ISSN 2395-1621

Design, Development and Analysis of Auto-Gripping Jaw System for Concrete Pipe Handling

#1Mr. Pawar Dhanesh Manohar, #2Prof. Shah B. R.

1dhaneshpawar1989@gmail.com

2brshahpune@gmail.com

#1Department of Mechanical Engineering, Flora Institute of Technology, Pune, India

#2Department of Mechanical Engineering, Flora Institute of Technology, Pune, India

ABSTRACT

Material handling is the primary activity of every manufacturing and construction organization. It has been estimated that at least 15 to 25% of the cost of the product is attributable to material handling activities. Unlike many other operations, material handling adds to the cost of the product and not to its value. It is therefore important first to eliminate or at least minimize the need for material handling and second to minimize the cost of handling. Presently the concrete pipes are handled manually by use of crow bar and human worker which is time consuming, damages the pipes while transportation, unsafe work practice hence there is a need of concrete pipe suspender for fast and safe handling of concrete pipes. It is important to keep the pipes properly by lifting the concrete pipes. If the tool is prepared incorrectly, it may cause partial or total damage of the pipes. Worker safety conditions highlight the use of auto-gripping jaw for concrete pipe handling. Lifting and placement of the concrete pipes can be managed safely by the concrete pipe lifter equipped by jaws. Light weight, structure is simple, so the usage of it is very favourable. The concrete pipe can be kept lifted by turning the hanging force into clamping force.

Keywords— **safety, economy, auto gripping.**

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

I. INTRODUCTION

Lifting and handling of concrete pipe is a main task in most of the industrial and commercial purpose. Concrete pipes are commonly used for rainwater drainage and sewerage in most civil works. There are various techniques available for concrete pipe handling; also various types of grippers are used for this purpose.

A. Types of grip

The type of gripper jaws which is used generally has a major role in determining the force which is required in the functioning of a gripper. Friction grip rely totally on the force of the gripper to hold the part, the "squeeze" of the gripper does all of the work. The gripper jaws are generally of 2 types or are found in two styles

1) Friction grip
2) Encompassing grip

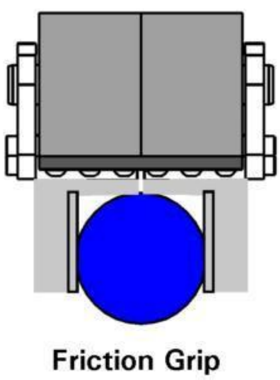

Fig.1 Friction Grip [1]

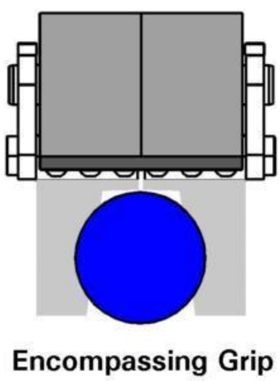

Fig.2 Encompassing Grip [1]

The friction force depends on two factors:

The materials that are in contact. The two materials and the nature of their surfaces. Rougher surfaces have higher coefficient of frictions but to slide apart. This makes sense in terms of a model in which friction is described as arising from chemical bonds between the atoms of the two surfaces at their points of contact: very flat surfaces allow more atoms to come in contact

The force pushing the two surfaces together. Pushing the surfaces together causes the more of the asperities to come together and increases the surface area in contact with each other.

B. Types of Gripper

Grippers are broadly classified as Simple mechanical gripper, pneumatic gripers, single surface gripper, magnetic gripper, vacuum gripper, clamping gripper, flexible gripper, hydraulic gripper and electrical grippers.

1) Mechanical Gripper:

A mechanical gripper uses mechanical fingers actuated by a mechanism to grasp an object. The fingers are the appendages of the gripper that actually make contact with the object either by physically constraining the object with the fingers or by retaining the object with the help of friction between the fingers. Most mechanical drives used in grippers are based on cam and followers or rack and pinion gears as force convertors.

2) Pneumatic Grippers:

The most widely used gripper is the pneumatically powered gripper; it is basically a cylinder that operates on compressed air. When the air is supplied, the gripper jaws will close on an object and firmly hold the object while some operation is performed, and when the air direction is changed, the gripper will release the object.

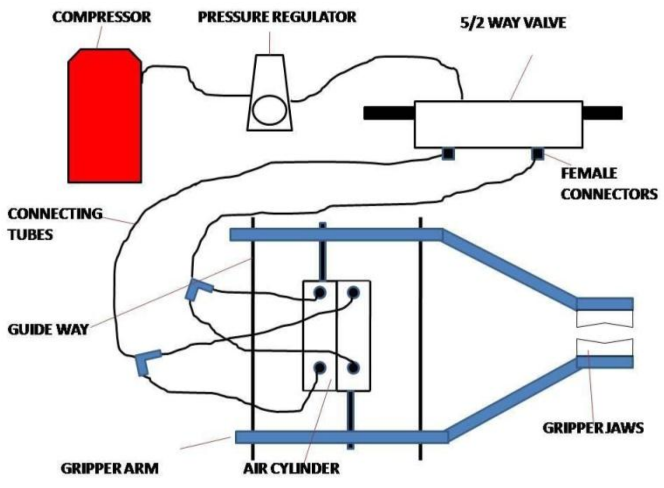

Fig.3 Pneumatic robotic gripper [1]

3) Single-Surface Grippers:

When only one surface of the component is available, the single-surface grippers' matches perfect for gripping this types of components. These types of grippers are useful for gripping light and heavy weight and flat components which are difficult to handle by other means. The gripper types that are included in single-surface grippers are magnetic, vacuum and adhesive grippers. These types of grippers are gripping the components by pulling force rather than a pushing force which is more common for robotic-grippers. The adhesive type of gripper will not be discussed here because they are usually used for picking up fabric or similar material.

4) Magnetic Grippers:

There are two types of magnetic grippers, permanent magnets and electro-magnets. The magnetic grippers are only suitable for picking up ferrous objects and are very easy to control for picking and releasing. A permanent-magnet is an object that is made from a magnetized material. The permanent magnets require a mechanism for releasing the gripped object as shown in figure.

5) Vacuum Grippers:

Vacuum-grippers become in suction cups, the suctions cups is made of rubber. The suction cups are connected through tubes with under pressure devices for picking up items and for releasing items air is pumped out into the suction cups. The under pressure can be created with the following devices:

1. Vacuum pumps
2. Ejectors
3. Suction bellows
4. Pneumatic cylinders

The vacuum grippers use suction cups (vacuum cups) as pick up devices. There are different types of suction cups and the cups are generally made of polyurethane or rubber and can be used at temperatures between -50 and 200°C. The suction cup can be categorized into four different types; universal suction cups, flat suction cups with bars, suction cups with bellow and depth suction cups as shown in figure 4

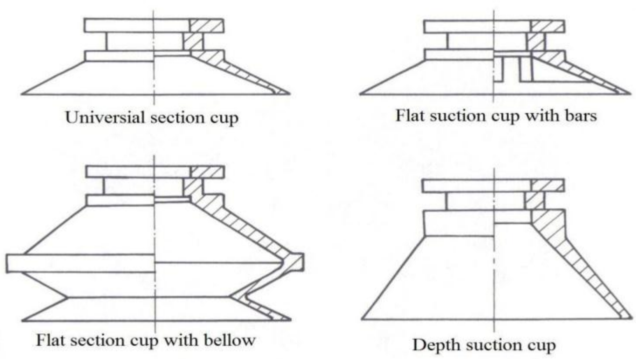

Fig.4 Vacuum Grippers [2]

The universal suction cups are used for flat or slightly arched surfaces. Universal suction cups are one of the cheapest suction cups in the market but there are several disadvantages with this type of suction cups. When the under pressure is too high, the suction cup decreases a lot which leads to a greater wear. The flat suction cups with bars are suitable for flat or flexible items that need assistance when lifted. These types of suction cups provides a small movement under load and maintains the area that the under pressure is acting on, this reduces the wear of the flat suction cup with bars, this leads to a faster and safer movement. Suction cups with bellows are usually used for curved surfaces, for example when separation is needed or when a smaller item is being gripped and needs a shorter movement.

This type of suction cups can be used in several areas but they allow a lot of movement at gripping and low stability with small under pressure. The depth suction cup can be used for surfaces that are very irregular and curved or when an item needs to be lifted over an edge. Items with rough surfaces (surface roughness ≤ 5 μm for some types of suction cups) or items .That is made of porous material will have difficulty with vacuum grippers. An item with holes, slots and gaps on the surfaces is not recommended to be handled with vacuum grippers. The air in the suction is sucked out with one of the techniques described earlier, if the material is porous or has holes on its surface; it will be difficult to suck out the air. In such cases the leakage of air can be reduced if smaller suction cups are used. Figure 5 shows different types of suction cups.

Fig.5 Different types of suction cups [2]

6) Clamping Grippers:

Two-jaw grippers and three jaw-grippers are related to clamping grippers and occur frequently in manufacturing factories. Clamping grippers can be designed relatively simple; therefore the price can be cheaper. Clamping grippers straps the object that is being picked up by applying pressure internally or externally to more than one of the object surfaces. This type of grippers is driven pneumatic or hydraulic. For smaller object that doesn't need big forces the pneumatic technique is used and for heavy object that requires big forces the hydraulic technique is used. The pneumatic technique is more common because of the low price, low weight, and ease of use.

7) Two and Three Jaw Grippers:

Two-jaw gripper is the simplest type of jaw grippers. Two-jaw gripper consists with two gripping fingers that apply pressure externally or internally on the object depending on the jaw design. Depending on shape and size of the object the jaw-fingers can be designed Different for an accurately and securely movement. The two-jaw grippers can be used for large and small objects. The mechanics for the movement of the jaw-fingers can include linkage, cams, pinion and actuators, and as described earlier pneumatic and hydraulic cylinders. When the shapes get more complex than the two-jaw gripper can handle, the three-jaw gripper is option for objects with more complex shapes. The three-jaw grippers consist with three gripping fingers and apply pressure like the two-jaw grippers. The three-jaw grippers are more complex and therefore more expensive than two-jaw grippers. Figure 6 presents two and three jaw grippers. [2]

Fig.6 Two and Three-jaw grippers [2]

8) Flexible Grippers:

Flexible grippers consist with several linkages on each finger and two or several fingers. Each linkage have normally an individual steering, this types of grippers can be compared with the human hand. The flexible grippers are indented to handle a number of different items. A variety of these grippers have been produced by various researches. Multi fingered grippers that are related to flexible grippers are like a human hand lookalike gripper with more than two fingers. This type of gripper can grasp object with very complex shapes because of the linkages in the fingers that can be controlled individually. The fingers in these types of grippers can be simulated after the shape of the object that will be grasped. Other types of flexible grippers are soft grippers, bladder grippers and adjustable-jaw grippers. Figure
6 shows a multi fingered gripper.[2]

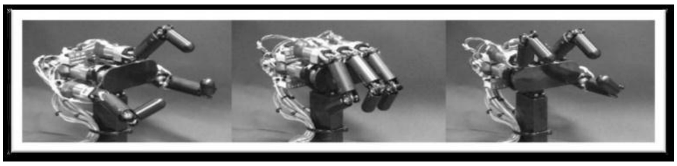

Fig.7 A multi fingered gripper [2]

9) Hydraulic Gripper:

Most hydraulic grippers are designed for hydraulic systems where the cylinder diameter is made with less surface area and this operates on compressed fluid. In general, hydraulic and pneumatic grippers have the same basic actuation principle. They include direct acting piston cylinder design. One single motor powers the hydraulic fluid that supplies energy to multiple devices.

10) Electrical Grippers:

In electrical grippers, the primary input power supply is the electric energy from the electric distribution system. Electrical motor drives the gripping mechanism. Power supply is widely available with high power conversion efficiency. It has high accuracy and repeatability.

11) Angular Grippers:

Angular grippers are simple in design. It open and close around a central pivot point, moving in an arcing motion. Angular grippers are used when there is a need to get the tooling out of the way. It has several disadvantages including jaws are not parallel and changing centre of grasp while closing.

12) Parallel Jaw Gripper:

It moves in a motion parallel in relation to the gripper's body. An advantage of parallel type gripper is that the centre of the jaws does not move perpendicular to the axis of motion. Thus, once the gripper is centered on the object, it remains centered while the jaws close. Most of the time, parallel grippers are self centering grippers.

II. LITERATURE REVIEW

In field of Industrial Robotics and gripper design and analysis, many research works have been done by many researchers. Some of the distinguished ones which are relevant and carry basic information for this paper have been highlighted briefly.

Khadeeruddin et al. [1] presented the design and analysis of jaw actuated pneumatic gripper. The force and torque for the gripper have been calculated for different set of conditions. CAD Modelling is carried out on Solid works and analysis is carried out on ANSYS tool. Authors concluded that the pneumatic gripper makes pick and drop work easier and much faster than the conventional techniques. Such Pneumatic grippers are generally cost-effective because air hoses, valves, and other pneumatic devices are easy to maintain.

Fantoni et al. [3] developed an expert system for the selection of robot grippers. The system is based on a set of rules that can be easily updated. This turns into an increase in terms of effectiveness and efficiency. The system adequately defined the grasping principles capable to perform the required operation together with some fundamental recommendations. However, finding a way to evaluate every possibility, including the variability of the objects, still requires further study and work that could be done iteratively.

Tilli et al. [4] investigated the concept, the design, the selection and the test of a gripper for the handling of heavy and deformable materials as coffee sacks. Authors proposed a set of new devices and developed some prototypes. The features of the grippers and their grasping reliability on jute coffee sacks have been evaluated and scored through Multiple Attribute Decision Making MADM criteria in order to identify the best gripping tools for the handling of non-rigid materials.Being at the prototype phase, such grippers can be modified, in order to improve their features, especially the ones with bad votes. Authors selected one of the gripper with the highest scores to fully designed and tested. The concept resulted to be simple and reliable, the design satisfies all the requirements and both the force exerted and the actuation time meets the unloading requirements. Unfortunately at the present, manufacturing issues and the lack of suitable miniaturized components prevent an extreme downscaling process of the gripper.

Zaki et al. [5] designed and implemented a robotic gripper with electric actuation using brushless dc servo motor. Authors proposed new system controller using fuzzy logic based on empirical investigation of the human hand skills. The gripper control was achieved through two control schemes. System modelling had been introduced using ANFIS approach. The two proposed controllers for the gripper system based on different feedback variables are developed and simulation results are presented. The advantage of using one fixed finger and the other movable appears in the need for only one motor for actuation and also easier control when avoiding complicated mechanical system.

Kostal et al.[6] explained about the robotized assembly system, and briefly classified the end effectors required for various applications. The end effectors design must take head to lot of special requests apart a common mechanical engineering parts. Trends in this area is a continuous accuracy increasing and develop a new methods to gripper design.

Kim and Bernold [2007] [7] compared the two innovative technologies for safe pipe installation. In that authors discussed about the conventional method of pipe installing and Stewart Platform based Pipe Manipulator (SPPM). The Stewart Platform, which provides 6-DOF and it was directly connected to the boom instead of the bucket. The SPPM was built with sufficient DOF to manipulate a pipe accurately but its motion control interface is hard for operators to learn. The conventional pipe-laying method consists of a set of repetitive tasks which requires 4-5 workers. The quality of the finished work is influenced by the experience and skill of the operator of the backhoe excavator, pipe installers and helpers. Recently, increasing labor costs have contributed to the increase in the cost of pipe installation. Authors compared the two approaches and technical solutions. It highlights some of the lessons learned during the field tests, which considered the different pipe installation methods commonly used.

Kim et al. [2009] [8] carried out work on a performance evaluation of a Stewart platform based Hume concrete pipe manipulator (HCPM).Authors identified the problems in conventional process of Hume concrete pipe laying work. HCPM was developed to improve the safety, quality, and productivity of conventional Hume concrete pipe laying work. Authors developed a model for performance evaluation of the HCPM, and then utilize the model to analyze the HCPM's overall work performance. It was found that the productivity of the HCPM method compared to that of the conventional method is found to be 165%. This means that the automated method provides a 65% improvement in productivity. It was also anticipated that this productivity improvement will be greater if it used the skilled operator or the HCPM upgraded as a commercial unit. The economic feasibility of the HCPM method was evaluated by using benefit/cost ratio, rate of return (ROR), and breakeven point analysis methods. The economic analysis results of the HCPM method showed that construction cost savings of 33%.

Rad and Kalivitis [2011] [9] described various stages of design and development of a low cost sensor-based gripper. Grippers are useful for applying right gripping forces to different objects. The gripper was also equipped with range sensors in order to avoid collisions of the gripper with objects. It was a fully functional automated pick and place gripper which can be used in many industrial applications. Yet it can also be altered or further developed in order to suit a larger number of industrial activities.

Alexander et al. [2003] [10] invented concrete pipe lifting jaw. Authors proposed design of jaw system for multiple size pipes. The main objective of this research was to provide pipe lifting apparatus and method suitable for use on various ranges of concrete pipe sizes.

By all this literature survey I concluded that, there are two basic systems available for concrete pipe handling i.e. with the use of crow bar and human worker and second is fully automated system. In US and Korea, availability of worker is less; hence they are using fully automated gripping system. But in our country workers are easily available. Hence it needs to concentrate on cost and worker's safety. Therefore it needs to be design semi-automated system which reduces the cost of equipment and improves the worker safety.

III. DESIGN OF AUTO GRIPPING JAW SYSTEM

Concrete pipes are available in 150 mm diameter to 1500 mm diameter, also in variety of thickness. For drainage systems and irrigation systems 150 mm to 305 mm inner diameter with 40 mm thickness are mostly use. So I designed the Auto Gripping Jaw system for the same with the range of 100 kg to 250 kg weight of pipe.

A. Selection of material

The Jaw sets are the important parts of systems. Its material should bear the load. These parts are difficult to manufacture and are more costly than other parts. So I select higher factor of safety for the jaw. I select Low carbon steel with S_{yt}=240 N/mm^2. This material is easily available in market. It has good strength and low cost. It has good machining ability, weld ability.

B. Design of Jaw set

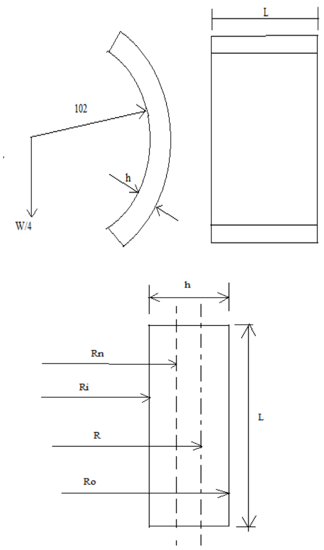

Fig.8 Force acting on jaw and its cross-section

Ri=102 mm, Assume h= 10 mm

Ro=112 mm, Wt=150 Kg

Bending Moment due to weight M=W/4*102=37523.25 Nmm

Bending Stress $\sigma_b = \frac{Mh}{AeRi}$

A= 10 L mm^2, e= R-Rn, R= Ri + h/2, $Rn = \frac{h}{\ln(\frac{Ro}{Ri})}$

Allowable bending stress = $\sigma_{allowable} = \frac{Syt}{Fos}$ = 240/5

L= 95.8 mm ≈ 100 mm, h= 10mm.

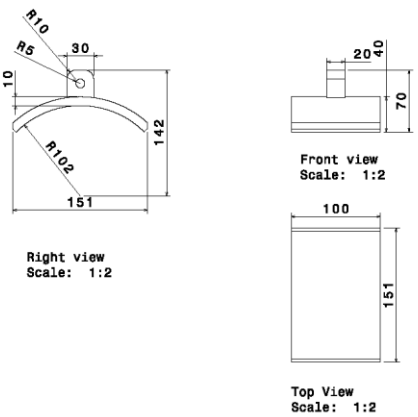

Fig.9 Manufacturing drawing of Jaw Set

C. Design of pin

Weight of Pipe W= 1471.5 N

$$\frac{0.5\,Syt}{FOS} = \frac{W/4}{2(\frac{\pi}{4}d^2)}$$

Considering FOS = 4 and Syt = 240 Mpa

d = 2.79 mm

but for standardization I select pin diameter d= 10 mm.

Crushing failure of pin:

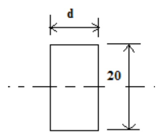

Fig.10 Cross-section of pin

Compressive Stress on Pin $\sigma_c = \frac{W/4}{dp*20}$ = 3.065 MPa

Allowable Compressive Stress = $\frac{2\,Syt}{FOS}$ = 120 MPa

Compressive Stress is less than allowable Compressive Stress hence Pin is safe against crushing failure.

D. Design of rotating arm

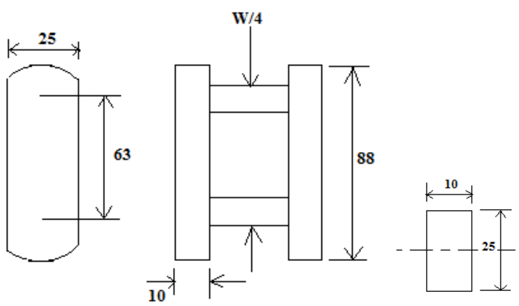

Fig.11 Force acting on rotating arm and its cross-section

1) Check for compression:

Compressive stress = $\frac{W/4}{10*25}$ = 1.47 MPa
Allowable compressive stress = 120 Mpa
Compressive stress ‹ Allowable compressive stress, hence safe.

2) Check for bending:
Bending stress = $\sigma_b = \frac{My}{I}$
Bending Moment M = W/8* 63
y= 12.5
I = $\frac{10*12.5^3}{12}$
σ_b = 88.99 MPa
Allowable Bending stress = Syt / FOS = 240 / 2.5 = 96 MPa
Since σ_b ‹ $\sigma_{allowable}$ Design is safe.

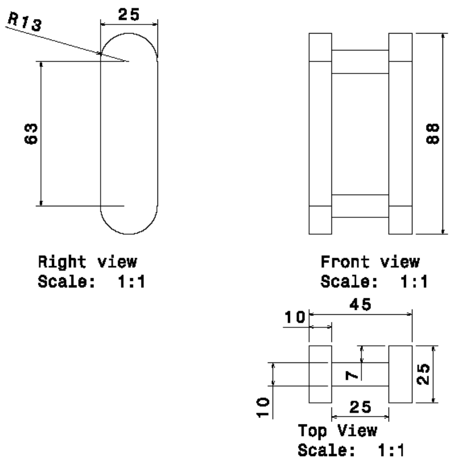

Fig.12 Manufacturing drawing of Rotating Arm.

E. Design of Frame

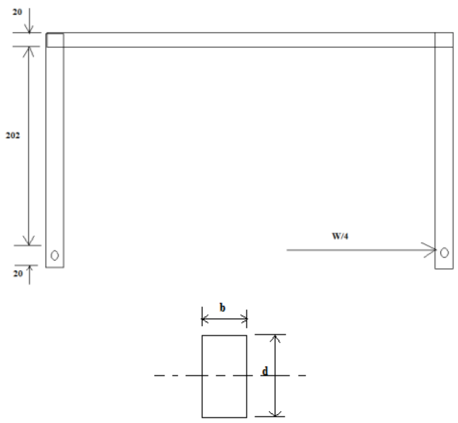

Fig.13 Force acting on frame and its cross-section
Bending Moment = M = W/4 * 202 = 74310.75 Nmm.
y = d/2,
I= $\frac{b*d^3}{12}$ Assume d= 2 b
$\sigma_{allowable}$ = 240/2 = 120 MPa
Bending stress = $\sigma_b = \frac{My}{I}$
d = 19.51 mm ≈ 20 mm
b = 10 mm.

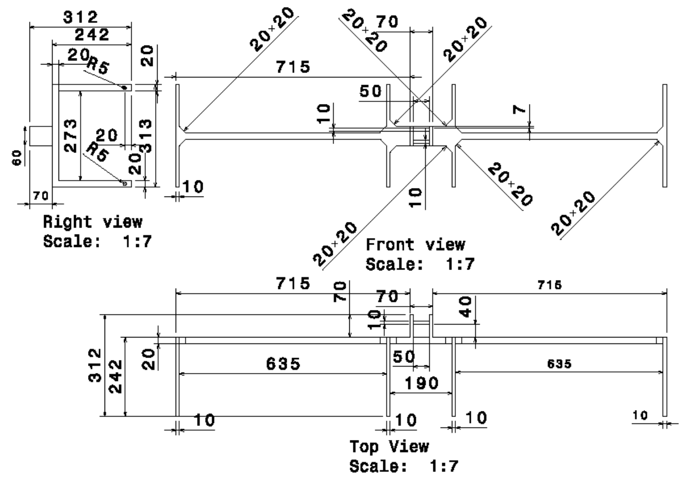

Fig.13 Manufacturing drawing of Supporting Frame.

F. Design of torsion rod
Torsion equation = $\frac{\tau}{r} = \frac{T}{J}$
J = Polar Moment of inertia = $\frac{\pi}{32}d^4$,
Torque = T= W/2 * 5 = 3678.75 Nmm
Allowable Shear Stress = τ = 0.5 Syt / FOS
d= 7.765 mm ≈ 10 mm.

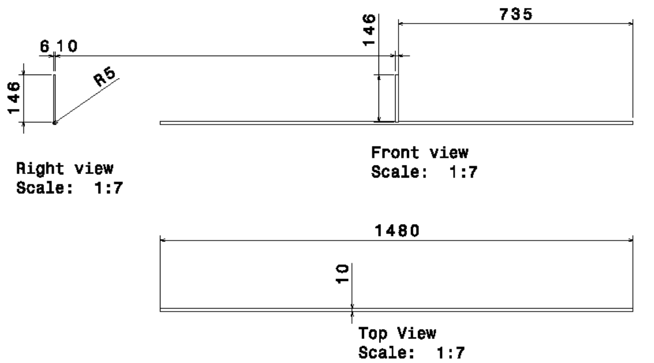

Fig.14 Manufacturing drawing of Torsion rod.

G. Selection of Rope
Load on Rope Ft = W/2 = 735.75 N
FOS for cranes and hoist for general purpose = 5
Fatigue strength = Ft * 5 = 3678.75 N
Permissible bearing pressure Pb for 6*7 type of rope Pb = 10.1 MPa
Now, $\frac{Pb*D*dr}{2} = Ft * FOS$
D= Diameter of sleeve = 42 *dr
dr= Diameter of wire rope.
dr= 4.16 mm.
Selecting Standard diameter dr= 8 mm

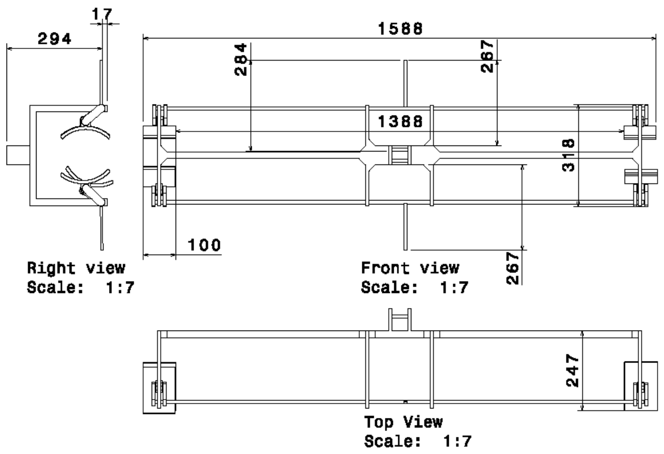

Fig.15 Assembly of Auto-Gripping Jaw System

IV. FINITE ELEMENT ANALYSIS OF SYSTEM

Static Structural Analysis of horizontal pipe lifting jaw:

A general-purpose commercial finite element code, HyperMesh and Ansys is applied to conduct the static simulations. The FEA model of horizontal pipe lifting jaw in this study is constructed based on the geometry. A full 3-D solid model is constructed for the static test simulation. The schematic of an FEA model used in static test simulations is shown in figure 16.

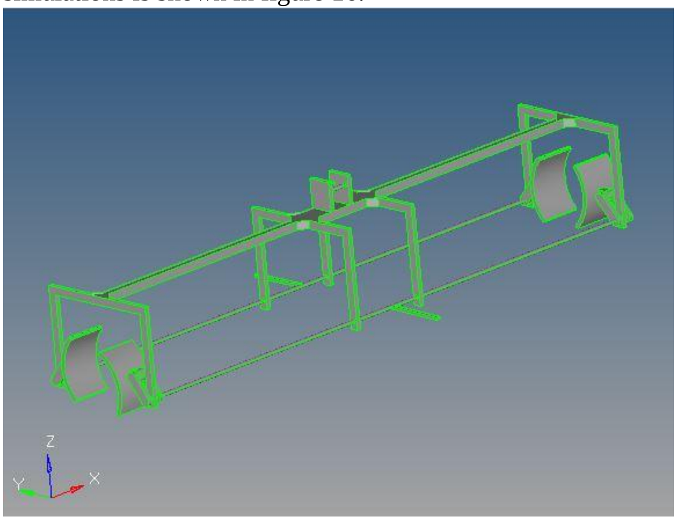
Fig.16 Geometry of horizontal pipe lifting jaw

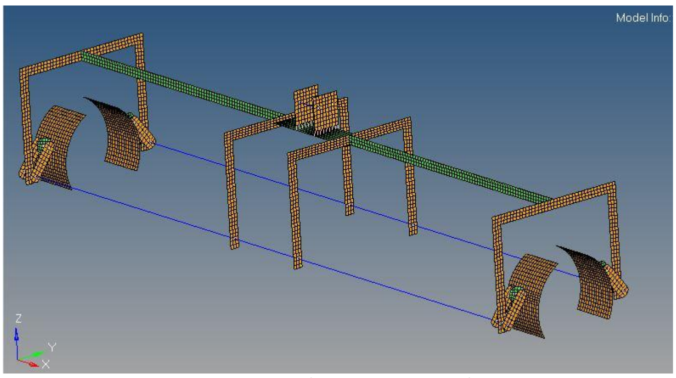
Fig.17 Meshed model of horizontal pipe lifting jaw

The cad model in IGES format is imported in HyperMesh for the preparation of FE model. Then geometry cleanup was done by using options like 'geom. cleanup' and 'defeature' to modify the geometry data and prepare it for meshing operation. This process involves deletion of curvature of very small radius (less than 2mm) which has less structural significance. Mixed type of elements which contains quadrilateral as well as triangular elements, have been used in analysis. The sensitive regions have been re-meshed by manually considering the shape and size of the parts. Quality check of all the elements has been performed and mesh is accordingly optimized as shown in figure 17.

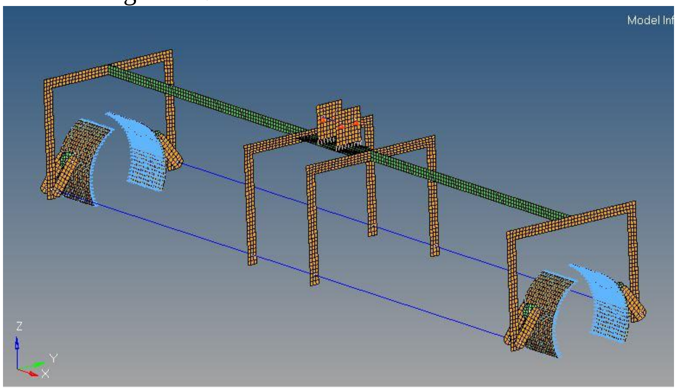
Fig.18 Rigids at mounting locations

The lifting jaw assembly is meshed with shell elements basically, because the components of the assembly are considered as 2D as the third dimension is negligibly small as compared the other two.

Some default quality criteria are available in HyperMesh, including following:

a. Min. Side Length: Length of the smallest side of an element.
b. Max. Side Length: Length of the largest side of the element.
c. Aspect Ratio: Ratio of longest side to the shortest side of element.
d. Warpage: Deviation of an element or element face from being planar.
e. Min/Max Quad Internal Angle: The minimum/maximum angle of a quad element.
f. Min/Max Tria Internal Angle: The minimum/maximum angle of triangle element.
g. Percentage of Triangular Elements: The ratio of the number of triangular element to the total number of elements.

For quality criterion was prepared as listed in the below and it is maintained throughout the meshing process.

Quality Parameter Allowable

1. Maximum Aspect Ratio 5
2. Maximum Warpage Angle 15
3. Minimum Quads Internal Angle 45
4. Maximum Quads Internal Angle 135
5. Minimum Tria Internal Angle 15
6. Maximum Tria Internal Angle 120
7. Percentage of Triangular Elements 5

Loading and Boundary Condition:

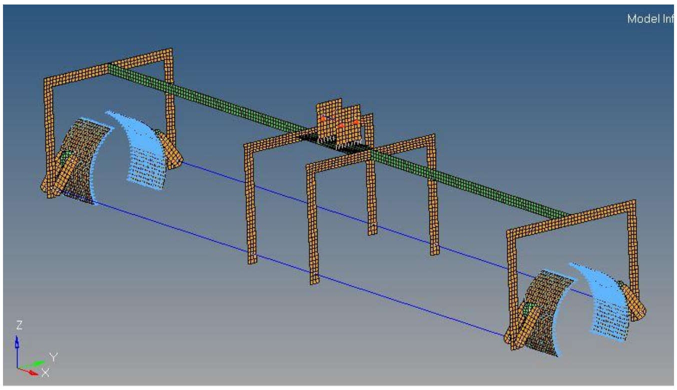

Fig.19 Constraint at the mounting location

Rigids are being formulated for the ease of application of boundary conditions. The rigids are concentrated on an independent node on which the forces are to be applied as shown in figure 18. The boundary conditions include gripping force on jaw and the constraints are put on the mounting areas arresting all degrees of freedom as shown in figure 19.

Fig.20 Displacement Plot

From above plot figure 20, the maximum displacement value for horizontal pipe lifting jaw is 0.2 mm which is very less hence the design for horizontal pipe lifting jaw is safe.

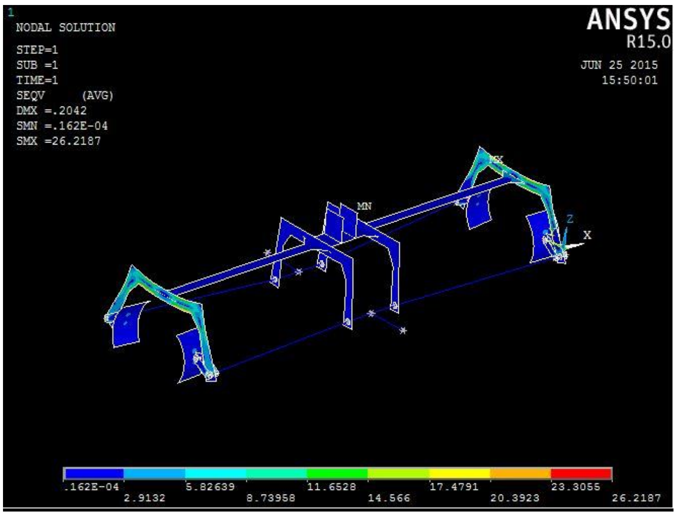

Fig.21 Stress Plot

From above plot, figure 21, the maximum stress value for horizontal pipe lifting jaw is 26.21 MPa which is less than yield strength hence the design is safe.

In order to assure the mesh model is accurate enough, a mesh convergence has been studied to ensure that the displacement of the model is convergent. In figure 22 the abscissa represents the element number of model. It shows that the maximum displacement response at the contact point is almost convergent for mesh size 8 mm. In this study, the simulation model for horizontal lifting jaw is meshed with size 8 mm. The model is meshed with about 5793 nodes and 4940 elements.

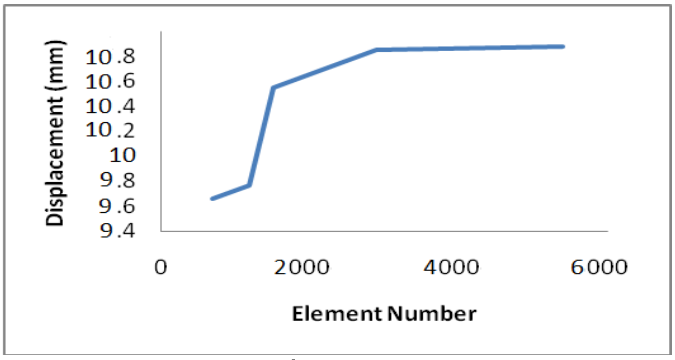

Fig. 22 Mesh convergence

V. CONCLUSIONS

Authors studied various types of concrete pipe installation methods i.e. conventional and automatic and compared the various advantages and disadvantages of all types of pipe handling methods. From that it is concluded that, both the systems i.e. conventional and automated, have some advantages as well as disadvantages. So it is required to find the intermediate solution between these two. So designed the new Auto-gripping Jaw System for concrete pipe handling.

The concrete pipe lifter system comprises of two jaws coupled by chain mechanism to the crane hook. The pull in the chain mechanism is converted into clamping force between jaws by the clamping system. Lifting and placement of the concrete pipes can be managed safely by the concrete pipe lifter equipped by jaws. Light weight, structure is simple, so the usage of it is very favorable.

ACKNOWLEDGMENT

Authors would like to express my special thanks to our principal Dr. Padalkar Atul, who helped in preparing a paper to publish in IJSRD.

REFERENCES

[1] Mohammed.Khadeeruddin, T.V.S.R.K Prasad, Raffi Mohammed "Design & Analysis of a Two-jaw parallel Pneumatic Gripper", International Journal of Computational Engineering Research, Vol. 03 Issue. 12

[2] Karokh Mohammed, ISRN UTH-INGUTB-EX-M2010/24-SE Examensarbete 15 hp November 2010 "Design of a gripper tool for robotic picking and placing"

[3] Gualtiero Fantoni, Saverio Capiferri Jacopo Tilli, "Method for supporting the selection of robot grippers " 24th CIRP Design Conference, Procedia CIRP 21 (2014) 330 – 335.

[4] Jacopo Tillia, Alberto Brandob, Gualtiero Fantonia, “Gripping device for heavy and deformable materials handling: concept,design, selection and test”, 24th CIRP Design Conference, Procedia CIRP 21 (2014) 373 – 378.

[5] A.M. Zaki, O. A. Mahgoub, A.M. El-Shafei, A. M. Soliman, “Design and Implementation of Efficient Intelligent Robotic Gripper”, Wseas Transactions on Systems, Issue 11, Volume 9, November 2010.

[6] Peter Kostal, Jarmila Oravcova, Miriam Matusova, “Grippers for Industrial Robots”, 50TH Anniversary of Technical Science Novi Sad Machine Design ISSN 1821-1259, May 18th 2010.

[7] Kim and Bernold, “A Comparison of two innovative technologies for safe pipe installation-pipeman and Stewart platform based pipe manipulator”, Automation in construction 17, 2008.

[8] Kim , Leem and Jung, “A performance evaluation of a Stewart platform based Hume concrete pipe manipulator”, Automation in construction 18, 2009.

[9] Rad and Kalivitis, “Development of an Autonomous Friction Gripper for Industrial Robots”, World Academy of Science, Engineering and Technology, 2011, Vol:5.

[10] Alexander, Moore and Wen,”Pipe Lifting Apparatus And Method”, United States Patent, 2003.

