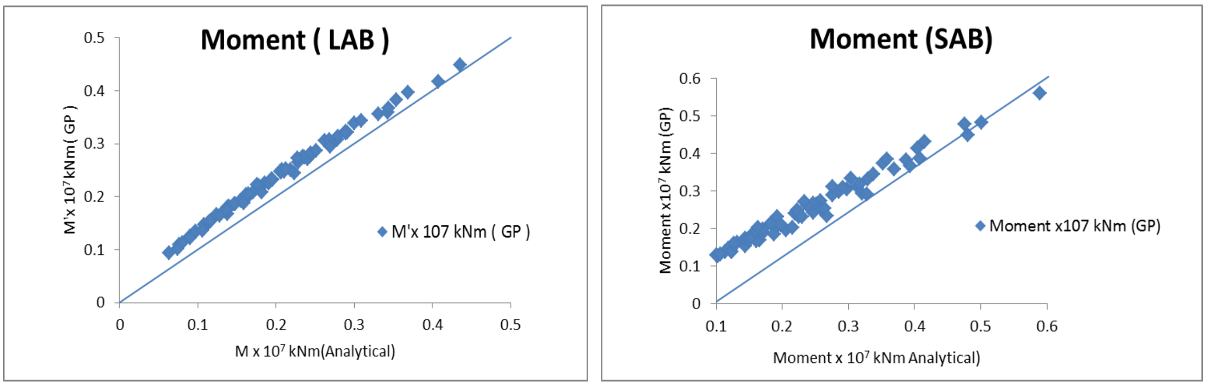


Fig. 5.2 Comparison of Base Moment obtained analytically and predicted by GP

CHAPTER – 6

CONCLUSIONS

6.1 General

This present study has been conducted to study the application of Genetic Programming for the determination of wind pressure coefficients on gable roof buildings and for the estimation of Gust Factor and Base Moment due to the along wind direction on tall buildings.

As a first step of the study, database has been developed for the estimation of wind pressure coefficients using the experimental data by Kwatra et al. (2002). Thereafter, equations have been developed using Genetic Programming for various zones for varying angle of wind incidence and roof slopes. The pressure coefficients thus obtained from these equations have been compared with the experimental data. Also, the equations for various zones have been developed for all azimuths using Genetic Programming and the values of pressure coefficients thus obtained from these equations have been compared with the experimental data. Also, the values of pressure coeffiecients obtained by Genetic Programming for various zones have been compared with the codal values as mentioned in Indian Standard Code (IS 875- Part 3, 1987).

In the second phase of the study, Gust Factor and Base Moment for the along wind direction has been estimated using Genetic Programming on tall buildings. The database has been developed analytically as mentioned in IS875-1987, Part-3 given by A.G. Davenport. Thereafter, equations have been developed for estimation of Gust Factor and Base Moment for Long After Body (LAB) and Short after Body (SAB) using Genetic Programming. The values thus obtained from GP have been compared with the analytical values.

6.2 Main Conclusions

- The main conclusion drawn from this study is that the Genetic Programming is seen to predict successfully the wind pressure coefficients for gable building for any roof slope.The minimum pressure coefficients (Cpmin) obtained by Genetic Programming are of the same order as given in Indian Standard Code (IS875 Part-3, 1987).

- The Genetic Programming estimates the Gust Factor and Base Moment for along wind direction for Long After Body (LAB) and Short After Body (SAB) on tall buildings successfully, thus reducing the laborious work involved in their estimation through analytical approach or through wind tunnel testing.

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