Optimization of two hinge steel arch using MATLAB

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Abstract*— Two hinge steel arch is statically indeterminate structure. the degree of static indeterminacy is one for two hinged arch. the strain energy of a statically indeterminate structure is calculated by least work method. In this paper solid rectangular section of two hinge steel parabolic arch is optimized. Horizontal loading is not be considered for this study. Deflection at crown of two hinge steel arch calculated by unit load method. Optimization of two hinge steel arch done in MATLAB using artificial neural network(ANN) toolbox. Analysis of two hinge steel arch is carried out by making script in MATLAB. Cross section area of solid rectangular section and height to span ratio considered as a variable for optimization. Maximum deflection at crown, maximum bending and axial stresses, maximum shear stress consider as a constraint for optimization. Weight of arch is taken as a objective function for optimization. Supervised learning method used in a ANN toolbox. Type of neural network used for optimization is single-layer feed forward network.

***Index Terms*—weight optimization, least work method, supervised learning, single-layer feed forward method**

I. INTRODUCTION

In the case of two-hinged arch, we have four unknown reactions, but there are only three equations of equilibrium available. Hence, the degree of static indeterminacy is one for two hinged arch. The fourth equation is written considering deformation of the arch. The unknown redundant reaction is calculated by noting that the horizontal displacement of hinge at B is zero. In-general the horizontal reaction in the two hinged arch is evaluated by straightforward application of the theorem of least work which states that the partial derivative of the strain energy of a statically indeterminate structure with respect to statically indeterminate action should vanish. Hence to obtain, horizontal reaction, one must develop an expression for strain energy. Typically, any section of the arch is subjected to shear force V, bending moment M and the axial compression N. unit load method is used for find a vertical displacement at crown.

Optimization is the act of obtaining the best result under given circumstances. In design, construction, and maintenance of any engineering system, engineers have to take many technological and managerial decisions at several stages. The ultimate goal of such decisions is either to minimize the effort required or to maximize the desired benefit. Since the effort required or the benefit desired in any practical situation can be expressed as a function of certain decisions variables. Optimization can be define as the process of finding the conditions that give the maximum or minimum value of a function. Artificial neural network technique is used for optimization. As soon as 1943 Warren McCulloch and Walter Pitts introduced models of neurological networks, recreated threshold switches based on neurons and showed that even simple networks of this kind are able to calculate nearly any logic or arithmetic function. Furthermore, the first computer precursors ("electronic brains") were developed, among others supported by Konrad Zuse, who was tired of calculating ballistic trajectories by hand. If we compare computer and brain1, we will note that, theoretically, the computer should be more powerful than our brain: It comprises 109 transistors with switching time of 10−9 seconds. The brain contains 1011 neurons, but these only have a switching time of about 10−3 seconds. Weight of the two hinge steel arch optimized by ANN. Supervise learning is used as a learning method and single-layer feedforward network is used as a type of neural network.

II. METHODOLOGY IN MATLAB STUDY

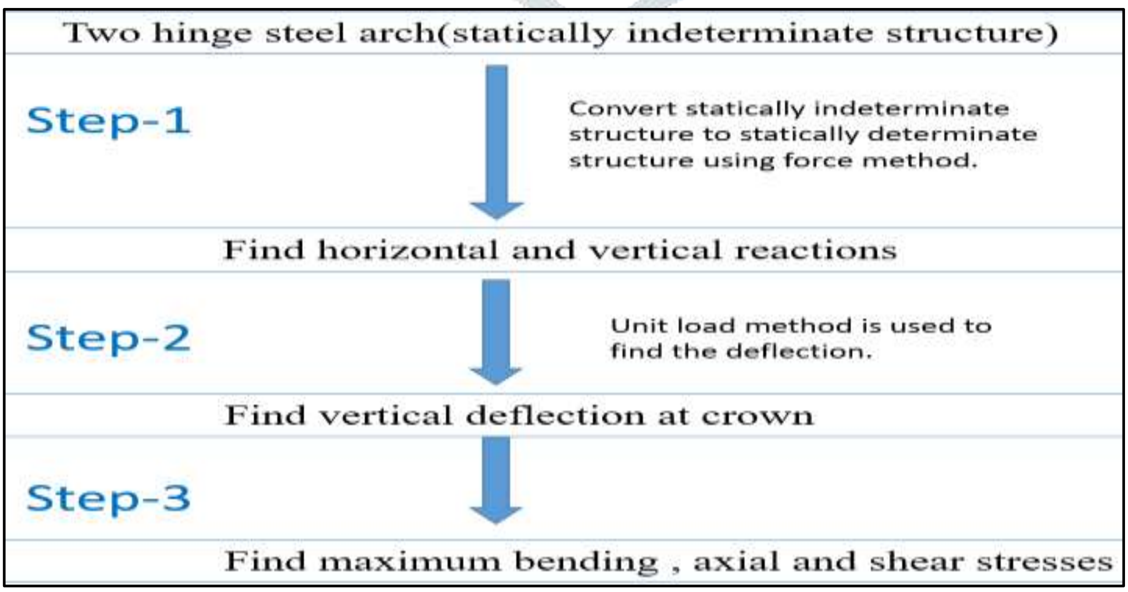


Fig 1. Steps for analysis of two hinge steel arch

```
w = zeros();
w0 = [4;2]; % integration weights
for i = 2:N/2+1
    w = [w; [4; 2]];
end
w = [1;w];
w = (L_span / (3*N)) * w;
ds_func = sqrt ( 1.0 + dy_dx .^2);
L_arch = sum ( w .* ds_func);
```

step-1 find reactions:
find horizontal force using force method:

- $H_B = \frac{\Delta}{\delta_{BB}}$

δ_{BB} = Deflection due to applied unit load;
Simpson's 1/3 rule for numerical integration:

- $\int_a^b f(x)dx = \frac{h}{3}[f(x_0) + 4f(x_1) + 2f(x_2) + 4f(x_3) + 2f(x_4) + \cdots + 4f(x_{n-1}) + f(x_n)]$

Where, h = $\frac{b-a}{n}$

- $\delta_{BB} = \int_s \frac{M \times m}{EI} ds$

moment in the primary structure when load = 1kN;
For M = -y and m = -y;

- $\delta_{BB} = \int_s \frac{y^2}{EI} ds$
  Where y = rise at any point.
- To find, Δ = Deflection due to external loading
  Where y = rise at any point.
- To find, Δ = Deflection due to external loading

```
M_1_bar = - y;

d_11_M_fun =  M_1_bar .* M_1_bar/(E*I) ;
d_11_M = sum (  w .* d_11_M_fun .* ds_func );
d_11 = d_11_M;
```

- Find reaction va and vb,

```
total_udl_answer=0;
udl_total_load_answer=0;
for r = 1:num_of_udl

    temp1=[udl_load_magnitude(r)*(udl_x2(r)-udl_x1(r))];
    temp2=[(udl_x1(r)+udl_x2(r))/2];

    total_udl(r)=temp1*temp2;
      total_udl_answer=total_udl_answer+total_udl(r);
      udl_total_load(r)=udl_load_magnitude(r)*(udl_x2(r)-udl_x1(r));
      udl_total_load_answer=udl_total_load_answer+udl_total_load(r);

end
```

```
sigma_moment=total_udl_answer+total_pl_answer;
vb=sigma_moment/L_span;
global va;
va=udl_total_load_answer+total_pl_load_answer-vb;

fprintf('VA = %f , VB = %f',va,vb);
```

Step-1 find horizontal reaction:

Δ = Deflection due to external loading;
Xa = $V_A - w \times x$;

$$ds = \sqrt[2]{1 + (\frac{dy}{dx})^2}$$

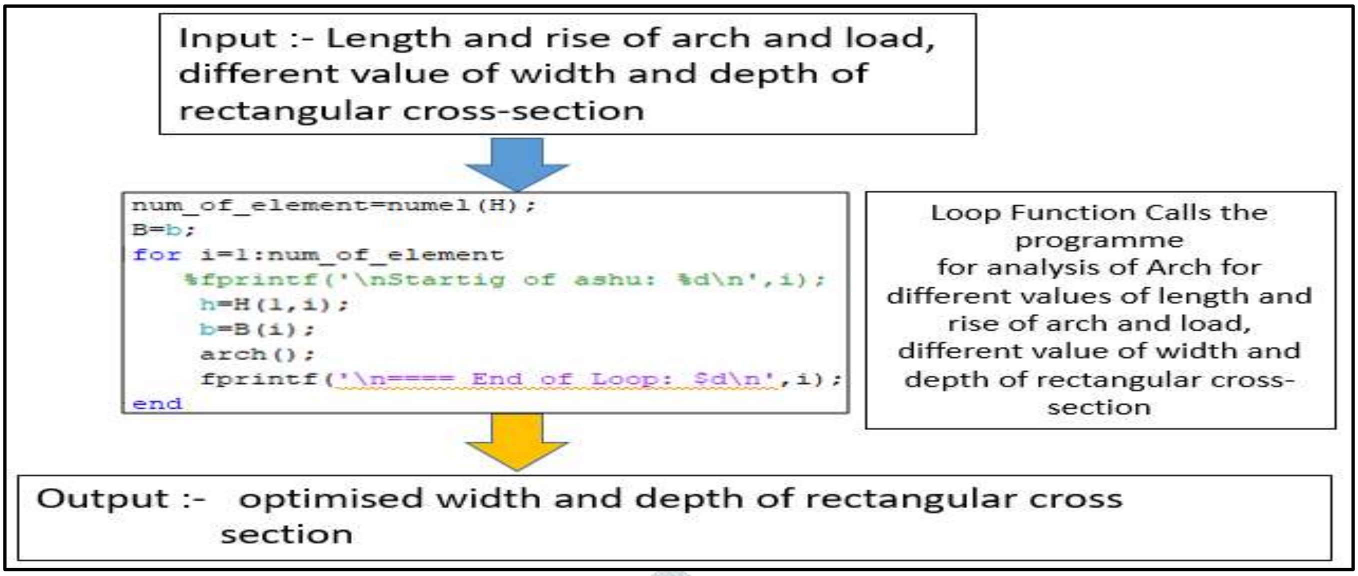
$$\Delta = \frac{1}{E*I}\int_0^{12}\left(V_A \times x - \frac{W \times x^2}{2}\right) \times y + \frac{1}{A \times E}\int_0^{12}($$
$$H \times \sin\emptyset)$$

```
L=L_span;
G=86.95*10^6;
h=(x2-x1)/n;
x= (x1:(x2-x1)/n :x2);
xa = va-(w1.*x);

temp1=((va.*x(1)-(0.5*w1.*x(1)^2))*(L.*x(1)-x(1)^2)*4*f)./(L_span^2*E*I);
temp2=(xa(1)*sin_Fi(1)*cos_Fi(1))./(A*E);
temp3=-(xa(1)*sin_Fi(1)*cos_Fi(1))./(A*G);
sum=(temp1+temp2+temp3).*ds_func(1);

for i=1:n
    z(i)=x1+h*i;
    temp1=((va.*z(i)-(0.5*w1.*z(i)^2))*(L.*z(i)-z(i)^2)*4*f)./(L_span^2*E*I);
temp2=(xa(i)*sin_Fi(i)*cos_Fi(i))./(A*E);
temp3=-(xa(i)*sin_Fi(i)*cos_Fi(i))./(A*G);
 if mod(i,2)==0
        sum=sum+2*((temp1+temp2+temp3).*ds_func(i));
    else
       sum=sum+4*((temp1+temp2+temp3).*ds_func(i));

    end

end
```

- Horizontal reaction $H = \frac{\Delta}{\delta_{BB}}$

```
temp1=(final_udl+final_pl);
final_d10=temp1;
fprintf(' final_d10\n\n====================');
fprintf('\nFinal d_10: %f',final_d10);
H=final_d10/d_11;
```

- now as same as find maximum vertical deflection at
- To get optimized value of width and depth of solid rectangular cross-section entered some input values like length and rise of arch and load. That input and output data used for train a neuron in neural network toolbox. Here we get 200 data set of input and output for train a neuron in neural network toolbox. This loops function calls for analysis of arch for different values of load, length and rise of arch and range of width 150 mm to 750 mm and range of depth 75 mm to 325 mm of rectangular cross section.



Input data

No.	span(m)	rise(m)	load(N)
1	12	3	1000
2	12	3	1000
3	13	3.25	1000
4	13.5	3.375	1000
5	14	3	1000
6	15	3	1000
7	15.5	3.875	1500
8	15.5	3.875	1100
9	15.5	3.875	1050
10	15.5	3.875	1150
11	15.5	3.875	1200
12	15.5	3.875	1250
13	16	4	1300
14	16	4	1000
15	16	4	1100
16	16	4	1150
17	16	4	1250
18	16	4	1350
19	16	4	1450
20	16	4	1550
21	16	4	1650
22	16	4	1750
23	16	4	1850
24	16	4	1950
25	16	4	2050
26	16	4	2150
27	16	4	2300

Output data

No.	width(m)	depth(m)
1	0.3500	0.3250
2	0.5000	0.2500
3	0.4700	0.2350
4	0.4750	0.2375
5	0.4800	0.2400
6	0.4850	0.2425
7	0.5200	0.2600
8	0.4950	0.2475
9	0.4900	0.2450
10	0.4950	0.2475
11	0.5000	0.2500
12	0.5050	0.2525
13	0.5100	0.2550
14	0.4850	0.2425
15	0.4950	0.2475
16	0.5000	0.2500
17	0.5050	0.2525
18	0.5100	0.2550
19	0.5200	0.2600
20	0.5250	0.2625
21	0.5300	0.2650
22	0.5350	0.2675
23	0.5400	0.2700
24	0.5450	0.2725
25	0.5500	0.2750
26	0.5550	0.2775
27	0.5600	0.2800

Input data

No.	span(m)	rise(m)	load(N)
28	16	4	2400
29	16	4	2550
30	16	4	2700
31	16	4	2800
32	16	4	2950
33	16	4	3150
34	16	4	3300
35	16	4	3450
36	16	4	3650
37	16	4	3800
38	16	4	4000
39	16	4	6000
40	16	4	5000
41	16	4	6500
42	16	4	7000
43	16	4	7500
44	16	4	8000
45	16	4	7750
46	16	4	8250
47	16	4	8500
48	16	4	9500
49	16	4	10250
50	16	4	11000
51	16	4	11500
52	16	4	11750
53	16	4	12000
54	16	4	12500

Output data

No.	width(m)	depth(m)
28	0.5650	0.2825
29	0.5700	0.2850
30	0.5750	0.2875
31	0.5800	0.2900
32	0.5850	0.2925
33	0.5900	0.2950
34	0.5950	0.2975
35	0.6000	0.3000
36	0.6050	0.3025
37	0.6100	0.3050
38	0.6150	0.3075
39	0.6550	0.3275
40	0.6350	0.3175
41	0.6650	0.3325
42	0.6750	0.3375
43	0.6800	0.3400
44	0.6900	0.3450
45	0.6850	0.3425
46	0.6900	0.3450
47	0.6950	0.3475
48	0.7000	0.3500
49	0.7050	0.3525
50	0.7100	0.3550
51	0.7150	0.3600
52	0.7200	0.3625
53	0.7250	0.3650
54	0.7300	0.3675

Input data

No.	span(m)	rise(m)	load(N)
55	16	4	12750
56	16	4	13000
57	16	4	13500
58	18	4.5	1000
59	18	4.5	800
60	18	4.5	850
61	18	4.5	900
62	18	4.5	950
63	18	4.5	1050
64	18	4.5	1150
65	18	4.5	1250
66	18	4.5	1200
67	18	4.5	1350
68	18	4.5	1450
69	18	4.5	1600
70	18	4.5	1500
71	18	4.5	1700
72	18	4.5	1600
73	18	4.5	1800
74	18	4.5	1900
75	18	4.5	2000
76	18	4.5	2100
77	18	4.5	2200
78	18	4.5	2300
79	18	4.5	2450
80	18	4.5	2600
81	18	4.5	2750

Output data

No.	width(m)	depth(m)
55	0.7350	0.3400
56	0.7400	0.3425
57	0.7450	0.3450
58	0.4950	0.2475
59	0.4750	0.2375
60	0.4800	0.2400
61	0.4850	0.2425
62	0.4900	0.2450
63	0.5000	0.2500
64	0.5050	0.2525
65	0.5150	0.2575
66	0.5100	0.2550
67	0.5200	0.2600
68	0.5250	0.2625
69	0.5350	0.2675
70	0.5300	0.2650
71	0.5400	0.2700
72	0.5350	0.2675
73	0.5450	0.2725
74	0.5500	0.2750
75	0.5550	0.2775
76	0.5600	0.2800
77	0.5650	0.2825
78	0.5700	0.2850
79	0.5750	0.2875
80	0.5800	0.2900
81	0.5850	0.2925

Input data

No.	span(m)	rise(m)	load(N)
82	18	4.5	2900
83	18	4.5	3050
84	18	4.5	3250
85	18	4.5	3500
86	18	4.5	3750
87	18	4.5	3600
88	18	4.5	3850
89	18	4.5	3750
90	18	4.5	4250
91	18	4.5	4150
92	18	4.5	5000
93	18	4.5	4600
94	18	4.5	4800
95	18	4.5	5250
96	18	4.5	5500
97	18	4.5	5750
98	18	4.5	6000
99	18	4.5	6250
100	18	4.5	6500
101	18	4.5	6750
102	18	4.5	7000
103	18	4.5	7250
104	18	4.5	7500
105	18	4.5	8000
106	18	4.5	8500
107	20	5	1000
108	20	5	1100

Output data

No.	width(m)	depth(m)
82	0.5950	0.2975
83	0.6000	0.3000
84	0.6050	0.3025
85	0.6150	0.3075
86	0.6100	0.3050
87	0.6200	0.3100
88	0.6150	0.3075
89	0.6300	0.3150
90	0.6250	0.3125
91	0.6450	0.3225
92	0.6350	0.3175
93	0.6400	0.3200
94	0.6500	0.3250
95	0.6550	0.3275
96	0.6600	0.3300
97	0.6650	0.3325
98	0.6700	0.3350
99	0.6750	0.3375
100	0.6800	0.3400
101	0.6850	0.3425
102	0.6900	0.3450
103	0.6950	0.3475
104	0.7000	0.3500
105	0.7050	0.3525
106	0.6000	0.3000
107	0.6100	0.3050
108	0.6050	0.3025

Input data

No.	span(m)	rise(m)	load(N)
109	20	5	1150
110	20	5	1200
111	20	5	1300
112	20	5	1400
113	20	5	1500
114	20	5	1450
115	20	5	1600
116	20	5	1550
117	20	5	1700
118	20	5	1800
119	20	5	1900
120	22	5.5	1000
121	22	5.5	1050
122	22	5.5	1100
123	22	5.5	1150
124	22	5.5	1200
125	22	5.5	1250
126	22	5.5	1350
127	22	5.5	1450
128	22	5.5	1550
129	22	5.5	1500
130	22	5.5	1600
131	22	5.5	1700
132	22	5.5	1650
133	22	5.5	1750
134	22	5.5	1800
135	22	5.5	1900

Output data

No.	width(m)	depth(m)
109	0.6150	0.3075
110	0.6200	0.3100
111	0.6250	0.3125
112	0.6300	0.3150
113	0.6400	0.3200
114	0.6350	0.3175
115	0.6500	0.3250
116	0.6450	0.3225
117	0.6550	0.3275
118	0.6600	0.3300
119	0.6650	0.3325
120	0.6300	0.3150
121	0.6350	0.3175
122	0.6400	0.3200
123	0.6450	0.3225
124	0.6500	0.3250
125	0.6550	0.3275
126	0.6600	0.3300
127	0.6650	0.3325
128	0.6750	0.3375
129	0.6700	0.3350
130	0.6750	0.3375
131	0.6850	0.3425
132	0.6800	0.3400
133	0.6900	0.3450
134	0.6950	0.3475
135	0.7000	0.3500

Input data

No.	span(m)	rise(m)	load(N)
136	10	2.5	900
137	10	2.5	950
138	10	2.5	1000
139	10	2.5	1050
140	10	2.5	1100
141	10	2.5	1150
142	10	2.5	1250
143	10	2.5	1400
144	10	2.5	1550
145	10	2.5	1700
146	10	2.5	1650
147	10	2.5	1800
148	10	2.5	1950
149	10	2.5	2050
150	10	2.5	2200
151	10	2.5	2350
152	10	2.5	2500
153	10	2.5	2650
154	10	2.5	2800
155	10	2.5	2950
156	10	2.5	3100
157	10	2.5	3250
158	10	2.5	3500
159	10	2.5	3750
160	10	2.5	4000
161	10	2.5	4250
162	10	2.5	4500

Output data

No.	width(m)	depth(m)
136	0.4150	0.2075
137	0.4200	0.2100
138	0.4250	0.2125
139	0.4300	0.2150
140	0.4350	0.2175
141	0.4400	0.2200
142	0.4450	0.2225
143	0.4500	0.2250
144	0.4550	0.2275
145	0.4650	0.2325
146	0.4600	0.2300
147	0.4700	0.2350
148	0.4725	0.2375
149	0.4800	0.2400
150	0.4850	0.2425
151	0.4900	0.2450
152	0.4950	0.2475
153	0.5000	0.2500
154	0.5050	0.2525
155	0.5100	0.2550
156	0.5150	0.2575
157	0.5200	0.2600
158	0.5250	0.2625
159	0.5300	0.2650
160	0.5350	0.2675
161	0.5400	0.2700
162	0.5450	0.2725

Input data

No.	span(m)	rise(m)	load(N)
163	10	2.5	4750
164	10	2.5	5000
165	10	2.5	5250
166	10	2.5	5500
167	10	2.5	5750
168	10	2.5	6200
169	10	2.5	6600
170	10	2.5	7000
171	10	2.5	7400
172	10	2.5	7800
173	10	2.5	8200
174	10	2.5	8600
175	10	2.5	9000
176	10	2.5	9400
177	10	2.5	9800
178	10	2.5	10200
179	10	2.5	10600
180	10	2.5	11100
181	10	2.5	11600
182	10	2.5	12100
183	24	6	900
184	24	6	850
185	24	6	800
186	24	6	950
187	24	6	1000
188	24	6	1050
189	24	6	1100

Output data

No.	width(m)	depth(m)
163	0.5500	0.2750
164	0.5550	0.2775
165	0.5600	0.2800
166	0.5650	0.2825
167	0.5700	0.2850
168	0.5750	0.2875
169	0.5800	0.2900
170	0.5850	0.2925
171	0.5900	0.2950
172	0.5950	0.2975
173	0.6000	0.3000
174	0.6050	0.3025
175	0.6100	0.3050
176	0.6150	0.3075
177	0.6200	0.3100
178	0.6250	0.3125
179	0.6300	0.3150
180	0.6350	0.3175
181	0.6400	0.3200
182	0.6450	0.3225
183	0.6450	0.3225
184	0.6400	0.3200
185	0.6350	0.3175
186	0.6500	0.3250
187	0.6550	0.3275
188	0.6600	0.3300
189	0.6650	0.3325

Input data

No.	span(m)	rise(m)	load(N)
190	24	6	1150
191	24	6	1200

Output data

No.	width(m)	depth(m)
190	0.6700	0.3350
191	0.6750	0.3375

III. neural network

- Now optimize width and depth of cross-section using artificial neural network:
- ***Input data in ANN:***

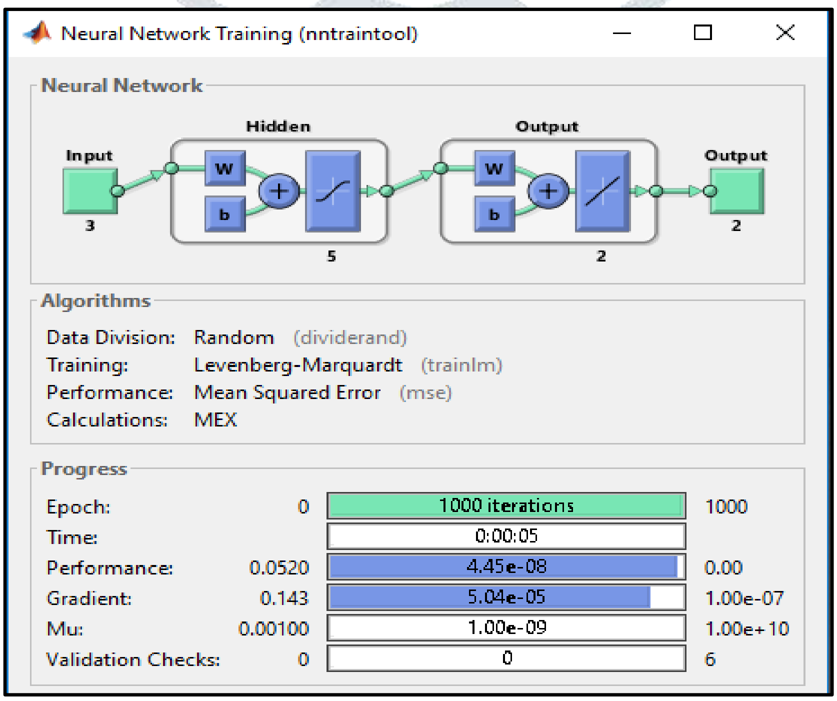
1) Load on arch:
2) Length of arch:
3) Rise of arch:

- ***Target data in ANN:***

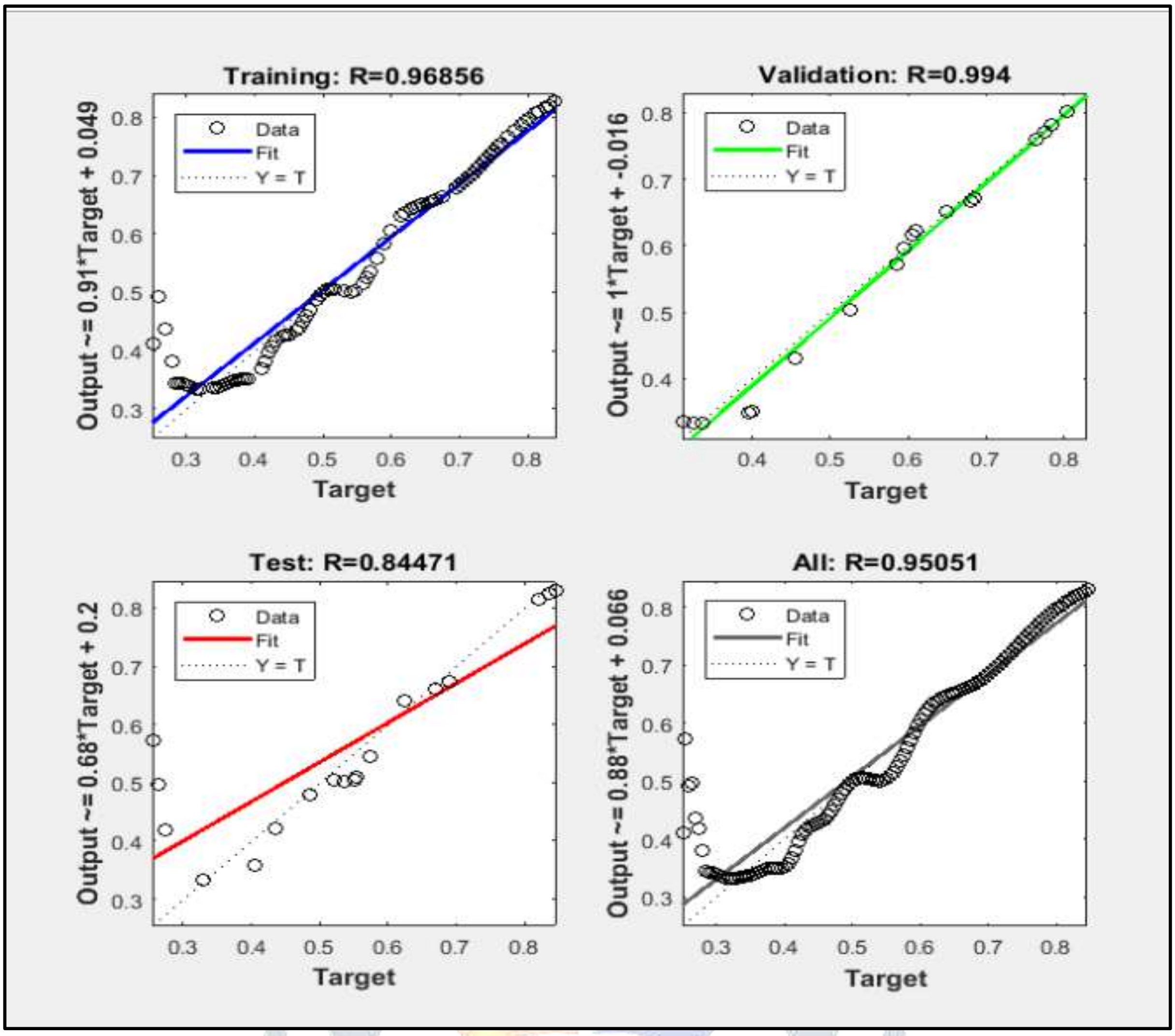
1) Optimized depth of cross section:
2) Optimized width of cross section:

- ***Training of neuron***

5 neuron hidden layer

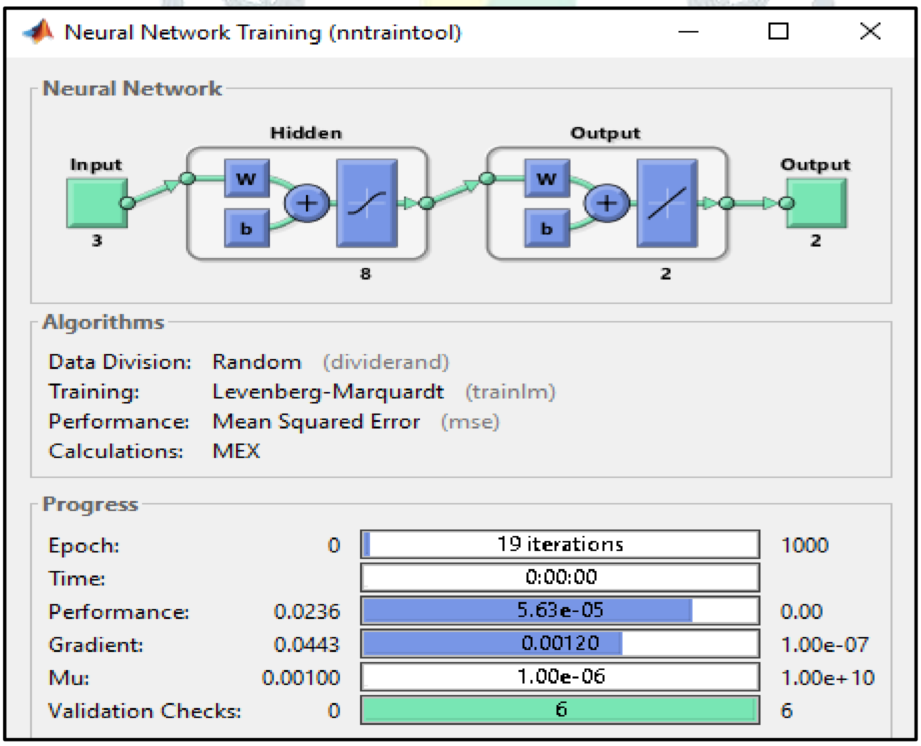


Neural network training

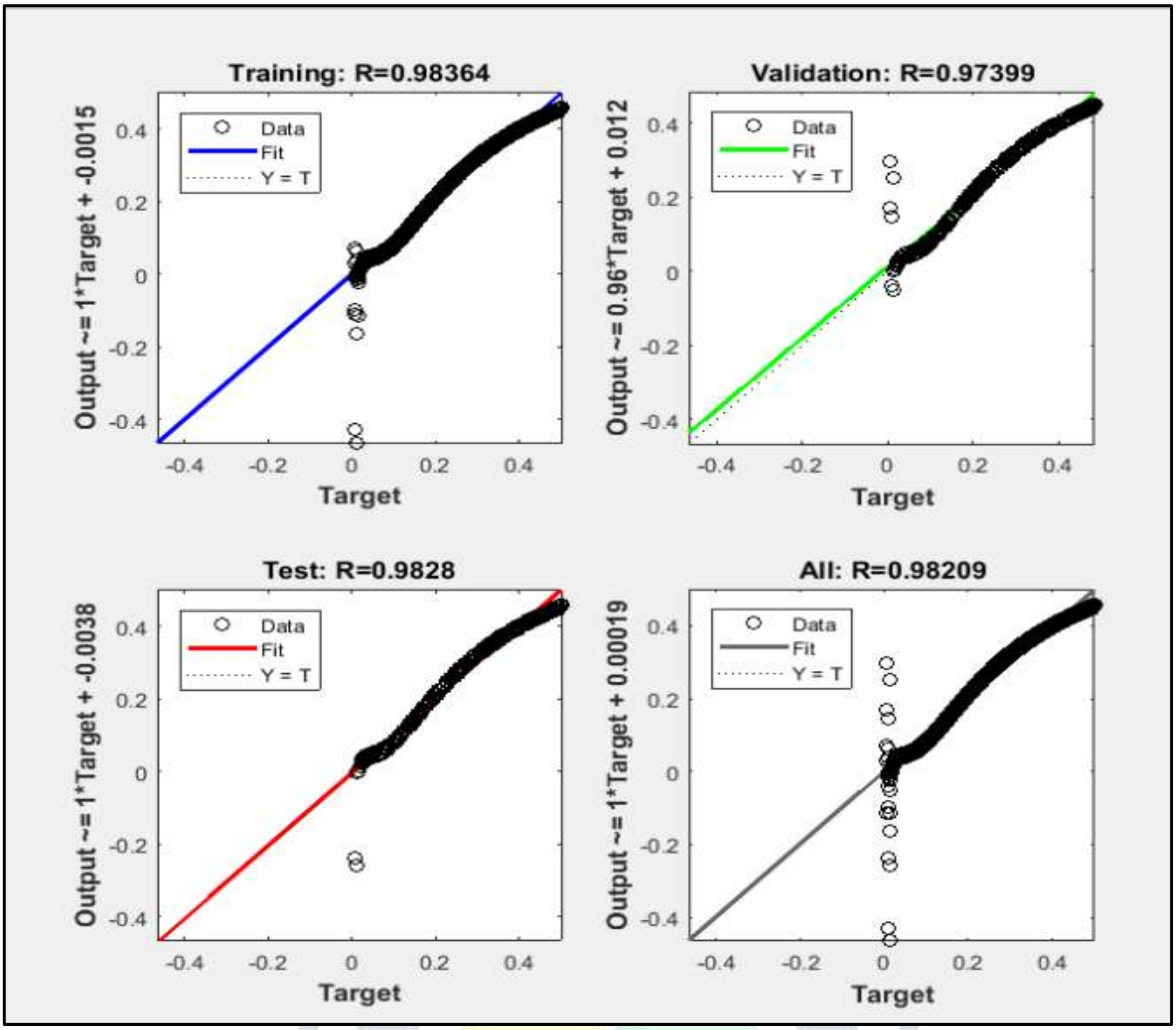


Neural network training Regression

- *8 neuron in hidden layer*

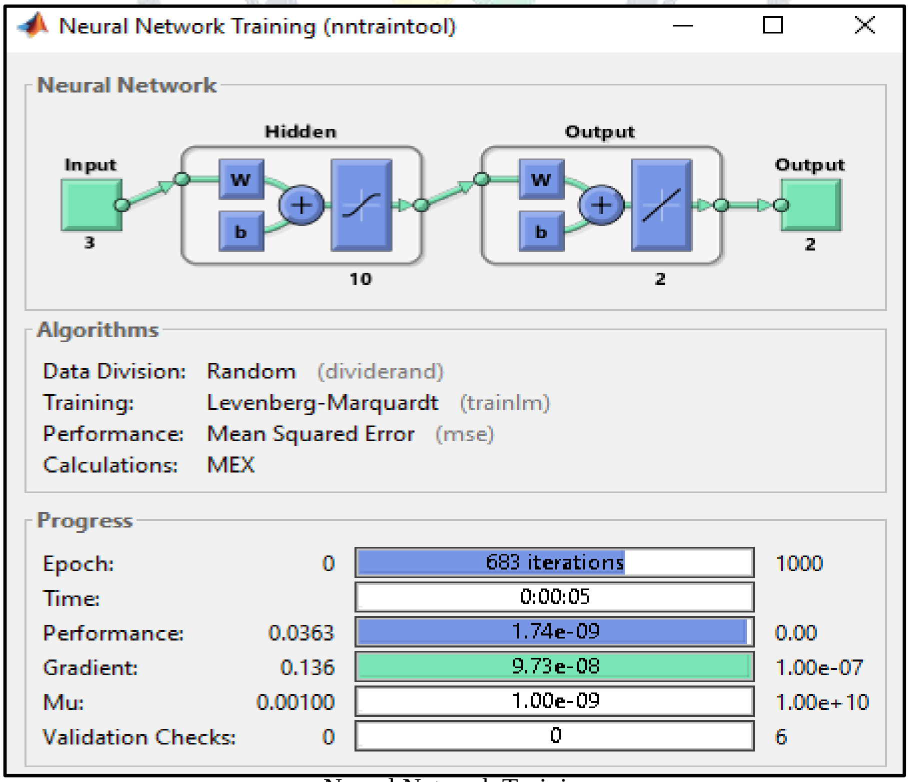


Neural Network Training

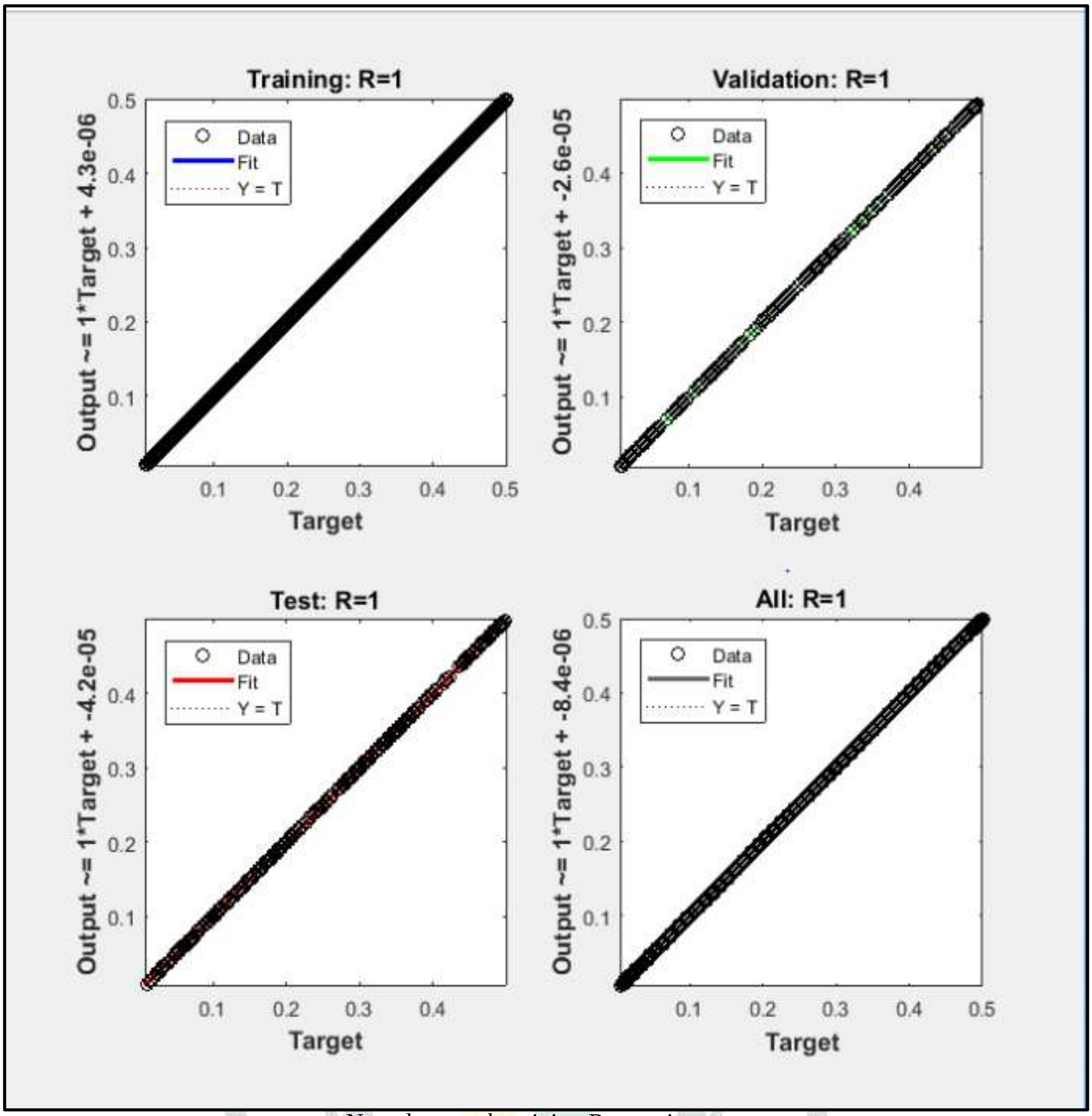


Neural network training Regression

- *10 neuron in hidden layer*



Neural Network Training



Neural network training Regression

IV. RESULT DISCUSSION

We used different neuron in hidden layer to improve the final outcome of the trained neural network. Here 5,8,10 neurons are used in hidden layer to reach the desired outcome for optimization. Result shows that 10 neuron in hidden layer gives the best optimization result compare to others.

Number of neuron in hidden layer	5	8	10	Exact (original)
Width(m)	0.2164	0.2059	0.2015	0.2015
Depth(m)	0.2057	0.1990	0.1965	0.1965

Table 1 COMPARISON BETWEEN DIFFERENT NEURON IN HIDDEN LAYER OF NN

V. CONCLUSION

Optimization of weight of two hinge steel arch is very difficult task to perform. But with use of neural network it can be done very efficiently. This optimization method is little time consuming while training of dataset in neural network, but once it trained after that we easily find the optimization result within fraction of time. In this paper we take two hinge steel parabolic arch with full span UDL and no horizontal force considered in this paper.

The conclusions achieved from present work are:

1. The efficiency of the Feed Forward Back-Propagation algorithm for training neural network and for optimization was examined and found to be good.
2. This seamless procedure reduces the post processing time and gives all the optimized area results for user verification in a single click of the button with well documented format.

In the present work, Optimization of two hinge steel arch is to perform. For that we use various variables like height to span ratio, load and width and depth of solid rectangular cross-section. For further study, horizontal force should be taken.

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