Design and Analysis of Air Assisted Stone Splitter Machine

Bharat J Kapadiya
Student
Department of Mechanical Engineering
Vadodara institute of Engineering, Vadodara, India

Abstract— On construction site it is required to cut large stone (slab) in small sizes having face cut, straight cut or angle cut. Splitting is a method for cutting the stone using a cutting blade to force the stone past an opposition cutting blade. Hydro-pneumatic system is used for cutting action. It converts small pneumatic pressure into large hydraulic pressure. This study is related to design analysis of stone splitter machine which will increase the efficiency and production of stone cutting. The design of the various components such as angle, channel, lead screw, blades, table, springs is carried out as per respective Indian Standards and analysis is done using finite element software. By using ANSYS software static analysis is carried out for various components. This machine will provide precise split-face cuts, straight cut or angle cut, on natural stones and slabs.

Key words: Stone Splitting, Hydro-Pneumatic System, ANSYS Software

I. INTRODUCTION

In old time man used chisels to split the stone. A man doesn't have to look at the chisel anymore when he dresses a block of sandstone. His hammerhead instinctively finds the butt of the chisel, sending a steady clink, clink, clink ringing around the building site. The stone chips fly about, as he transforms another ordinary rock into a hand-tooled flagstone. It wasn't always that easy to hit the Chisel butt dead center. It is very difficult to cut the stone in straight line and this method required more time and human energy.

The principle of splitting is when the lower blade is forced to move upward, both the upper and lower blade are tried to come together and contact stone being splitted. These blades are in one straight line as shown in fig 1. The blades penetrate to a certain portion of the stone thickness until its shear strength is reached, at which point the un-penetrated portion of the metal fractures, and the stone will split. The cutting blade will penetrate 3 to 9 mm of the stone, depending on thickness of stone being cut.

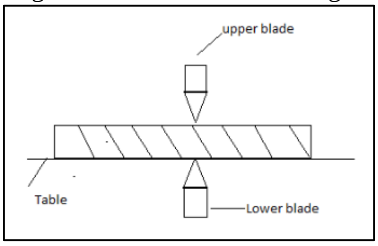

Fig. 1: Marble cutting

II. DESIGN AND MATERIAL SELECTION

A. Calculation for Force Required

Force required for cutting the stone are calculated below.

$\sigma = F/A$

For concrete block

σ = shear stress = 2 Mpa

A= shear area = $(210 \times 450)\ mm^2$

F = required force

So F= 181485 N.

So design force Fd =F × friction factor

$F_d = 181485 \times 1.03 = 186930$ N

Type of Stone	Shear strength (Mpa)	Maximum Height and width can be cut(mm × mm)
Concrete Masonry Block	2	210 × 450
Granite	14	30 ×450
Sandstone	8	52 ×450
Mosaic tile	2.68	155 ×450

Table 1: Maximum size of various stone can be cut by this stone splitting machine.

All components' material are selected based on IS 2062 (Grade B). Blade material is D2 (High Carbon High chromium, T160Cr12, IS: 3748-1978)

C	Si	Mn	Cr	Mo	V
1.55	0.3	0.4	11.8	0.8	0.8

Table 2: Composition of D2 Material

B. Selection of Column

There are four columns to be designed.

$$\sigma = F/A$$

Total force F_t= 186930 N, Impact factor = 1.3

Design force F= 186930 × 1.3 = 243009 N

Force on each column = 243009/4=60752.25N

Angle size = 40 × 40 × 6 (mm × mm × mm)

Cross sectional area A=447 mm^2

Yield stress = σ_y =250 N/mm^2

Required factor of safety = 1.75

σ= 60752.25/447

σ = 135.911 N/mm^2

$\sigma_y/\sigma = 1.83 > 1.75$

So safe dimensions for angle are 40 × 40 × 6(mm×mm×mm) and length of angle is 1260 mm.

C. Selection of Channel

There are two channels assembled with screw. Here Channel is considered as a fixed-fixed beam.

$$\sigma_b/y = M/I$$

Channel size=100 × 50 × 5 (mm × mm × mm)

Length of channel = 500 mm

Total force F= 186930 N

Force on each channel=93465 N

y = 100/2 = 50 mm

I = 192 cm^4

Bending Moment due Point load, $M_1 = PL/8$

M_1= 5841562.5 Nmm

Bending Moment due self-weight, Self-weight of channel is 9.56 kg/m

$M_2 = WL/24 = 976.9125$ Nmm

$M = M_1 + M_2 = 5842539.413$ Nmm

σ_b = 152:149N=mm^2 < 158.4 N/mm^2
So safe dimensions for channels are 100 × 50 × 5 (mm × mm ×mm) and channel length 500 mm.

D. Selection of Screw

Screw is designed based on Rankine's Formula for column. Here the end conditions for the screw is consider as a Fixed-Hinged.

$$Pc = \frac{\sigma c \times A}{1+C\left(\frac{L}{K}\right)2}$$

Nominal dia. d_1 = 50 mm
Minor dia. d_c = 42 mm
Area of cross section = 1385 mm^2
Pitch = 8 mm
Required length of screw l = 340 mm
Equivalent length of column L =l/2 = 240.41 mm
Least radius of gyration K = d_c /4=10.5 mm
Total load P = 186930 N
For mild steel, σ_c =320 N/mm^2. Rankines constant c = 1/7500
Pc = 414243.1297 N
Pc/P = 2.2160
So Pc/P > 2 (stability factor)
So safe dimensions for screw
Nominal dia. d_1 = 50 mm, Pitch = 8 mm
Area of cross section = 1385 mm^2

E. Selection of Nut for Screw

Nut and screw are made of cast iron and C45 respectively.
n = no. of threads in contact with nut
Assume n= 12
d_1 = major diameter of nut = 50.5 mm
dc = minor diameter of nut= 42 mm

$$p_b = \frac{W}{\frac{\pi}{4}[(d1)^2-(dc)^2]n}$$

Hence safe bearing pressure (p_b) = 25.23 N/mm^2.
h = height of nut = p × n
p = pitch = 8 mm
So h = 96 mm

F. Dimensions for Lower Blade Holder

Considering the lower blade holder and blade as a composite section. This composite section is considering as a fixed-fixed beam.
Taking...
b_1 =55 mm, d_1=70 mm, b_2 =17.5 mm, d_2=32.5 mm, b_3 = 20 mm, d_3 = 32.5 mm, b_4 =20 mm, d_4=15 mm.

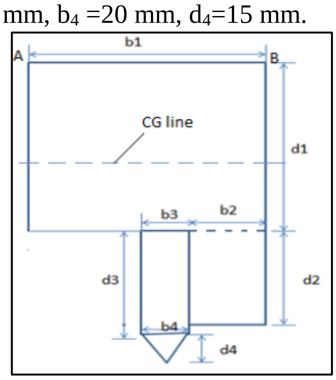

Fig. 2: Blade and blade holder assembly cross-section

For these value
I= 4191746.536 mm^4
CG(y)= 48.88262599 mm from top line AB

$$\sigma_b / y = M/I$$

Total force F= 186930 N
Total Length of blade holder and blade =480 mm

$$M_1 = FL/8$$

M =11215800 Nmm
σ_b = 115.208 N/mm2 < Permissible bending stress
So safe dimension for upper blade holder and blade are
b_1 =55 mm, d_1=70 mm, b_2 =17.5 mm, d_2 =32.5 mm, b_3 = 20 mm, d_3 = 32.5 mm, b_4 =20 mm, d_4=15 mm.

G. Dimensions for Upper Blade Holder

Considering the upper blade holder and blade as a composite section. This composite section is considering as a fixed-fixed beam.
Taking...
b_1 =55 mm, d_1=70 mm, b_2 =17.5 mm, d_2=32.5 mm, b_3 = 20 mm, d_3 = 32.5 mm, b_4 =20 mm, d_4=15 mm.
For this value
I= 4191746.536 mm^4
CG(y)= 48.88262599 mm from top line AB

$$\sigma_b / y = M/I$$

Total force F= 186930 N
Total Length of blade holder and blade =500 mm
M_1 = FL/8
M =11683125 Nmm
σ_b = 120.0093 N/mm^2 < Permissible bending stress
So safe dimension for upper blade holder and blade are
b_1 =55 mm, d_1=70 mm, b_2 =17.5 mm, d_2=32.5 mm, b_3 = 20 mm, d_3 = 32.5 mm, b_4 =20 mm, d_4=15 mm.

H. Design of Blade

Blade material is D2 (High Carbon High chromium, T160Cr12, IS: 3748-1978).
Tensile stress = 1736 Mpa
Factor of safety = 4
Permissible stress = 434 Mpa

$$\sigma = F/A$$

A = 430.71 mm^2
Total length of blade L=500 mm

$$430.71 = 500 \times x$$

x = nose radius = 0.86 mm

I. Design of Compression Spring

There are four spring to be designed. Total weight of the lower blade is 21.169 Kg (207.667 N).
Force on each spring W=52 N
Spring Index C = D/d =6
Where,
D = mean diameter of coil, d = diameter of wire
τ = 420 N/mm2
Wahl's stress factor

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C}$$

K = 1.2525
Maximum shear stress induced in the wire

$$\tau = K \times \frac{8WC}{\pi d^2}$$

d = 1.5396 mm For SWG 16, d =2 mm and D = 16 mm
Total deflection

$$\delta = \frac{8WC^3 n}{Gd}$$

Where.
δ = deflection of spring = 9 mm
n = no. of active turns

G = Modulus of rigidity= 80 kN/m^2
So, n = 17
For square and ground ends spring
n' = total no. of turns = n+2 = 19
Free Length of spring

$$Lf = n'd + \delta + 0.15\,\delta = 44.35 \text{ mm}$$

$$\text{Pitch} = \frac{Lf}{n'-1} = 2.46\text{mm}$$

J. *Design of Base*

Base is considered as a fixed-fixed beam.
Total force F= 186930 N
Total Length of base =500 mm

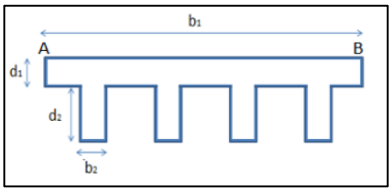

Fig. 3: Cross Section of Base.

Taking...

b_1 =250 mm, d_1=25 mm ,b_2=25 mm, d_2= 45 mm.

For this value...
I =2864855.88 mm^4
CG(y)= 27.15 mm from top line AB

$$M = FL/8$$

M =11683125 Nmm

$$\sigma_b / y = M/I$$

σ_b = 110.72 N/mm^2 < Permissible bending stress
So safe dimension for base are...

b_1 =250 mm, d_1=25 mm ,b_2=25 mm, d_2= 45 mm.

Maximum deflection of the base:

$$y_{max} = \frac{FL^3}{192EI}$$

E = 210 × 103 N/mm^2
I =2864855.88 mm^4
y_{max} = 0:202mm

K. *Design of Single Acting Hydraulic Cylinder*

Max. Force acting = 186930 N
p = 100 bar (1000 N/cm^2)

$$p = F/A$$

A= 186.93 cm^2

$$A = \frac{\pi}{4} D^2 \times p$$

So, D = 15.426 = 16cm
For single acting cylinder with 16 cm bore diameter having rod diameter is 14 cm.
Cylinder stroke (L) is 2 cm.
Volume of high pressure oil:

$$V = \frac{\pi}{4} D^2 \times L$$

V = 401.92 cm^3

III. MODELING OF STONE SPLITTER

3D model has been prepared for Stone Splitter Machine and its various components using Pro-e 4.

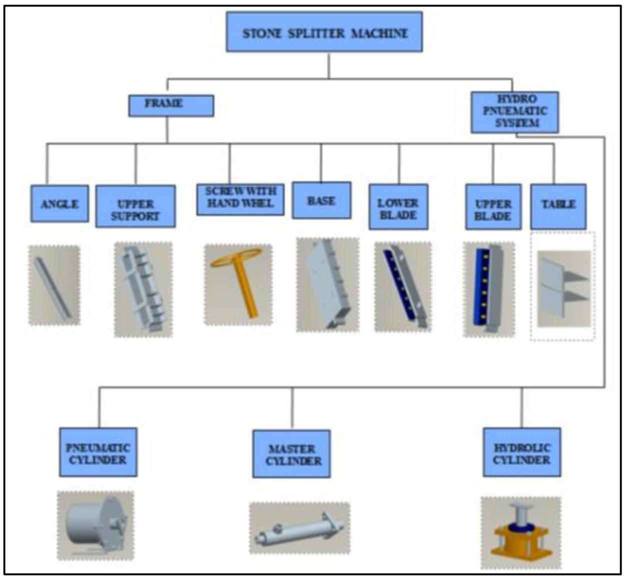

Fig. 4: Structural hierarchy of Air Assisted Stone Splitter machine

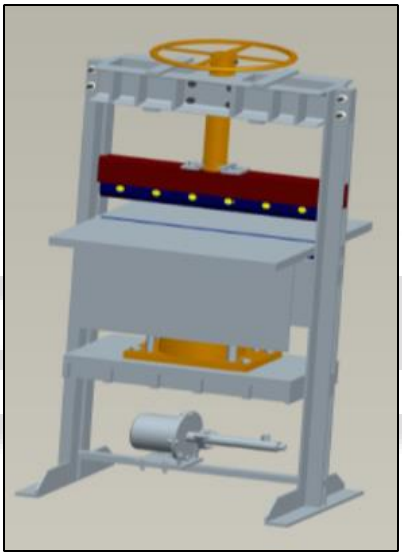

Fig. 5: 3D Model of Stone Splitter Machine

IV. FINITE ELEMENT ANALYSIS

A. *Finite Element Analysis of Base*

Base is fixed at the both ends i.e. there is no displacement at end face and force of 186930 N (compression force) has been applied in negative direction of Y axis on a face of 160 mm diameter circle.

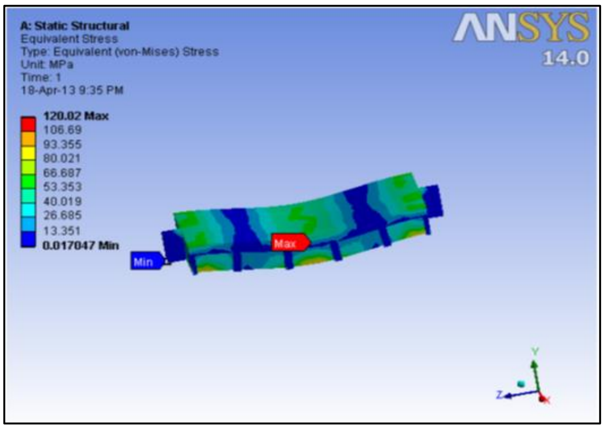

Fig. 6: Equivalent von-mises Stress

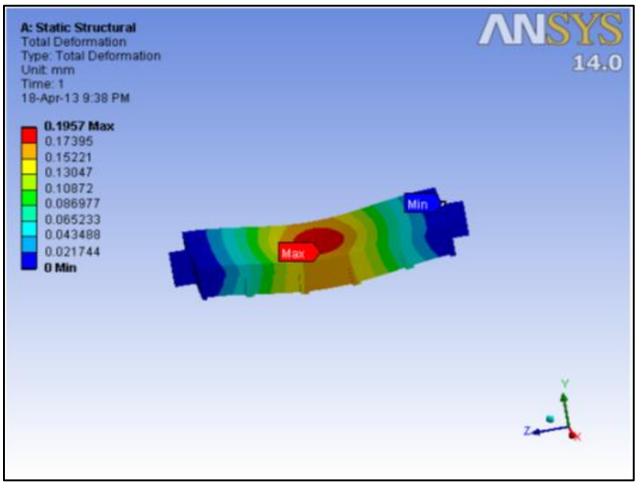

Fig. 7: Total Deformation

Parameter	Analytical	FEA
Equivalent von-misses stress	110.72 Mpa	120.02 Mpa
Deflection	0.2022 mm	0.1957 mm

Table 3: Comparison of analytical and FEA results

B. Finite Element Analysis of Blade And Blade Holder

Blade is fixed at the both ends i.e. there is no displacement at both end faces and force of 186930 N (compression force) has been applied in negative direction of Y axis on the edge of blade.

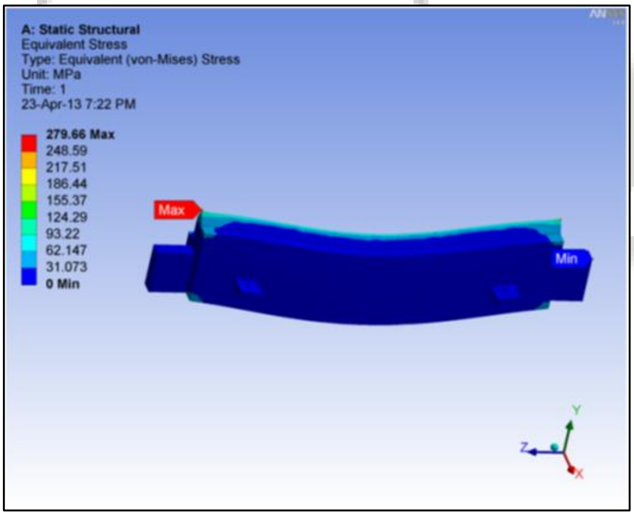

Fig. 8: Equivalent von-mises Stress on blade

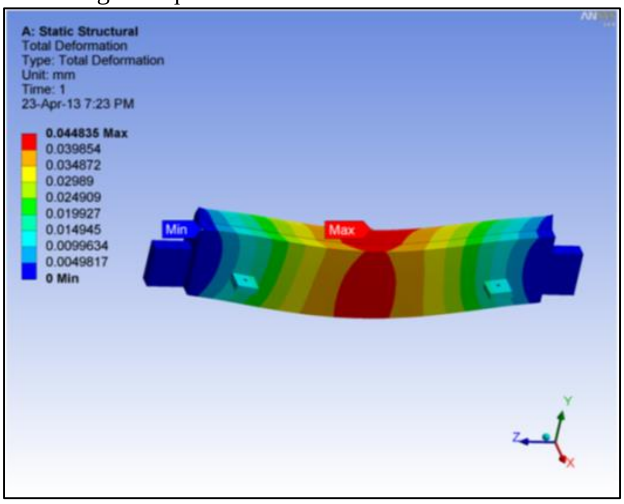

Fig. 9: Total Deformation

C. Finite Element Analysis of Screw

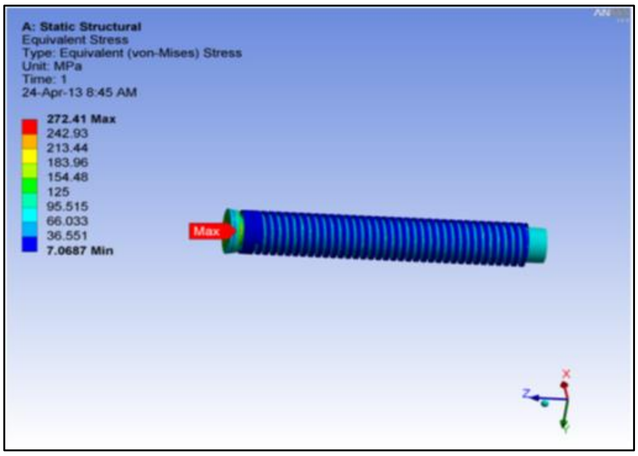

Fig. 10: Equivalent von-mises Stress

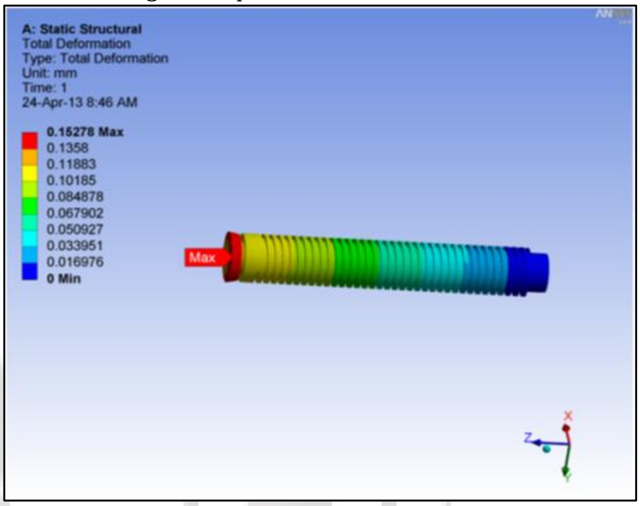

Fig. 11: Total Deformation

By going through the Finite element analysis, following results are obtain:

- Maximum Von Mises Stress = 272.41 Mpa
- Minimum Von Mises Stress = 7.0687 Mpa
- Maximum displacement=0.15278 mm
- Minimum displacement= 0 mm

EN8 material is selected for the screw. Through hardening is done on the screw and hardness is HRC 45.

D. Finite Element Analysis of Stone Splitter Machine

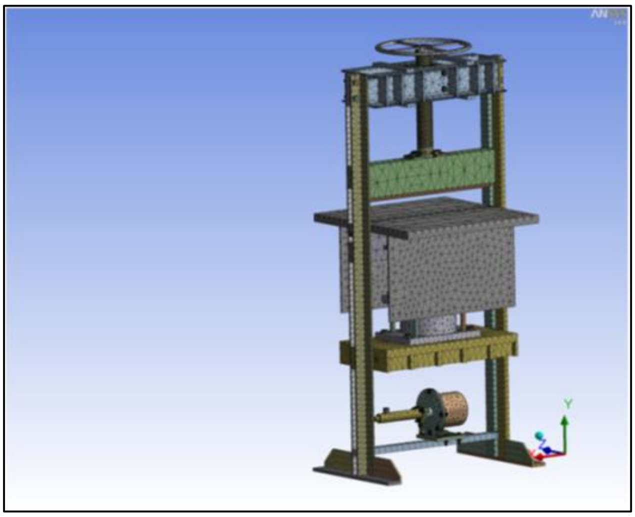
Fig. 12: Mesh model of stone splitter machine

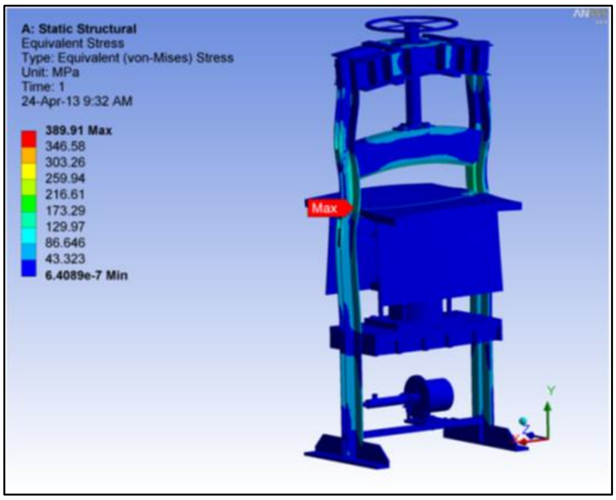

Fig. 13: Equivalent von-mises Stress

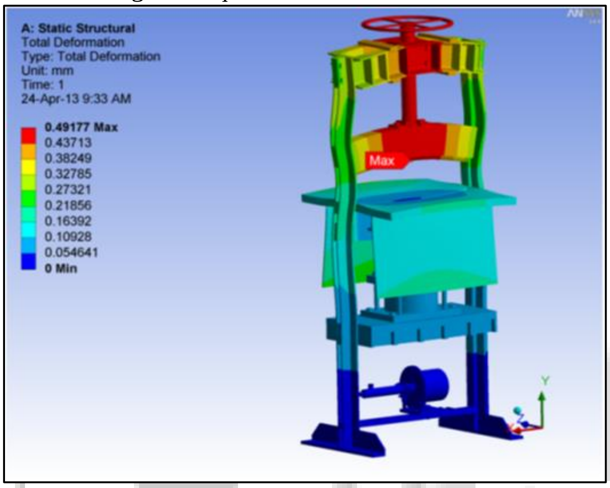

Fig. 14: Total Deformation

By going through the Finite element analysis, following results are obtain:

- Maximum Von Mises Stress = 389.91 Mpa
- Minimum Von Mises Stress = 0.64089 Mpa
- Maximum displacement=0.49177 mm
- Minimum displacement= 0 mm

Maximum stress 389.91 Mpa produced on the edge of blade.
Maximum stress produced on column is 140.25 Mpa.

$$\frac{240Mpa\ (yield\ stress)}{140.25Mpa\ (Max.produced\ stress)} = 1.71 > 1.5\ (FOS)$$

So design is safe.

V. Conclusion

3D model of stone splitter machine has been prepared which provides action of cutting. The proposed model also includes upper and lower blade, screw, table, base, upper support etc. All the components of stone splitter machine have been designed analytically and analyzed using FEA software ANSYS. It is found that results for total deformation and equivalent (von-mises) stresses values are well under permissible limits for these components.

References

[1] E K. Wongt, E Leung G, C. W. Chuen, Object-Oriented CAD for Practical Hydraulic System Design, Engng Applic. Artif. Intell. Vol. 9, No. 5, page 499-514, 1996.

[2] Vanam B. C. L., Rajyalakshmi M. and Inala , Static analysis of an isotropic rectangular plate using _nite element analysis (FEA) ,Journal of Mechanical Engineering Research Vol. 4, page 148-162, 2012.

[3] Junying Ge, The Design and Realization of Visual Education System for Bridge Structure Analysis, International Conference on Future Electrical Power and Energy Systems, page 1885-1890, 2012.

[4] M.O zakca, N. Taysi, F. Kolcu, Buckling analysis and shape optimization of elastic variable thickness circular and annular platesI. Finite element formulation, Engineering Structures 25, page 181-192, 2003.

[5] Hanifi Copur, Linear stone cutting tests with chisel tools for identify cation of cutting principles and predicting performance of chain saw machines, International Journal of Rock Mechanics and Mining Sciences 47 , page 104-120, 2010.

[6] C.K. Lee , G.J. Wu, Shear lag analysis by the adaptive finite element method 1 Analysis of simple plated structures, Thin-Walled Structures 38, page 285-309, 2000.

[7] Y.H. Guu, AFM surface imaging of AISI D2 tool steel machined by the EDM process, Applied Surface Science 242, page 245-250, 2005.

[8] IS 2062:1999. Code for steel for general structural purpose. Bureau Of Indian Standards, 5th revision.

[9] IS 3748 : 1990, Tool and Die Steels - Specification. Bureau Of Indian Standards

[10] PSG Design Data Book, PSG College of Technology, Page 6.4-6.8, 3rd edition,(2000).

[11] Hydraulic and Pneumatic controls, 2nd edition, R SRINIVASAN.