SEPTEMBER 2019 M.Sc. Thesis- Civil Engineering MEHMET KURT

UNIVERSITY OF GAZIANTEP

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ULTIMATE STRENGTH PREDICTION OF ELLIPTICAL HOLLOW SECTION COLUMNS IN COMPRESSION AND BENDING

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Supervisor

Assoc. Prof. Dr. Esra METE GÜNEYİSİ

BY

Mehmet KURT

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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.

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Mehmet KURT

ABSTRACT

ULTIMATE STRENGTH PREDICTION OF ELLIPTICAL HOLLOW SECTION COLUMNS IN COMPRESSION AND BENDING

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M.Sc. in Civil Engineering

Supervisor: Assoc. Prof. Dr. Esra METE GÜNEYİSİ

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In composite structures, tubular sections are widely utilized as structural members due to their effective load carrying capacities and visual aspects. The well-known tubular members include rectangular, square and circular hollow sections. Elliptical hollow section (EHS) is a relatively new shape of high strength, hot milled steel sections. In the recent years, it has been used in constructional building applications thanks to its intrinsic aesthetics as well as its constructional opportunities of sections having minor and major axis features. In this study, the prediction models for ultimate load carrying capacity (N_u) of EHS steel tube columns under the effect of compression and bending through popular soft computing methods named gene expression programming (GEP) and artificial neural networks (NN) were aimed to be derived. For this, experimental data from the literature were collected for training and testing the models. The column specimens were tested for flexural buckling in their minor and major axes considering with and without eccentricity. The parameters were selected as axis of buckling, eccentricity in y and z axes, larger and smaller outer diameters, wall thickness of the section, yield and tensile strength of steel, and member length. Explicit formulation of the N_u through GEP and NN were compared to the actual values to analyze the robustness and the repeatability of the proposed models.

Keywords: Column, Elliptical hollow section, Load carrying capacity, Modeling, Prediction, Steel tube.

ÖZET

BASINÇ VE EĞİLME ETKİSİNDEKİ ELİPTİK KESİTLİ KOLONLARIN TAŞIMA KAPASİTESİNİN TAHMİNİ

KURT, Mehmet
Yüksek lisans tezi, İnşaat Mühendisliği
Danışman: Doç. Dr. Esra METE GÜNEYİSİ
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Kompozit yapılarda, boru şekilli profiller etkili yük taşıma kapasiteleri ve görsel yönleri nedeniyle yapısal elemanlar olarak yaygın şekilde kullanılmaktadır. İyi bilinen boru biçimli elemanlar dikdörtgen, kare ve dairesel boşluklu kesitleri içermektedir. Eliptik boşluklu kesit ise yüksek mukavemetli ve sıcak haddelenmiş çelik profillerin nispeten daha yeni şeklidir. İçsel estetik özelliklerin yanı sıra küçük ve büyük eksen özelliklerine sahip olmalarından ötürü son zamanlarda yapısal uygulamalarda kullanılmaktadırlar. Bu çalışmada, gen ekspresyonu programlama ve yapay sinir ağları adlı popüler yapay zeka hesaplama yöntemleri kullanılarak, basınç ve eğilme etkisi altındaki eliptik kesitli kolonlarının nihai yük taşıma kapasitesi için tahmin modelleri geliştirilmiştir. Modellerin eğitimi ve test yapılması için literatürden elde edilen deneysel veriler kullanılmıştır. Kolon numuneleri eksantrikli ve eksantriksiz, küçük ve büyük eksenler dikkate alınarak eğilme burkulması açısından test edilmiştir. Araştırmada kullanılan değişkenler ise, burkulma ekseni, y ve z eksenlerinde eksantriklik, büyük ve küçük dış çaplar, kesitin et kalınlığı, çeliğin akma ve çekme dayanımı ve eleman uzunluğudur. Gen ekspresyonu programı ve yapay sinir ağları, ile elde edilen eliptik kesitli kolonların yük taşıma kapasitesi açık formülasyonları, önerilen modellerin sağlamlığı ve tekrarlanabilirliği açısından gerçek deneysel verilerle karşılaştırılmalı olarak analiz edilmiştir.

Anahtar Kelimeler: Kolon, Eliptik boşluklu kesit, Yük taşıma kapasitesi, Modelleme, Tahmin, Çelik boru.

To my beloved mother,

Binefş

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Finally, I want to say that to my beloved friend, the best friend and my brother, Bilal KOTAN, Veysi GÖKHAN and Taha Tuna GÖKSU my prayers and my heart are with you and my success will be for you until forever.

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LIST OF SYMBOLS

a	Major axis radius
A(H)	Major diameter
A	Cross sectional area
A_{net}	Net cross sectional area
A_s	Surface area
A_v	Shear area
b	Minor axis radius
B	Minor diameter
c_t	Torsional modulus constant
D	Diameter
d_0	Axis of buckling
d_1	Eccentricity in y axis
d_2	Eccentricity in z axis
d_3	Larger outer diameter
d_4	Smaller outer diameter
d_5	Wall thickness of the section
d_6	Yield stress
d_7	Ultimate tensile stress
d_8	Member length
$D_{Eq,EHS}$	Equivalent diameter
E	Young’s modulus
e_y	Eccentricity in y axis
e_z	Eccentricity in z axis
f	Elementary function
$F(S_i)$	Greater fitness values
f_u	Ultimate strenght of steel

f_{yd}	Yield strenght of steel
h	Height
I_t	Torsional moment of inertia
I_x	Major axis moment of inertia
I_y	Minor axis moment of inertia
i	Radius of gyration
J	Torsional inertia constant
K	Buckling coefficient
L	Length
L_0	Perimeter
L_{cr}	Column length
M	Mass per unit length
$M_{c,Rd}$	Design resistance of a cross section to bending moment
M_{el}	Yield moment capacity
M_{pl}	Plastic moment
$M_{t,Rd}$	Design resistance of a cross section to torsional moment
M_V	V coordinate displacement
N	Number of design variables
n	Structure of neuron
$N_{b,rd}$	Design buckling capacity
$N_{pl,Rd}$	Design plastic capacity
N_u	Ultimate load
p	Internal pressure
p_i	Predicted values
P_m	Mean perimeter
Q (S_i)	Measure of quality
r	Radius of curvature
r_x	Major axis radius of gyration
r_y	Minor axis radius of gyration
S	Curved length
s	Circumference of section

S_x	Major axis elastic section modulus
S_y	Minor axis elastic section modulus
S_0	Longitudinal elongation
t	Thickness
U	Numerical values of the nodes calculated
V_{ed}	(Acting) design shear load
$V_{pl,Rd}$	Shear capacity
w	Plate width
W_t	Section modulus for torsion
x	Cartesian co-ordinates
y	Cartesian co-ordinates
Z	Plastic section modulus
Z_x	Major axis plastic section modulus
Z_y	Minor axis plastic section modulus
ν	Poisson's ratio
χ	Reduction factor
χ_i	Real value
γ_M	Partial factor
γ_{M2}	Partial safety factor
ξ	Eccentricity
σ_{CHS}	Elastic buckling stres of CHS
σ_{cr}	Elastic buckling stress
σ_{EHS}^{K}	Elastic buckling stress of compressed EHS
σ_{EHS}^{C}	Elastic buckling stress of cross-section EHS
σ_{plate}	Elastic buckling stres of flat plate
λ	Slenderness
$\bar{\lambda}$	Non-dimensional slenderness
$\bar{\lambda}$	Relative slenderness ratio
λ_E	Euler slenderness
τ	Shear stress
β	True value

β_D	D coordinate rotation
β_F	F coordinate rotation
β_V	V coordinate rotation
β_{max}	Maximum true values of either inputs or outputs
β_{min}	Minimum true values of either inputs or outputs
ϕ_1	Larger outer diameter
ϕ_2	Smaller outer diameter

CHAPTER 1
INTRODUCTION

1.1 General Background

In the middle of the nineteenth century structural tubes of elliptical form were used. Such as designed by Brunel and built in 1859, the elliptical tubes made of wrought iron plates were used in the compression elements of the main belt of the Royal Albert Bridge. Hot-rolled structural members and cold-formed structural members include these structural members in elliptical hollow sections (EHS_s). Recently, it has been observed that these structural elements are used in the construction of steel structures (Ruiz-Teran and Gardner, 2008). It has been seen that elliptical hollow section structural tubes have been used for a long time and are still in use. EHS are commonly used for exposed structural (e.g. wind towers, buildings, off-shore structures, land-based pipelines, bridges etc.) elements owing to their aesthetic appearance and efficiency. The known range of tubular members at the present time contain circular hollow sections, square and rectangular. After all, EHS_s have recently begun to be widely discussed in the construction industry and are widely used in steel constructions. So, EHS can offer more efficiency than from other hollow sections. For example; The use of EHS as steel column has been used in some airports and in some important structures. So, since EHS_s are very advantageous in terms of static and aesthetics, steel EHS columns are used in many structures. The application of EHS can be found in several structures around the world, hardly it has been done so without appropriate design guidelines. To ensure the safe, but economical, application of EHS into structures, it is mandatory that design equations and/or procedures be established (Haque and Packer, 2012). Figure 1.1 shows the three-dimensional view of EHS. In which t shows the thickness of EHS, L shows the length, b is minor axis radius, a is major axis radius.

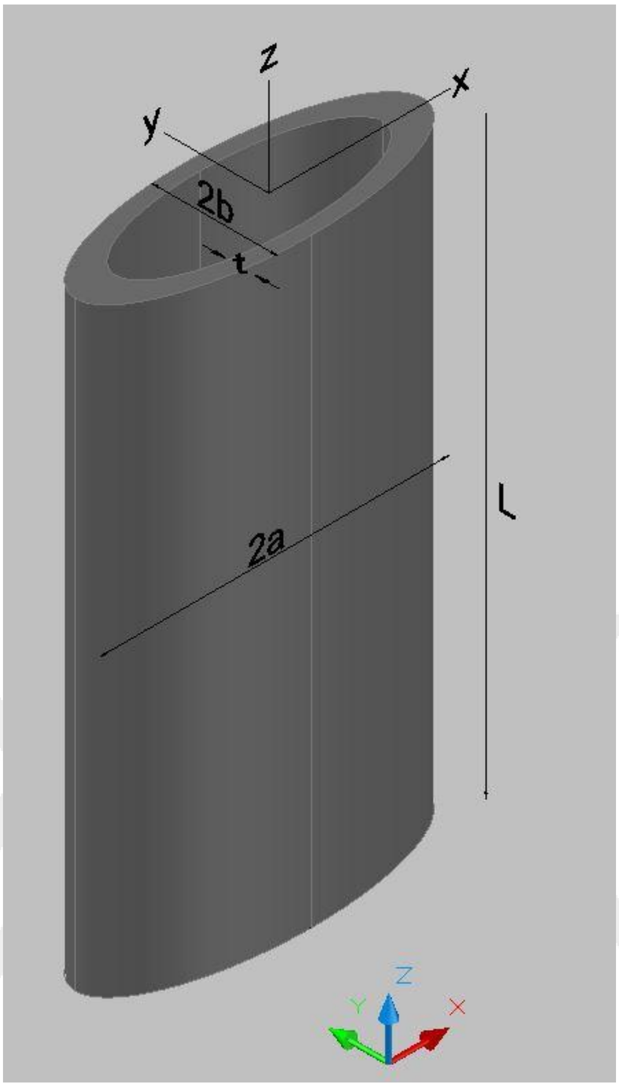


Figure 1.1 The three-dimensional EHS

Genetic programming (GP) is a method to develop computer programs. We do intend to improve and use the GP methodology to create an approach function structure with the best possible quality and to use it in the global or mid-range approach technique. GP is a self-contained method used to create a active computer program from a more complex problem expression of an active problem. The GP starts with a high-level statement of "what to do" and creates a self-contained program to overcome the problem. In order to find the best quality approach, it shouldn't determine the size of the model, the formulation or structural complexity of the symbolic regression problem before the problem. In place of this, the specific characteristics of the existing problem should emerge as part of the solution in the process of solving the problem. GP shows that there is a way to write automatically in the most potential computer programs. So, we can implement genetic programming we need a problem to solve (Haque and Packer, 2012).

Exactly, an artificial neural network (ANN) is the name of a computing paradigm inspired by the process information of biological neural systems such as the human brain. The new structure of the data processing system is the key element of this paradigm. The remarkable ability of neural network (NN) is deriving of complex and indefinite data. It can be extract patterns. Another ability of NN is detecting trends. These are complicated problems. These can not be solved human or computer methods. NN is understood to have high performance since NN determines random calculation, which generally consists of a reasonable number of substantially parallel nonlinear steps. However, it is estimated that the calculation of the results obtained from the experiments may be difficult to interpret and may have counterintuitive properties when investigated through automatically controlled learning and back propagation (Pahuja et al., 2014).

Moreover, NN is based on how the human brain functions. The new structure of the computing system depends on the key factor of that paradigm. Neurons are made up of too many processing elements connected together because neurons move together to solve specific problems. So, verified as a strong data modeling tool, NN captures and represents complex input / output relationships. In the category of information given for analysis, a trained neural network can be considered an "expert" (Prince, 2011).

1.2 Objective and Scope

The principal purpose of this study is to estimate the ultimate strength prediction of elliptical hollow section (EHS) columns in compression and bending by numerical modelling. The results obtained from the numerical modeling are compared with the results of real experiments. In modelling, gene expression programming (GEP) and neural network (NN) are used. For this purpose, an experimental data set is emplowed to develop models. The performance of the proposed models are evaluated by means of the error analysis. Finally, the result based on the generated models were compared and discussed accordingly.

1.3 Outline of the thesis

Chapter 1-Introduction: Aim and objectives of the thesis are introduced.

Chapter 2-Literature review: A literature survey is examined on the hollow section columns in compression and bending. Moreover, various numerical modeling tecniques are discussed.

Chapter 3-Methodology: In the methodology part, the load carrying capacity of elliptical hollow section columns are explained. Description of experimental database, numerical simulations and overview of soft-computing techniques are also provided.

Chapter 4- Discussions of results: Indication, evaluation, and discussion of the numerical modelling results are presented.

Chapter 5-Conclusions: The conclusions are given in the light of findings from the overall results of the analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Hollow Sections

2.1.1 Mechanical Properties

Hollow sections (HS) are manufactured such as steel for the usage of another steel sections and it shows the same mechanical properties. Table 2.1 and Table 2.3 are the examples for hot finished of non-alloy and fine grain constructional steels. These examples can be given the examples of European standard EN 10210-1 (2006).

EN 10219-1 (2006) is shown for cold formed sections. The constructions of EN 10219-1 (2006) is hollow with non-alloy and also fine particle, these constructions are given in Table 2.2 and Table 2.4 The characteristics of EN 10210-1 and EN 10219-1 approximately similar.

HS can be manufacture with different or special type steels. Strength steel can be given as an example for this. The yield point of strength can be rise to 690 N/mm2 or better than given values. Some examples can be given such as weathering steels and special type chemical compositions (Wardenier et al., 2010).

Deformation capacity or rotation capacity are necessary in statically uncertain constructions under redistribution of loads. In that point, rotation capacity can be supply by yielding of members or yielding of the joints. Tensile member is manufactured by ductile steel. This steel can be brittle. This brittleness are valid when particular cross section enervated such that holes and this type of cross section will be fails. This failing will be done before the entire member yields. Therefore, it is necessary for the yielding appears initial. The ratio of the yield to ultimate strength is so significant especially for the constructions under non-uniform stress distributions. This type of situation appearing for tubular type joints. Eurocode 3 (EN 1993-1-1, 2005) is an example for determining the necessity of minimum ratios:

$$\frac{f_u}{f_{yd}} \geq 1{,}1 \tag{2.1}$$

The advices of IIW (2009) and offshore codes need to get higher values of Eq. 2.1:

$$\frac{f_u}{f_{yd}} \geq 1{,}25 \text{ or } \frac{f_{yd}}{f_u} \leq 0{,}8 \tag{2.2}$$

This value needs for ductility. However, it shows the similar characteristics such as ductile manner under impact loading. At that point, Charpy test standard needs for sufficient notch toughness. Other type of characterization is necessary for coarse walled sections. These sections are loaded in the direction of diam. Therefore, not only strength but also ductility can be adequate for preventing cracking which is shown in Figure 2.1 and this type of cracking called as a lamellar tearing. Many constructional steel requirements can be provide minimum necessary ultimate tensile strength, yield strength, and elongation and also Charpy V-notch values can be specified. The specifications of the design standards show the limitations for the fu/fy ratio and it depends on application. CTOD values with limiting necessaries can be given in the diam direction for the Z quality. Cold forming affects the characteristics of main steel. The ratio of the ultimate tensile strength to yield strength can be increased particularly at the corners under the cold forming of HS conditions and Figure 2.2 shows this case. In addition to that, the elongation relatively decreased. Cold formed sections can be supply the necessaries to provide minimum inside corner radius to warrant adequate ductility which is shown in Table 2.5 for the completely aluminum killed steel (Wardenier et al., 2010).

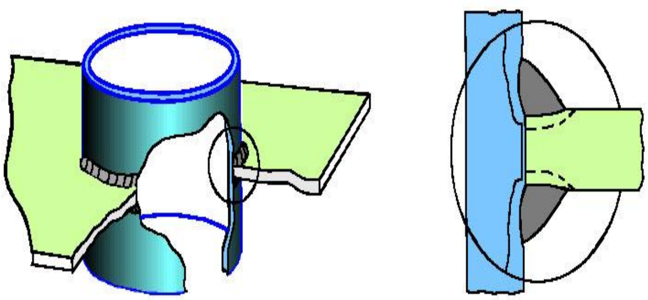


Figure 2.1 Lamellar tearing (Wardenier et al., 2010)

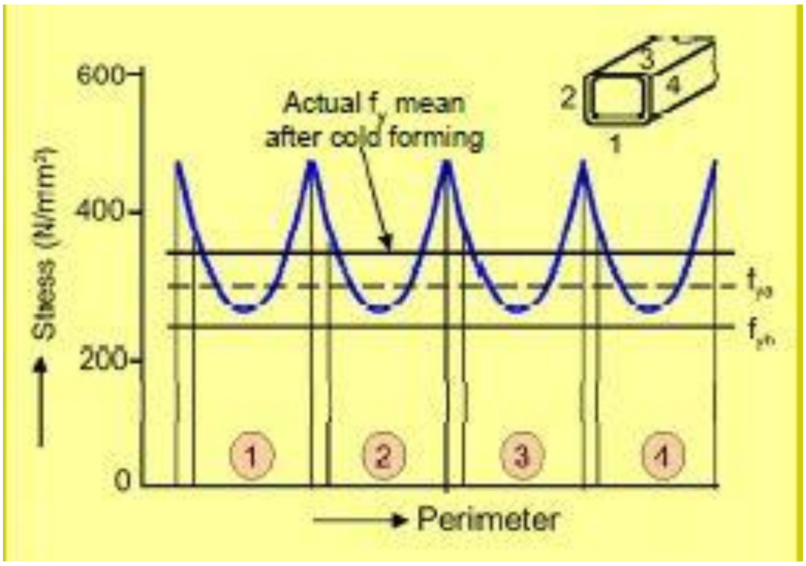


Figure 2.2 For a square hollow section, influence of cold forming on the yield strength, dimensions 100x100x4 mm (Wardenier et al., 2010)

Table 2.1 Hot finished constructional HS unalloyed steel features (EN 10210-1, 2006)

Steel	Min. yield strenght[(a)] (N/mm²)			Min. tensile strenght (N/mm²)		Longitudinal[(b)] min. extension (%) on gauge $L_0=5.65\sqrt{S_0}$		Charpy impact strenght (10 × 10 mm)	
	t≤16 mm	16<t≤40 mm	40<t≤63 mm	t<3 mm	3≤t≤100 mm	3<t≤40 mm	40<t≤63 mm	Temp.℃	J
S235JRH	235	225	215	360-510	360-510	26	25	20	27
S275J0H S275J2H	275	265	255	430-580	410-560	23	22	0 -20	27 27
S355J0H S355J2H S355K2H	355	345	335	510-680	470-630	22	21	0 -20 -20	27 27 40[(c)]

[(a)] For thicknesses greater than 63 mm. These are further decreased.

[(b)] In transvestic direction two percent less than.

[(c)] Correspond with 27 J at -30 ℃

Table 2.2 Cold formed welded constructional HS unalloyed steel (EN 10219-1, 2006) Steel features different from EN 10210-1 (2006)

Steel	Min. longitudinal extension (%) all of thicknesses, t_{max} = 40mm
S235JRH	24[a]
S275J0H S275J2H	20[b]
S355J0H S355J2H S355K2H	20[b]

[a] For t > 3 mm and d/t < 15 or $\frac{b+h}{2t}$ <12.5 the least extension is decreased by 2 to 22%; for t ≤ 3 mm the least extension is 17%.

[b] For d/t < 15 or $\frac{b+h}{2t}$ <12.5 the least extension is decreased by 2 to 18%.

Table 2.3 Hot finished constructional HS- Fine grain steel features (EN 10210-1, 2006)

Steel	Min. yield strenght (N/mm^2)			Min. tensile strenght (N/mm^2)	Longitudinal min. extension (%) on gauge $L_0=5.65\sqrt{S_0}$ t≤ 65 mm		Charpy impact strenght (10 × 10 mm)	
	t≤16 mm	16<t≤40 mm	40<t≤65 mm	t≤65 mm	Long.	Trans.	Temp. °C	J
S275NH S275NLH	275	265	255	370-510	24	22	-20 -50	40[a] 27
S355NH S355NLH	355	345	335	470-630	22	20	-20 -50	40[a] 27
S420NH S420NLH	420	400	390	520-680	19	17	-20 -50	40[a] 27
S460NH S460NLH	460	440	430	540-720	17	15	-20 -50	40[a] 27

[a] Correspond with 27 J at -30 ℃

Table 2.4 Cold formed welded constructional HS – Fine grain steel (EN 10219-1, 2006) Steel features different from EN 10210-1 (2006)

Steel	Feed stock condition M[a]	
	Min. tensile strength (N/mm^2)	Min. longitudinal extension (%)[b]
S275MH S275MHL	360-510	24
S355MH S355MHL	450-610	22
S420NH S420NHL	520-660	19
S460NH S460NHL	530-720	17

[a] M is stating thermal mechanical rolled steels.

[b] For d/t < 15 or $\frac{b+h}{2t}$ < 12.5 the least extension is decreased by 2, for example from 24 percent to 22 percent for S275MH and S275MLH

Table 2.5 Minimum inner corner radius of cold formed RHS considering EN 1993-1-8 (2005)

r/t	Strain because of cold forming (%)	Max. wall thickness t (mm)		
		General		Aluminium-killed steel (Al≥0,02%)
		Overwhelmingly static loading	Fatigue dominative	
≥ 25	≤2	nary	nary	nary
≥10	≤5	nary	16	nary
≥3.0	≤14	24	12	24
≥2.0	≤20	12	10	12
≥1.5	≤25	8	8	10
≥1.0	≤33	4	4	6

2.1.2 Constructional Hollow Section Dimensional Tolerances and Dimensions

The sectional properties and the dimensions of constructional HS are standardized with EN such as EN (2006; EN 10219-2, 2006-EN 10210-2) and other examples for standardizing are ISO standards such as (200; ISO 4019, 2001- ISO 657-14), respectively; these examples are given because of hot finished and cold formed constructional HS.

Two practicable standards are popular in Europe. These standards are EN 10210-2 (2006) and EN 10219 (2006). EN 10210-2 (2006) is used for hot finished constructional HS in the non-alloy types and fine grain type steels. EN 10219 (2006) is used for cold formed welded constructional HS with non-alloy type steels and fine grain type steels. EN 10219 (2006) also used for dimensions, sectional properties etc. However, lots of companies is not comply with the given sizes in standards. At this point the tolerances of EN 10219 (2006) shows the same characteristics with EN 10210-2, this are given in Tables 2.6 and Table 2.8

Square, rectangular or circular cross sectional hollow sections are general types of shapes. Different types of shape are the time exist shapes i.e. any fabricators can be deliver its shapes and this types of shapes are shown in Table 2.7. EHS will be become for popular architectural designs in future (Wardenier et al., 2010).

Table 2.6 Hot finished constructional HS tolerances (EN 10210-2, 2006)

Section kind		Square/rectangular	Circular
Outside dimension		the bigger of ± 0.5 mm and ± 1% [a]	the bigger of ± 0.5 mm and ± 1% however not more than 10 mm
Diam	Welded	-10%	
	Solderless	-10% and -12.5% at max. 25% cross section	
Mass	Welded	± 6% on individual lengths	
	Solderless	-6%; +8%	
Flatness		0.2% of the all length and 3 mm over nary 1 m length	
Length (certain)		+10 mm, -0 mm, but only for certain lengths of 2000 to 6000 mm	
Out of circularity		-	2% for $d/t \leq 100$
Squareness of sides		90° ± 1°	-
Corner radius	Outside	3.0t max.	-
Concaveness/convexness		± 1% of the side	-
Bend		2 mm + 0.5 mm/m [a]	-

[a] For EHS with $h \leq 250$ mm, the tolerances are twice the values shown in that table.

Table 2.7 Special shapes available (Wardenier et al., 2010)

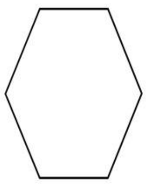
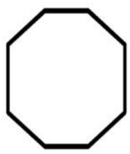
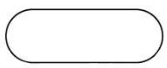
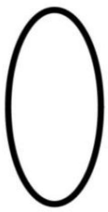
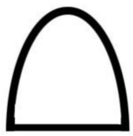
	Triangle	Hexagon	Octagon	Flat- elliptic	Elliptic	Semi-elliptic
Form						

Table 2.8 Cold formed welded constructional HS (EN 10219-2, 2006) tolerances different from EN 10210-2 (2006)

Section kind		**Square/rectangular**	**Circular**
Outside dimension		b < 100 mm: the bigger of ± 0.5 mm and ± 1 percent 100 mm≤ h, b≤200 mm: ± 0.8 percent b > 200 mm: ± 0.6 percent	± 1 percent, min. ± 0.5 mm Max. ± 10 mm
Diam	Welded	t≤ 5 mm: ± 10 percent t > 5 mm: ± 0.5 mm	for d≤ 406.4 mm: t≤5 mm: ± 10 percent t > 5 mm: ± 0.5 mm for d > 406.4 mm ± 10 percent with max. ± 2.0 mm
Mass		± 6 percent	± 6 percent
flatness		0.15% of the all length and 3 mm over nary 1 m length	
Outside corner radius (for profile)		t≤6 mm: 1.6 to 2.4t 6 mm < t≤10 mm: 2.0 to 3.0t t > 10 mm: 2.4 to 3.6t	-
Concaveness/convexnes		Max. 0.8 percent with a min. of 0.5 mm	-

2.1.3 Geometric Properties of Hollow Sections

2.1.3.1 Tension Properties of Hollow Sections

The capacity of the design Nt,rd of a member depends on the yield strength and of the cross sectional area under the tensile loading. These cases are valid for free sectional shape. There is not any advantage or disadvantage with using HS. It is neceassary for the material amount. The capacity of the design is written by: (Wardenier et al., 2010).

$$N_{t,rd} = Af_{yd} \tag{2.3}$$

However, bolt holes weaken the the cross-section. After that, final cross-section can be checked such as other sections with similar way. This can be written by Eurocode 3 (EN 1993-1-8, 2005):

$$N_{t,rd} = \frac{A_{net}f_u}{\gamma_{M2}} 0,9 \tag{2.4}$$

where, the partial factor of safety γ_{M2} = 1,25.

In the Eq. 2.4, the 0.9 values can be changed with country, it is based on partial factor γ_M.

2.1.3.2 Compression Properties of Hollow Sections

Slightness and shape of section are the examples if critical buckling load under compression for centrally loaded members. The slightness can be written in Eq. 2.5, it is the ratio of the buckling length to the radius of gyration (Wardenier et al., 2010).

$$\lambda = \frac{\ell_b}{i} \tag{2.5}$$

where λ is slightness (slenderness), ℓ_b is buckling length and i shows the radius of gyration.

I describes (the radius of gyration) for HS (in relationship to the member mass). It is usually greater than thin axis of an open section. The length, which is known, shows distinct results in the lower slightness for the HS. By means of the lower mass, it can be compared with open section. The first eccentricities, geometrical parameters, straightness and the non-uniformity of steel between stress and strain affects the buckling attitude. Lots of comprehensive researches are done by CIDECT and the European Convention for Constructional Steelwork (ECCS). In the Table 2.9 and Figure 2.3 are given for "European buckling curves". This curves express the summary of difference steel sections for HS. This curves are combined with Eurocode 3 (EN 1993-1-1, 2005). The factor of χ express the reducement factor in Eq. 2.6. It is the ratio of ($N_{b,rd}$) to ($N_{pl,Rd}$).

$$\chi = \frac{N_{b,rd}}{N_{pl,Rd}} = \frac{f_{b,Rd}}{f_{yd}} \tag{2.6}$$

where: $N_{b,rd}$ is the design buckling capacity and $N_{pl,Rd}$ shows the axial plastic capacity

$$f_{b,Rd} = \frac{N_{b,rd}}{A} \tag{2.7}$$

The dimensionless slightness $\bar{\lambda}$ is specified by:

$$\bar{\lambda} = \frac{\lambda}{\lambda_E} \tag{2.8}$$

where:

$$\lambda_E = \pi\sqrt{\frac{E}{f_y}} \text{ (Euler slenderness)} \tag{2.9}$$

Table 2.9 are written for HS with buckling curves. Lots of open sections defines the curves of "c" and "b". The remarkable savingness of material can be supplied from hot-formed HS under buckling case. Shown in Figure 2.4 the buckling length is equal to 3 meters. This length is compared with the necessary mass of open and HS for the case of known load. Slightly slender sections and HS under the low loads provide advantage for the pretty lower usage of materials. The case of higher loads, the percentage of advantage will be lower than lower loads in the low slightness. The increasing of the diameter or width to wall thickness shows the developing of the HS for the all buckling attitude. As late as, that development is limitative by local buckling. The prohibiting of this is are shown with b/t or d/t limits. Eurocode 3 (EN 1993-1-1, 2005) can be given as an example for this. It is given in Table 2.10. So, slender walled sections, relation between local and global buckling must be evaluated.

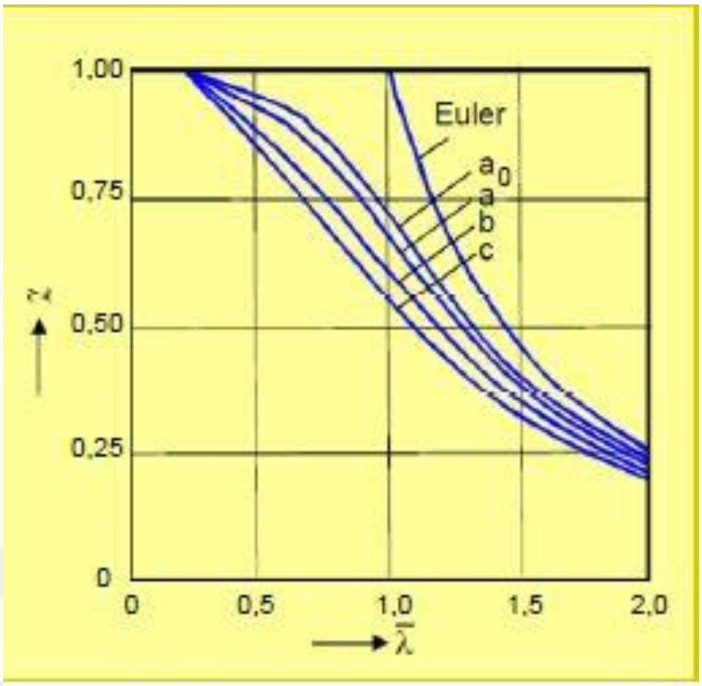


Figure 2.3 Buckling curves in Eurocode 3 (EN 1993-1-1, 2005)

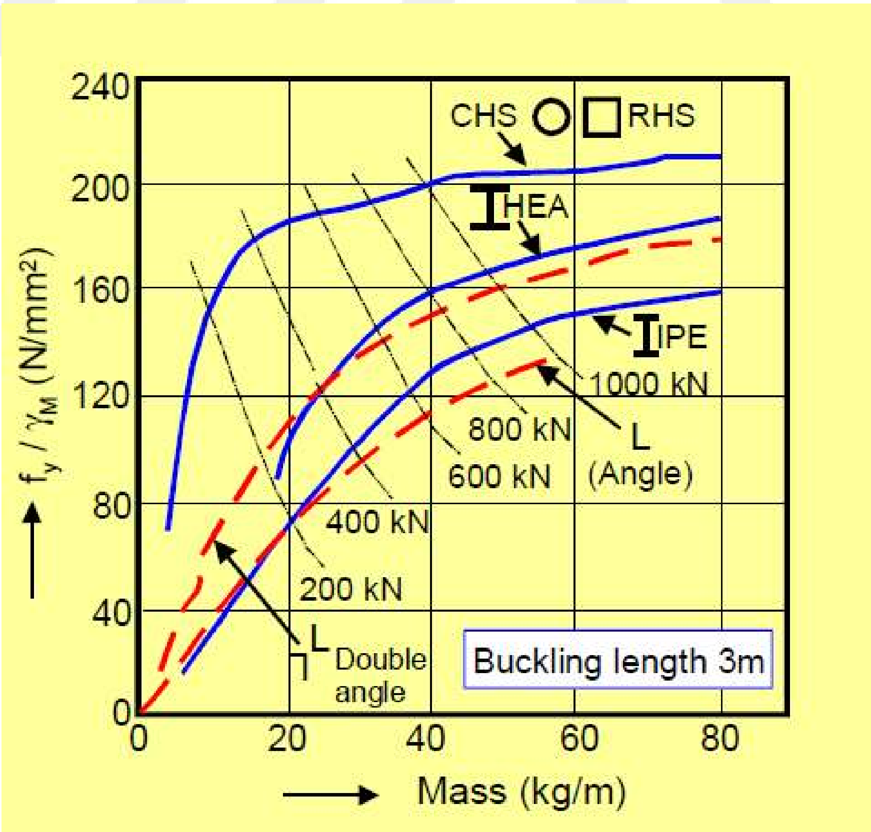


Figure 2.4 Checking of the masses of open and HS under compression in relationship to the loading (Wardenier et al., 2010)

Table 2.9 European buckling curves in comparison with production processes (EN 1993-1-1, 2005)

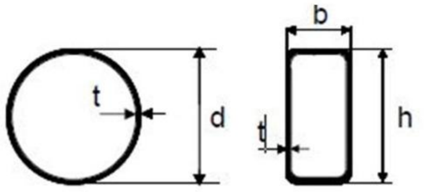
Cross section	Production process	Buckling curves
	Hot finished 420 $N/mm^2 < f_y \le 460$ N/mm^2	a_0
	Hot finished $f_y \le 420$ N/mm^2	a
	Cold formed	c

Table 2.10 Boundaries for d/t, h/t and b/t for cross section classes c, b and a (EN 1993-1-1, 2005)

			Class	a				b				c			
				f_{yd} (N/mm^2=MPa)				f_{yd} (N/mm^2=MPa)				f_{yd} (N/mm^2=MPa)			
Cross section	Load kind	Considered factor		235	275	355	460	235	275	355	460	235	275	355	460
RHS b/t[a]	Compression	Top face		$\frac{b}{t} \le c\sqrt{\frac{235}{f_{yd}}} + 3$											
				c=33				c=38				c=42			
				36.0	33.5	29.8	26.6	41.0	38.1	33.9	30.2	45.0	41.8	37.2	33.0
RHS h/t[a]	Bending	Side Wall[b]		$\frac{h}{t} \le c\sqrt{\frac{235}{f_{yd}}} + 3$											
				c=72				c=83				c=124			
				75.0	69.6	61.6	51.8	86.0	79.7	70.5	62.3	127.0	117.6	103.9	91.6
CHS d/t	Compression and/or Bending			$\frac{d}{t} \le c\frac{235}{f_{yd}}$											
				c=50				c=70				c=90			
				50.0	42.7	33.1	25.5	70.0	59.8	46.3	35.8	90.0	76.9	59.6	46.0

[(a)] For total hot finished and cold formed RHS, it is conservative to presumed that the width-to- diam ratio of the "flat" is $\frac{b-2t-2r}{t} = \frac{b}{t} - 3$.

[(b)] *Wilkinson & Hancock (1998) recommended decreasing the boundaries (EN 1993-1-1) for the side wall slightness of RHS well, for example; in a simplified form to:* $\frac{h}{t} \leq 77 - 0.83\frac{b}{t}$ $with$ $\frac{b}{t} \leq 34.$

Big radius of gyration developes the bucling altitude and it also improves the bucling curve for HS. It may also recommend advantages for the cage beams. Bending stifness and torsional of the members with the combination of the joint stiffness in the cage beams may decreases. It is shown in Figure 2.5. The efficient length of HS can be found with using Eurocode 3 (EN 1993-1-1). I.e. the length of HS with brace members is equal to 0.75 ℓ (ℓ describes the system length) or lower than given values in welded cage beams (Rondal et al., 1992).

Laterally supportless compression chords of cage beams is shown in Figure 2.6. As understanding from Figure 2.6, developing bending stifness and also torsional of the tubular members caused to decreased buckling length. The decision of the HS in beams or trusses can be found with using these factors. It also makes more positive (Baar, 1968; Mouty, 1981).

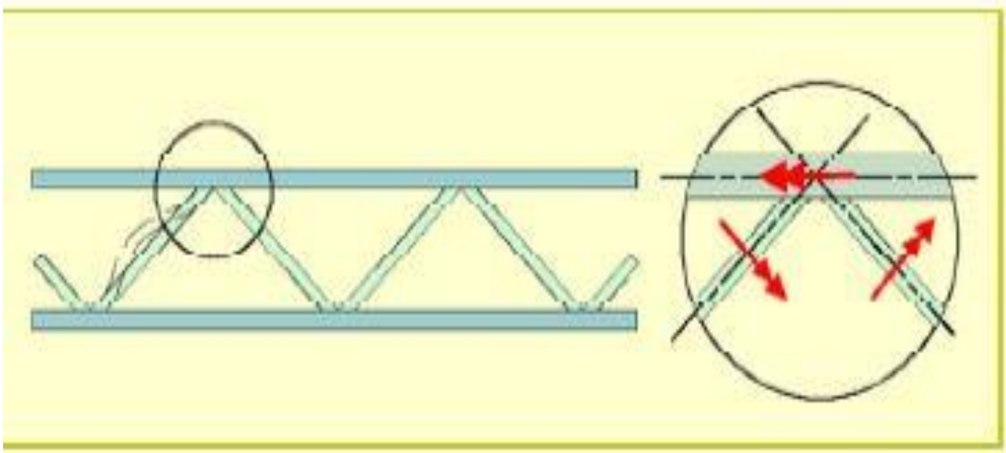


Figure 2.5 Restrictions for the buckling of a support member (Wardenier et al., 2010)

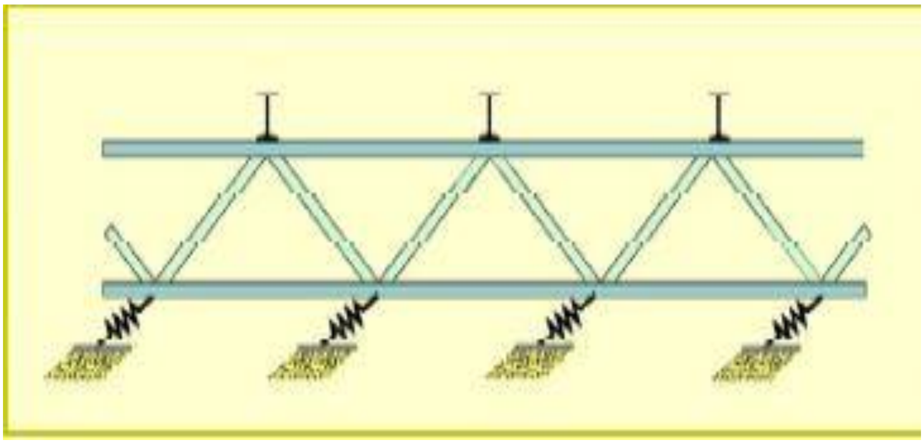


Figure 2.6 Bottom chord laterally spring underpinned by the toughness of the members, jointings and purlins (Wardenier et al., 2010)

2.1.3.3 Bending Properties of Hollow Sections

H and I sections are generally any longer economical under bending. This bending is around the major axis. I_{max} is bigger than for HS. Lateral buckling generally decreases with design resistance for the open sections. Thanks to this one, HS can provide advantage. This may be shown with computations. In the square type hollow sections, lateral instability is not critical point. The widely used RHS and CHS for bending which is around the strong axis. It can be seen from Table 2.11 that the displaying of the permissible span to depth ratios. This ratios generally uses for (EN 1993-1-1, 2005) sections. The investigation of Kaim (2006), limits were gotten too largely. HS can be used for elements. However, it depends on bending. It may be more economically engineered with using plastic design. As another steel sections, different moment-rotation attitude may be controlled. This is valid for loading in bending (Wardenier et al., 2010). The different moment-rotation diagrams is shown in Figure 2.7. These diagrams are shown for member loaded. It is done by the bending moments.

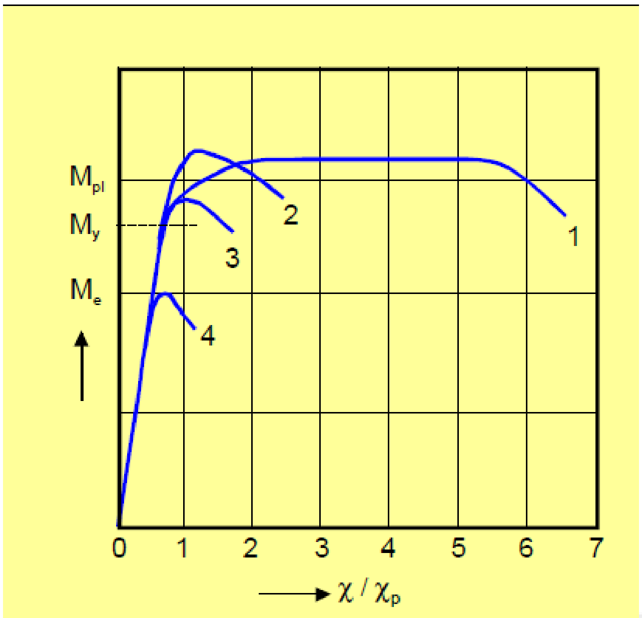
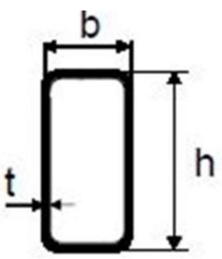


Figure 2.7 Moment-rotation curves (Wardenier et al., 2010)

Table 2.11 Permissible span-to-depth ratios L/(h-t) to prohibit lateral buckling depends on EN 1993-1-1 (2005)

	$\frac{b-t}{h-t}$	$\frac{L}{h-t} \leq$			
		S235	**S275**	**S355**	**S460**
	0.5	73.7	63.0	48.8	37.7
	0.6	93.1	79.5	61.6	47.5
	0.7	112.5	96.2	74.5	57.5
	0.8	132.0	112.8	87.4	67.4
	0.9	151.3	129.3	100.2	77.3
	1.0	170.6	145.8	112.9	87.2

"1" is moment-rotation curve. This curve displays moment exceedance the plastic moment M_{pl}. It additionally has noteworthy turn limit. "2" bend depicts the moment exceedance the plastic moment limit M_{pl}, anyway later the greatest, the moment drops in a split second, along these lines little moment turn limit gets. "3" bend symbolizes the limit which is lower than the plastic moment limit, be that as it may, it surpasses M_{el}. M_{el} is the yield moment limit. "4" bend the limit is as of now not as much as yield moment limit M_{el}. Notwithstanding that, it very well may be disappointment by versatile clasping. The impact existing apart from everything else revolution frame of mind is appeared in Figure 2.8 and Table 2.10. It reflects the classification of cross sections. This classifications are given for the width divided thickness or diameter.

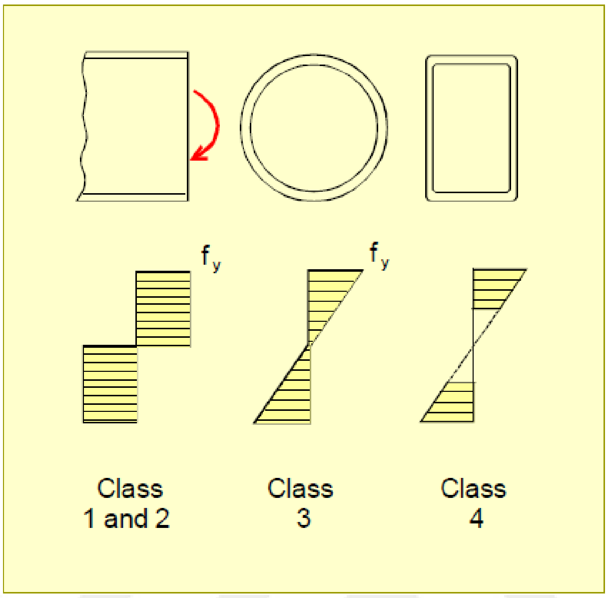


Figure 2.8 Stress distribution for bending (Wardenier et al., 2010)

The limits are depend on tests. It may be stated as:

$$\frac{d}{t} = c\frac{235}{f_{yd}} \qquad \text{for CHS} \qquad (2.10)$$

$$\frac{b}{t} - 3 = c\sqrt{\frac{235}{f_{yd}}} \qquad \text{for RHS} \qquad (2.11)$$

$$\frac{h}{t} - 3 = c\sqrt{\frac{235}{f_{yd}}} \qquad \text{for RHS} \qquad (2.12)$$

The unit of f_{yd} in MPa (N/mm^2). In the Eqs. 2.10, 2.11, and 2.12, c is based on the section class. C is also depends on the loading and the cross section. The "flat" is generally equal to depth h -3t or the external width b for RHS. Radically clamped 1 beam class depends on the distributing loading q for the both points. The plastic moment distribution indicates the later attaining of moment capacity on that point. Girder may be loaded until a further plastic knuckle appears on mid span, it is shown in Figure 2.9 (Wardenier et al., 2010).

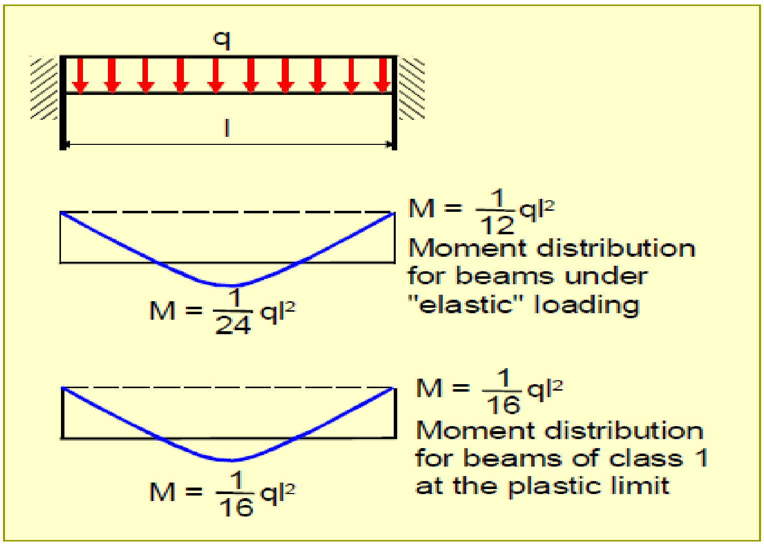


Figure 2.9 Moment distribution in relation tothe cross section classification (Wardenier et al., 2010)

The investigation of Wilkinson and Hancock (1998) exposed the limits for the side wall slightness of RHS. It is particularly required for decreasing significantly. For example for class 1 sections, those propose reduction the Eurocode 3 limits (EN 1993-1-1) for the side wall slightness to:

$$\frac{(h-2t-2r)}{t} \leq 70 - \frac{5(b-2t-2r)}{6t} \text{ with } \frac{b-2t-2r}{t} \leq 30 \qquad (2.13)$$

For r is equal to t, this may be simplified to:

$$\frac{\mathrm{h}}{\mathrm{t}} \leq 77 - 0.83\frac{\mathrm{b}}{\mathrm{t}} \text{ with } \frac{\mathrm{b}}{\mathrm{t}} \leq 34 \qquad (2.14)$$

The shear powers can be lower than half of the shear limit $V_{pl,Rd}$. The impact of shear can be disregarded and the bowing minute limit around one hub is appeared by: (Wardenier et al., 2010).

$M_{c,Rd} = W_{pl} f_{yd}$ for cross area classes 2 or 1 (2.15)

$M_{c,Rd} = W_{el} f_{yd}$ for cross area class 3 (2.16)

$M_{c,Rd} = W_{eff}\ f_{yd}$ for cross area class 4 (2.17)

According to Eurocode 3 (EN 1993-1-1), unifiy stacking must be see again for the instance of shear power more noteworthy than its ability.

2.1.3.4 Shear Properties of Hollow Sections

The elastic shear stress may be stated with easy mechanics for RHS and CHS by;

$$\tau = \frac{SV_{Ed}}{2It} \leq \frac{f_{yd}}{\sqrt{3}} \tag{2.18}$$

the flexible pressure dissemination is appeared in Figure 2.10. The limit of configuration relies upon plastic plan. It might be easefully expressed relies upon the Huber Hencky Von Mises. It accept the shear yield quality in these pieces of cross area dynamic (Wardenier et al., 2010).

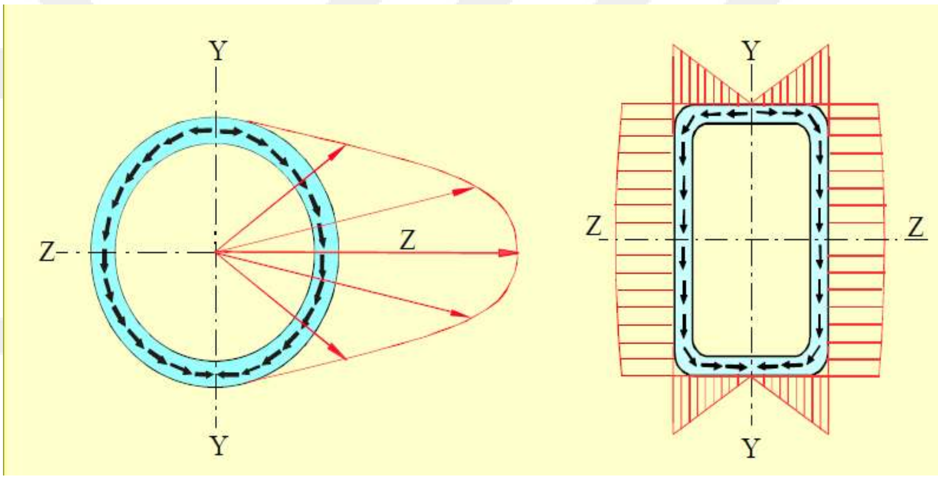


Figure 2.10 Elastic shear stress distribution (Wardenier et al., 2010)

$$v_{pl,Rd} = A_v \frac{f_y}{\sqrt{3}} \tag{2.19}$$

Where:

$$A_v = A\,\frac{h}{b+h} \qquad \text{for RHS} \tag{2.20}$$

(else only 2 h t) and V in the direction of h.

$$A_v = A\frac{2}{\pi} \qquad \text{for CHS} \tag{2.21}$$

2.1.3.5 Torsion Properties of Hollow Sections

All HS, particularly round sort empty area, are usefull cross areas for safe torsional minutes. It originates from consistently appropriated around the polar hub. A checking of open and HS are nearly a similar mass in Table 2.12. It very well may be seen that torsional consistent of HS is about multiple times of open areas. Limit of the plan for torsional minutes is related to: (Wardenier et al., 2010).

$$M_{t,Rd} = W_t \frac{f_{yd}}{\sqrt{3}} \tag{2.22}$$

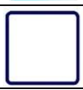
For CHS:

$$W_t = \frac{2I_t}{d-t} = \frac{\pi}{2}(d-t)t \tag{2.23}$$

Where:

$$I_t \approx \frac{\pi}{4}(d-t)^3 t \tag{2.24}$$

Table 2.12 Torsional strength of several sections (Wardenier et al., 2010)

Section		Mass (kg/m)	Torsion constant It (10^4 mm^4) or (cm^4)
	UPN 200	25.3	11.9
	INP 200	26.2	13.5
	HEB 120	26.7	13.8
	HEA 140	24.7	8.1
	140 x 140 x 6	24.9	1475
	168.3 x 6	24.0	2017

2.1.3.6 Internal Pressure Properties of Hollow Sections

The CHS is most proper to resist an internal pressure p. Capacity of the design per unit length, see in Figure 2.11, is shown by:

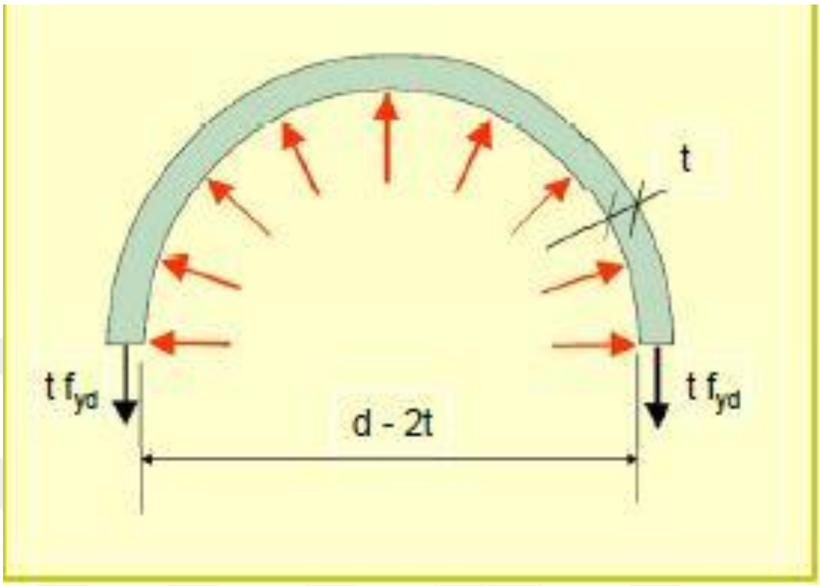


Figure 2.11 Internal pressure (Wardenier et al., 2010)

$$P = f_{yd}\frac{2t}{d-2t} \qquad (2.25)$$

In Eq. (2.25), γ_{M0} = 1.0 anyway for carriage type pipeline. The γ_{M0} worth can be fundamentally more prominent than different causes. It depends on the danger of the item. It likewise relies upon impact of disappointment on natural or controllability. The limits of plan for RHS areas exposed to p are a lot increasingly unpredictable. P is the inside weight. (Deutscher Dampfkesselausschuβ, 1975).

2.1.3.7 Combined Loadings for Hollow Sections

Several combinations of loadings are feasible, for example; bending, tension, shear, torsion, and compression. Based on the cross s several interplay formulae. It must be implemented. Reference is given Eurocode 3 (EN 1993-1-1).

2.1.3.8 Aesthetic for Hollow Sections

The levelheaded utilization of HS by and large causes to cleaner and again satisfaction developments. HS may supply slight aesthetical segments, with variable segment properties anyway flush outside measurements. Since their torsional unbending nature, HS have particular preferences in collapsed developments, V-type pillars, and so forth. Confine structure that is ordinarily made of HS legitimately associated with one other with no stiffener or prop plate is commonly particular by designers for developments with evident steel components. In any case, that is difficult to state stylish properties in monetary correlations. Sometimes HS are utilized only because of stylish intrigue. It is appeared in Figure 2.12, its significance is lower (Wardenier et al., 2010).

Figure 2.12 Aesthetically appealing structures (Wardenier et al., 2010)

2.2 Definition of Elliptical Hollow Section (EHS)

Circular empty segments (EHSs) are a sort of empty auxiliary area (HSS) that are a moderately new shape to the steel development world. An oval is a particular oval shape which has two unique tomahawks of symmetry. EHSs are characterized as having one huge measurement and one little measurement. The proportion of the huge measurement (H = 2a) to the little measurement (B = 2b) it's known for angle proportion. Perspective proportion of all at present fabricated EHS = 2 (Packer, 2008). The general condition for a circle is given in Eq. (2.26) (Ruiz-Teran and Gardner, 2008).

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \tag{2.26}$$

where x and y are the Cartesian co-ordinates, and a and b are the half of the large and small outer dimensions of the EHS, respectively. The terms a and b are also called as major and minor radius, respectively (see Figure 2.13) (Haque and Packer, 2012)

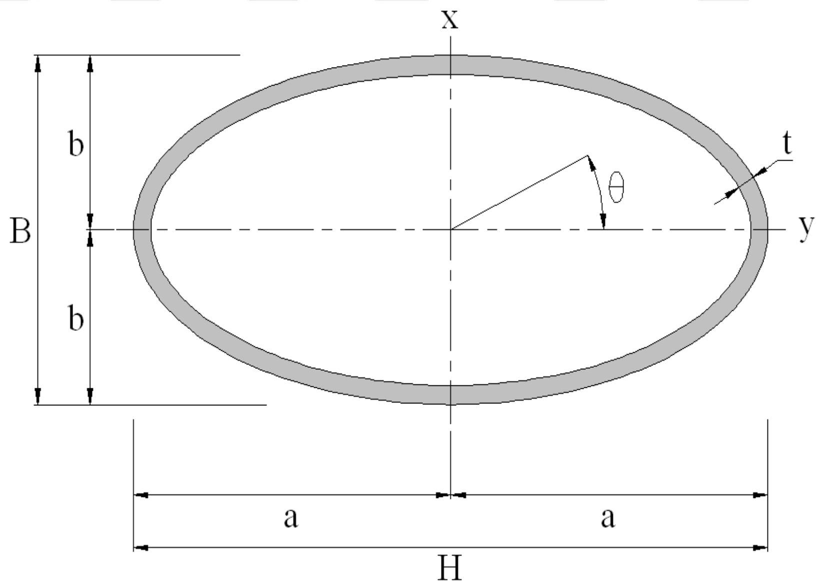


Figure 2.13 Basic dimensions of EHS (Haque and Packer, 2012)

By and large, HSSs are cylindrical segments that can be either cold and hot shape (or hot-worked). EHSs, notwithstanding, are fabricated distinctly by the hot-worked process, and all things considered, they meet G40.20-04/G40.21-04 (CSA, 2004) class H or A501 (ASTM, 2007) standards in North America (Packer, 2008). In general, HSS can be fabricated by a weldless process or a welding operation. Weldless fabricating involves an extrusion-type process that pierces solid material to form the tube shape. Weld manufacturing involves bending flat-rolled steel into a tubular shape and then seam welding the edges (CSA, 2003). EHS are as of now produced by electric opposition welding from a plate and after that hot-completing to the last shape (Corus, 2005). The conduct of EHS is a blend between that of round empty areas (CHS) and rectangular empty segment (RHS). EHS resembles CHS as far as many general properties and conduct; be that as it may, they are diverse since EHS has a changing sweep of shape though CHS does not (Haque and Packer, 2012).

2.2.1 History

EHS is a comparatively new shape of high strength, hot milled steel sections. It is used in constructional building applications. The reason of using in building application is intrinsic aesthetics. EHS propose constructional advantages of sections with varying minor and major axis properties, compared with CHS (Haque and Packer, 2012). Extensive application of EHS needs main and systematical test data. The requirement comes from verifying constructional design guiding of the EHS. Nevertheless, despite the relevance in their usage, test results are insufficient and constructional performance of elliptical sections. There is a restricted intellection of properties. In the previous investigation has been carrying out on Circular Hollow Section (CHS) regarding the regional buckling form. Elastic buckling stress (EBS) of CHS can be calculated with using Eq. (2.27) to expose theoretical compression (Zhu and Wilkinson, 2007).

$$\sigma_{cr} = \frac{2Et}{D\sqrt{3(1-\nu^2)}} \tag{2.27}$$

where ν shows Poisson’s ratio. D can be resolved as the breadth. E demonstrates the material Young's modulus, t demonstrates the thickness of the round cross area. From that equation, it can be sighted that the ratio of D/t is the key parameter influence regional buckling of CHS (Zhu and Wilkinson, 2007).

The first attention were gotten for the characteristic of post-buckling and elastic critical buckling between 1900s and 1960s in USA. Marguerre (1951) and Kempner (1962) were examined the prediction formulas of critical buckling and post-buckling response of EHS. These study was carried out under axial loading. Versatile basic clasping worry for a circular cross segment uncover hypothetical pressure is given by Eq. (2.28).

$$\sigma_{cr} = \frac{Et}{(\frac{A^2}{B})\sqrt{3(1-\nu^2)}} \tag{2.28}$$

Post buckling react such as circular cylindrical shell. It is significantly different from a flat plate. As shown in Figure 2.14 whenas a flat plate display a constant post buckling react, the post buckling react of a circular cylindrical shell is unstable. The resulting of this is in high defect sensitivity. The attitude of an elliptical (oval) section can be assumed to be medium point between these two bounds (Gardner and Ministro, 2004).

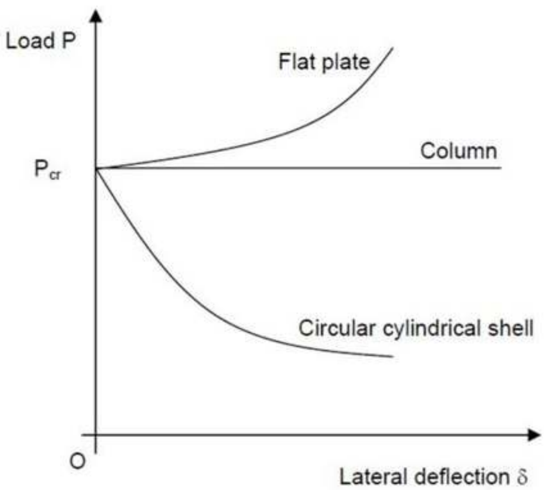


Figure 2.14 Post-buckling react of an axially compressed circular cylindrical shell and a flat plate (Gardner and Ministro, 2004)

Analytical methods were used in the second half of the twentieth century to learn the response of the compacted non-circular hollow section. The initial research was carried out bu Marguerre in 1951. The focus of study is a cylindrical shells of varying curvature. This can be also defined by Fourier polynomial terms as seen in Eq. (2.29) (Gardner and Ministro, 2004).

$$\frac{1}{r} = \frac{1}{r_0} = \left(1 + \xi\cos\left(\frac{4\pi s}{L_0}\right)\right) \tag{2.29}$$

where demonstrates the bended length of the segment, r demonstrates the span of shape, ξ is the capriciousness of area. L_0 demonstrates that it is the fringe length of area. "r_0" can be characterized the span of round area with indistinguishable fringe length.

Marguerre demonstrated that a non-roundabout empty area characterized by Eq. (2.29) was of practically equivalent to shape to a circle just so $0 \le \xi \le 1$. For $\xi = 0$, Eq. (2.29) totally display CHS, while for $\xi = 1$, the greatest span of ebb and flow of the NCHS is equivalent to endlessness. Notwithstanding that angle proportion of segment is equivalent to 2.06 (Ruiz-Teran and Gardner, 2008).

2.2.2 Limit Attitude of EHS

EHS is geometrically known by the length of two essential axes minor (2b) axes. the major (2a) axes as written by Eq. (2.26). When the major and minor axes have equal length, aspect ratio of cross-section is unity. It will be become a CHS. In addition to that the length of minor axis can be ignore in comparision with length of major axis. It is shown in Figure 2.14 (Gardner and Ministro, 2004).

Thus, the EBS must be a function of aspect ratio for EHS. It must be also limited by the EBS of a CHS. However, it is in the case of the major and minor axes have equal length. In addition to that the EBS of a flat plate are limited in the case of the aspect ratio nears eternity. EBS of a CHS, proven freely by Timoshenko (1910), is given by Eq. (2.30) (Rotter, 2004).

$$\sigma_{CHS} = \frac{E}{\sqrt{3(1-\nu^2)}}\frac{t}{r} \tag{2.30}$$

where r is radius of curvature, we can define t as the thickness of CHS, E is Young’s modulus. ν is also defined as the Poisson’s ratio of material. Elastic local buckling stress depends on the length of pipe. Therefore, it is the reason of influencing the limits conditions. The larger pipe length caused to the lower the buckling stress. The EBS, encapsuling on length effects, is written in Eurocode 3 Part 1.6 by Eq. (2.31).

$$\sigma_{CHS} = \frac{E}{\sqrt{3(1-\nu^2)}}\frac{t}{r}C_x \tag{2.31}$$

where C_x is a ratio determinated by relavent length of CHS. This case is for cenral length cylinders $C_x = 1$. C_x is bigger than 1 for small cylinders. C_x is lower than 1 for long cylinders. Depends on the classifications, it is suggested by Eurocode 3 Part 1.6, total practical constructionalsteel pipes would be considered as either middle length or long cylinders.

The EBS of a compressed flat plate, proven by Bryan (1891), is given by Eq. (2.32) (Timoshenko, 1961).

$$\sigma_{plate} = \frac{KE\pi^2}{12(1-\nu^2)}\left(\frac{t}{W}\right)^2 \tag{2.32}$$

t can be defined the thickness of plate and W can be defined the width of plate and K is a buckling ratio. K is depends on aspect ratio. K is also depends on the limits conditions of plate.

Lots of previous investigation has been done for EHS. It is depends on the suggestion of Kempner. It was afterwards substantiating by Hutchinson. This the EBS in compression. It can be chosen as that of CHS. The radius this is equal to the maximal radius of curvature in elliptical section. It is written in Eq. (2.33) (Ruiz-Teran and Gardner, 2008).

$$r = \frac{a^2}{b} \tag{2.33}$$

The presumed EBS under compressed is thus written in Eq. (2.34)

$$\sigma^{K}_{EHS} = \frac{E}{\sqrt{3(1-\nu^2)}}\frac{t}{a^2/b} \tag{2.34}$$

In first design pilotage for EHS improved by steel producer, Corus 2004. It was suggested that the equivalence radius classification may be taken as in Eq. (2.35). It can also be taken as a result in EBS of Eq. (2.36) (Ruiz-Teran and Gardner, 2008).

$$r = a\sqrt{\frac{a}{b}} \tag{2.35}$$

$$\sigma_{EHS}^{C} = \frac{E}{\sqrt{3(1-\nu^2)}} \frac{t}{a\sqrt{a/b}} \tag{2.36}$$

The viewpoint proportion in Eq. (2.34) and Eq. (2.36) gives similar outcomes. It is equivalent to solidarity. These are additionally equivalent to that of Eq. (2.30) and Eq. (2.31) with Cx = 1. Along these lines, the two conditions go along of CHS limit. Barely, high angle proportion in the EBS must be in propensity to that of a level plate, which neither Eq. (2.34) neither Eq. (2.36) anticipate for EHS. The definition of EBS for EHS with similar breaking points for CHS and furthermore plates are subsequently looked for after. Depicting the proportionality breadth of EHS, DEq,EHS as the measurement of a CHS with a similar worth is equivalent to EBS, and the relative comparability distance across as the proportion between that identicalness width DEq,EHS and the real pivot measurement (2a) of the EHS, caused to Eq. (2.37) and Eq. (2.38) for CHS and plate limits, individually (Ruiz-Teran and Gardner, 2008).

$$\frac{D_{Eq,EHS\left(\frac{a}{b}=1\right)}}{2a} = 1 \tag{2.37}$$

$$\frac{D_{Eq,EHS\left(\frac{a}{b}\to\infty\right)}}{2a} = \frac{8\sqrt{3(1-\nu^2)}}{K\pi^2}\frac{2a}{t} \tag{2.38}$$

From equations (2.37) and (2.38) it very well may be controlled this. The equality distance across is the capacity of both the relative thickness and perspective proportion. The relative thickness is t/2a and viewpoint proportion is a/b. The relative proportionality widths relies upon Kempner's supposition, condition (2.33), and Corus' proposition, condition (2.35), are written in Eq. (2.39) and Eq . (2.40) individually; unmistakably nor of these articulations mirror as far as possible written in Eq. (2.38) (Ruiz-Teran and Gardner, 2008).

$$\frac{D_{Eq,EHS}^{K}}{2a} = \frac{a}{b} \tag{2.39}$$

$$\frac{D_{Eq,EHS}^{C}}{2a} = \sqrt{\frac{a}{b}} \tag{2.40}$$

For every one of the two points, two unique kinds of farthest point conditions are utilized. These are utilized for recreating the test state. The focuses were separated into a fixed point and a versatile point. At the fixed point, dislodging degrees of opportunity in D, F, V headings (M_D, M_F, M_V) just as rotational degrees of opportunity in D, F, V bearings (β_D, β_F, β_V) were controlled to be zero. At the mobile end, load was applied with an even pressure dissemination the longitudinal way M_V. The rearranged portrayal of point of confinement conditions is given in Figure 2.15 (Zhu and Wilkinson, 2007).

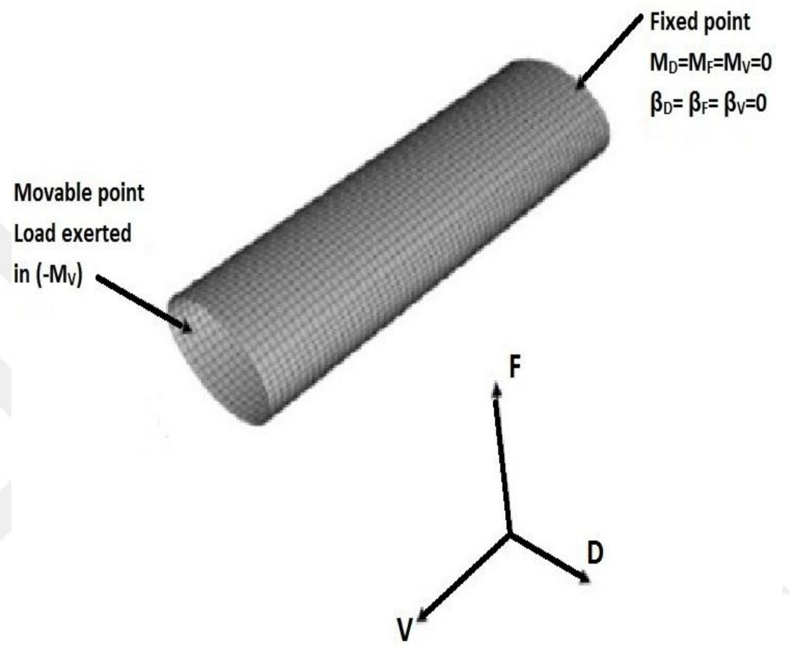


Figure 2.15 Limit conditions for EHS in compression (Zhu and Wilkinson, 2007)

2.2.3 Properties of EHS

EHS are completely absent from Canadian codes and guidelines. Even the basic EHS sectional property equations and EHS mechanical properties are absent. These properties have been published in the European EN10210 (CEN, 2006a and 2006b), but they have yet to be incorporated into the Canadian Handbook of Steel Construction (CISC, 2010).

2.2.3.1 Geometrical Properties

The EHS sectional properties and dimensions equations that have been published in EN10210 (CEN, 2006a; CEN, 2006b) are shown in Table 2.13.

Table 2.13 Dimension and sectional property equations EN10210 (CEN, 2006a; CEN, 2006b)

Sectional Property	Formula	Units
Superficial (Surface) Area	$A_s = \frac{P}{10^3}$	(m^2m)
Cross Sectional Area	$A = \frac{\pi[HB-(H-2t)(B-2t)]}{4}$	(mm^2)
Mass per unit length	$M = 0{,}00785A$	(kg/m)
Moment of Inertia		
Major Axis	$I_x = \frac{\pi}{64}[BH^3 - (B-2t)(H-2t)^3]$	(mm^4)
Minor Axis	$I_y = \frac{\pi}{64}[HB^3 - (H-2t)(B-2t)^3]$	(mm^4)
Radius of Gyration		
Major Axis	$r_x = \sqrt{\frac{I_x}{A}}$	(mm)
Minor Axis	$r_y = \sqrt{\frac{I_y}{A}}$	(mm)
Elastic Section Modulus		
Major Axis	$s_x = \frac{2I_x}{H}$	(mm^3)
Minor Axis	$s_y = \frac{2I_y}{B}$	(mm^3)
Plastic Section Modulus		
Major Axis	$Z_x = \frac{[H^2B - (H-2t)^2(B-2t)]}{6}$	(mm^3)
Minor Axis	$Z_y = \frac{[B^2H - (B-2t)^2(H-2t)]}{6}$	(mm^3)
Torsional Inertia Constant	$J = \frac{4A_m^2t}{U} + \frac{Ut^3}{3}$	(mm^4)
Torsional Modulus Constant	$c_t = \frac{J}{t + \frac{2A_m}{U}}$	(mm^3)
	$A_m = \frac{\pi(H-t)(B-t)}{4}$	(mm^2)
	$P = \frac{\pi}{2}(H-B)\left(1 + 0{,}25(\frac{H-B}{H+B})^2\right)$	(mm)
	$U = \frac{\pi}{2}(H+B-2t)\left(1 + 0{,}25(\frac{H-B}{H+B-2t})^2\right)$	(mm)

Note: H = 2a and B = 2b

A portion of the conditions found in Table 2.13 have been examined for their over-conservatism. One of these over-moderate CEN conditions is the cross-sectional territory recipe (Chan and Gardner, 2007), which is rehashed as Eq. (2.41):

$$A=\frac{\pi}{4}[2a \times 2b - (2a - 2t)(2b - 2t)] \tag{2.41}$$

Chan and Gardner (2007) suggested that an increasingly proper cross-sectional zone (A) future a result of the mean border (Pm) and thickness (t) of the cross-segment, see Eq. (2.42). Pm would be determined dependent on the mean edge plan created by Ramanujan (Chan and Gardner, 2007), see Eq. (2.43):

$$A= P_m \times t \tag{2.42}$$

$$P_m = \pi(a_m + b_m)\left(1 + \frac{3h_m}{10+\sqrt{4-3h_m}}\right) \tag{2.43}$$

where $h_m = (a_m - b_m)^2/(a_m + b_m)^2$ and $a_m = (2a - t)/2$, $b_m = (2b - t)/2$

In extra to the cross-sectional zone, S (the flexible segment modulus) and Z (plastic area modulus) of an EHS appeared in Table 2.13 are excessively moderate also, as per Chan and Gardner (2008a). They proposed the accompanying conditions for the x-axis (real axis) and y-axis (minor axis), where am and bm are equivalent to previously, I_y and I_x are the snapshots of idleness about the minor and significant tomahawks, seriatim, and θ is estimated counter-clockwise from the y-axis:

$$S_x = \frac{I_x}{a} = \frac{4a_m^3 t}{a}\int_0^{\frac{\pi}{2}} \cos^2\theta \sqrt{\sin^2\theta + \cos^2\theta\,\frac{b_m^2}{a_m^2}}\,d\theta \tag{2.44}$$

$$S_y = \frac{I_x}{b} = \frac{4a_m b_m^2 t}{b}\int_0^{\frac{\pi}{2}} \sin^2\theta \sqrt{\sin^2\theta + \cos^2\theta\,\frac{b_m^2}{a_m^2}}\,d\theta \tag{2.45}$$

$$Z_x = 4a_m^3 t\int_0^{\frac{\pi}{2}} \cos\theta \sqrt{\sin^2\theta + \cos^2\theta\,\frac{b_m^2}{a_m^2}}\,d\theta \tag{2.46}$$

$$Z_y = 4a_m b_m t\int_0^{\frac{\pi}{2}} \sin\theta \sqrt{\sin^2\theta + \cos^2\theta\,\frac{b_m^2}{a_m^2}}\,d\theta \tag{2.47}$$

2.2.3.2 Mechanical Properties

EHS are as of now created as hot-completed HS at normalizing temperatures as per EN10210 with the regular evaluation being S355J2H: the yield quality fy ≥ 355MPa, with a Charpy sway obstruction of 27 J at - 20°C (Packer, 2008 and 2009). The resiliences on the shapes are as per the following (Table 2.14 and Table 2.15) as indicated by EN 10210 (CEN, 2006a; CEN, 2006b):

Table 2.14 EHS tolerances EN 10210 (CEN, 2006a; CEN, 2006b)

Characteristic	**Tolerance**
Outside Dimension	+/- 1% (doubled if H < 250 mm) with minimum +/- 0.5mm
Thickness	-10%
Twist	2 mm plus 0.5 mm/m length (both values doubled if H < 250 mm)
Straightness	0.2% (doubled if H < 250 mm) of all length and 3 mm over nary 1 meter length
Mass	+/- 6% on individual given lengths (+8/-6% for seamless HS)

Table 2.15 EHS mechanical properties EN 10210 (CEN, 2006a; CEN, 2006b)

Specified Diam (mm)	**Min. Yield Strength (N/mm^2)**	**Specified Diam (mm)**	**Tensile Strength (N/mm^2)**	**Specified Diam (mm)**	**Min. Elongation (%)**
t ≤ 16	355	t ≤ 3	510-680	t ≤ 40	22
16 ≤ t ≤ 40	345	3 ≤ t ≤ 100	470-630	40 ≤ t ≤ 63	21
0 ≤ t ≤ 63	335	100 ≤ t ≤ 120	450-600	63 ≤ t ≤ 100	20
63 ≤ t ≤ 80	325			100 ≤ t ≤ 120	18
80 ≤ t ≤ 100	315				
100 ≤ t ≤ 120	295				

The development of the compressive resistance of EHS and the study of EHS behaviour undergoing axial compression have been investigated for over fifty years. This segment will portray the history behind EHS compressive obstruction advancement, in addition to the trial tests and limited essential models to determine cross-sectional characterization and plan rules for EHS under axis pressure (Bradford and Roufeginejad, 2008).

2.2.3.3 Advantages of EHS

Even though minimal design guidance is available, EHS are increasingly being used for certain advantages listed here. An architectural reason for the use of EHS is their modern look (Packer et al., 2009), plus they are interesting and unusual in appearance (Ruiz-Teran and Gardner, 2008). In coating frameworks, they give an exquisite visual intrigue and give a feeling of being light weight. Notwithstanding their tasteful intrigue, hot-shaped EHS have better mechanical properties thought about than North American produced HSS (Packer et al., 2009). This incorporates their fine grained structure, full weldability, unimportant lingering pressure, and perfect nature for hot-plunge arousing (Corus, 2005). Since it is a hotfinished item, it has better obstruction than by and large flexural locking when utilized in pressure (Bortolotti et al., 2003). Since EHS have two distinctive chief tomahawks, there are diverse flexural toughnesses about every one of these tomahawks. This enables the area to be arranged to all around proficiently oppose the connected burden (Ruiz-Teran and Gardner, 2008), all the more explicitly wind load for coating frameworks (Bortolotti et al., 2003). EHS areas additionally have high torsional solidness since they are shut segments. Contrasted with a CHS with a similar territory or weight, an EHS has more noteworthy bowing limit as a result of the diverse chief tomahawks while keeping up a smooth, shut shape (Packer, 2008). What's more, the clasping disappointment mode for slim CHS might be unexpected while it isn't for slight EHS (Bradford and Roufeginejad, 2008).

2.2.3.4 Common Applications

EHS have been produced since 1994 in France by Tubeurop, now owned by Condesa (Packer, 2008). Currently, the other world producers include Corus in the United Kingdom, that manufacture the line Celsius® 355 Ovals, and Ancofer Stahlhandel GmbH in Germany (Packer et al., 2009).

The primary basic structure which endeavored to incorporate EHS goes back to 1845 for the Britannia Bridge. In the principle box bar, this EHS were initially intended for the pressure spine (Ruiz-Teran and Gardner, 2008). In 1859, the Royal Albert Bridge anticipated by Brunel manufactured curved segments out of created iron and utilized them for the essential pressure curves (Ruiz-Teran and Gardner, 2008).

All the more as of late, EHS have turned out to be well known for coating frameworks (glass façades and glass rooftops) since they give great protection from bowing when the solid pivot is situated towards the forced burdens, that is, the breeze loads. What's more, they give a rich visual intrigue and give a feeling of being light weight (Packer et al., 2009). Models incorporate the Coeur Défense chamber in Paris, France by modeler J.P. Viguier (Packer et al., 2009) and a bracket support glass framework in the AXA structure in Paris (Bortolotti et al., 2003).

EHS are also used as columns, as seen in the Swords office at the Airside Business Park in Dublin Airport, Ireland by architects RKD Architects and engineers Thomas Garland and Partners (Packer et al., 2009). Another structural application of EHS is in the Jarold Department Store in Norwich, United Kingdom (Corus, 2005).

EHS can be found in some of the newest steel sculptures, as seen at the Honda Exhibit at the Festival of Sound 2005 in Goodwood by architect Gerry Judah and engineer NRM Bobrowski (see Figure 2.16). The main structure is composed of three 45-metre CHS arches, 457 mm in diameter that support six, 55 metre EHS arms that swing up and down creating a sense of kinetic wonder for the audiences. Each arm supports one of the featured cars and is supported further by small EHS 400x200 to stiffen the arms and enhance appearance (Corus, 2005).

Canadian examples of EHS being used in buildings are the Legends Centre in Oshawa, Ontario and the Electronic Arts stairwell in Vancouver. The latter was the first building in Canada to have used EHS. The Legends Centre in Oshawa is a multipurpose recreational centre where the aquatic centre of the building incorporates EHS columns and was the first in Ontario to have used EHS. This building was awarded the CISC (the Canadian Institute of Steel Construction) 2006 Ontario Steel Design Award in the Architectural Category (Corus, 2005).

EHS are also found in modern airports for example the bus terminal in Terminal 3. Another examples is the main structure in Terminal 5 of Heathrow Airport in London. One example can be given in Madrid such that the main structure in Terminal 4 (Ruiz-Teran and Gardner, 2008). EHS are also used in electricity transmission line steel props by EDF, France, pedestrianism bridges in the UK, wind turbine posts, urban furniture (like bus asylums), and safety rails (Packer, 2008). Despite being used in a variety of practices, structural design lead is required in order that EHS are more widely and more efficiently used (Chan and Gardner, 2007).

Figure 2.16 Honda exhibit (Corus, 2005)

2.3. Finite Element Method

It is a numerical strategy used to explain Finite element (FE) technique limit esteem issues utilizing differential conditions and fundamental conditions. Those differential conditions are fathomed by either evacuating the differential conditions precisely or by rendering those differential conditions into customary differential conditions which are then numerically incorporated utilizing standard procedures (Nithiyaasri et al., 2017).

2.3.1 Practises of FE Method

- The FE strategy shows the dislodging and conveyance of stresses and gives a point by point perspective on where the structures are bowed.
- FE method can readily conduct very complex geometry.
- FE method can also conduct complex loading.
- FE technique enables whole plans to be organized, refined, and enhanced before the arranging is delivered.
- FE method provides stiffness and strength visualizations.
- FE strategy likewise guarantees a wide scope of reenactment choices for checking the multifaceted nature of both displaying and investigation of a framework (Nithiyaasri et al., 2017).

2.3.2 Modelling

FE strategy is the predominant discretization procedure in auxiliary mechanics. The division of numerical model by common geometry into non-covering segments is known as the FE technique displaying. The reaction of every component as the value of an obscure capacity is meant regarding a limited number of degrees of opportunity. The FE strategy is utilized for covering of material models for the segment portions of the composite material. In cutting edge building models, the FE framework fills in as judicious intends to clarify the association conduct among steel and cement. The FE framework can be utilized productively to help and grow test examine and to gauge the conduct of structures and basic subtleties. The ATENA program, a limited component bundle intended for PC recreation of solid structures in the limited component framework has been created. ATENA program is implemented in computer code. Successful results were obtained in the ATENA program and solved many anchoring problems. In our world, where research and development proceeds very quickly, using the computers via ATENA program, it enables the virtual testing of structures. Material properties are very important in the design of a structure. Therefore, the use of the ATENA package program for simulating the connections between steel and concrete will contribute to achieving successful results (Nithiyaasri et al., 2017).

FE Analysis is also actualized with using ABAQUS. It is used for replicating the local buckling attitude of stub columns with elliptical and circular type hollow section. In addition to elements, ABAQUS contains general objective shell elements. These are valid for thin and thick shell troubles. Elements kind S4R were used in current study. S4R is a general objective, strain-finite-membrane, curtailed integration shell element. The aspect ratio of this type of element is approximate 1/1. Distinct type of braid density was embraced for entire column. Higher braid density was used for denser corners of the higher aspect ratio ellipses in the crosswise direction. The braid density was kept stability in the longways direction. Throught the length, model has generally element around circumference. The braid density for ABAQUS models of EHS and CHS is given in Figure 2.17 and Figure 2.18. (Zhu and Wilkinson, 2007).

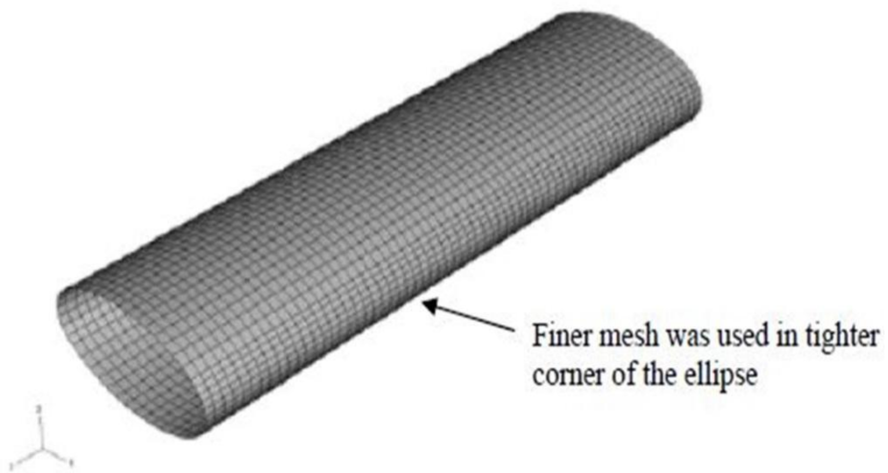


Figure 2.17 ABAQUS braid of EHS Columns (Zhu and Wilkinson, 2007)

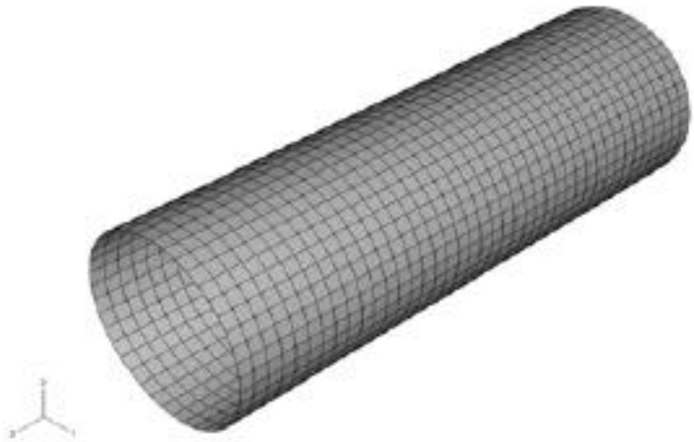


Figure 2.18 ABAQUS braid of CHS Columns (Zhu and Wilkinson, 2007)

FE examination is a modernized technique for foreseeing how a basic segment responds to powers, vibration, heat, liquid stream, and other physical impacts. FEA indicates whether an item will break, wear out, or work the manner in which it was planned. It is called examination, however in the structure advancement process, it is utilized to foresee what will happen when the structure is utilized. It is finished by pre-handling (limited component demonstrating) and post preparing (Nithiyaasri et al., 2017).

ABAQUS is a product application utilized for both the displaying and investigation of mechanical segments and gatherings (pre-handling) and picturing the FEA result. The ABAQUS suite of programming for FE investigation is known for its elite, quality and capacity to tackle a bigger number of sorts of testing recreations than some other programming (Nithiyaasri et al., 2017).

Lots of materials are interested firstly for reaction elastically in the field of engineering. If the load on the material is greater than limit, a part of the deformation remains in the case of load removing. The pliancy hypotheses of model and mechanical response of the material as it experienced such nonrecoverable distortion in a mouldable style. Heaps of hypotheses about the model in ABAQUS are expanding. And furthermore, mechanical strain rate is decoupled into a flexible part and a plastic part (Zhu and Wilkinson, 2007).

2.3.3 Significance of FE Modelling

To model all of hollow sections analytically in its non-linear region is difficult. Formulas derived from experiments for past designs provided engineers with confidence in formulas. The FE method makes it possible to take into account non-linear response. The FE strategy makes it conceivable to consider non-straight reaction. The FE strategy is an investigative device which can demonstrate all of empty area and can ascertain the non-straight conduct of the basic individuals. FE strategy is the prevailing discretization system in examination of structure. The primary idea of the FE Method is the subdivision of the numerical model into disjoint (non-covering) parts of basic geometry called limited components or components for short. The FE model is valuable for accomplishing the heap avoidance conduct and the break game plan under different stacking conditions (Nithiyaasri et al., 2017).

A FE investigation on the product framework requires the accompanying data (Nithiyaasri et al., 2017).

- Nodal point spatial areas (geometry).
- Elements interfacing the nodal focuses.
- Mass properties.
- Border conditions or restrictions.
- Loading or driving capacity subtleties.
- Test choices

The development of computer programs by the researchers and the development of FE methods will result in the use of powerful methods of analysis, and therefore the physical experiment will end. Therefore, the finite element method will perform simply the nonlinear response of the hollow sections and has become a powerful computational tool for complex analysis (Nithiyaasri et al., 2017).

2.4 Genetic Programming

Genetic Programming abbreviation is GP. GP procedure is applied for creating of approach functions. This functions were gotten from the reaction surface procedure. Two significant perspectives of the troubles are addressed. The first one is the preference of the plan of testing. The second one is the model tuning. It utilizes the least-squares response surface fitting. Different models demonstrate the usage of the procedure to inconveniences. The estimations of response capacities are gained from numerical reenactment or research center testing (Alvarez et al., 2000).

2.4.1 GP for Structures

GP is somewhat just barely type of computerized reasoning. It is relies upon the suppositions of Darwinian development. It is additionally founded on hereditary qualities. GP is a noteworthy of Genetic Algorithms (GA). The GP worldview is intrigued with the issue of definition in the hereditary calculations by expansion the intricacy of the developments progressing adjustment (Alvarez et al., 2000).

Though a GA utilizes a progression of in the arrangement, the GP comprises PC programs with a tree development. An observational model which is spoken to by program is utilized for methodology of response works in a tough situation. Normaly program speak to the articulation $(x_1/x_2+x_3)^2$ (Alvarez et al., 2000). The articulation is shown in Figure 2.19.

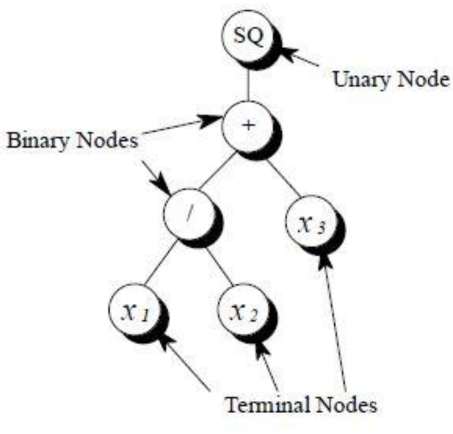


Figure 2.19 Typical tree constructions for $\left(\frac{x_1}{x_2}+x_3\right)^2$ (Alvarez et al., 2000)

Those haphazardly produced programs are generally and hierarchical. It is changed from size and form. The main aim of GP is to solve a trouble by researching. When solving problem or trouble extremely fit computer programs is used. In addition to that, this is in the space of total possible programs. Global or local solutions can be find with using this approach. The first population creating is a blind haphazardly research. It is in the space and it is defined by the trouble. On the contrary a GA, the output of the GP is a program (e.g. an empirical model used for approach), while the output of a GA is a quantity. The programs are consisted of factors. This factor comes from terminal and functional set. These are called as nodes (Alvarez et al., 2000).

Terminal Set	Design variables: x_1 , x_2 , ..., x_N
Functional Set	Mathematical operators that produce the regression model: { +, *, /, x^y, etc. }

The functional set may be subdivided into dual nodes. This gets together with two arguments such as unary nodes. Dunctions or terminals should be connecting to make pass information. It is called as closure feature. The evolution of the programs executed with the genetic operators. This evolution can also be carried out with the evaluation of the fitness function (Alvarez et al., 2000).

2.4.1.1 Genetic Operators for Structures

Model constructions are developed by the influence of three basic genetic operators. These operators are mutation, crossover, and reproduction. The flow diagram of the process is displayed in Figure 2.21 (Alvarez et al., 2000).

The strategy of the reproduction stage should be embraced. At that point programs must die. Trees with fitness are killed with using this implementation under the lower of the average. After that population is filled with the surviving trees in comparison with fitness proportional selection (Alvarez et al., 2000).

The passing in Figure 2.20 associate decent data from two trees (parents). This is used because of developing the fitness of the next generation. After at that point, main algorithm can be written such that:

- two trees can be browse the all populace;
- within every one of those trees, heedlessly pick one hub;
- change the subtrees under the picked hubs, because of this one creating can be have a place with another populace.

Mutation is shown in Figure 2.22. It protects the model against untimely convergence. It can also be develop the non-local features of research. The ongoing algorithm example in below is used:

- haphazardly pick one hub inside tree;
- replace that hub with other one from the indistinguishable set (a capacity substitutes a capacity and a terminal substitutes a terminal) out of without anyone else (Alvarez et al., 2000). The expression is displayed in Figure 2.19.

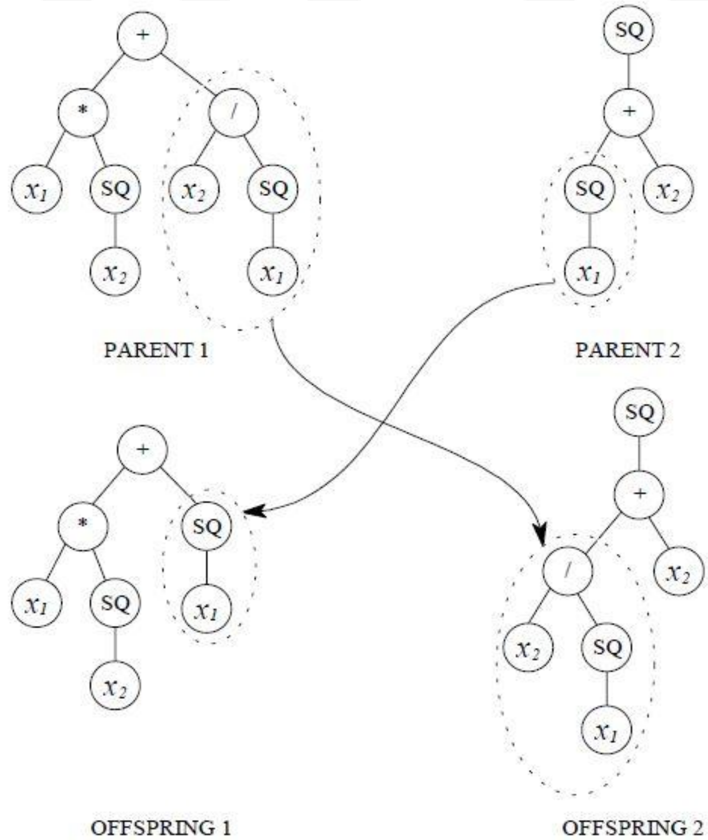


Figure 2.20 Crossover (Alvarez et al., 2000)

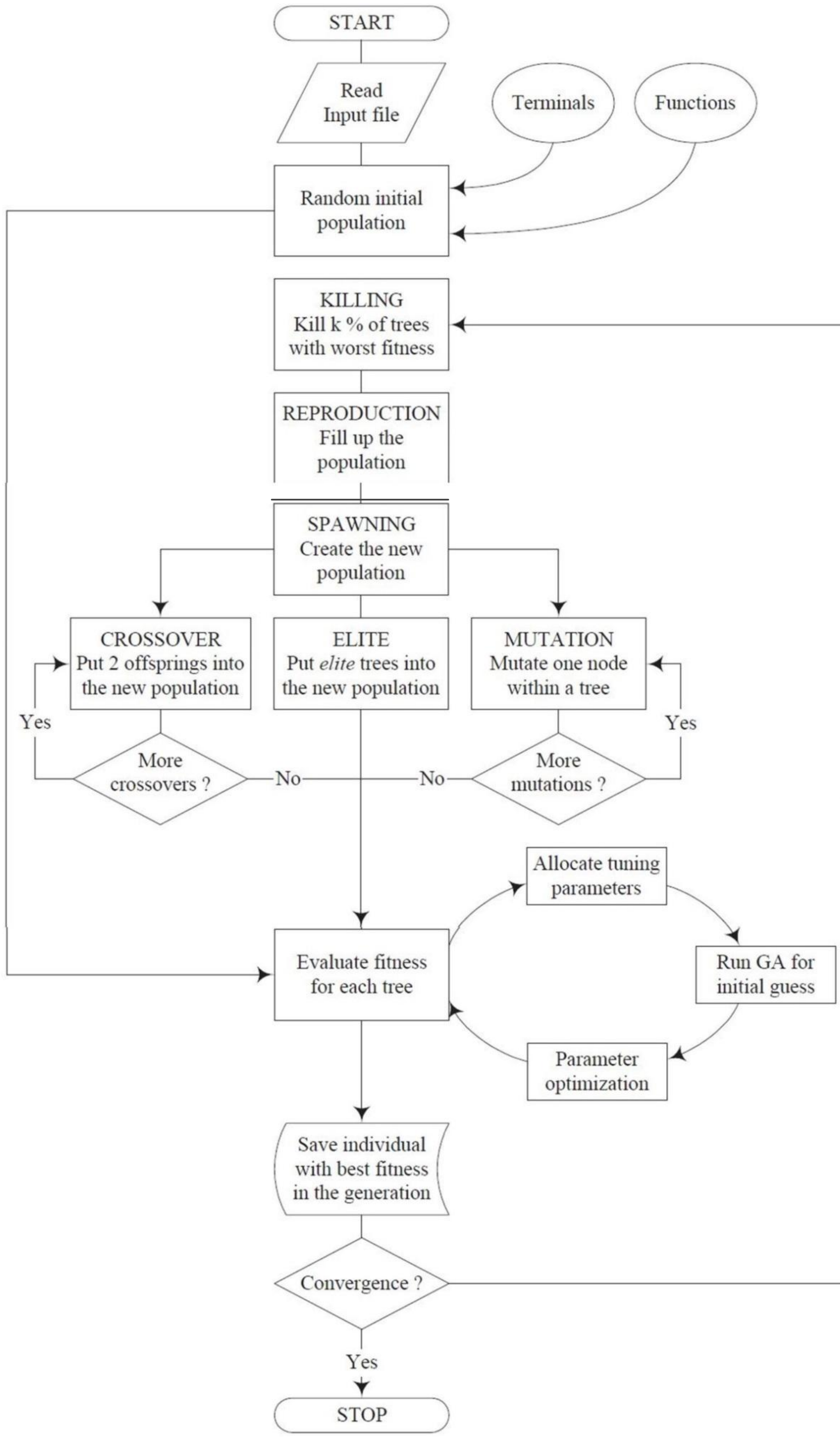


Figure 2.21 Flowchart of GP methodology (Alvarez et al., 2000)

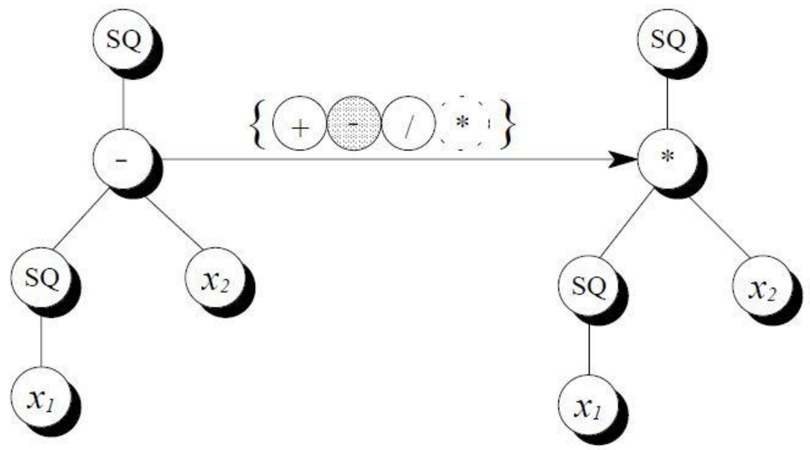


Figure 2.22 Mutations (Alvarez et al., 2000)

A supplement operator and elite transfer is used for permission a slightly low number of the fittest programs. It is called as elite. It is to be transferred unaltered to a next generation. The reason of doing this transfer is to keep the optimal solutions finding by now. Consequently, a new population of trees of identical size as the original one is created, however it has a higher average fitness value (Alvarez et al., 2000).

2.4.1.2 Terminal and Fuction sets

Terminal set is constants or a set of input variables. A set of domain appropriate functions used together with terminal set. The reason of this is to find potential solutions of a given problem. For symbolic decline that could consist of a set of main mathematical function, meanwhile boolean and conditioned operators could be subsumed for classification problems (Alvarez et al., 2000).

2.4.1.3 Function Suitability

The suitable proportional technique or method uses for any chosen haphazardly a tree examininig in here. That technique specifies the possibility of choose on the main suitable of the solution. The suitability of a solution shall reflect:

(a) The quality of approach of the probatory donnee by a present expression epitomised by a tree;

(b) The length of tree to achieve more compact expressions. Empricial model of problems created. The prediction of the maximum obvious selection is sum of square of variations. The summing are carried out with stripped model output (2) and the conclusions of runs of the original model (1) over certain selected plan (design) of tests. Eq. (2.48) measure the quality of solution in non-dimensional form (Alvarez et al., 2000).

$$Q(\mathrm{S_i}) = \frac{\sum_{\mathrm{P=1}}^{\mathrm{P}}(\mathrm{F_P}-\tilde{\mathrm{F}}_\mathrm{P})^2}{\sum_{\mathrm{P=1}}^{\mathrm{P}}\mathrm{F_P^2}} \tag{2.48}$$

If together with the values of the original function F_p their initial order derivatives at point p $F_{P,\, l} = \frac{\partial}{\partial_{xi}} F_P$ $(i=1,.., N)(p=1,...,P)$ are known, the numerator in Eq. (2.48) is modified by the following expression:

$$\sum_{P=1}^{P}\left(\left(F_P - \tilde{F}_P\right)^2 + \gamma\frac{\sum_{i=1}^{N}\left(F_{P,i}-\tilde{F}_{P,i}\right)^2}{\sum_{i=1}^{N}{F_{P,i}}^2}\right) \tag{2.49}$$

where $\gamma > 0$ is the parameter characterizing a degree of disparity of the additive of the response. It also describes the susceptibility of data. It was taken here as 0.5. In Eq. (2.48) $Q(S_i)$ is the measurement of quality of solution S_i. $Q_{\max}$ describes the max value of that quantity out of total N_t members of the population, ntp_i. It is the number of adjustment parameters. It includes in the solution "S_i". "c" is a coefficient penalizing the excessive length of expression. Suitability of function Φ (S_i) may be denoted in the below form:

$$\Phi\ (S_i) = Q_{\max} - Q\ (S_i) - c * ntp_i^2 \tag{2.50}$$

Programs with bigger suitability values of F(S_i) have a bigger possibility of being chosen. This is valid in a subsequent genetic action. Pretty suitable programs live and increases. However, less suitable programs or the limited functional programs will die. The suitability function identified as the sum of squares of the error between model output and probatory data has been applied before to the model creating in fluid flow problems and dynamic systems. Other possible preference is the statistical concept of correl. It can determines and quantifies whether a connection between two data sets there exists. That description was used for the identification of industrial processes (Alvarez et al., 2000).

2.4.1.4 GP Facilitated

With the constructions defined, as a whole the evaluation and processing routines are now elemantarily handled by standard iterations routines. As a whole the subtree swapping related with crossover become easy pointer processing. The one risk to talk of is the memory partitioning calls should be made with the ultra care (Alvarez et al., 2000).

2.4.2 Application

The algorithms have been applied in C++. In the operation of finding the construction of estimations by the genetic search as defined above. In addition to that it is essential to address two significant problems. In the first problem, the preference of the design (plan) of tests. In the second problem, the model tuning prior to the fitness assessment (tuning parameters) (Alvarez et al., 2000).

2.4.2.1 Experiments Design

The excerpting of points for design is changeable space. In this space, the response function is to be evaluated is widely called experiments design. The preference of the experiments design may have a big influence on the precision of the approach and the cost of full justification the response surface (Alvarez et al., 2000).

It considers a traditionless criterion for elaboration of designs of experiments which is not dependent on the mathematical model of the object or operation under opinion. The input data for the elaboration of the design just appendto the number of factors N and K (Alvarez et al., 2000).

Where N is number of design variables and K is the number of experiments.

The base principles in that approximation are as follows:

- the number of levels of factors. This one is identical for each factor. In addition to that, it is equal to the number of tests and for each level there is just one test;
- the points of tests are distributed as commensurably as feasible in the domain of variables. That is a physical analogy with the least of potential energy of repulsive forces for a set of points of unit mass, if the size of these repulsive forces is inversely proportional to the distance squared between the points:

$$\sum_{p}^{P} \sum_{q=p+1}^{P} \frac{1}{L_{pq^2}} \rightarrow \min \tag{2.51}$$

The plan of test is characterised by a matrix which continuing the levels of factors for each of P experiments. For instance, for a number of factors (plan variables) N is equal to 2 and P is equal to 10, the matrix is

$$\begin{vmatrix} 8\ 10\ 4\ 6\ 2\ 3\ 9\ 5\ 7\ 1 \\ 1\ 7\ 10\ 6\ 8\ 5\ 4\ 2\ 9\ 3 \end{vmatrix} \tag{2.52}$$

The corresponding design of experiments is displayed in Figure 2.23

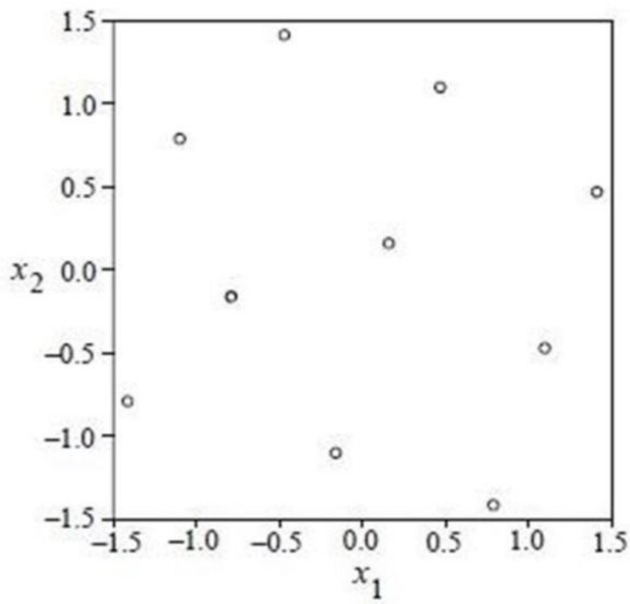


Figure 2.23 Design of experiments for *N* is equal to 2 and *K* is equal to 10 (Alvarez et al., 2000)

2.4.2.2 Design Adjustment

The approach funtion is characterized with constructions and also set of adjustment parameters. The construction is designed with GP. Some examples can be given such that the minimum squares fitting of design into which are the set values of the main response function: (Alvarez et al., 2000).

$$G(a) = \sum_{p=1}^{P} \left(F_p - \tilde{F}_p(a)\right)^2 \rightarrow \text{least} \tag{2.53}$$

The *a* parameters is the partitioning of adjusmtment parameters. This paramaters is shown in Figure 2.24. This parameters is used for individual tree. The rules of this parameters is shown in Figure 2.25 and this rules is the main algebraic rules. Adjustment paramaters are the partitioning parameters in tree downwards. This parameters are depends on type of current node. According to below algoritm, construction of subtree can be carried out:

a. Current node is of type bin

- “m” is multiplication parameters. It is the division operations just need one tuning parameter, i.e.

$\tilde{F} = x_1 * x_2 \Rightarrow \tilde{F}\ (a) = a_1 * x_1 * x_2$;

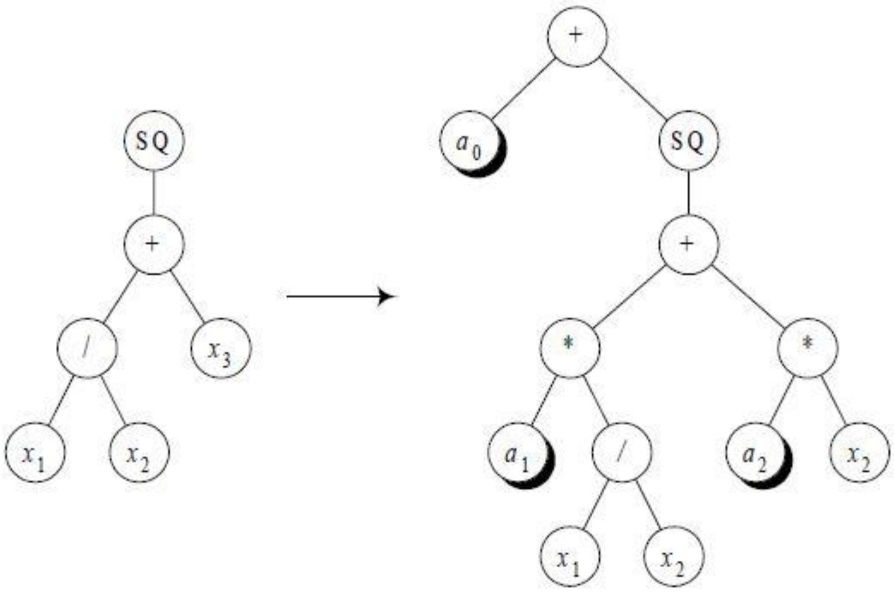


Figure 2.24 Partitioning of adjustment parameters to a tree (Alvarez et al., 2000)

total another operations need two adjustment parameters, i.e.

$\tilde{F} = x_1 + x_2 \Rightarrow \tilde{F}(a) = a_1 * x_1 + a_2 * x_2$;

$\tilde{F} = x_1 \hat{} x_2 \Rightarrow \tilde{F}(a) = (a_1 * x_1) \hat{} (a_2 * x_2)$;

- when $\tilde{F}$ is a combination of the previous two approaches, adjustment parameters are just applied to operations diversified from multiplication and division, i.e.

$\tilde{F} = x_1 * (x_2/x_3 + x_4) \Rightarrow \tilde{F}(a) = x_1 * (a_1 * x_2/x_3 + a_2 * x_4)$

$\tilde{F} = (x_1 + x_2) \hat{} (x_3 * x_4) \Rightarrow \tilde{F}(a) = (a_1 * x_1 + a_2 * x_2) \hat{} (x_3 * x_4)$

b. Current node is of type Unary: na
c. Current node is of type changeable

- one adjustment parameter is inserted, i.e.

$\tilde{F} = (x_1)^2 \Rightarrow \tilde{F}(a) = (a_1 * x_1)^2$

d. Insert a free parameter, i.e.

$\tilde{F}(a) = a_1 * x_1 \Rightarrow \tilde{F}(a) = a_1 * x_1 + a_0$

The identification of parameter to expose is done from non-linear minimum squares fitting. For example, the solving problem with minimisation can be used when sensitiveness are available. The combination of GA with non-lineare optimization technique is used for minimization of solving problem (Alvarez et al., 2000).

The first estimation of the output of the GA is used for subsequent derivative-based optimisation. This method is used for evaluating the variation of Newtons's method. In Newtons's method, Hessian matrix is the approximate from secand (quasi-Newton). Quasi-Newton is not an update method. When this method close to a local solution adequately, convergence will be get quickly. When accelerating the converging, adaptive updating of the Hessian method can be used. As a result, the algorithm is decreased with a Gauss-Newton or Levenberg-Marquardt method (Alvarez et al., 2000).

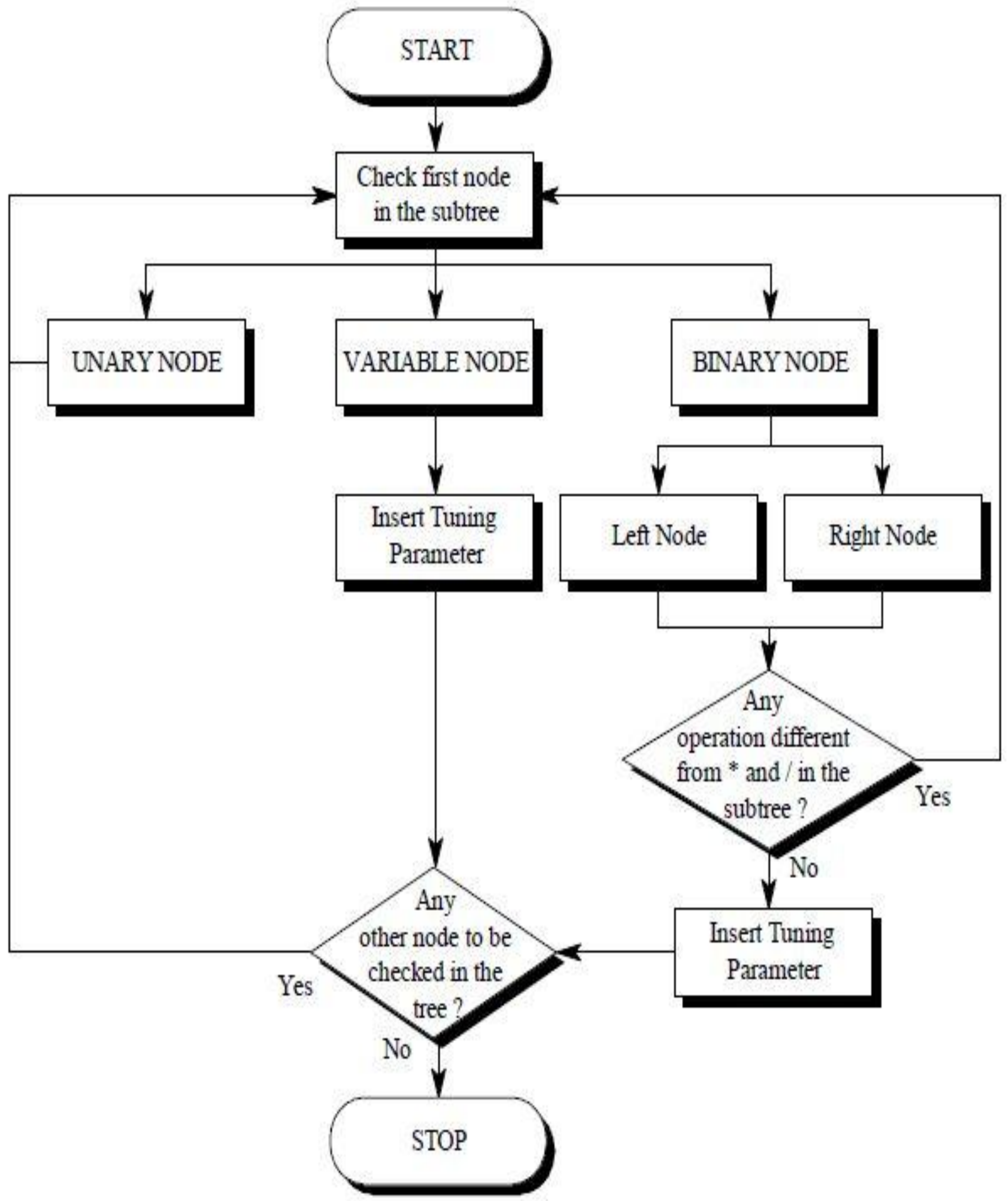


Figure 2.25 Tuning Parameter Allocation Diagram (Alvarez et al., 2000)

2.5 Neural Networks

2.5.1 Purpose of Neural Network

An Artificial Neural Network (ANN) is a data operation specimen this is inspired by the way biological nervous systems, like the brain, process data. The key element of that paradigm is the original construction of the data operation system. That is composed of a large number of very much interconnected processing elements (neurones) working in associate to solve particular problems. ANN, such as people, learn with instance. ANN is configured for a particular application, like pattern recognition or information classification, through a learning process. Learning in biological systems contains adjustments to the synaptic connections this exist between neurones. This can also be applied to ANN (Pahuja et al., 2014).

2.5.2 History of Neural Networks

Neural network (NN) simulations are seen as the latest improvement. But this area was established before computers were invented, and minimum a major disruption and many eras. Several significant advancements have been boosted by the use of inexpensive computer emulations. After first period of exuberance, the field survived a period of disappointment and disestimation. Throughout this period when fund raising and vocational support was least, significant advances were made by comparatively some reserchers. That initiators able to improve convincing technology which surpassed the restrictions identified by Papert and Minsky. In 1969, Papert and Minsky published a book of disappointment among researchers and were accepted without research by researchers. Now, the NN area needs increased interest and corresponding funding. The initial artificial neuron was generated in 1943 by the logician Walter Pits and the neurophysiologist Warren McCulloch. However at that time, because of the limited technology available, they could not do much (Pahuja et al., 2014).

2.5.3 Where Neural Networks Use by Scientists

The remarkable ability of NN is deriving of complex and indefinite data. It can be extract patterns. Another ability of NN is detecting trends. These are complicated problems. These can not be solved human or computer methods. Trained NN is a expert for analyzing. This expert gives a response for "what if" questions. In addition to that, there are other advantages of NN:

1. Customisable learning: the skill of learning how to do assignments based on the information given training or first experience.
2. Self-Organization: ANN may create its own organization or representation of the data it receives throughout the learning period.
3. Real-Time Processing: ANN computations can be carried out in parallel, and specific hardware devices are being designed and produced which take advantage of that capability.
4. Error Tolerance through Redundant Information Coding: Partial devastation of a network leads to the corresponding degradation of performance. But, some network capabilities can be retained even with big network loss (Pahuja et al., 2014).

2.5.4 Neural Computation

Lots of NN researches are carried out for increasing the attention. The first model of artificial neurons are represented by Warren McCulloch and Walter Pitts in 1943. After this point, the sophisticated types are developing. The mysteries problem of mathematical analysis is solved by this new models. However, lots of questions comes out for future studies. At that point, it has to be said that the neuron interconnections and their role are the brains base buiding blocks about the study of neurons. This blocks are the most dynamic and significant researches for modern biology. The relevance of this study is to show in the range of 1901 and 1991. In this time, Nobel Prizes in the field of Physiology and Medicine were given to scientists because of understanding of brain. In the last fifty years, there is not study for learning more information about nervous system (Rojas, 1996).

2.5.4.1 Natural and Artificial Neural Networks

When aim is to understand the processing capacity of nervous system, ANN can be usable. Therefore, the most important point at that point is to know the properties of biological NN. After that point, ANN will be designed or it can be analyzed. The nervous system of animals are different. Therefore, it is hard to say that the structure defining of brain is easy. The main operation of neural is “control through communication”. The composition of animal nervous system is interconnected cells to each other with millions. All of them are complex. Complex arrangement helps to incoming signals in distinct ways. However, neurons are slower than electronic logic gates. It can be succeed with using switching times of a few nanoseconds. However, at that point, neurons required that several miliseconds for reacting to stimulus. However, brain can be solve problems without anything and any digital computer can not overcome it (Rojas, 1996).

2.5.4.2 Models of Computation

ANN is an approach for computation of problem. The definitions of computability was asserted in 1930s and 1940s. Five different alternative studies were carried out at the same time. After that, computer times was started. This period was not carried out only one single approach, but also contest of alternative computing models. As the known information about von Neumann computer, it was the undisputed winner in this confrontation. However, the victory of von Neumann did not caused to dismissal of the other computing models (Rojas, 1996). Five pirinciple of contenders are shown in Figure 2.26:

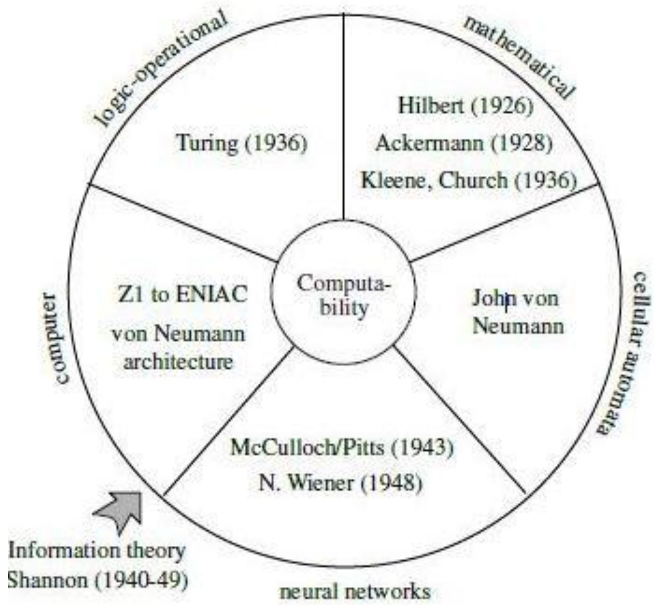


Figure 2.26 Five models of computation (Rojas, 1996)

1. The Mathematical Model
2. The Logic-Operational Model (Turing Machines)
3. The Computer Model
4. Cellular automata
5. The biological model (NN)

2.5.5 Functions and Elements

The primitive functions and composition rules are defined in this section such as an example for computational models. When computing with a conventional von Neumann processor, the minimal set of machine instructions is needed to carry out all computable functions. The elementary functions are located in nodes for ANN. The rules of composition are included the indirectly in interconnection pattern of nodes, synchrony or asynchrony of the transmission of information or absence of cycles (Rojas, 1996).

2.5.5.1 Networks of Primitive Functions

The structure of neuron with "n" inputs are schematically in Figure 2.27. Each input channel i can transmit a real value χ_i. The elementary function "f" of abstract neuron may be choisen randomly. The weight of input channel is a incoming information which is χ_i. The χ_i is generally multiplied with corresponding weight ω_i. the information of carrying is integrated at the neuron. This is generally just by adding the different signals. After that, this primitive function can be evaluated (Rojas, 1996).

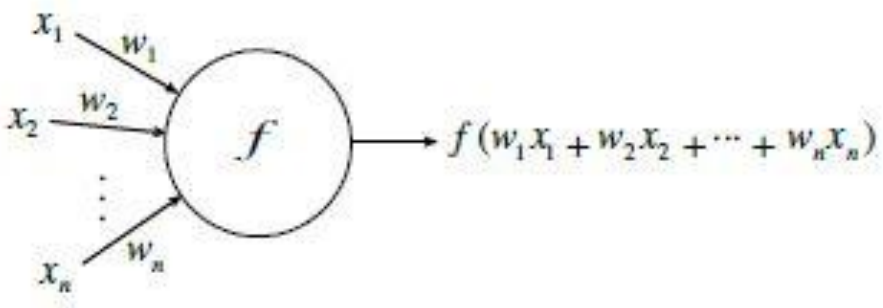


Figure 2.27 An abstract neuron (Rojas, 1996)

When designing of each node in ANN, the primitive function can make transforming of input. At that point, defined output can makes completely for transforming. When doing an assumption about primitive functions, interconnection pattern, and timing of the transmission of information, different type of models will be used for ANN (Rojas, 1996).

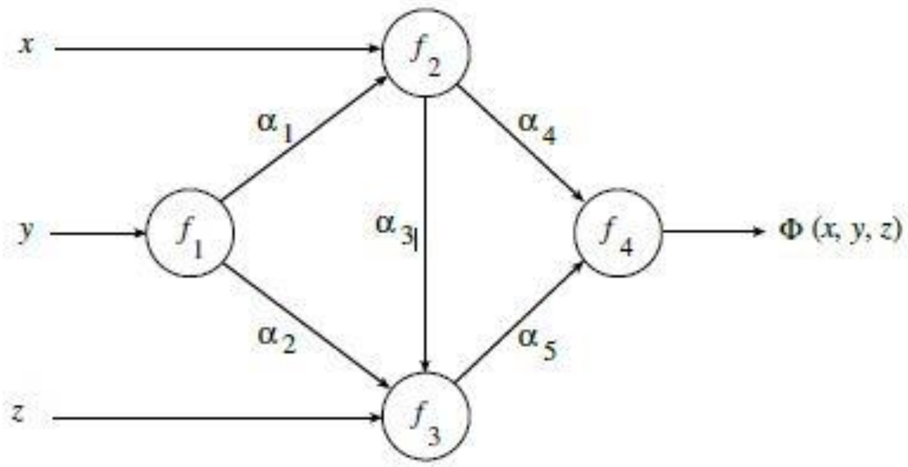


Figure 2.28 Functional model of an artificial neural network (Rojas, 1996)

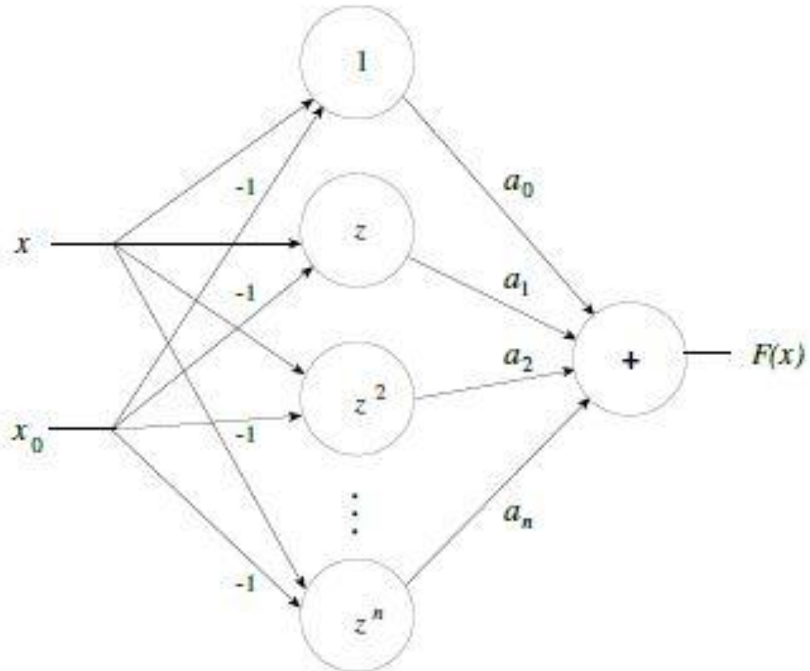


Figure 2.29 A Taylor Network (Rojas, 1996)

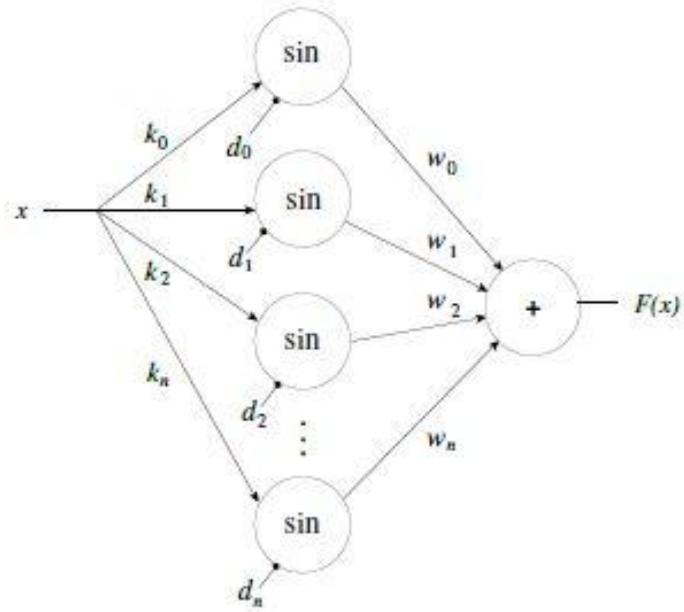


Figure 2.30 A Fourier network (Rojas, 1996)

2.5.5.2 Element of an Artificial Neural System (ANS)

ANS is fundamentaly as an analog computer. In addition to that, it uses simple processing elements. This elements are connected. The connection is in a highly parallel manner. At that point, processing element carried out with too simple Boolean or Arithmetic functions on their inputs. The weight of each elements is a key of functioning for artificial neural system. This weights represents information stored in the system. When doing a train a NN, the weights of each units must be adjust. The error between the desired output and the actual output can be decreased with using this way. This process needs to evaluate of error derivative of weights (EW). It can be say that it can be calculate how the error changes as each weight is raised or reduced slightly. The determining methof of EW is back propagation algorithm. This algorithm is the most popular method. Typical artificial neuron is shown in Figure 2.31. This typical artificial neuron have multiple inputs. However, it has also only one output. The brain of human includes around 10^10 neuron. This neurons have thousands of connections (Prince, 2011).

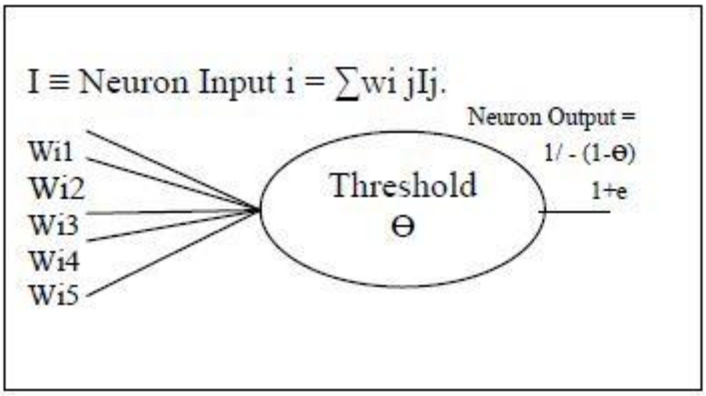


Figure 2.31 Neural Processing Element (Prince, 2011)

Conventional computer architecture and artificial neural network system (ANS) architecture are different each other. These architectures are modeled. The modelling are done after the present brain theories. The information about brain theories is represented by using weights. When making this arrangement, direct correlation is not includes. This correlation is betwen specific weight and specific item of stored information. The distribution displaying of information is the same like hologram. In the lines of hologram makes out a diffraction grating to reconstruct the stored image when laser light is passing through. If there is much empirical datas or no algorithm exists NN is a good approximation. This can be provide the solving of problem with sufficient accuracy and speed (Prince, 2011).

2.5.6 Network Architecture

The network architecture is a second design decision. At that point, the meaning of specification of units and interconnectivity will be defined. The main reason of using network architecture can be solve with H and S. However, units will be defined. Because problem of mapping orthography to semantics is not linearly separable. Recurrent connections are need to allow the network to improve semantic attractors. The existence of this is constitutes major theoretical assertion of work. The selection of numbers of intermediate and clean-up units and connectivity density are an attempt for giving the adequate flexibility to solve the task and build strong semantic attractors. However, this units are restricted with connections among sememe units. This can be used for keeping the size of the network manageable. Some of the aspects of design especially the using selection of intra-sememe connections are rather inelegant and ad hoc. Therefore, systematic comparison of effects of damage are performed in a range of network architectures. This is done because of the allowing of comparisions basic aspects of the H and S network. It is shown in figure 2.33. Each version of these networks are depends on the whole range of lesion locations and severities. It can also evaluated the using response criteria and output system. Results showed that after damaging the error of qualitative is too irresponsive for architectural details. However, this situation is valid for keeping on of operate downstream from the lesion. The lesions are further the level of attractor operate, network gives too few error responses expilicitly. However, the performance of correctness can be reasonable. The lesions of phonological clean-up pathway is defined in Figure 2.32 with using this way at these conditions. Similarity of error patterns are made from wide diversity of architectures at critical point. However, the basic results are depends on any idiosyncratic characteristics of the H and S network (Plaut and Shallice, 1994).

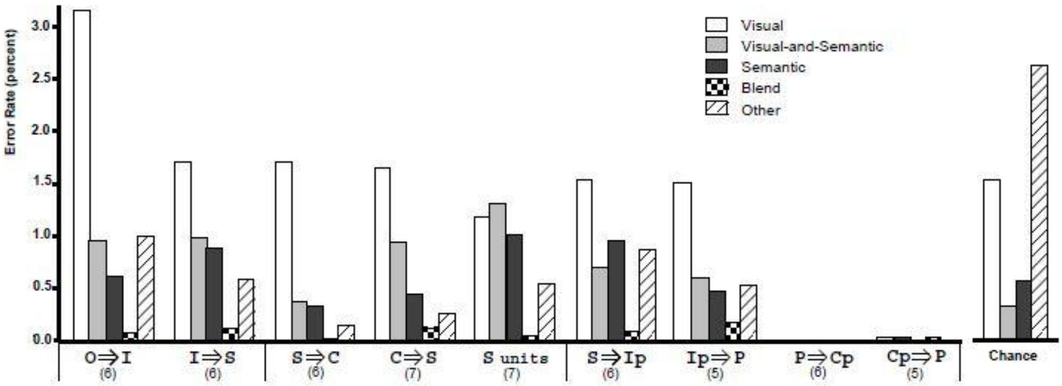


Figure 2.32 Error distributions for the extended back-propagation network (Plaut and Shallice, 1994)

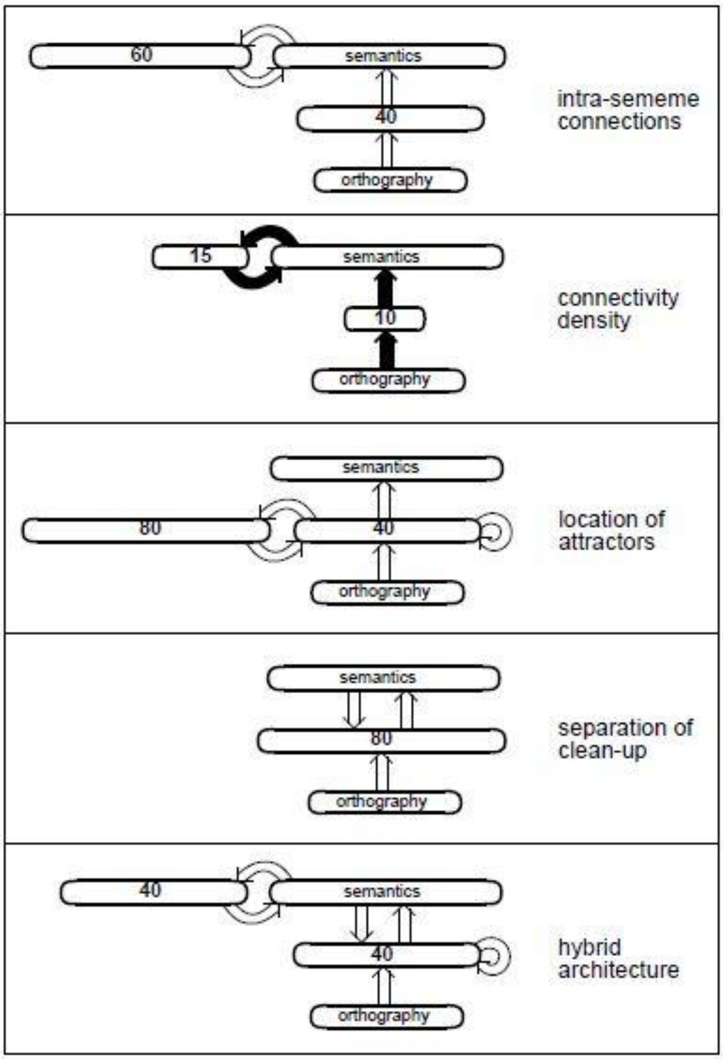


Figure 2.33 Five alternative network architectures for mapping orthography to semantics, and the issues they are designed to address (Plaut and Shallice, 1994)

2.5.7 Learning Algorithms

Exercise a NN model fundamentally means excerpting one model from the set of allowed models (or, in a Bayesian framework, determining a divisionis over the set of allowed models) that minimizes the cost criterion. There are numerous algorithms existing for exercise NN models. Almost all of it may be accepted as a understandable application of statistical prediction and optimization theory. Almost all of the algorithms used in exercise ANN employ some form of gradient descent. That is done by taking the derivative of the cost function according to the network parameters and then modifying those parameters in a way that is related to the gradient. Non-parametric methods, evolutionary methods, simulated annealing, expectation-maximization, gene expression programming, and particle swarm optimization are some widely used methods for exercise NN (Pahuja et al., 2014).

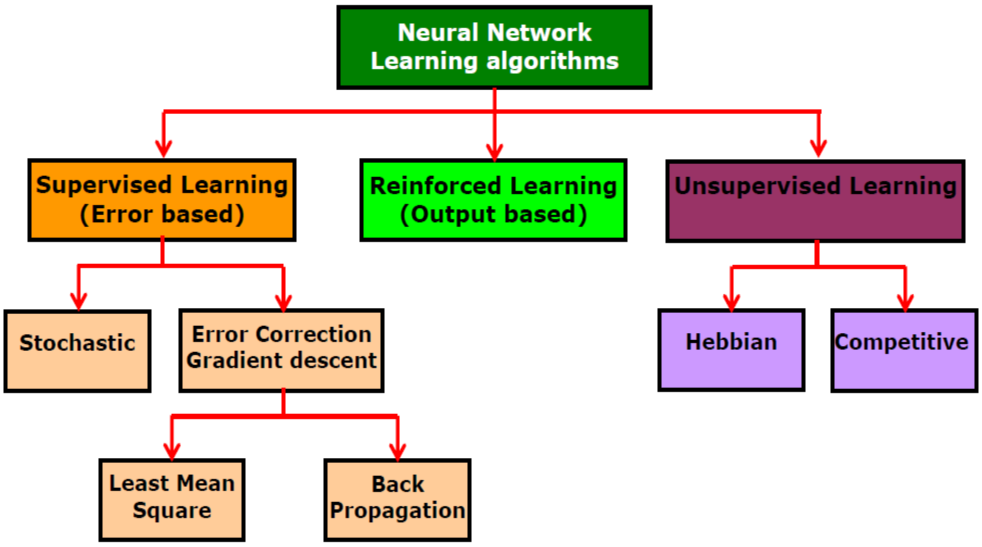


Figure 2.34 Neural Network Learning (Pahuja et al., 2014)

2.5.8 Neuralnet: Training of Neural Networks

Functional relationship between covariates and response variables have great importance. Covariates is known as input variables. Response variables are also known as output variables. For example, when modeling complex diseases, potential risk factors. Their effects on the disease are examined to identify risk factors. In addition to that, it can be used to improve prevention or intervention strategies. ANN can be applied to approximate any complex functional relationship. Unlike generalized linear models (GLM, McCullagh and Nelder, 1983), it is not necessary to prespecify the type of relationship between covariates and response variables as for instance as linear combination. This makes the ANN a valuable statistical tool. They are in particular direct extensions of GLMs and can be applied in a similar manner. Observed data are used to train the NN and the NN learns an approximation of the relationship by iteratively adapting its parameters (Günther and Fritsch, 2010).

2.5.8.1 Multi-Layer Perceptrons

The package neuralnet focuses on multi-layer perceptrons (MLP, Bishop, 1995), which are well applicable when modeling functional relationships. The underlying structure of an MLP is a directed graph. For example, it includes vertices or directed edges. At this point, it is called as neurons and synapses. Neurons can be organized in the layers. These are generally fully connected by synapses. In neuralnet, a synapse can only connect with subsequent layers. The input layer includes of all covariates in separate neurons. These layers are hidden layers. Hidden layers can not be seen directly. Input layer and hidden layers include a constant neuron relating to intercept synapses. The synapses that are not directly influenced by any covariate. Figure 2.35 gives an example of a NN with one hidden layer that consists of three hidden neurons. This NN models the relationship between the two co-variates A and B and the response variable Y. Neuralnet theoretically allows inclusion of arbitrary numbers of covariates and response variables. However, there can occur convergence difficulties using a huge number of both covariates and response variables (Günther and Fritsch, 2010).

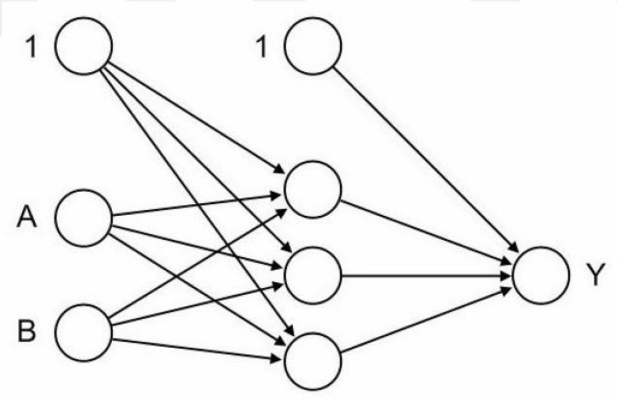


Figure 2.35 Example of a NN with two input neurons (A and B), one output neuron (Y) and one hidden layer consisting of three hidden neurons (Günther and Fritsch, 2010)

CHAPTER 3

METHODOLOGY ON LOAD CARRYING CAPACITY OF ELLIPTICAL HOLLOW SECTION COLUMNS

3.1 Description of Experimental Database

A prediction model on the load carring capacity of elliptical hollow section (EHS) columns under the effect of compression and uniaxial bending was derived based on the experimental data existed in the literature (Chan and Gardner, 2009; Theofanous et al., 2009; Law and Gardner, 2013). A total of 54 experimental test result were used in the current study. Table 3.1 shows the details of the database. As seen from the table, the geometrical and mechanical properties of the test specimens were varied. They were tested for flexural buckling in their minor and major axes. For some specimens, eccentricity in y and z axes was also introduced. It was also worty to note that the slender test specimens were used. They have the length of about 700 to 3180 mm, the length over larger outer diameter of 4.6 to 21.2, and the length over smaller outer diameter of 9.3 to 42.4. Nine vital parameters were considered as predictive ones. They were the axis of buckling, eccentricity in y axis, e_y (mm), eccentricity in z axis, e_z (mm), larger outer diameter, ϕ_1=2a (mm), smaller outer diameter, ϕ_2=2b (mm), wall thickness of the section, t (mm), yield stress of steel, f_y (MPa), ultimate tensile stress, f_u (MPa) and member (column) length, L_{cr} (mm). Moreover, in Table 3.1, the variation in the values of the ultimate load (N_u) of each test member as an output parameter is revealed. The details of the test configmation of the experimental setup is presented in Figure 3.1. The EHS column geometry is shown in Figure 3.2. The explaination on the modelling of the load carring capacity of the columns is given in the next section.

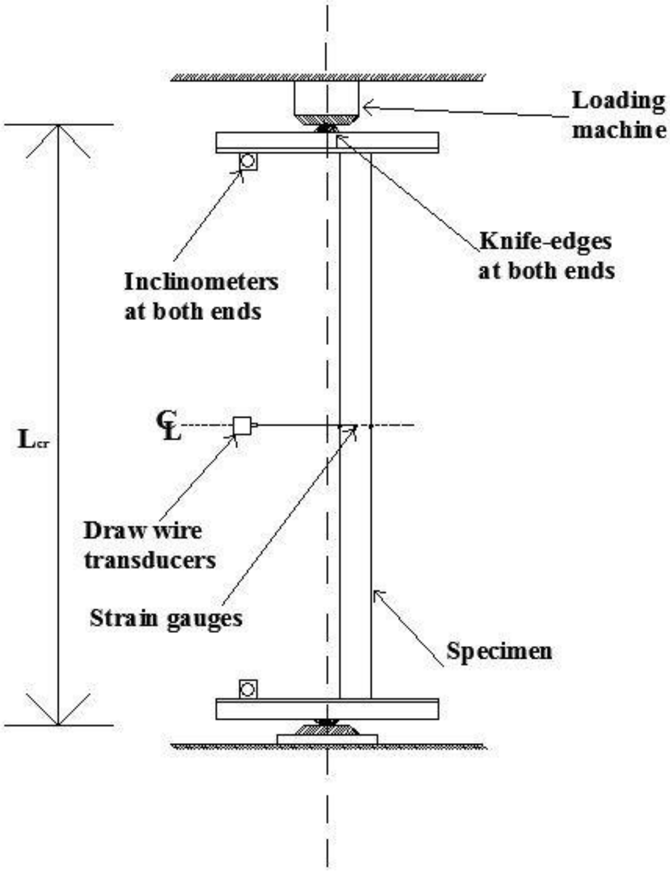


Figure 3.1 Tested specimens arrangement: Schematic view (Law and Gardner, 2013)

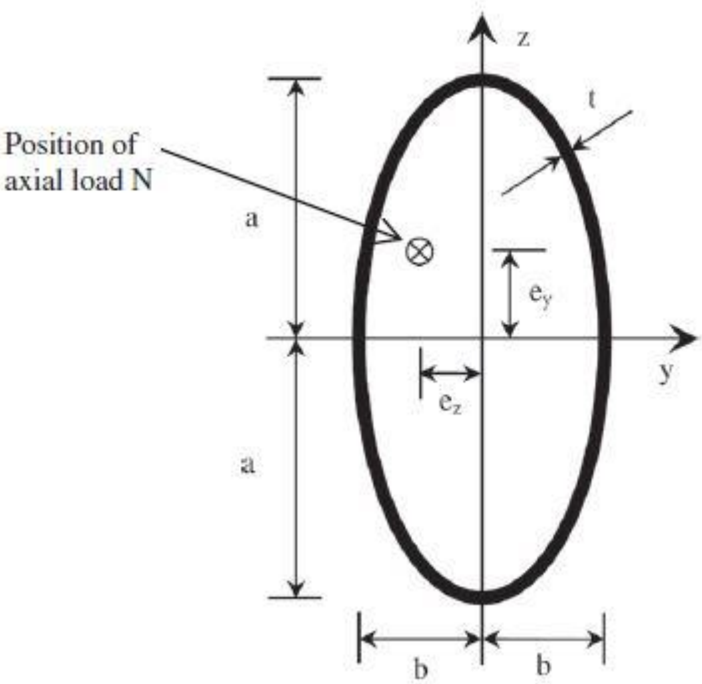


Figure 3.2 An elliptical hollow section geometry (Law and Gardner, 2013)

Table 3.1 Details of the database used for the derivation of the proposed models

Source	No	Axis of buckling	Eccentricity e_y (mm)	e_z (mm)	Larger outer diameter, 2a (mm)	Smaller outer diameter, 2b (mm)	Thickness, t (mm)	Yield stress, f_y (N/mm^2)	Ultimate tensile stress, f_u (N/mm^2)	Member length, L_{cr} (mm)	Ultimate load, Nu (kN)
Chan and Gardner (2009)	1	0	0	0	150.56	75.48	4.14	380	512	700	495
	2	0	0	0	150.08	76	5.13	374	506	700	614
	3	0	0	0	150.37	75.25	6.27	381	509	700	820
	4	1	0	0	150.54	75.4	4.24	373	514	700	573
	5	1	0	0	150.21	75.64	5.11	364	503	700	677
	6	1	0	0	150.28	75.53	6.35	400	515	700	866
	7	0	0	0	150.44	75.53	4.2	380	512	1500	507
	8	0	0	0	150.31	75.48	5.19	374	506	1500	647
	9	0	0	0	148.36	75.62	6.3	381	509	1500	789
	10	1	0	0	150.05	75.51	4.26	373	514	1500	538
	11	1	0	0	150.1	76.08	5.1	364	503	1500	680
	12	1	0	0	148.47	75.9	6.33	400	515	1500	836
	13	0	0	0	150.26	75.4	4.22	380	512	2300	365
	14	0	0	0	150.11	75.4	5.12	374	506	2300	393
	15	0	0	0	148.82	75.92	6.31	381	509	2300	452
	16	1	0	0	150.34	75.46	4.17	373	514	2300	489
	17	1	0	0	150.05	75.54	5.09	364	503	2300	611
	18	1	0	0	148.77	75.78	6.21	400	515	2300	814
	19	0	0	0	150.5	75.45	4.22	380	512	3100	234
	20	0	0	0	149.93	75.79	5.09	374	506	3100	242
	21	0	0	0	148.77	75.85	6.28	381	509	3100	292
	22	1	0	0	150.46	75.43	4.18	373	514	3100	429
	23	1	0	0	150.03	75.67	5.13	364	503	3100	509
	24	1	0	0	148.6	75.91	6.21	400	515	3100	648
Theofanous et al. (2009)	25	0	0	0	85.41	57.16	3.11	335	591.5	699.5	181.8
	26	1	0	0	85.48	56.84	3.09	335	591.5	700.6	196.9
	27	0	0	0	86.05	56.21	3.11	335	591.5	1499.6	116.1
	28	1	0	0	85.91	56.7	3.15	335	591.5	1500.5	150.8
	29	0	0	0	86.18	56.22	3.11	335	591.5	2299.3	72.3
	30	1	0	0	86.02	56.33	3.12	335	591.5	3100.3	40.6

Table 3.1 (Continued)

Source	No	Axis of buckling	Eccentricity ey (mm)	ez (mm)	Larger outer diameter, 2a (mm)	Smaller outer diameter, 2b (mm)	Thickness, t (mm)	Yield stress, fy (N/mm2)	Ultimate tensile stress, fu (N/mm2)	Member length, Lcr (mm)	Ultimate load, Nu (kN)
Law and Gardner (2013)	31	1	0	0	150.35	75.74	4.93	358	468	1330	645.4
	32	1	25	0	150.42	75.33	5.01	344	470	1310	390.8
	33	1	50	0	150.5	75.58	5.02	360	485	1310	323.4
	34	1	150	0	150.33	75.87	4.98	388	510	1310	142.4
	35	0	0	0	150.46	75.56	4.97	358	468	1330	636.7
	36	0	0	15	150.27	75.8	4.97	326	452	1310	350.5
	37	0	0	25	150.36	75.81	5.08	326	452	1310	271.5
	38	0	0	100	150.2	75.7	4.98	326	452	1310	112.3
	39	1	0	0	150.32	75.7	4.98	377	491	2330	594.9
	40	1	25	0	150	75.88	4.93	344	470	2310	339.8
	41	1	50	0	150.28	75.73	4.95	388	510	2310	245.7
	42	1	150	0	150.36	75.33	4.99	373	489	2310	123.5
	43	0	0	0	150.33	75.41	4.98	377	491	2330	430.3
	44	0	0	25	150.03	75.84	5.06	344	470	2310	211.7
	45	0	0	50	150	75.57	5.03	344	470	2310	146.2
	46	0	0	150	150.16	75.86	4.98	373	489	2310	73.3
	47	1	0	0	150.16	75.64	4.84	326	452	3190	475.4
	48	1	25	0	150.16	75.5	4.92	341	473	3170	281.8
	49	1	50	0	150.03	75.95	4.9	341	473	3170	212.5
	50	1	150	0	150.13	75.62	4.96	341	473	3170	113.5
	51	0	0	0	150.18	75.68	4.82	388	510	3180	226
	52	0	0	50	150.17	75.4	4.93	326	452	3170	109.4
	53	0	0	100	150.3	75.52	4.95	358	468	3170	80.2
	54	0	0	200	149.95	75.54	4.96	358	468	3170	51.6

3.2 Numerical simulations

Numerical solution is a evaluation with using run in computer. Any programs gives response for mathematical model in a physical sytem. In numerical simulations a computation is obtained that runs on computers and a mathematical model is applied to a physical system. That are needed to work for learning of the behaviour of systems. These systems are very complicated. The aim of it is to provide analytical solutions. It is generally used for most nonlinear systems. Numerical simulations bear an advantage over analytical equations because they do not require the assumptions inherent in the traditional approach the steady-state approximation the steady-state approach, the free ligand approach and the speedy balance approach. In fact, simulation involves all methods that can reproduce the operations of systems in digital or analog form (D'Aniello et al., 2014).

3.2.1 Overview of soft-computing techniques

Zadeh (1994) said that soft-computing is collection. The goal of it is to success tractability, uncertainity of tolerances for imprecision, and also robustness. It has also low solution cost. Human mind are taken as a reference. The main parts of soft-computing are Fuzzy logic, neuro-computing, and probabilistic reasoning. Lots of soft-computing techniques are using for application. Neural network (NN) or genetic programming (GP) are choisen. These are the popular methods. These are used for improving a mathematical model because of estimation the ultimate strength of EHS columns in compression and bending (D'Aniello et al., 2014).

3.2.1.1 Basic aspects of GP

GP is an application. This application of GP is of genetic algorithms (Koza,1992). It can be thought that it is an extension of GA. It can be said that GP is the domain. This domain are based on independent method. It is influenced with biological evolution. The problem is created by user is to be solve with programs. This solving are providing from the genetically breeds a population. In fact, the goal of GP is to convert any population in programs used on computers to a new generation. These are done by implementing similar of unaffectedly genetic operations. Genetic processes consist of many things. These are generally mutations, crosses, gene proliferation, reproduction and gene deletion. Embryo are transforming to fully developed existence in the analogues of developmental processes. The study of Goldberg (1989) said that GP has been carried out for solving separated, non-differentiable, combinational, and overall non-linear engineering optimization troubles, successfully. Ferreira (2001) introduced with Gene expression programming (GEP). It is the natural improvement in the field of genetic algorithms. It is also valid for programming. GEP enhances aprogramme with varying sizes and shapes. It can be carried out with encoded in linear chromosomes and this chromosomes are in fixed-length. The initial start of a GEP algorithm is done accidentally. It is the production of chromosomes of fixed length. This is the valid for each individual for first population. After that, chromosomes are defined the fitness of each one. The calculation of this are depends on quality for solution (D'Aniello et al., 2015). GEP are using in the GeneXproTools.4.0 software in the current study.

3.2.1.2 Fundamental aspects of NN

The microstructure can be displayed with NN. This microstructure is in biological nervous system. Some examples can be given for that such as brain (Zhang, 2003). The nomenclature or terminology of NN comes from neuroscience. The main and basic components of natural neuron is shown in Figure 3.3 (Wasserman, 1989). One of the main sensing functioning capacity of brain are based on numbers of components. Another perception of brain is depends on multiples. The novel structure are made of the main and important element of information processing paradigm. It includes numerous of well interconnected processing elements. It also includes neurons. This are working for solving the consistence specific problems. NN uses for artificial neurons. The aim of that is providing the learning of machine system. Learning process consist of especially the adjustments of synaptic connections among neurons for biological systems. The main parts of artificial neuron are weightiness, prejudice, and an activation function etc. In addition, the inputs of each neuron gets such as I_1, I_2, . . . , I_n attached with a weightiness t w_i. It seems the link strength of input for each one. After this point, each entry corresponding to the neuron is multiplied by the weight of the neuron connection. The prejudice may be expressed that it is a connection type of weight with non-zero value. This is also a constant value. This values are put to sum with weighted inputs. It can be seen in Eq. 3.1. Generalized algebraic matrix operations are written in Eq. 3.2. This equation is a mathematical operations in an artificial neuron, clearly (D'Aniello et al., 2015).

$$U_k = Bias_k + \sum_{j=1}^{n} w_{k,j} I_j \tag{3.1}$$

$$U_k = \begin{bmatrix} w_{11} & w_{12} & . & . & . & w_{1n} \\ w_{21} & . & & & & . \\ . & & & & & \\ . & & . & & & . \\ . & & & . & & . \\ . & & & & . & . \\ w_{m1} & . & . & . & . & w_{mn} \end{bmatrix}_{m\times n} \begin{bmatrix} I_1 \\ I_2 \\ . \\ . \\ . \\ I_n \end{bmatrix}_{n\times 1} + \begin{bmatrix} Bias_1 \\ Bias_2 \\ . \\ . \\ . \\ Bias_m \end{bmatrix}_{m\times 1} = \begin{bmatrix} U_1 \\ U_2 \\ . \\ . \\ . \\ U_m \end{bmatrix}_{m\times 1} \tag{3.2}$$

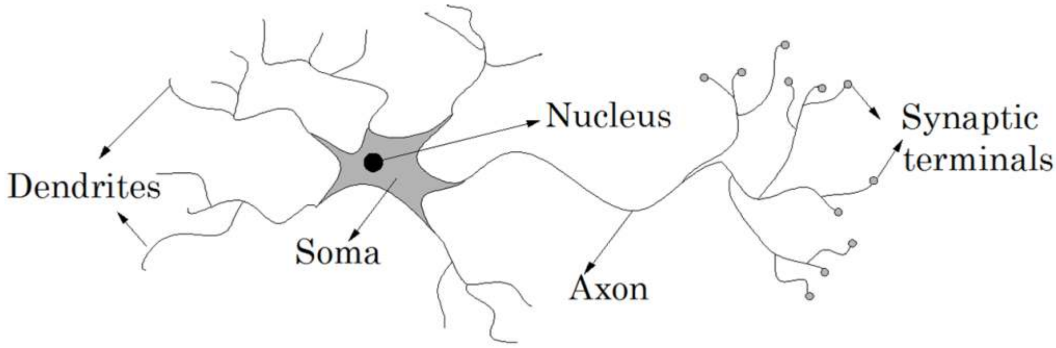


Figure 3.3 Clarify model of a biological neuron (Wasserman, 1989)

NN can be used for map in fitting problems. There are two elements on this map. The first is numeric inputs and the second is targets. The map is therefore between the data set of these two elements. In addition to that, the nftool can create a train network. To calculate the performance of the train network, Nftool can calculate using regression analysis and mean square error. The network comprising Sigmoid latent neurons and linear output neurons, a two-layer feed-forward network, arbitrarily fits multidimensional mapping problems. When performing dimensional mapping problems, consistent donnee and sufficient neurons are in its secret layer. Levenberg-Marquardt's back propagation algorithm was used to train networks (Levenberg, 1944). In the current work, Matlab V. R2012a providing neural network fitting tool (Nftool) was employed to make the humenical modelling.

Nftool uses standardised values in [-1, 1]. Thanks to Eq. (3.3) input parameters were normalized. This is done because of obtaining the prediction results. These results are obtained after the training process of NN has been completed. Additionally, the results in the experiments were normalized. So, Eq. (3.3) and *a* and *b* normalization coefficients for the outputs, normalization process is applied and the results are monitored (D'Aniello et al., 2015).

$$\beta_{normalized} = a\beta + b \tag{3.3}$$

where β written in Table 3.1. This is the true input parameter or output values. *a* and *b* parameters are the normalization coefficients. It is written in the Eq. (3.4) and Eq. (3.5).

$$a = \frac{2}{\beta_{\max} - \beta_{\min}} \tag{3.4}$$

$$b = -\frac{\beta_{\max} + \beta_{\min}}{\beta_{\max} - \beta_{\min}} \tag{3.5}$$

where β_{max} is maximum true values of either inputs or outputs. β_{min} is minimum true values of either inputs or outputs. The normalization coefficients for input and output variables are shown in Table 3.2.

Table 3.2 Normalization coefficients for the database

Input Parameters	***Normalization Parameters***			
	β_{max}	β_{min}	**a**	**b**
AB	1	0	2	-1
e_y (mm)	15	0	0.133333333	-1
e_z (mm)	200	0	0.01	-1
ϕ_1 (mm)	150.56	85.41	0.030698388	-3.62195
ϕ_2 (mm)	76.08	56.21	0.100654253	-6.65778
t (mm)	6.35	3.09	0.613496933	-2.89571
f_y (MPa)	400	326	0.027027027	-9.81081
f_u (MPa)	591.5	452	0.014336918	-7.48029
L_{cr} (mm)	3190	699.5	0.000803052	-1.56173
N_u (kN)	866	40.6	0.002423068	-1.09838

Note: AB = Axis of buckling

CHAPTER 4

DISCUSSION OF RESULTS

4.1. Proposed models

4.1.1 GEP model

The forecasting model comes from GEP. It is given in Eq. (4.1). In this equation, the load carring capacity of the elliptical hollow section (EHS) columns (N_u) is shown. GEP parameters are utilized for derivation of mathematical models. These parameters are written in Table 4.1. It can be observed from Table 4.1, 5 genes and various mathematical operations were used for providing an accurate modelling. Figure 4.1 shows the genes. These are corresponds to 1. These are distinct in expression tree (ET). The advantages of it is to provide perceiving quickly. Another advantages of ET is compregension of mathematical/logical upheavels. This trees are linked with exact model by addition. When finding any forecasting value, input parameters are substituted in the sub-expression functions. These functions are written in Eq. 4.1 and Eq. (4.1a)-Eq. (4.1e). Trigonometric function are defined as in radians. The significant advantage of model is utilized values. These values are not need for standardisation or any other conversion. In addition to that, the performance of the suggested GEP model written in Eq. (4.1) is shown in Figure 4.2. These are the data of training and testing. The harmony of experimental and training data seems good. The plot shows that the datas of similar are somewhat scatter for the testing database. However, it can be concluded generally that it is a good result for the consistency. It is also an evidence for good fitness of the proposed model. It is note that the correlation coefficient, of the traning and testing sets are about 0.936 and 0.841, respectively.

$$N_{U\,=}\; N_1 \times N_2 \times N_3 \times N_4 \times N_5 \tag{4.1}$$

$$N_1 = e^{K_1} \qquad K_1 = \left[\log\left(\log\left(\log(d_5)^2 + \frac{d_6+d_7}{d_8-d_7}\right)\right)\right]^3 \tag{4.1a}$$

$$N_2 = e^{K_2} \quad K_2 = \frac{d_5}{\left(d_1 + \sqrt[3]{d_8}\right) \times (0.376282)^2 + 3.166931} \tag{4.1b}$$

$$N_3 = \sqrt[3]{e^{\sqrt[3]{d_3}} - (d_1 + 9.720703) + d_0 \times \arctan(e^{d_5})} \tag{4.1c}$$

$$N_4 = \sqrt[3]{2d_4 + (d_5 + d_0) \times (d_0 - 7.112671) - 7.112671 - d_1 + d_3} \tag{4.1d}$$

$$N_5 = \frac{d_3}{log(e^{d_4} + d_0 \times d_2) - log(d_3) + d_2 - 1.180572} \tag{4.1e}$$

Where d_0 is axis of buckling (dummy variables; 0 for minor axis, 1 for major axis), d_1 is eccentricity in y axis, e_y, (mm), d_2 is eccentricity in z axis, e_z, (mm), d_3 is larger outer diameter, ϕ_1, (mm), d_4 is smaller outer diameter, ϕ_2, (mm), d_5 is wall thickness of the section, t, (mm), d_6 is yield stress, f_y, (MPa), d_7 is ultimate tensile stress, f_u, (MPa) and d_8 is member length, L_{cr}, (mm).

Table 4.1 GEP parameters used in the model

P1	Function Set	+, -, *, /, √, ^, ln, exp
P2	Number of generation	74541
P3	Choromosomes	30
P4	Head size	10
P5	Linking function	Multiplication
P6	Number of genes	5
P7	Mutation rate	0.044
P8	Inversion rate	0.1
P9	One-point recombination rate	0.3
P10	Two-point recombination rate	0.3
P11	Gene recombination rate	0.1
P12	Gene transposition rate	0.1

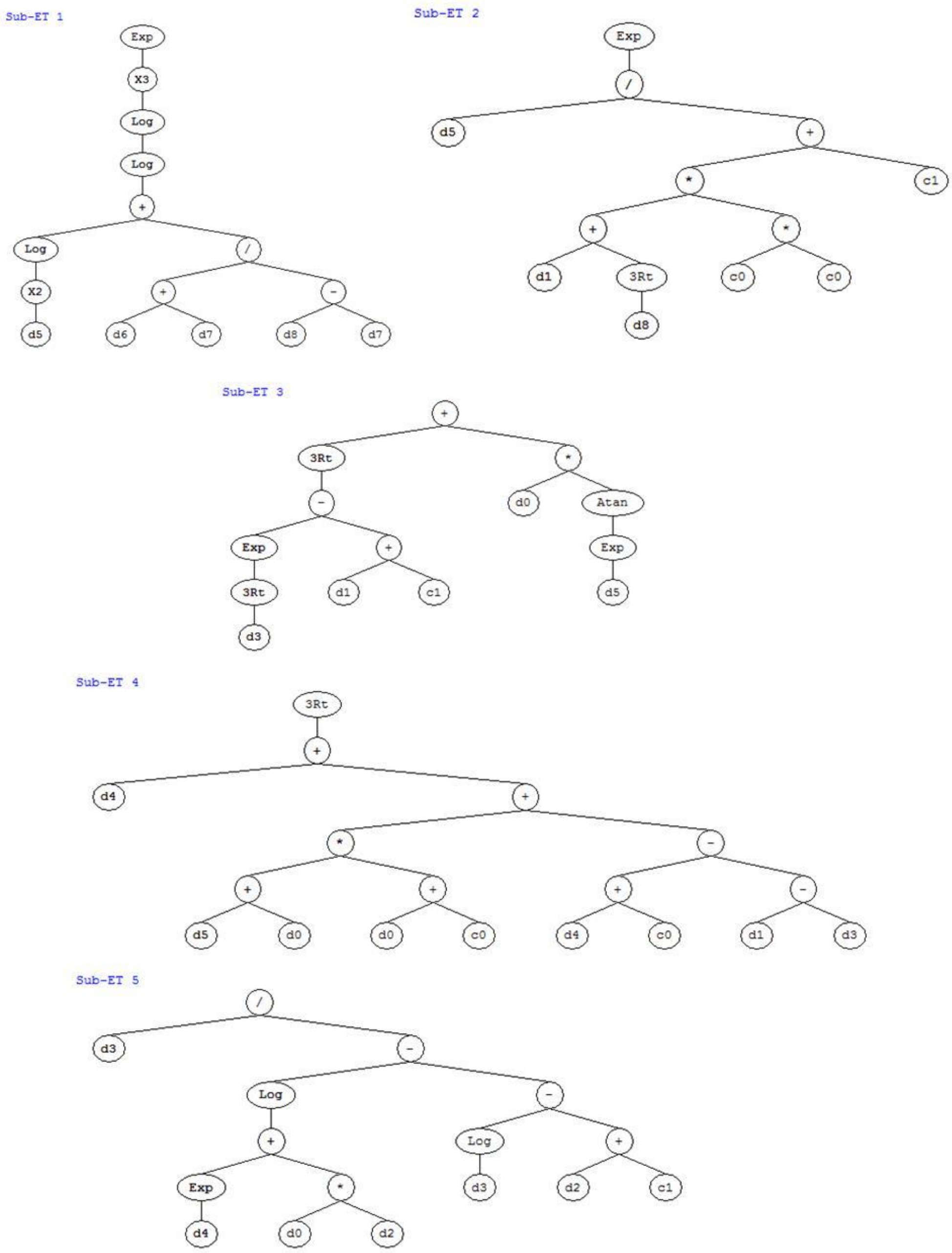
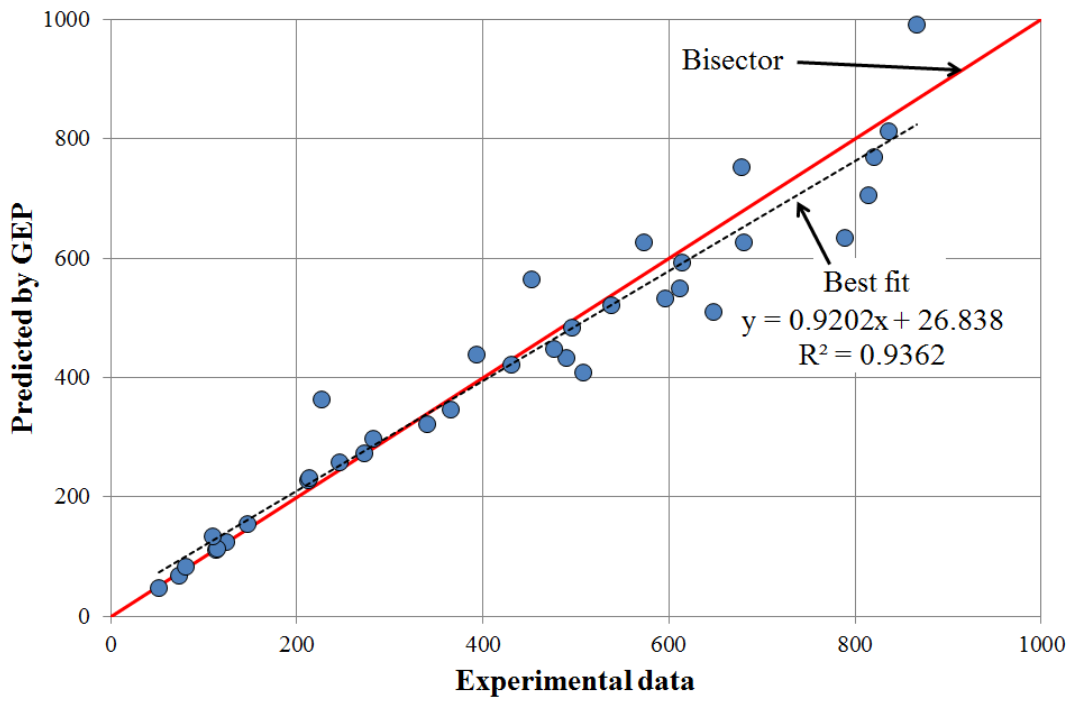
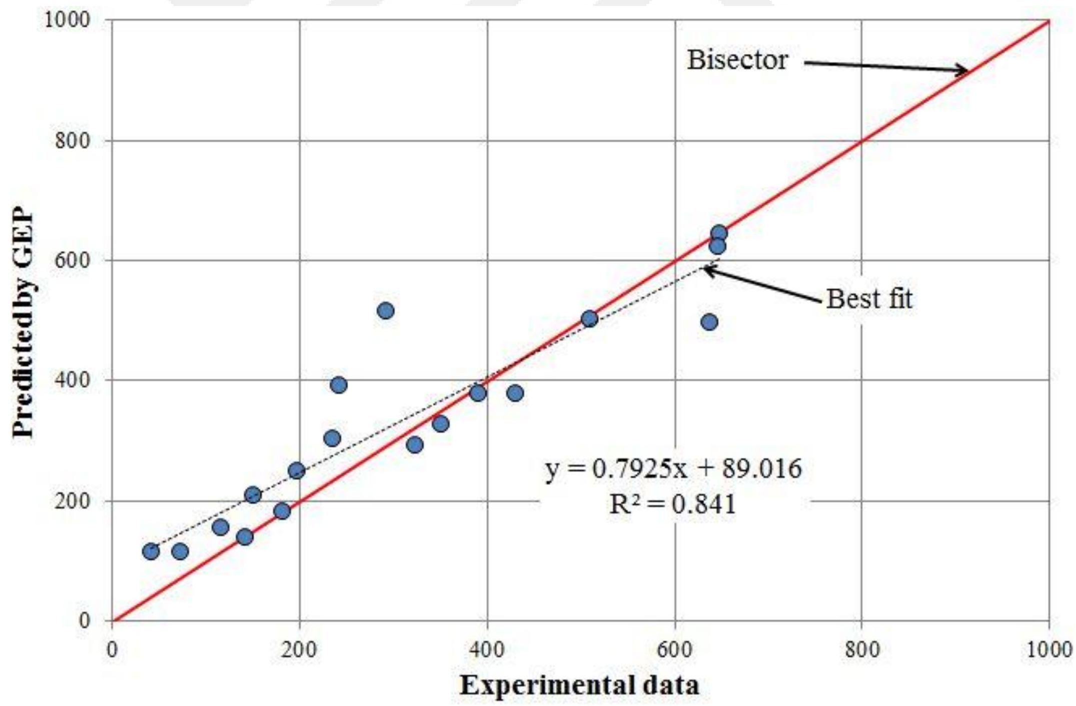


Figure 4.1 Expression tree for GEP model [d_0: Axis of buckling (dummy variables; 0 for minor axis, 1 for major axis), d_1: eccentricity in y axis, e_y, (mm), d_2: eccentricity in z axis, e_z, (mm), d_3: Larger outer diameter, ϕ_1, (mm), d_4: Smaller outer diameter, ϕ_2, (mm), d_5: Wall thickness of the section, t, (mm), d_6: Yield stress, f_y, (MPa), d_7: Ultimate tensile stress, f_u, (MPa), d_8: Member length, L_{cr}, (mm), c_0 and c_1: constants (c_0= 0.376282, c_1= 3.166931 for Sub-ET2, c_1= -1.759613 for Sub-ET3, c_0 = -7.112671, for Sub-ET4, c_1 = -1.180572 for Sub-ET5]



(a)



(b)

Figure 4.2 The relation between predicted ultimate load values from GEP based model and actual: a) Training data set and b) Testing data set

In these two figures (a and b), the actual values obtained by experimental results were compared with the GEP model method.

Ones:

- Although the drawing shows that similar data is partially scattered for the test database, the compatibility of experimental and traning data appears to be good.
- Consistent results were obtained from the comparison data and it was concluded that was a good result.
- The suitability of the proposed GEP model has been proven.
- In the future, it is expected that GEP model could be used in analysis and healthy data would be obtained.

4.1.2 NN model

A 9-10-1 NN architecture was used to derive the NN model. It is shown in Figure 4.3. 9-10-1 expressed that 9 inputs – 10 neurons – 1 output. The 9 nodes used in the input layer correspond to *AB*, e_y, e_z, ϕ_1, ϕ_2, t, f_y, f_u, and L_{cr} while 10 nodes in the hidden layer, and one in the output layer corresponding to the ultimate strength prediction of elliptical hollow section columns in compression and bending. The symbol AB indicates the axis of buckling and considers as dummy variable in the model. The optimum number of nodes in hidden layer was defined as in preliminary trial-error study.

The NN model and corresponding mathematical operations are written in Eqs. 4.2-4.5. The numerical variables are standardized in the range of [-1, 1] before introducing to the NN. Thus, one must set out on the standardized values in the mathematical operations noted for NN model.

$$N_{U,\,Normalized} = \left[-0.85563\right] + \begin{bmatrix} 1.1094 \\ -0.5611 \\ -0.7535 \\ -0.4084 \\ 0.3063 \\ -0.8912 \\ -1.0649 \\ 0.4799 \\ 0.6560 \\ -1.0305 \end{bmatrix}^{T} \times \begin{bmatrix} f(U_1) \\ f(U_2) \\ f(U_3) \\ f(U_4) \\ f(U_5) \\ f(U_6) \\ f(U_7) \\ f(U_8) \\ f(U_9) \\ f(U_{10}) \end{bmatrix} \tag{4.2}$$

Where U values are the numerical values of the nodes calculated in Eq 4.3. *f(x)* is activation function expressed by Eq 4.4.

$$U=\begin{bmatrix} 0.3533 & -1.4871 & -1.818 & -1.2095 & 0.1977 & 0.1029 & 0.3386 & -0.7101 & -0.6207 \\ 0.0399 & -0.4668 & 0.8858 & -0.5144 & -1.1263 & 0.268 & -1.2816 & 0.1315 & 0.3882 \\ -0.3066 & -0.9782 & 1.0615 & 0.2953 & -1.0664 & -0.1362 & -0.068 & -1.2445 & -0.5342 \\ -0.0791 & 0.2975 & 0.6775 & -0.2269 & 0.125 & -0.7673 & 1.9201 & 0.793 & -0.5507 \\ -0.6908 & 0.7073 & 1.2581 & -0.5178 & 0.1585 & -0.1707 & 0.4447 & -0.7484 & 0.3106 \\ 1.2544 & -1.262 & 0.6247 & -0.383 & 0.1829 & -0.9236 & -0.5814 & -1.00201 & -1.6158 \\ -1.1735 & 1.3337 & -0.6248 & 0.8202 & -0.1267 & 0.5817 & 0.3688 & 0.8762 & 1.6906 \\ -0.9088 & -0.0409 & 0.047 & 0.3543 & -0.7393 & 0.2833 & 1.1415 & 0.3975 & -0.987 \\ -0.2954 & -2.1719 & -0.2803 & -0.7164 & -0.8888 & -0.7839 & -0.2705 & -0.9041 & 0.0919 \\ 0.0144 & -0.44 & 0.1033 & -1.3161 & -0.8 & -0.9774 & -0.511 & -0.0694 & -0.0612 \end{bmatrix}_{10\times 9} \times \begin{bmatrix} AB \\ e_y \\ e_z \\ \phi_1 \\ \phi_2 \\ t \\ f_y \\ f_u \\ L_{cr} \end{bmatrix}_{9\times 1} + \begin{bmatrix} -2.8334 \\ -1.7412 \\ 0.3633 \\ 0.2692 \\ 0.2125 \\ 0.2961 \\ -1.0923 \\ -0.5574 \\ -1.7980 \\ -1.8702 \end{bmatrix}_{10\times 1} = \begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \\ U_5 \\ U_6 \\ U_7 \\ U_8 \\ U_9 \\ U_{10} \end{bmatrix}_{10\times 1} \tag{4.3}$$

$$f(x)=\frac{2}{1-e^{-2x}}-1 \tag{4.4}$$

$$N_U=\frac{N_{U,Normalized}+1.0983765447056}{0.00242306760358614} \tag{4.5}$$

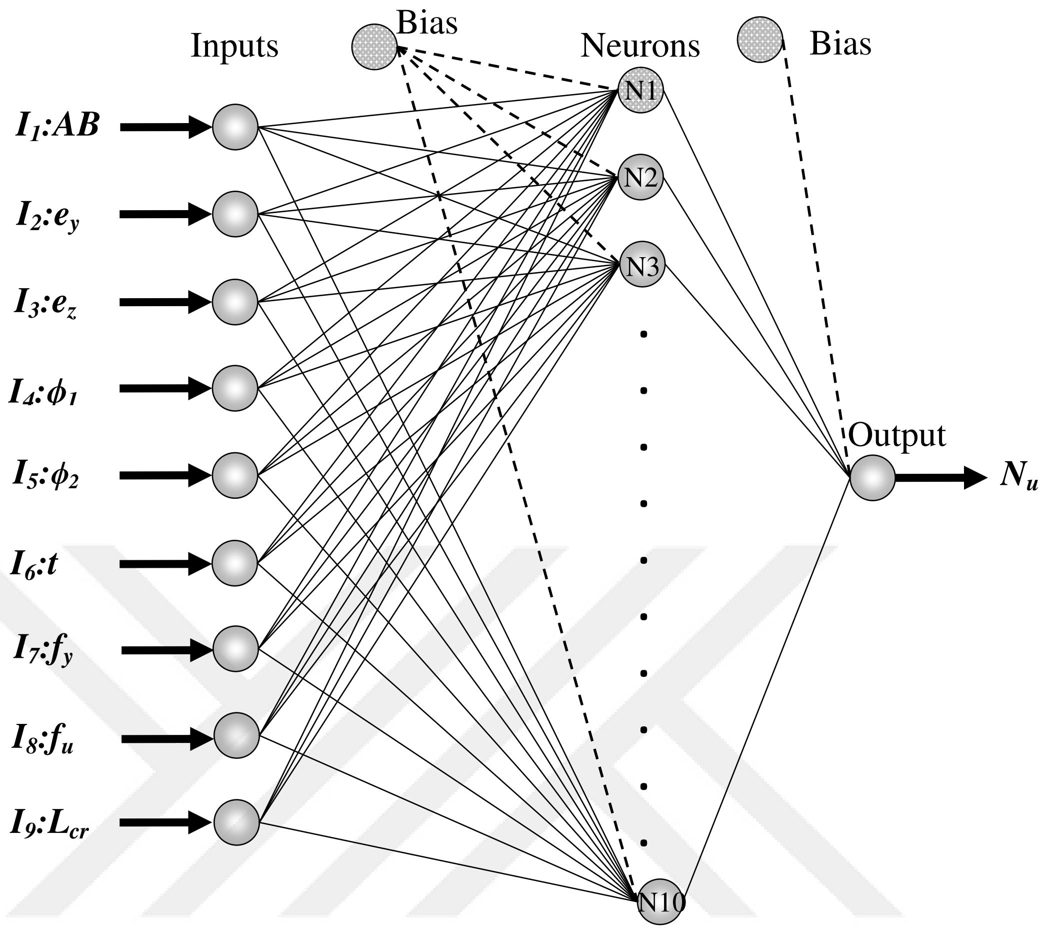
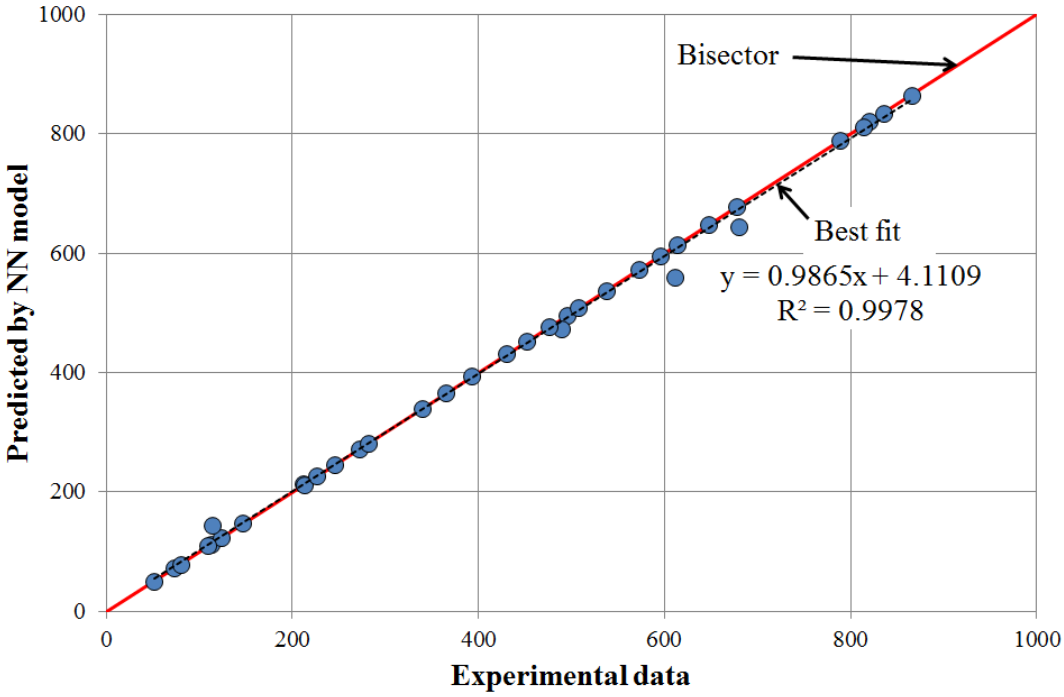
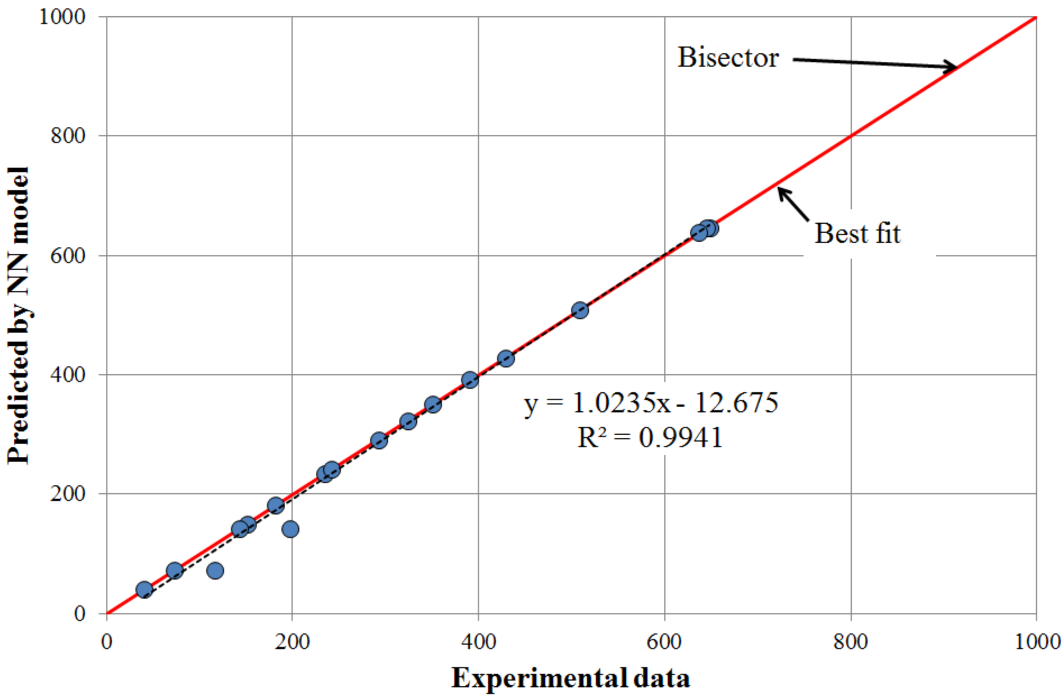


Figure 4.3 9-10-1 architecture for development of the NN based model

Figure 4.4 shows the obtained results from NN model for the ultimate load capacity of EHS columns. This figures indicates that the closer trend for traning and testing data sets. The former has a correlation coefficient of 0.998 while the later has a that of 0.994. Moreover, the values are so close to 100% agreement line. It is observed that the error of proposed NN model is lower than GEP model. The accuracy band of NN model is higher than GEP model.



(a)



(b)

Figure 4.4 The relation between predicted ultimate load values from NN based model and actual: a) Training data set and b) Testing data set

In these two figures (a and b), the actual values obtained by experimental results were compared with the NN model method.

Ones:

- The results obtained by NN modeling show almost 100 percent compatibility of experimental data.
- Consistent results were obtained between the traning and testing data sets.
- The data obtained with the NN model show that the result is closer to the best fit graph than the GEP model.
- Similar to GEP modelling, it is expected that NN model could be used in analysis and healthy data would be obtained**.**

4.2 Performance of the proposed models

Figure 4.5 shows the comparison of the performance of the suggested models with regars to the normalized values versus corresponding experimental ones. This is drawn to show the accuracy of the models. The normalized data was calculated as the ratio of the value by the proposed model to that by the experiment. Results showed that the normalized values are mostly correspondig to the value equal to 1.0. As understanding from these results, the perfect estimation were done. Figure 4.5 clearly indicated that the closest trend in variation of the normalized values around 1. It was detected for the NN model especially for the getting normalized data between 0.623 and 1.274. Although for both of the proposed models the tendency of the normalized values is to slightly underestimate or sometime overestimate, for the most three outer normalized data in the data set the estimation performance of especially NN model was almost excellent (normalized values are 0.999, 1.001, 1.004). It was detected for the GEP model especially for the getting normalized data between 0.79 and 2.88. In the data set the estimation performance of GEP model was good in the case of the experimental data greater than 300 kN. However, it had poor performance for the experimental data less than 300 kN. As a result of the comparison of two models, it was seen that NN model gave results better than GEP model. In order to make further evaluation of the performance of the prediction models, the following statistical parameters given in Eqs. (4.6) - (4.8) were computed and reported in Table 4.2.

Table 4.2 Statistical parameters of the proposed models

Model	MAPE		MSE		RMSE		R^2	
	Train	Test	Train	Test	Train	Test	Train	Test
GEP model	10.034	32.092	3959.36	6490.86	62.923	80.566	0.9362	0.841
NN model	1.488	3.848	144.295	276.196	12.012	16.619	0.9978	0.9941

Mean absolute percent error; $MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{m_i - p_i}{m_i}\right| \times 100$ (4.6)

Mean square error; $MSE = \frac{\sum_{i=1}^{n}(m_i - p_i)^2}{n}$ (4.7)

Root mean square error $RMSE = \sqrt{\frac{\sum_{i=1}^{n}(m_i - p_i)^2}{n}}$ (4.8)

where m and p are values of the measured (m_i) and predicted (p_i) values, respectively.

Using the above equations, error values were calculated for both models. As clearly observed in Table 4.2, the error values calculated for both models were not close to each other. The NN model yield significantly less errors. For example, MAPE values for NN model were about 3.8 and 1.5 for the training and testing data sets, respectively. However, those for GEP model were about 32.1 and 10.0, respectively. Moreover, the correlation coefficients calculated for the NN model were considerably higher than that of the GEP model. So, the strength or goodness of the relationship between the predicted values and actual values for the NN model was more than that of the GEP model.

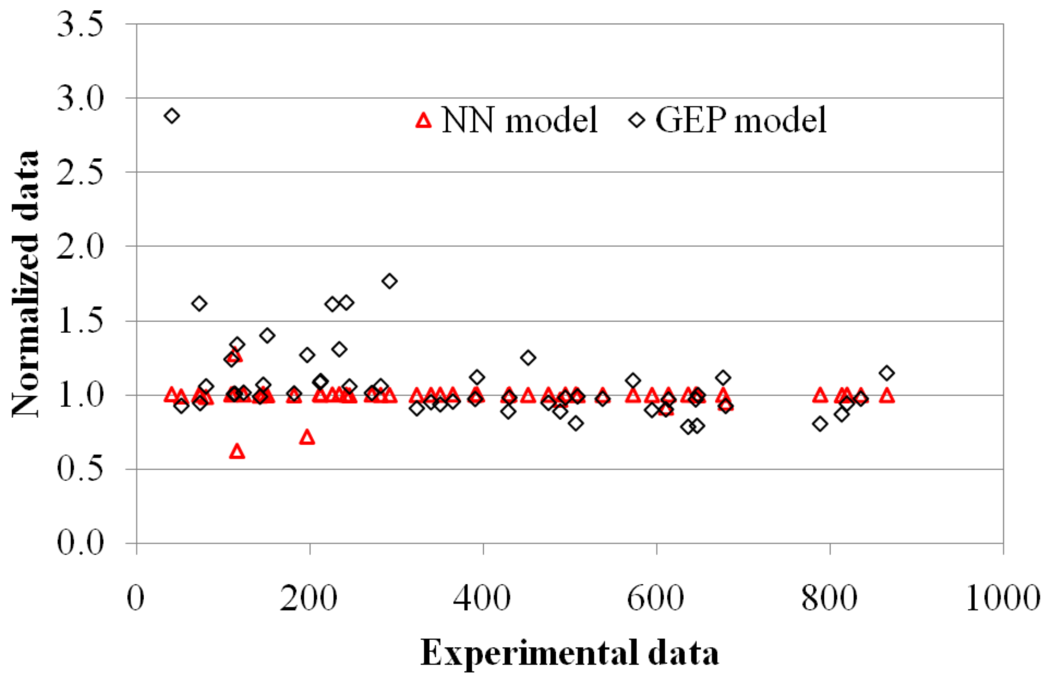


Figure 4.5 Performance of the proposed models

For the proposed GEP and NN models, a comparison was made with the experimental data on the normalized data.

Ones:

- As a result of comparison of two models, it was shown that NN model gave results better than GEP model.
- NN model was seen to give the closest value in 1.0 variation.
- For the most three outer normalized data in the data set the estimation performance of NN model was almost excellent.

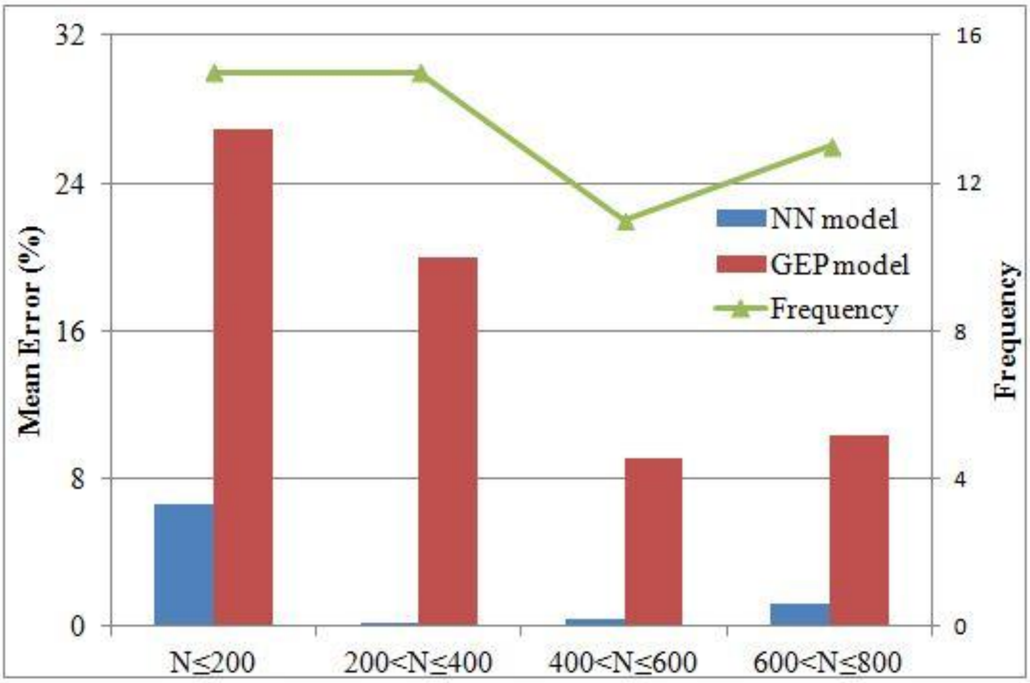


Figure 4.6 Error analysis of the proposed models

Figure 4.6 shows the average absolute errors for the specific intervals of GEP model and NN model N values compared. The average errors calculated for both proposed models were very close to each other regardless the N values, while the errors for GEP model decreased as the N values increased. The highest average error for GEP model was about 26.93% in the interval N≤200, whereas the highest average error for NN model was about 6.63% in the interval N≤200. The smallest mean error for the NN model is about 0.23% in the interval 200 <N≤400. The smallest mean error for the GEP model is about 9.10% in the interval 400 <N≤600.

Ones:

- It was seen that NN model gives less error than GEP model.
- The smaller the N value, the higher the error rate in the GEP model.
- The best results for the NN model were in the interval 200<N≤ 400.
- The best results for the GEP model were in the interval 400<N≤ 600.

CHAPTER 5

CONCLUSIONS

The following conclusion were drawn from the analysis of the result;

1) It was observed that the proposed models could be successfully used to predict the ultimate strength of the elliptical hollow section columns under compression and bending. As a result of comprasion of two models, it was shown that NN model gave results better than GEP model.

2) The analysis of the result showed that the correlation coefficients for GEP model were 0.936 and 0.841 for the training and testing data sets, respectively. However, those for NN model were recorded as 0.999 and 0.994.

3) NN model was seen to give values very closer to the actual results. NN model in the analysis yielded consistent results. It was detected for the NN model especially for the getting normalized data between 0.623 and 1.274.

4) It was seen for the GEP model that the normalized data was between 0.79 and 2.88. In the data set, the estimation performance of GEP model was not well in comparison to NN model. It was more scatter than NN model.

5) The highest average error for GEP model was about 26.9% in the interval $N \leq 200$, whereas the highest average error NN model was about 6.6% in the interval $N \leq 200$.

6) The lowest mean error for the NN model was about 0.23% in the interval $200 < N \leq 400$. While the lowest mean error for the GEP model was about 9.10% in the interval $400 < N \leq 600$.

7) It was also observed that the statistical parameters based on MAPE, MSE and RMSE confirmed the superiority of NN results over GEP ones.

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