



ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES

**Stress Analysis of Elevator Car Frame Bottom Support
Using Finite Element Method**

**A Thesis Submitted to the Graduate School of Addis Ababa University in
Partial Fulfillment of the Requirements for the Degree of Masters of Science in
Mechanical Engineering (Mechanical Design)**

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By
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Submitted in accordance with the requirements for the degree
MASTER OF SCIENCE (M.Sc.)

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ABSTRACT

Stress analysis of elevator car frame bottom support using Finite Element method

Amar Yimam

Addis Ababa University, 2017

Elevator is a mechatronic system used to move passengers and goods safely, swift and comfortable in high-rise buildings. The central and most visible component of an elevator is the supporting elevator car frame. The supporting elevator car frame is the structural part of the car and holds the platform and the cab that carries the passengers. The supporting elevator car frame structure consists of the upper crosshead beam, two vertical uprights (stiles) joining upper and lower members, and lower safety plank and provides the supporting structure for the car.

The main objective of this study is stress analysis of elevator car frame bottom support using FEM. The study covers the mathematical modeling, find out the effect of stresses in different parameters of shape, and stress analysis by considering dynamic loading condition, the performance strength weight ratio supporting elevator car frame structure using FEM and comparison of stress value with stiffeners and without stiffeners of beam.

The 3D modeling of the assembly has been carried out on SOLIDWORK 16 and after the assembly is accomplished on solid work, it has been exported to ANSYS R16. During the analysis of lower beam structure behavior in ANSYS software, the parameters used are vertical load, nominal velocity and gravitational acceleration. From ANSYS software simulation result, when the elevator is in normal running and mechanical break is used, the total deformation, equivalent von-mises stress and equivalent elastic strain and the stress value of the bottom support C channel beam due to force applied have been compared. After stress analysis from ANSYS result, shifting the stress concentration point and optimize the strength weight ratio of elevating car frame structure. It has been observed that the web opening longitudinal stiffeners enable a better stress redistribution around the opening region contributing for an increase of the beams ultimate load carrying capacity. The bottom channel web opening supporter beam is 2 % weight reduction in total mass channel beam and from analytical result, it has been observed that we can improve 13.2% strength weight ratio than the current solid channel beam for the same materiel.

Key point: stress analysis, web opening C channel beam, strength weight ratio, ANSYS16.

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NOMENCLATURE

P: Rated loaded

Q: car weight

D: depth of C channel beam

B: Width of flange of C channel beam

t_w : thickness of web opening c channel beam

T_f : thickness of flange opening c channel beam

Do: depth of opening provided

D: Over all depth of the opening

S: C/C Spacing between the two openings

e: clear distance between two opening

m: The mass of object

z: elastic modulus

SSF: factor of safety

δ : deflection towards the lower member of axis

F: reaction force towards the lower member

E: elasticity

L: the distance between the bottom beam

I: moment of inertia

σ_m : bending stress

M_m : bending moment

W: cross sectional area modulus

Fb: force applied to the bottom beam

L: maximum distance between lower members

F_T : Total force applied in the lower member

Fb: The braking force

ρ : Density of material

EN: European standard of elevator

FEM: finite element method

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

When people think about the development of cities, rarely do they contemplate the critical role of vertical transportation. Consider, however, that each day, more than 7 billion elevator journeys are taken in tall buildings all over the world [1].

Since the time man has occupied more than one floor of a building, he has given consideration to some form of vertical movement. The earliest forms were, of course, ladders, stairways, animal-powered hoists, and manually driven windlasses. Ancient Roman ruins show signs of shaft ways where some guided movable platform type of hoist was installed. Guides or vertical rails are a characteristic of every modern elevator. In the modern sense, an elevator is defined as a conveyance designed to lift people and/or material vertically. The conveyance should include a device to prevent it from falling in the event the lifting means or linkage fails. Up until about 1903, either drum-type elevator machines, wherein the rope was wound on a cylindrical drum, or the hydraulic-type elevator (the direct-plunger hydraulic or the roped hydraulic machine) was the principal means of hoisting force. Both had severe rise limitations: the drum type, in the size of the drum; and the hydraulic type, in the length of the cylinder. The drum-type elevator had the further disadvantage of requiring mechanical stopping devices to shut off power to prevent the car from being drawn into the overhead if the machine failed to stop by normal electrical means. On a hydraulic machine this is prevented by a stop ring on the plunger. The traction machine had none of the rise disadvantage of either the hydraulic or drum machine. The traction principle is a means of transmitting lifting force to the hoist ropes of an elevator by friction between the grooves in the machine drive sheave and the hoist ropes. [2]

Elevator is a mechatronic system used to move passengers and goods safely, swift and comfortable in tall-rise buildings. The supporting elevator car frame is the structural part of the car and holds the platform and the cab that carries the passengers. Elevators consist of complex structural, mechanical, and electrical components gives a description of the engineering detail of elevator systems. The main components of a typical traction elevator are shown in Figure 1. The central and most visible component of an elevator is the passenger car. The supporting car, frame consists

of the upper crosshead beam, two vertical uprights (stiles) joining upper and lower members, and lower safety plank, provides the supporting structure for the car. The suspension ropes are attached to the crosshead beam. The safety plank supports the car platform, on which passengers or other loads rest during travel. A pair of guide rails is placed on two opposite sides of the car, guiding the car during its vertical motion. The weight of the car and part of its load is balanced by the counterweight. The counterweight consists of steel frame and stacked fillers or weights secured by two or more tie-rods. These weights fill up to two-third of the height of the counterweight. Both passenger car and counterweight are connected through traction ropes that pass through traction system at the top of the hoist way consisting of driving sheaves and electric motor. Similar to the passenger car, the counterweight is also guided by two guide rails along its sides during the vertical motion [3].

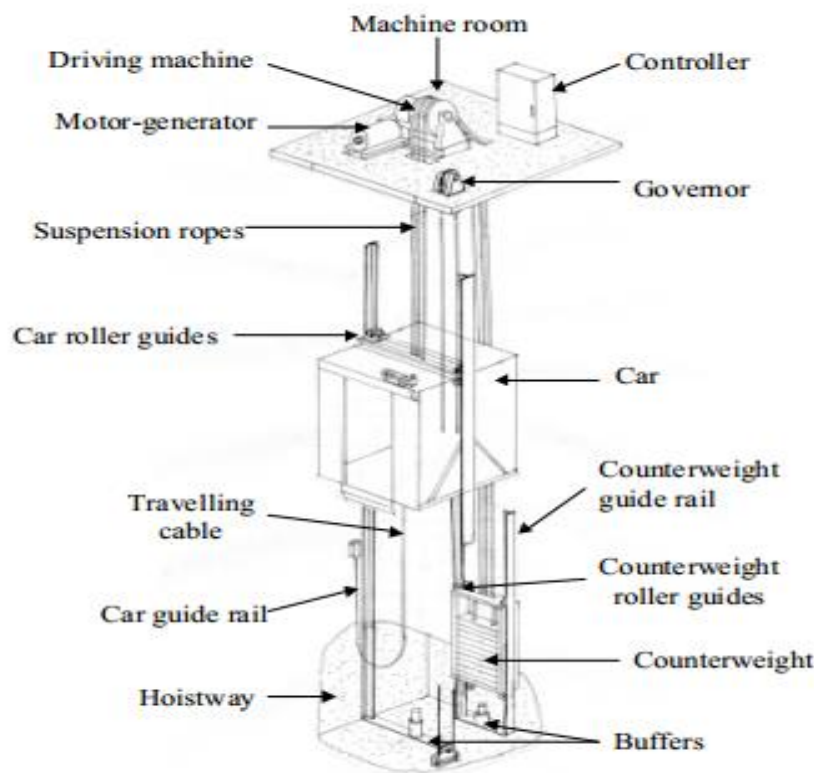


Figure 1 Main components of a typical traction-type passenger elevator. [4]

1.1.1 Elevator Structure

There are many variations of car layout, depending on the door arrangements. We can begin by a simple approach, regarding the car as a box supported by the lower member of the sling. Although it might seem that the acceleration of the lift influences the forces in the entire car and sling, and therefore the structure, this is really only true for the floor. The major factor determining the strength necessary in the floor, walls, ceiling and sliding doors is use and misuse by passengers. To a certain extent this is amenable to strict mechanical analysis, but detailed consideration on these lines is not pursued here because the magnitude and nature of the loads are so uncertain. Now we have enough information to begin examining the sling that supports the car and load. It comprises a frame rather like a picture frame made up of a beam across the top, a beam across the bottom, and two vertical 'suspension members' connecting them. The car sits inside it (Figure 2) design of the beam require an estimate of the bending moment that it must resist [5].

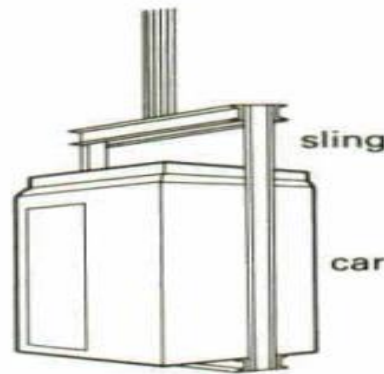


Figure 2 The car sits inside it the sling or frame [6]

1.1.2 Car frame structure and material

The car frame is a frame-shaped rigid steel structure which carries car and car loads. Elevator car frame comprises crosshead beams, bottom beams, vertical beams, upper and lower guide shoes, safety gear, car platform, hauling ropes, etc. Crosshead, bottom and vertical beams are the main components of a car frame but the other components of the car frame stated above are indispensable for the vertical movement of an elevator. The car frame components are connected by bolting, riveting or welding each other at the end of the beams. The bottom beams consist of two NPU-shaped or C-shaped steel profiles connected by welding to the support. The bottom beams are similar to, and they may be NPU-shaped or C channel shaped steel profiles. The bottom

beams support the car platform on which passengers and/or loads are transferred during the travel [7].

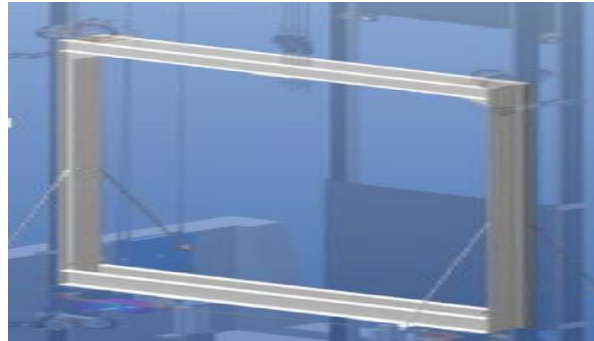


Figure 3 The basic C channel shape beam profile for elevator car frame structure [8].



Figure 4 The C channel shapes profile on lower and crosshead beam [9].

1.1.3 Overview of web opening beam

The introduction of an opening in the web of the beam alters the stress distribution within the member and also influences its collapse behavior. Thus, the efficient design of beams and plate girder sections with web openings has become one of the important considerations in modern structures. Castellated beams are used for various structures widely. The reasons of using castellated beams are increased depth of section without any additional weight, high strength to weight ratio, their lower maintenance and painting cost. Increasing in vertical bending stiffness, facility of service provision and attractive appearance are also important [10]

Depth of beam increased in processes of castellation by 40, 50 and 60%, with hexagonal shaped openings of angle 60° . Since the castellated beams are relatively slender and have web openings, which have an influence on their resistance. The major failure modes of castellated beams are web post buckling [11] and lateral-torsional buckling

1.1.4 Terminology in Castellated Beam as per EURCODE 3

Before going to see the design standards for castellated beam it is important to understand the some of basic terminologies used in the design of castellated beam, these terms are illustrated in the following.

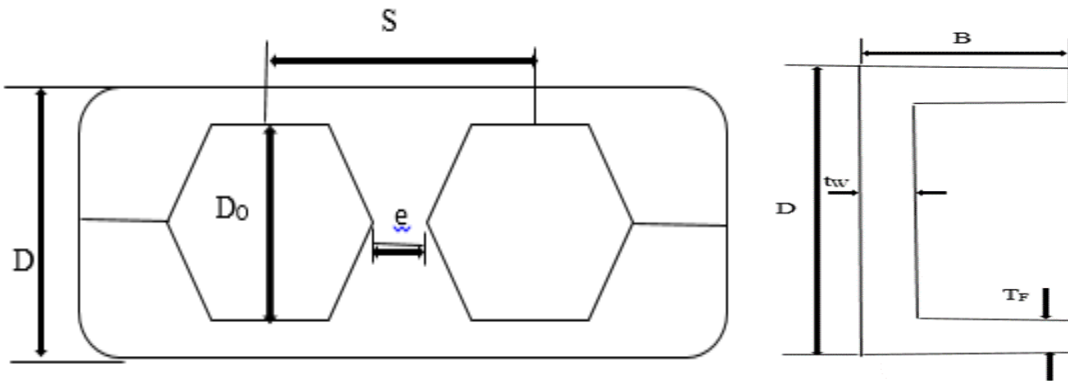


Figure 5 Typical cross – section of the beam

Where

D_o = depth of opening provided

D = Over all depth of the opening

S = C/C Spacing between the two opening

e = clear distance between two opening

t_w = thickness of web opening c channel beam

T_f = thickness of flange opening c channel beam

A) Guidelines for Perforations in Web

The perforations made in the web are greatly affecting the structural performance of the beam. Therefore, some logical and practical considerations need to be observed while providing perforations in the beam. Following are the general guidelines which are given by Eurocodes and some of them are based on the field or practical considerations. These standards in web perforations can be changed or modified without affecting the structural performance of the beam. These guidelines are as follows;

- 1) $1.08 < \frac{S}{D_o} < 1.5$
- 2) $1.25 < \frac{D}{D_o} < 1.75$
- 3) $D_o < 0.8D_o$
- 4) $e < 0.4D_o$
- 5) width of end post $> 0.5D_o$

1.1.5 Formation of Vierendeel Mechanism

Vierendeel bending is caused by the need to transfer the shear force across the opening to be consistent with the rate of change of bending moment, in the absence of local or overall instability, hexagonal castellated beams have two basic modes of plastic collapse, depending on the opening geometry. The failure is dependent on the presence of a shear force of high magnitude in the holes through span. It is found that all steel beams with large web openings of various shapes subjected to important parameter in assessing the structural behavior of perforated sections is the length of tee sections above and below the web opening which controls the magnitude of local Vierendeel moments acting on the beam section [11]

1.2 Statement of the Problem

The elevators are utilized in all over the world in urban areas in tall buildings, airports, hotel and office etc. The lower horizontal member of sling plays several roles, among which the clearest and most important is to support the car and its occupants, transmitting forces to the suspension members during normal running, and to the buffers or guide rails in emergency. The forces acting on the supporting elevator car frame members are more complex than those acting on any other part of the elevator equipment due to the nature of its design and the fact that it must carry variable loads. Due to the fluctuation loads in different case such as emergency brake collapse of buffer and misuse of passenger to cause of the stress concentration happen in lower horizontal member after periodical change. Due to this, many researches are done on car frame structure but their main concern is car layout dimension and performed stress and displacement calculations with considering load distribution on the car platform because the beam deflects under the action of the load. The purpose of study is stress analysis of elevator car frame bottom support using FEM by consider different parameter of web opening channel beam and optimize strength weight ratio of the bottom channel support beam

1.3 Objective of the Study

1.3.1 General objective

The main objective of the study is Stress analysis of elevator car frame bottom support using FEM.

1.3.2 Specific Objective

- Show the mathematical modeling of stress and deformation analysis.
- Find out the effect stress in different parameter of web opening C channel beam by using ANSYS 16
- Compare stress with present modal and the existing modal of C channel support beam
- Optimize the strength weight ratio of elevating car frame structure.

1.4 Scope of the Study

The research focus on a typical traction-type passenger elevator and also the analysis focus on the supporting elevator car frame structure. The scope of this project to show the mathematical modeling , the effect of stress in different parameter of shape and stress analysis by considering dynamic loading condition and the performance strength weight ratio supporting elevator car frame structure using FEM and comparison stress value with stiffeners and without stiffeners of beams of beam. Furthermore there is no physical testing and manufacturing process of supporting elevator car frame structure.

1.5 Methodology of the Study

To fulfill the objective of the study firstly data were collected by browsing different published papers and journals related to elevator system and observing different elevator car frame structure. Modeling of the supporting elevator car frame structure was developed by SOLID WORK 16. The Finite Element Method simulation and analysis were done by using the Finite element analysis software, ANSYS Workbench 16.0. Finally conclusion and recommendation for further researches are suggested based on the analysis.

1.6. Organization of the paper

This thesis is organized in to five chapters. In the first chapter background, statement of the problem, motivation of the research, objectives and methodology of the study are discussed. In chapter two a survey of literatures related to the research have been investigated. The journals,

articles and publications that are related to this research work are reviewed. In the third chapter, materials used, the conditions and the methods of analysis are stated. Modeling and FEM methods for dynamic analysis have been discussed clearly. In chapter four the FEA results are displayed and an appropriate discussion is performed. The conclusions, recommendations and future work of the research are stated in the last chapter, chapter five.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

The literature search mainly focuses on conventional elevator cars frame. This is one of the portions of the paper that reviews the previous related works which are basic guide for the introduction of the current work. Some of them may have a direct relation with this work whereas the others may have indirect relations. But the main principles they have used and the major methodologies and approaches they precede will be selected generally and applied for the formulation of specific model and analysis. There are many journals, conference papers, design works and books related to the elevator technology commonly used for this study

2.2 Studies on Stress Analysis of Elevator Car Frame Structure

Solmazoğlu and Akışın is about comparison between a conventional calculation on a freight elevator and one made on the basis of the single-side operation of a safety gear. They have considered that two NPU-200 beam supporting beam profiles and two lateral beam profiles, with the above sections [12].

Onur, Y.A., and Imrak, C.E Authors, in recent studies have proposed a frame-shaped steel construction for stress analysis and performed stress and displacement calculations with considering load distribution on the car platform [13].

Giagopoulos, D. and Natsiavas, after development of the nominal FE model, an experimental modal analysis of the devise was performed to quantify its dynamic characteristics. The system was tested in fixed-free boundary condition. First, all the necessary elements of the FRF matrix required for determining the response of the frame substructure were determined by imposing impulsive loading [14].

Janovsky has discussed the calculation methods of stress in individual parts of car frame and welded slings in [15].

2.3 Studies on Supporting Elevator Structure

George W. Gibson has discussed the standard codes for general structure of elevator supporting car frame. In addition to the strength requirements of the structural member, there is the requirement of rigidity. The beam deflects under the action of the load and we must set some limits

on this deflection; otherwise while the beam must be strong enough to resist the load, it might, on the other hand, be too flexible and act like a spring. Many of the structures encountered in our elevator system cannot be treated in the simplest form of a beam, however. In these instances, the member may be part of a frame. A frame, by definition, consists of a few, or many, structural members rigidly connected to each other at joints. As we did before with the simple beam, let us put a load, P , on the center of the horizontal beam. As noted above, we are dealing with elastic members, and consequently, under the action of the load, the cross beam will deflect [16].

2.4 Studies on the Supporting Elevator Car Frame Structure Material

George W. Gibson has discussed the construction of supporting elevator car frame structure consists of a welded C channel shaped frame with intermediate stringer channels welded to the outer frame. A steel floor plate is then welded to the stringers and frame. For purposes of design analysis, the stringers are supported by at least three points; namely, the front and rear end channels (members) and at the center by the car frame planks. Depending upon the load ranges and the specific manufacturer, there may be additional intermediate supports. The platform end channels are supported by the side braces [17].

2.5 Studies on web opening stress analysis

Sudhir Sastry Y B et al (2014) analyzed both thin Walled Dropped Flange and Rounded edge Channel beams of Aircraft Structures for buckling and finite element analysis of these structures for buckling were done using ANSYS . The behavior of the beams was examined by changing various parameter involved such as the length, thickness of the sheet, radius of the Circular ends, ratio of breadth and height with the help of finite element analysis. It concluded after the comparisons on the grounds of same thickness and mass that the open section c channel with Circular ends has more strength when compared with open section C channel with elongated open circular ends [18]

K. S. Sivakumaran in their paper “Some studies on cold-formed steel sections with web openings” dealt with the influence of a web opening on the (a) strength of compressive elements and (b) web crippling strength of cold-formed steel sections and has been examined through experimental research on C-shaped lipped channel section. The study concluded with some intense results, the effective design width equation as given in the Canadian design code may overestimate the

strength, the web opening reduces the strength and the influence should be considered in the design and the shape of an opening does not appear to be a governing parameter [19].

F. Erdal and M. P. Saka Studied the load carrying capacity of optimally designed castellated beam with various number of holes and spacing. Finite element analysis of same beams is also carried out under the application of centrally applied point load and failure patterns are studied and verified using ANSYS. Study shows that, even though the members are relatively short spans, lateral supports are governing factor for the analysis of beams due to torsional buckling. Also, it is shown that when load is applied above the circular opening then beam fails in Vierendeel mode and when load is applied on the portion other than prescribed above then beam fails in web post buckling [20].

Gustavo De Souza Veríssimo and Ricardo Hallal Fakury in “Design Aids for Unreinforced Web Openings in Steel and Composite Beams with W-Shapes” presented the results of computational simulations in non-composite and composite steel beams with web openings, based on a unified procedure developed by Darwin (1990), and it is limited to W-shape sections. They provide design aids that allow the identification of the beam region where unreinforced openings with specific characteristics do not reduce the member capacity. And they are compatible with the LRFD Specification for Structural Steel Buildings (AISC, 1999-a) were obtained from computational analyses based on Darwin (1990) to facilitate the design of web openings in steel and composite beams with W-shapes. The set of design aids allow to identify the “neutral zone”, a region in the beam web in which openings with some particular characteristics do not reduce the beam strength. This leads to more economical web penetrations [21].

2.6 Summary of literature review

Most studies and literatures discussed the stress concentration and beam deflects under the action of the load. Due to this, many researchers are done on car frame structure but their main concern is the car layout dimension and beam profile under the performed stress and deformation analysis considering variable loads apply.

2.7 The researcher idea and gap

The study covered stress analysis of elevator car frame bottom support different beam profiles cross sectional shape, without and with web opening. This is due to increased depth of section without any additional weight, shifting the stress concentration point and high strength to weight ratio, their lower maintenance and painting cost. Therefore, the shape, size and location of the openings provided on the web are always an important issue of concern considering the structural performance of the beam. In this work a comparative analysis of steel beams having different cross section has been done in which different loading conditions are considered.

CHAPTER 3**3. MATERIALS, METHODS AND CONDITIONS****3.1 Material Selection**

Determining the right material during the selection process is very important. The material selected should meet the expectation of the engineer. The material should prove mechanically feasible and should be economical. Apart from this the selected material must convincingly prove better than the currently used material. The proposed material properties may help the material engineers to perform the right material selection during the selection stage.

The selection of material for passenger elevator car frame structure depend on the following factors.

- Availability of the material
- Suitability of the material for the working condition in service
- Affordability of the material for the end use

From the above Material selection criteria for the existing elevator car frame component such crosshead beam, bottom beam and vertical beam has approximately similar material. For the conventional elevator car frame manufactured A36 steel standards.

Table 1 Mechanical property A36 steel [22]

Items	Mechanical Property	Value
1	Poisson's ratio	0.26
3	Ultimate tensile strength (MPa)	400-550
4	Tensile strength, yield (MPa)	250
	Modulus of Elasticity (GPa)	200
4	Density kg/m ³	7850
5	Elongation at brake in 50mm (%)	50

3.2 Specifications of the elevator [23, 24]

- Elevator kind: (traction Elevator)
- Travel height: max 30 m (medium)
- Number of passenger = 6
- Rated load = 400 Kg
- Number of Stops: 10
- Car nominal Speed: 0.4 m/s
- Length of upper and lower beam 1230mm
- Length of vertical beam (h) 2600 mm
- Car width internal (b1) 1100mm
- Car depth internal (d1) 1000mm
- Height of car internal (h) 2200 mm

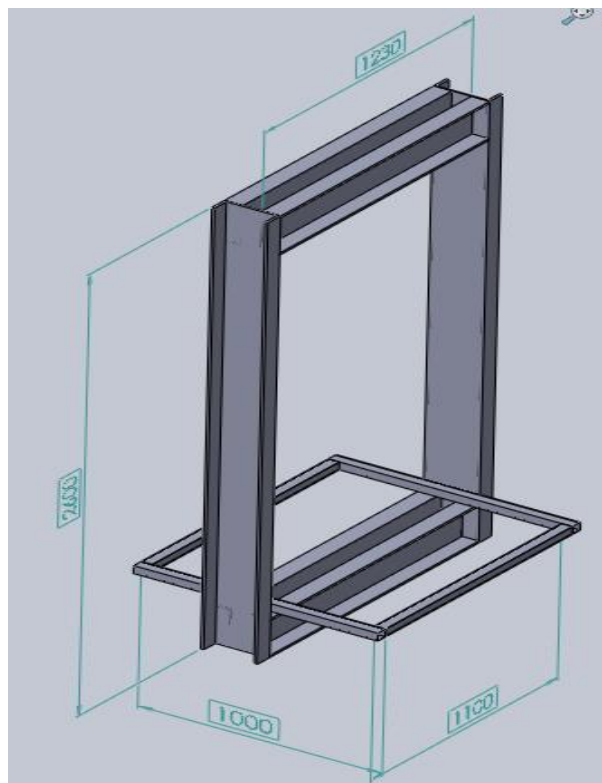


Figure.6 Some dimensions and modeling of solid C channel beam support elevator car frame

3.3 Methods

Before modelling in the FEA, it is always best to represent the mathematical model structure of elevator car frame. Analyze the results can help to validate the results from the FEA. The ANSYS 16.0 FEM software were used as the analysis for determine the structural behavior of under the given loading conditions.

3.4 Conditions of the analysis

The condition for analysis has been assumed as dynamic load condition. It is extremely hard to predict the position of passengers who have entered the car as well as their distributions in normal running condition. Loads imposed on car frame components are more complex than other elevator equipment since there are various types of loads that board into the car.

Table 2 General loading condition and operation in the supporting elevator car frame

Loading conditions		Operation
Normal usage	Car loaded	Normal, “running” car frame is moved up and down
	Full loaded car	
	Over loaded car	
Emergency conditions	Car loaded	use mechanical brake
	Full loaded car	
	Over loaded car	

3.5 Mathematical Modelling on Car Frame Analysis

The car frame is a frame-shaped rigid steel structure which carries car and car loads. Elevator car frame comprises crosshead beams, bottom beams, vertical beams, upper and lower guide shoes, safety gear, car platform, hauling ropes, etc. Crosshead, bottom and vertical beams are the main components of a car frame but the other components of the car frame stated above are indispensable for the vertical movement of an elevator. Loads imposed on car frame components are more complex than other elevator equipment since there are various types of loads that board into the car. In this case, certain assumptions have to be done regarding locations and types of loads. In this study, loads on crosshead beams are considered as a single load (rated load plus car load). Loads on the bottom beams are considered as a single rated load at the center of the beams. We shall assume again that the load is uniformly distributed over the lit floor and that the floor

bears evenly on the lower horizontal member of the sling. The only member that we will look at in detail is car this 'buffer channel' beam. Notice how it plays several roles, among which the clearest and most important is to support the car and its occupants, transmitting forces to the suspension members during normal running and to the buffers or guide rails in emergency

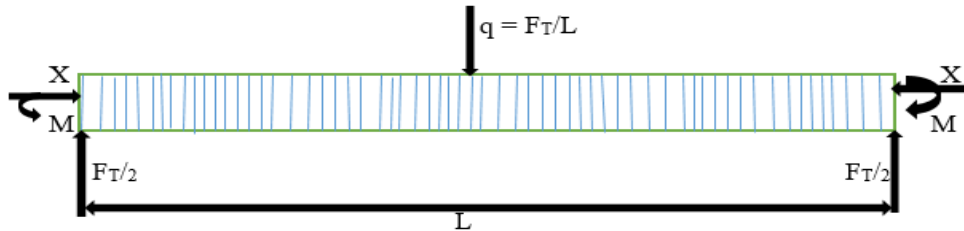


Figure.7 Force and moment distribution on the bottom supporting elevator car frame.

3.5.1 Selection of Cross section of C channel Beam

How are we to choose the cross-section of the channels? It is obviously important that the beams should be sufficient and strong. They support the car enclosure during normal operation of the lift and also when the emergency gear is called upon to function. Their security is vital. The loading on them is a repeated one, and might involve impacts that we have not been able to foresee, let alone calculate. There will be holes in the beam which, in addition to reducing the beam's cross-sectional area, cause a localized increase of stress. For all these reasons we need a substantial safety factor. This is not the place for a further exposition of the meaning and role of safety factor, but you should recall that it can represent the difference between: (1) calculated values and true values, (2) safe stresses and yield stresses

The beam section will be governed by the equation $\sigma = M_y/I$, where I refers to the two channels taken together and σ is the safe working stress ($\sigma = \sigma_y/SSF$). This equation has two unknowns and so cannot be solved as it stands. However, each cross-section that is available from a steel manufacturer has a fixed value of I and y. The ratio I / y for a given section is given the name section (or elastic) modulus, denoted by Z.

For the whole beam $Z = M/\sigma = SSF * M/\sigma_y$

From the above material property $\sigma_y = 250$ MPa take factory safety 2 and the bending moment from the analytical calculation on car frame we get the maximum uniformly distributed load in the case of emergency brake condition 44144 Nm or 44.144 KNm

Therefore section modulus $Z = 2.5 * 44.144 * 10^3 / 250 * 10^6$

$$Z = 0.442 * 10^{-3}$$

For each channel $0.221 * 10^{-3} \text{ m}^3 (=221 * 10^3 \text{ mm}^3)$

From section (elastic) modules Z value take Standard tables of steel sections can be used which give the properties of [25].

The nominal size c channel beam selected $(D*B) = 230*75 \text{ mm}$ and section modulus of $(Z) = 233.3 * 10^3 \text{ mm}^3$. The C channel has a mass of 25.1 kg m^{-1} . The mass of this pair in the length required (just over 1.23 m) would be about $1.23 * 25.1 * 2 = 61.8 \text{ kg}$

Area of solid C channel beam = 3270 mm^2 .

The area of this pair C channel beam required would be about $2 * 3270$

$$A = 6540 \text{ mm}^2$$

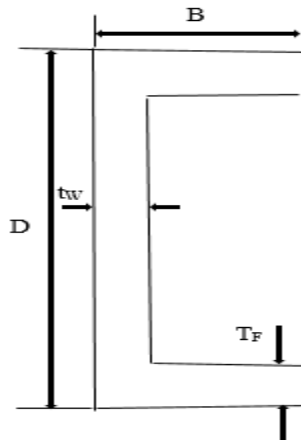


Figure.8 Cross section C section beam

Where

D = depth of C channel beam

B = Width of flange of C channel beam

t_w = thickness of web of C channel beam

T_F = thickness of flange of C channel beams.

3.5.2 Loads and Forces

This equation says that the upward force on that load must support its weight and also give it the acceleration By Newton's Third Law there is an opposite force on the beam we can apply the same arguments to the distributed load on the lift buffer beam, the total force is

$$\text{Along y } F - mg = ma$$

$$\text{So } F = mg + ma \dots\dots\dots 2$$

Where F is total force exerted on the bottom beam

But the load acting uniformly distributed on the bottom beam and to calculate the distributed load

$$q = \frac{F_T}{L} \dots\dots\dots 3$$

Where F_T total force apply on the lower beam

L the length of the lower beam

In EN 81-1 for electric lift Section G.5.7 calculate the deflection

1. evaluate the deflections of a beam should be the following equations

$$\delta = 0.7 * \frac{F * l^3}{48 * E * I} \dots\dots\dots 4$$

where:

δ = deflection towards the axis, in mm,

F = reaction force towards the X axis, in Newton,

E = elasticity, in Newton per square mm,

L = the distance btewwn the bottom beam

I = moment of inertia towards the axis, in mm⁴

2. In EN 81-1 for electric lift Section G.5.2.2 calculate the bending stress

$$\sigma_m = \frac{M_m}{W} \dots\dots\dots 5$$

With

$$M_m = \frac{3 * F_b * L}{16}$$

Where

σ_m = bending stress in newtons per square millimeter

M_m = bending moment in newtons millimetres;

W = cross sectional area modulus in cubic millimetres;

F_b = force applied to the bottom beam in the different load cases in newtons;

L = maximum distance between guide brackets in millimetres.

3.5.3 Analytical calculation car frame Load consideration with load condition and some parameters of analysis

The loads that the beam supports against gravity and provides acceleration forces for (neglecting many minor loads) are the following.

1. The rated load: 400 kg, distributed over a length of 1.23 m
2. The car weight 525 kg, distributed over a length of 1.23m (an even distribution is a reasonable assumption to begin with).
3. Rope weight (Frope) = 40 kg (it is fixed assuming that it is hanged from the top by elevator ropes)
4. The beam itself. The part of the loading is the beam itself, which depends on its cross-section. The mass of the beam as 50kg

Every moving part must be taken into account with its own acceleration, considering the fastening ratio of the installation.

Under no circumstances should the acceleration taken into account be less than [26]

➤ 0,5 m/s² in normal cases

A) In normal usages of elevator

Depending on boundary conditions, different analysis parameters have used to the show stress and deformation values occurring on car frame components. Table 3 provides the analysis parameters related to loads and operation condition for car frame components. Analysis parameters are assigned proportionally in accordance with the number of passengers. For instance, when three additional passenger is in the elevator cabin for the elevator designed for 6.

Table 3 over loaded condition and total car weight

Running condition	Persons entrance	Rated load (Kg) (person/65)	Car weight (Kg)	Rope weight (Kg)	Bottom beam weight (Kg)	Total weight(kg)
Over loaded car	Additional 3 persons	595	525	40	50	1210

Note take 65kg as average weight of each passenger.

B) In emergency condition

Mechanical brakes are generally applied to the car side. Today, double sided safety systems are utilized, they are designed as preventing the motion of the empty car upwards and full cabin downwards.

The braking forces of which the safety gear capable shall be calculated as laid down in EN81-20 section 5.9.2.2 for the maximum and minimum applied to the bottom beam calculated as

$$P+Q = \frac{F_b}{16} \dots\dots\dots 6$$

P+Q = Total Mass, F_b the braking force

3.5.4 The vertical force acting on the lower member of beam

A) For case one When the elevator in normal running condition

In the running condition analysis take the acceleration 0.4m/s² and also total distributed load is the sum of all loads apply on the component of the beam and calculated as

D) loaded car condition

For instance, analysis parameter 1 expresses the situation in normal running condition when two passenger is exist in the elevator cabin designed for five passengers,

The Normal force = 765kg*0.4m/s² = 306N

The force of gravity = 765kg*9.81m/s²= 7504.65N

The total force exerted on the lower member of beam = Normal force + Force of gravity
7810.65 N

$$q = \frac{7810.65}{1.23} = 6350\text{N/m}$$

Which is, of course, equal to the sum of the reactions I calculated earlier 7810.65N is distributed over the 1.23 m length of lower beam (6350N/m).I shall replace the distributed load 1.23 m length of beam by a four-section approximation, 0.3075 in each section and then I can calculate at each point load

The load at each point = distributed load over the length of lower beam* length of the beam by four section approximation

The load at each point = 1952.62N

II) Fully loaded car condition

For instance, analysis parameter 2 expresses the situation in normal running condition when five passenger is exist in the elevator cabin designed for five passengers,

$$\text{The Normal force} = 1015\text{kg} \cdot 0.4\text{m/s}^2 = 406\text{N}$$

$$\text{The force of gravity} = 1015\text{kg} \cdot 9.81\text{m/s}^2 = 9957.15\text{N}$$

$$\begin{aligned} \text{The total force exerted on the lower member of beam} &= \text{Normal force} + \text{Force of gravity} \\ &10,363.15\text{N} \end{aligned}$$

$$q = \frac{10363.15}{1.23} = 8425.32\text{N/m}$$

which is, of course, equal to the sum of the reactions I calculated earlier 10,363.155N is distributed over the 1.23 m length of lower beam (8425.32N/m). I shall replace the distributed load 1.23 m length of beam by a four-section approximation, 0.3075 in each section and then I can calculate at each point load

The load at each point = distributed load over the length of lower beam* length of the beam by four section approximation

$$\text{The load at each point} = 2590.78 \text{ N}$$

III) Over loaded car condition.

Analysis parameters are assigned proportionally in accordance with the number of passengers. For instance, analysis parameter 3 expresses the situation in normal running condition when three passenger additional in the elevator cabin designed for five passengers

$$\text{The Normal force} = 1215\text{kg} \cdot 0.4\text{m/s}^2 = 486\text{N}$$

$$\text{The force of gravity} = 1215\text{kg} \cdot 9.81\text{m/s}^2 = 11,919.15\text{N}$$

$$\begin{aligned} \text{The total force exerted on the lower member of beam} &= \text{Normal force} + \text{Force of gravity} \\ &12,405.15\text{N} \end{aligned}$$

$$q = \frac{12405.15}{1.23} = 10,085\text{N/m}$$

Which is, of course, equal to the sum of the reactions I calculated earlier 12405.15N is distributed over the 1.23 m length of lower beam (10,085N/m). I shall replace the distributed load 1.23 m length of beam by a four-section approximation, 0.3075 in each section and then I can calculate at each point load

The load at each point = distributed load over the length of lower beam* length of the beam by four section approximation

The load at each point = 3,101.28 Nm

B) For case two when the elevator from a free fall after a mishap in safety operation of gear

When the safety gear operates, applying retarding forces to the vertical side members, these side members apply vertical supporting forces close to the ends of the lower buffer beam. The other forces on the buffer beam are those associated with the weight and acceleration of the rated load, the box, the safety gear and the beam itself.

In the emergency condition (when the safety gear operates to save the lift from a free fall after mishap) condition analysis take between the $0.2g$ and g , where g is the gravitational acceleration and for illustration I shall use the last of these conditions, adopting a mean value that is $0.6g$. [27]. The total distributed load is the sum of all loads apply on the component of the beam and calculated as.

I) loaded car condition

For instance, analysis parameter one expresses the situation in emergency condition (when the safety gear operates to save the lift from a free fall after mishap) when two passenger is exist in the elevator cabin designed for five passengers,

$$\text{The Normal force} = 765\text{kg} \cdot 5.88 \text{ m/s}^2 = 4498.2\text{N}$$

$$\text{The force of gravity} = 765\text{kg} \cdot 9.81\text{m/s}^2 = 7504.65\text{N}$$

The total force exerted on the lower member of beam = Normal force + Force of gravity

$$12002.85 \text{ N}$$

$$q = \frac{12002.85}{1.23} = 9758.4 \text{ N/m}$$

Which is, of course, equal to the sum of the reactions I calculated earlier 12002 N is distributed over the 1.23 m length of lower beam (9758.4 N/m). I shall replace the distributed load 1.23 m length of beam by a four-section approximation, 0.3075 in each section and then I can calculate at each point load

The load at each point = distributed load over the length of lower beam * length of the beam by four section approximation

$$\text{The load at each point} = 3000.71 \text{ N}$$

II) Fully loaded car condition

For instance, analysis parameter 2 expresses the situation in normal running condition when five passenger is exist in the elevator cabin designed for five passengers,

$$\text{The Normal force} = 1015\text{kg} \cdot 5.87\text{m/s}^2 = 5958\text{N}$$

$$\text{The force of gravity} = 1015\text{kg} \cdot 9.81\text{m/s}^2 = 9957.15\text{N}$$

$$\begin{aligned} \text{The total force exerted on the lower member of beam} &= \text{Normal force} + \text{Force of gravity} \\ &15915.2 \text{ N} \end{aligned}$$

$$q = \frac{15915.2}{1.23} = 12939.2 \text{ N/m}$$

Which is, of course, equal to the sum of the reactions I calculated earlier 15915.2 N is distributed over the 1.23 m length of lower beam (12939.2 N/m). I shall replace the distributed load 1.23 m length of beam by a four-section approximation, 0.3075 in each section and then I can calculate at each point load

The load at each point = distributed load over the length of lower beam* length of the beam by four section approximation

$$\text{The load at each point} = 3978.2 \text{ N}$$

III) Over loaded car condition.

Analysis parameters are assigned proportionally in accordance with the number of passengers. For instance, analysis parameter 3 expresses the situation in emergency condition when three passenger additional in the elevator cabin designed for five passengers

$$\text{The Normal force} = 1215\text{kg} \cdot 5.87 \text{ m/s}^2 = 7132.1\text{N}$$

$$\text{The force of gravity} = 1215\text{kg} \cdot 9.81\text{m/s}^2 = 11,919.15\text{N}$$

$$\begin{aligned} \text{The total force exerted on the lower member of beam} &= \text{Normal force} + \text{Force of gravity} \\ &19051.1\text{N} \end{aligned}$$

$$q = \frac{19051.1}{1.23} = 15488.7 \text{ N/m}$$

Which is, of course, equal to the sum of the reactions I calculated earlier 19051.1 N is distributed over the 1.23 m length of lower beam (15488.7 N/m). I shall replace the distributed load 1.23 m length of beam by a four-section approximation, 0.3075 in each section and then I can calculate at each point load

The load at each point = distributed load over the length of lower beam* length of the beam by four section approximation

The load at each point = 4762.7 Nm

C) For Case Three The Elevator Use Mechanical Brake

In the Emergency condition 2 the braking force apply in the lower beam of the component and calculated as

$$P+Q = \frac{Fb}{16}$$

Where loaded car condition P = 150, Q 525 the permissible total mas $675 = \frac{Fb}{16}$

$$F_b = 16 * 675 = 10800N$$

Therefor braking force due to gravity

$$F_b = 10800 * 9.81 = 105,948N$$

$$q = \frac{105,948}{1.23} = 86,136.58N/m$$

which is, of course, equal to the sum of the reactions I calculated earlier 105,948N is distributed over the 1.23 m length of lower beam (86,136.58N/m). I shall replace the distributed load 1.23 m length of beam by a four-section approximation, 0.3075 in each section and then I can calculate at each point load

The load at each point = distributed load over the length of lower beam* length of the beam by four section approximation

$$\text{The load at each point} = 26,487N$$

When fully loaded car condition P = 400, Q 525 the total weight $925 = \frac{Fb}{16}$

$$F_b = 16 * 925 = 14800N$$

Therefor braking force due to gravity

$$F_b = 14800 * 9.81 = 145,188N$$

$$q = \frac{145,188}{1.23} = 118,039N/m$$

Which is, of course, equal to the sum of the reactions I calculated earlier 145,188N is distributed over the 1.23 m length of lower beam (118,039N/m). I shall replace the distributed load 1.23 m length of beam by a four-section approximation, 0.3075 in each section and then I can calculate at each point load

The load at each point = distributed load over the length of lower beam* length of the beam by four section approximation

The load at each point = 36,297Nm

When over load car condition P =600, Q525 the total weight $1125 = \frac{Fb}{16}$

$$F_b = 16 * 1125 = 18000N$$

Therefor braking force due to gravity

$$F_b = 18000 * 9.81 = 176,580N$$

$$q = \frac{176,580}{1.23} = 143,560.97N/m$$

which is, of course, equal to the sum of the reactions I calculated earlier 176,580N is distributed over the 1.23 m length of lower beam (143,560.9N/m).I shall replace the distributed load 1.23 m length of beam by a four-section approximation, 0.3075 in each section and then I can calculate at each point load

The load at each point = distributed load over the length of lower beam* length of the beam by four section approximation

$$\text{The load at each point} = 44,144.7N$$

Note the maximum axle load is taken for the three different case for analysis.

3.5.5 Stress Analysis Elevator Car Frame with Different Parameters and Load Condition

The stress analysis consider in the bottom supporting elevator car frame structure without web openings and with opening and also the web opening use the castellated beams with hexagonal and octagonal openings beam. Each profile has different number of openings as 1, 3, web depth opening and cross sectional areas and loads are used. From this paper consider the web opening and without opening c channel beam profile and Use of castellated beams is become very popular now a days due to its advantageous structural applications. Castellated beams are those beams which has openings in its web portion. The openings made in the webs are of generally hexagonal, circular, diamond or square in shape. Therefore, considering structural performance of the beam, the size and shape of openings provided in the web are always an important issue of concern. There is lot of study has been done in optimizing sizes of castellated beams with hexagonal openings, and hence there is need to optimize the beams with other shaped openings. While the local failure associated with the castellated beam can be minimized by providing other shaped openings like circular, diamond shapes etc.

Each C channel -shaped beam is characterized by its span L , flange width b_f , flange thickness t_f , depth of parent h , depth of castellated beam h_c and web thickness t_w . Web perforations were hexagonal in shape, with side (s_h) and are uniformly spaced at distance S along the span of the beam. The size of the elements along the span of the beam is restricted not to exceed twice the size of the element across the flange. Several mesh configurations are attempted until the above-provided limitations are set after providing convergence of the predicted buckling load within reasonable execution time.

Depending upon the limitations of opening specified by the codes, different dimension of the web openings are selected. The parameter considered for the study is D/D_o ratios and S/D_o of the opening. Therefore, in parametric study of hexagonal and octagonal shaped openings only beams with S/D_o equals to 1.4 are taken in considerations while varying the D/D_o ratio from 1.25 to 1.75.

From the above channel steel section the following value take

Nominal size $D*B = 230*75$, $t_w = 6.5$ mm $t_f = 12$ mm $Z = 233 * 10^3 \text{mm}^3$ and span length 1230mm, take the maximum load in case of the elevator over load condition $F = 44.144 \text{kN}$

In order to decide the failure of the beam in ANSYS16, Von misses failure criteria has been used. The criteria states that, failure of the structure would take place if the von misses stresses in the structure reaches to the value of yield stress of the material. Thus, in the present work, as the material used is steel, the load has been worked out corresponding to the yield stress of Parameters considered for hexagonal and octagonal shaped opening

By considering the web opening depth I am consider for stress analysis take $0.8D, 0.6D, 0.5D$

From the guidelines perforation in web we get the value

- 1) $1.08 < S/D_o < 1.5$
- 2) $1.25 < D/D_o < 1.75$
- 3) $D_o < 0.8D_o$
- 4) $e < 0.4D_o$

Table 4 The data for the web opening shape

Do	D	D/Do	S/Do	S	e
122.28	164.8	1.35	1.3	160	40
87.96	123.36	1.40	1.3	115	30
72.3	103	1.42	1.3	90	25

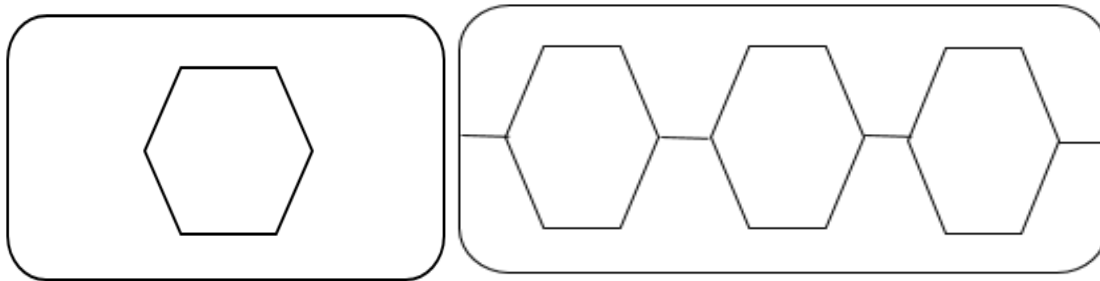


Figure 9 common type of hexagonal web opening castellated beam

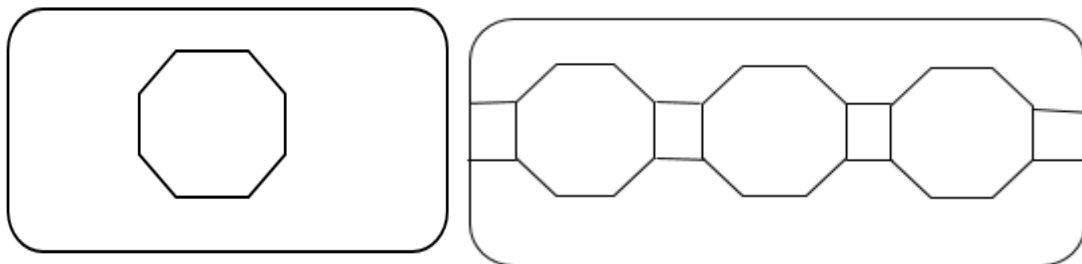


Figure 10 common type of octagonal web opening castellated beam

Analytical calculation of strength weight ratio for each cross section web opening channel support beam

$$\text{Strength weight ratio} = \frac{F/A}{m \cdot g} \dots\dots\dots$$

Take maximum load F= 44145N

For the solid C channel support beam D*B 230*75 tw= 6.2, tf = 12 calculate the total mass and area from the above

Mass of solid C channel pair beam = 61.8kg

Area of solid C channel pair beam = 6540mm²

Therefore Strength weight ratio on solid C channel pair beam = $\frac{F/A}{m \cdot g} = \frac{44145/6540}{61.8 \cdot 9.81} = 0.01113/\text{mm}^2$

For one web opening 0.5D

First calculate the area of removal surface of hexagonal shape opening

$$A_h = 0.866D_o * t_w = 0.866 * 71.3 * 6.2$$

$$\text{Area of hexagonal removal surface} = 388.2 \text{mm}^2$$

$$\text{Area of pair hexagonal removal surface of channel beam} = 2 * 388.2 = 776.4 \text{mm}^2$$

The total area of hexagonal web opening channel support beam = total area of solid beam - Area of hexagonal removal surface

$$\text{The total area of hexagonal web opening pair C channel support beam} = 6540 \text{mm}^2 - 776.4 \text{mm}^2 = 5764 \text{mm}^2$$

The total volume of hexagonal web opening channel beam = Area * span length of beam

$$5764 \text{mm}^2 * 1.23 \text{m} = 7089.2 \text{mm}^3$$

$$\text{Therefore } m = \frac{\rho}{V}$$

The total mass of hexagonal web opening C channel pair beam = 1.11kg

The total mass = the total mass of solid C channel beam – the total mass hexagonal web opening C channel beam of

$$61.8 \text{kg} - 1.11 \text{kg} = 60.69 \text{kg}$$

Therefore from the above input strength weight ratio

Strength weight ratio on hexagonal web opening C channel support beam

$$\frac{F/A}{m * g} = \frac{44145 / 5764}{60.69 * 9.81} = 0.0129 / \text{mm}^2$$

$$\% \text{ strength weight ratio improve} = \frac{0.0129 * 0.0113}{0.0129} * 100 = 13.2\%$$

For the above steps the other parameter 0.6D, 0.8D summarized below

Table 5 Properties after removal 0.5D, 0.6D, 0.8D strength weight ratio of one web opening the C channel support beam

Depth opening	Total area of (hexagonal) mm ² after removal of cross section area	Total area (octagonal) (mm ²) after removal of cross section area	Strength weight ratio $\frac{F/A}{m*g}$ (1/mm ²)	
			For hexagonal	For octagonal
0.5D	5764	5798	0.0129	0.0128
0.6D	5599	5637	0.0133	0.0132
0.8D	5227	5285	0.0142	0.0141

Table 6 Properties after removal 0.5D, 0.6D, 0.8D cross section area and total mass of one web opening the channel supporter beam

Depth opening	Total area of (hexagonal) mm ²	Total area (octagonal) (mm ²)	L (m)	Volume(mm ³) (A*L)		Mass(kg) ($\frac{\rho}{V}$)		m _T (kg)	
				V _h	V _o	m _h	m _o	m _{Th}	m _{To}
0.5D	5764	5798	1.23	7089.7	7132	1.11	1.10	60.69	60.7
0.6D	5599	5637	1.23	6887	6934	1.14	1.13	60.66	60.67
0.8D	5227	5285	1.23	6429	6501	1.22	1.21	60.58	60.59

Where

D_o depth of opening

D overall depth opening

L span length of channel beam

m_T after removal cross sectional area total mass of C channel beam

ρ Density of material take (7850Kg/mm^3)

m_h mass of hexagonal cross section in one single profile of beam

m_o mass of octagonal section in one single profile of beam

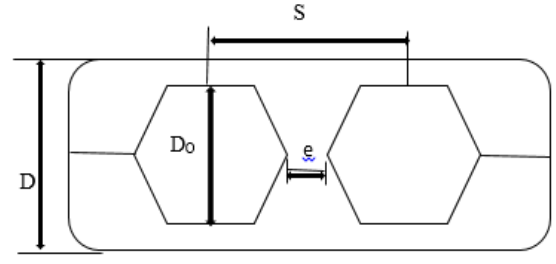
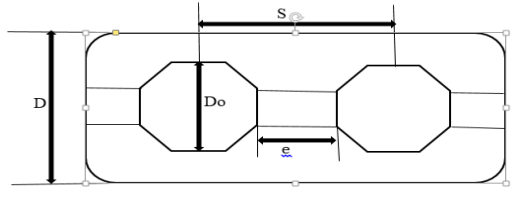
m_{Th} Total mass after removal of hexagonal cross section area

m_{To} Total mass after removal of octagonal cross section.

3.5.6 Modelling of the supporting elevator car frame

Modeling of the supporting structure of the lift car and car frame was carried out for the existing delivered technical solution of lift car and car frame, made by HONEX, [28]. In elevator installation, car dimensions have been occurred according to number of passengers. These specified dimensions have been used for modeling process. Carrying capacity of the modeled lift amounts to 400 kg or 6 persons. For an easier insight into the calculation and interpretation of results, as well as a precise diagnostics of influence of the structure elements on its global dynamic behavior, models of the supporting structure of the lift car and the lift car frame were separated. The elevator car frame with different geometric properties can be modelled from the existing model by just varying the few parameters on which it depends forming the bottom of the frame and safety plank supports the car platform, on which passengers and/or loads rest during the travel. [24].

Table 7 Detail of C channel beam section profile and depth of opening

Profile	Hexagonal profile in C channel beam	Octagonal profile in C channel beam
		
Nominal size of C channel steel beam section $D*B = 230*75*6.5$		
0.8D		
D (mm)	164.8	
Do (mm)	122.28	
S (mm)	160	
e (mm)	40	
0.6D		
D (mm)	123.36	
Do (mm)	87.96	
S (mm)	115	
e (mm)	30	
0.5D		
D (mm)	103	
Do (mm)	72.3	
S (mm)	90	
e (mm)	25	

Where

Do Depth of opening provided.

D = Overall depth of the opening.

S = C/C spacing between the two opening

e = Clear distance between two opening

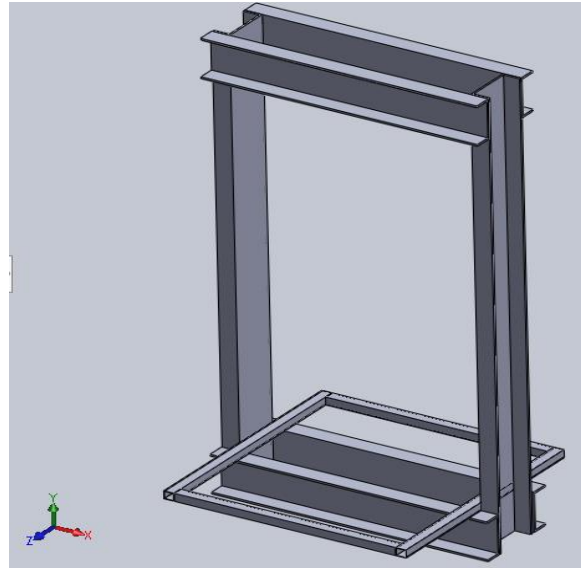
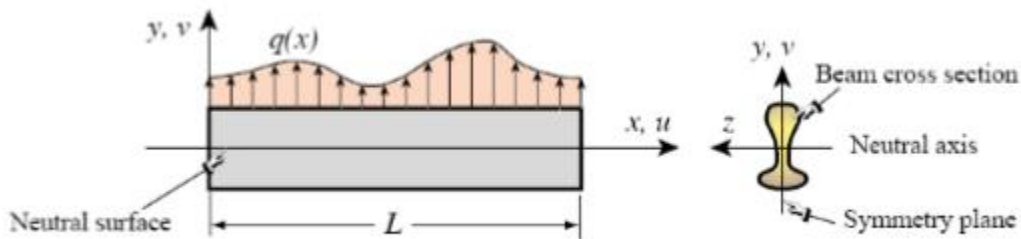


Figure 11 Modeling of solid C channel beam support elevator car frame

3.6 Finite Element Theory for Beam Structure

Finite element theory for beam structure is used to show supporting transfer load and carry it to the supports.

FEM Formulation



The Euler-Bernoulli equation for beam bending is

$$\frac{\partial^2}{\partial x^2} (EI \frac{\partial^2 v}{\partial x^2}) = q(x, t) \dots\dots\dots 15$$

The integral form of weighted residual of the above differential equation over a beam gives

$$I = \int W_i \frac{\partial^2}{\partial x^2} \left(EI \frac{\partial^2 v}{\partial x^2} \right) - q) dx \text{ for } i = 1 \text{ to } n \dots\dots\dots 16$$

Where L is the length of the beam and W is the weighting function. The weak formulation of the above equation is obtained from integration by parts twice for the second term of the equation. In addition, discretization of the beam into a number of finite elements gives

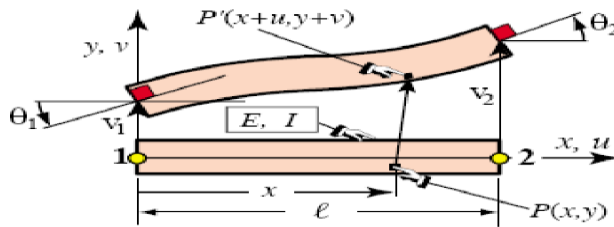
$$\int_{\Omega^e} EI \frac{\partial^2 v}{\partial x^2} \frac{\partial^2 W_i}{\partial x^2} dx [-VW_i - M \frac{\partial W_i}{\partial x}]_0^L \dots\dots\dots 17$$

Where $V = -EI \frac{\partial^2 v}{\partial x^3}$ is the shear force, $M = EI \frac{\partial^2 v}{\partial x^2}$ is the Bending Moment, Ω^e is an element domain and n is the number of element of beam

$$V(x) = C_0 + c_1x^1 + c_2x^2 + c_3x^3 \dots\dots\dots 18$$

From the assumption for the Euler-Bernoulli beam, slope is computed from Eq.

$$\theta(x) = C_1 + 2C_2x + C_3x^2 \dots\dots\dots 19$$



Evaluation of deflection and slope at both nodes yields

The boundary condition

$$v(0) = c_1 = v_1$$

$$\theta(0) = c_1 = \theta_1$$

$$v(l) = c_0 + c_1l^1 + c_2l^2 + c_3l^3 = v_2$$

$$\theta(l) = c_1 + 2c_2l + c_3l^2 = \theta_2$$

Solving for ci in terms of the nodal variables v_i and θ_i from Eq. 6 and substituting the results into the Eq. 11. Gives

$$V(x) = N_1(x)V_1 + N_1(x)\theta_1 + N_2(x)V_2 + N_2(x)\theta_2 \dots\dots\dots 20$$

Where

$$N_1(x) = 1 - \frac{3x^2}{l^2} + \frac{2x^3}{l^3}$$

$$N_2(x) = x - \frac{2x^2}{l} + \frac{x^3}{l^2}$$

$$N_3(x) = \frac{3x^2}{l^2} - \frac{2x^3}{l^3}$$

$$N_4(x) = -\frac{x^2}{l} + \frac{x^3}{l^2}$$

The functions N_i(x) are called Hermitian shape functions at which are C¹ - type which means both v and ∂v/∂x must be continuous between two neighboring elements..

Application of Hermitian shape functions and Galerkin’s method to Eq.10 results in the stiffness matrix of the beam element. That is,

$$[K^e] = \int_0^L [B]^T EI [B] dx \dots\dots\dots 21$$

Where

$$[B] = \{N_1'', N_2'', N_3'', N_4''\}$$

And the corresponding element nodal degrees of $\{d^e\} = \{v_1 \theta_1 v_2 \theta_2\}$ In Eq.10 double prime denotes the second derivative of the function and L is the length of a beam element. Assuming the beam rigidity EI is Constant within the elements, the element stiffness matrix is

$$[K^e] = \frac{EI}{L} \begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix} \dots\dots\dots 22$$

In case the beam rigidity is not constant within a beam element, the integral in Eq. 3 must be evaluated including EI as a function of x.

The third term in 3 results in the element force vector. For a generally distributed pressure loading, we need to compute

$$\{F^e\} = \int_0^L q(x) \begin{Bmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \end{Bmatrix} dx \dots\dots\dots 23$$

Final member end forces

$$\{F\} = [K]^G \{d\} \dots\dots\dots 24$$

The basic equation giving the stress in simple bending is

$$\sigma = \frac{My}{I} \dots\dots\dots 25$$

Where M is the bending moment, I is the second moment of area of the cross-section taken about the neutral axis, y is the distance of the extreme fiber from this axis, and σ is the longitudinal stress in that fiber stress at Different Point Calculated As

3.6.1 Solution Procedure Computer

The following steps are used in the solution procedure of Beam Problem **by** using ANSYS Workbench software for transient structural Finite Element Analysis of a mechanical problem.

1. The geometry of the elevator car structure to be analyzed is imported from modeling software to the
2. ANSYS Workbench in an acceptable format.

3. The material type and its properties are specified.
4. Meshing the imported panel model.
5. The boundary conditions and external loads are applied.
6. The solution is generated based on these input parameters.
7. Finally, the solution can be displayed.

3.6.2 Finite Element Modeling

The rapid developments in numerical techniques, faster computing ability and greater memory capacity are allowing engineers to create and test industrial equipment in virtual environments. Through finite element analysis these sophisticated simulations provide valuable information for designing and developing new products [29].

Among the numerical techniques, the finite element method is widely used due to availability of a much user-friendly commercial software. The first step with finite element method in numerical solution is to build a finite element model equivalent to the geometric model. Analysis for both conventional stainless steel elevator car frame material and bamboo rain forced/epoxy composite elevator car frame is done by using ANSYS 16.0, and analysis results of stress, deflection, natural frequency, fatigue failure (life prediction)

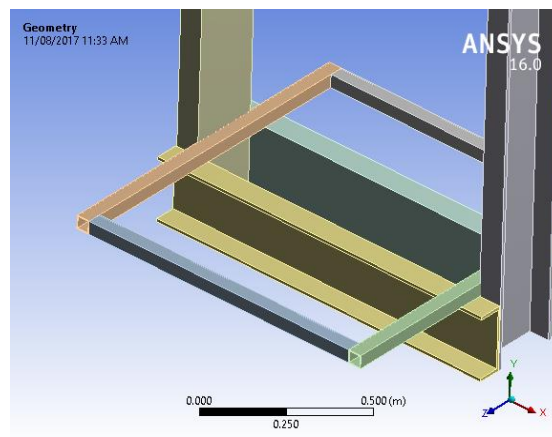


Figure 12 The Assembled part on ANSYS workbench

Table 8 Workbench ASTM A36 steel mechanical property specification

Properties of Outline Row 4: A36 steel				
	A	B	C	D E
1	Property	Value	Unit	
2	Density	7500	kg m ⁻³	
3	Isotropic Elasticity			
4	Derive from	Young's ...		
5	Young's Modulus	2E+11	Pa	
6	Poisson's Ratio	0.26		
7	Bulk Modulus	1.3889E+11	Pa	
8	Shear Modulus	7.9365E+10	Pa	
9	Field Variables			
10	Temperature	Yes		
11	Shear Angle	No		
12	Degradation Factor	No		
13	Tensile Yield Strength	2.5E+08	Pa	
14	Tensile Ultimate Strength	5E+08	Pa	

3.6.3 Meshing the imported 3D model

In the finite element analysis the basic concept is to analyze the structure which is an assembly of discrete pieces called elements which are connected together at a finite number of points called nodes. A network between these elements is known as meshing. This is the step that divides the complex geometry model into small elements that become solvable in an otherwise too complex situation. The meshing of the geometry under consideration may be generated directly, i.e., generation of nodes and elements, one at a time. Solid Modeling constitutes a part of the finite element analysis. Thus, the sole purpose of Solid Modeling is to create the mesh of the geometry, as conveniently and efficiently as possible. The meshing process can be performed only after the specification of element type. ANSYS offers several convenient options to assist in meshing. These include Automatic Meshing, Smart Sizing, and Mapped Meshing [30]

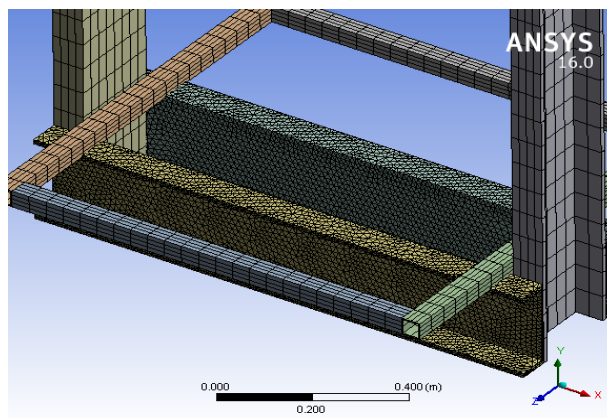


Figure 13 Mesh of assembled part on ANSYS workbench

3.6.4 Application of boundary conditions and external loads (referees appendix)

The next step of finite element analysis involves applying appropriate boundary conditions and the proper loading mechanism. There are two ways to apply the boundary conditions and loading to the model in ANSYS; either apply the conditions to the solid model (key point, lines and areas), or the conditions can be directly imposed on the nodes and elements. In this research work, the first approach is preferable; because if it is decided to change the meshing, there will not need to reapply the boundary conditions and the loads to the new finite element mode [31]. The main goal of a finite element analysis is to examine how a structure or component responds to certain loading conditions. Specifying the proper loading conditions is, therefore, a key step in the analysis. Loads can be applied on the model in a variety of ways in the ANSYS program. Also, with the help of load step options, one can control how the loads are actually used during solution

3.6.5 Generate solutions

The solution is generated based on the above input parameters. The total deformation and the equivalent (Von Mises) stress are the basic variables to be solved by this software analysis.

Finally, the solution of each dependent parameter can be displayed one by one. Once the solution is generated, each dependent parameter is solved and ready to be seen and interpreted. This will be clearly discussed in the next chapter.

CHAPTER FOUR

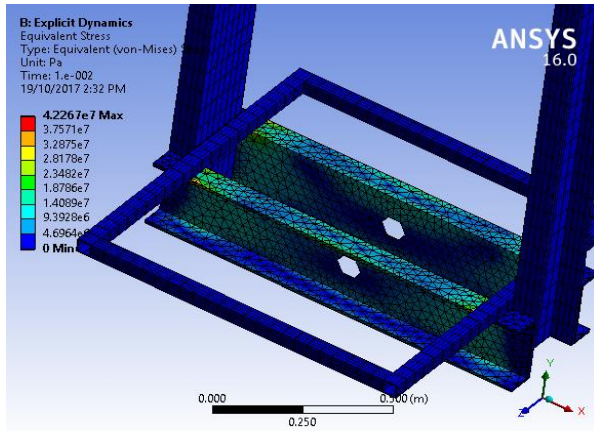
4. RESULT AND DISCUSSION

4.1 Result

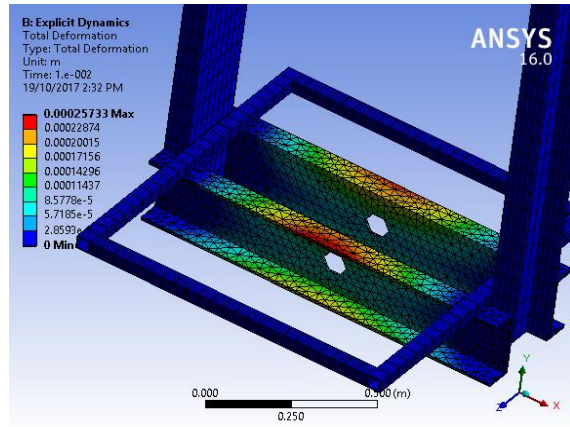
In the previous chapter, input parameters and steps that are used in the analysis of the supporting elevator car frame structure discussed briefly. The analysis has done using finite element method by using ANSYS Workbench 16. The analysis is performed by using finite element method consists of the explicit dynamics analysis. Explicit dynamics means Internal and external forces are summed at each node point, and a nodal acceleration is computed by dividing by nodal mass. The solution is advanced by integrating this acceleration in time. The maximum time step size is limited by the Courant condition, producing an algorithm which typically requires many relatively inexpensive time steps. There are several benefits of such a procedure and therefore the most significant is that it results in an algorithmic programmed which may be simplified programmed, does not need any matrix operation procedure and more is very appropriate for a quick parallel computing methodology and The explicit method requires short time step for an accurate solution, whereas the implicit method can give reliable results with large time.

In this chapter the other portion is analysis tool were used to study the behavior of the different web opening c channel section were assigned for each concept/model of beam. The result from the analysis includes total deformation, equivalent stress (Von-Mises stress) and strain. The solid C channel web opening modal is attached at the APPENDIX II. The results are shown with help of figures which were taken from the ANSYS modeling workbench and with graphs which were exported from ANSYS16 workbench results in the excel file format and take the maximum load condition in case of the elevator emergency braking condition.

A



B



C

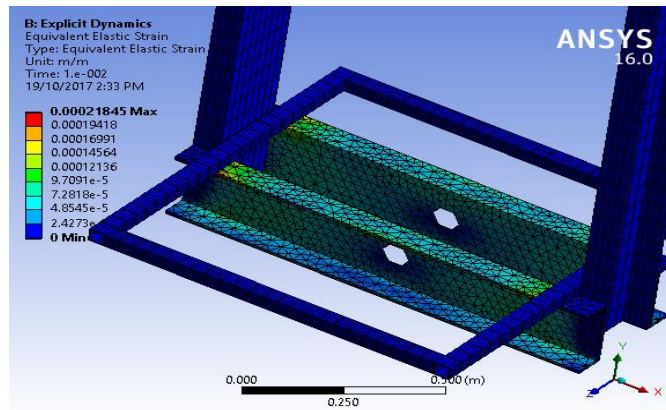
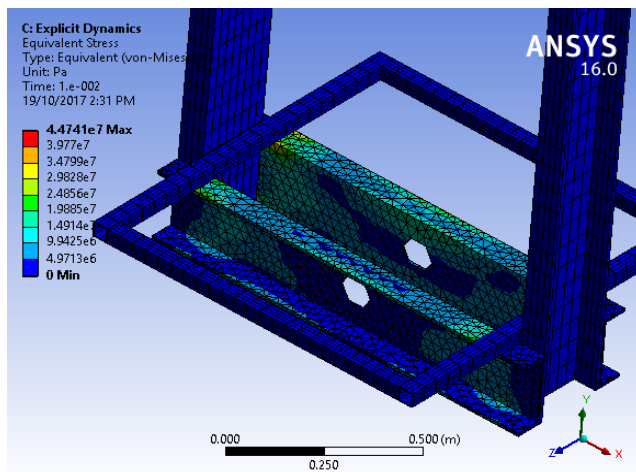
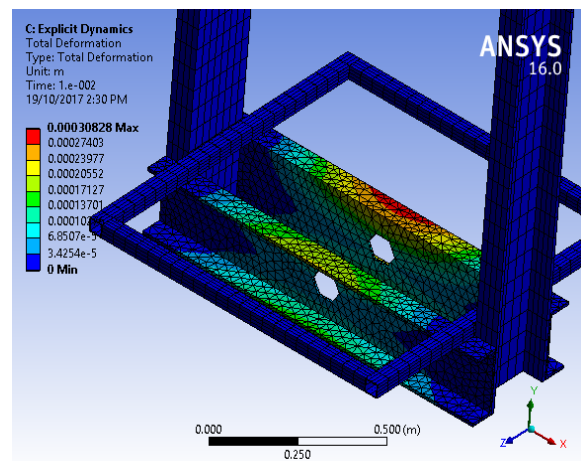


Figure 14 one web opening hexagonal c channel supporting beam with 0.5D at maximum load condition A) Equivalent Von- Mises Stress B) total deformation C) Equivalent Elastic str

A



B



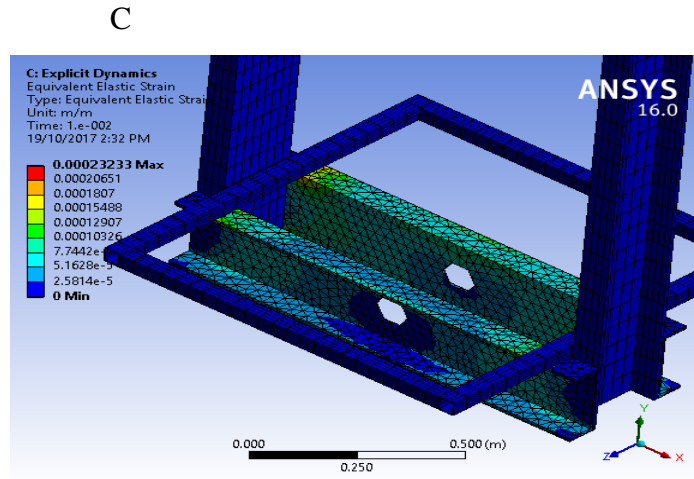


Figure 15 one web opening hexagonal C channel supporting beam with 0.6D at maximum load condition A) Equivalent Von- Mises Stress B) total deformation C) Equivalent Elastic strain

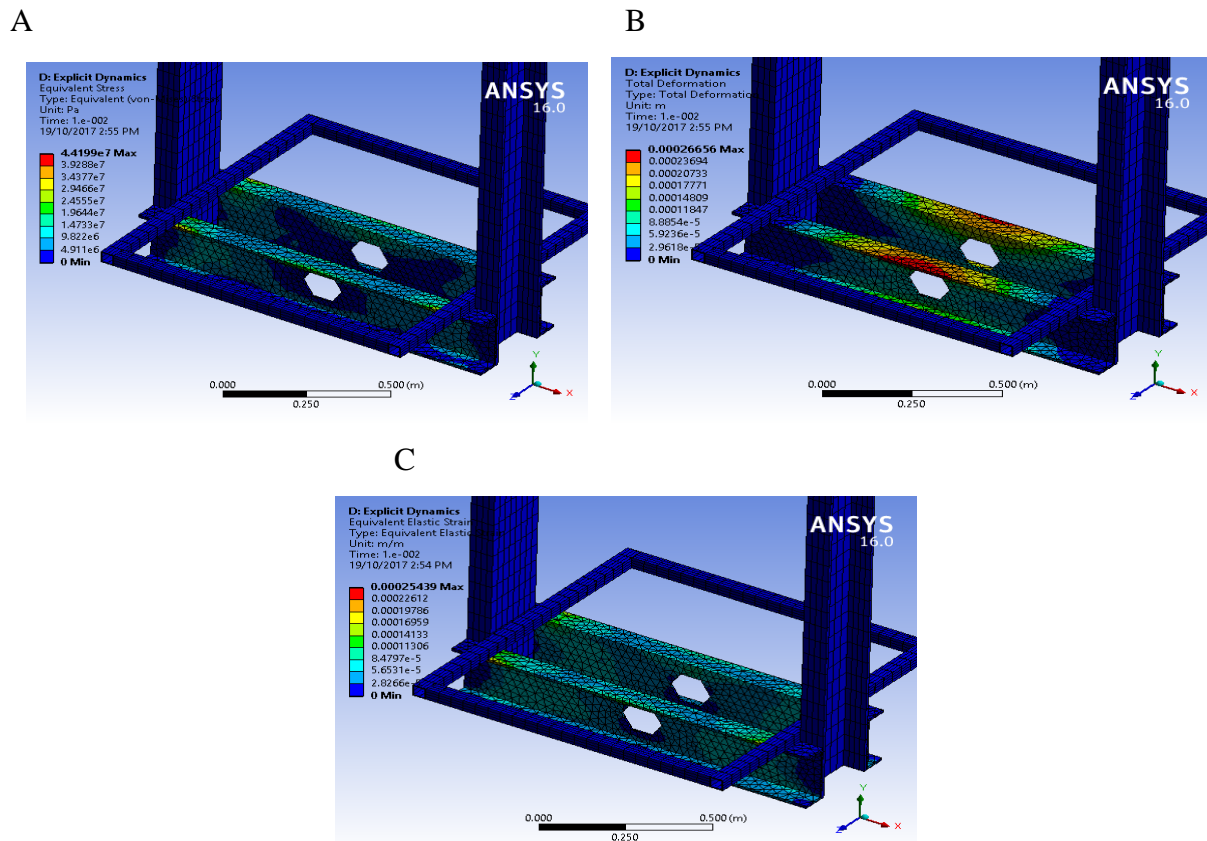


Figure 16 one web opening hexagonal C channel supporting beam with 0.8D at maximum load condition A) Equivalent Von- Mises Stress B) total deformation C) Equivalent Elastic strain

A

B

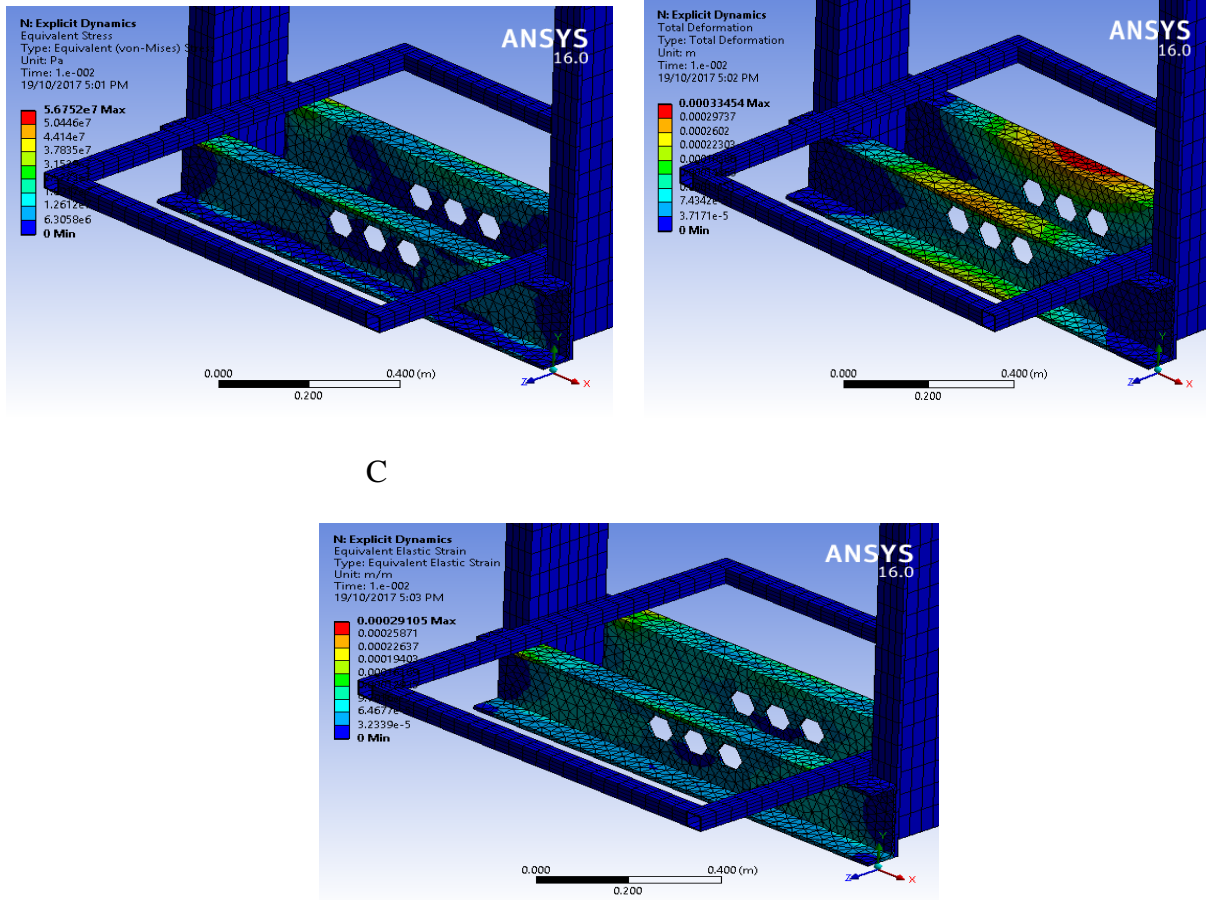
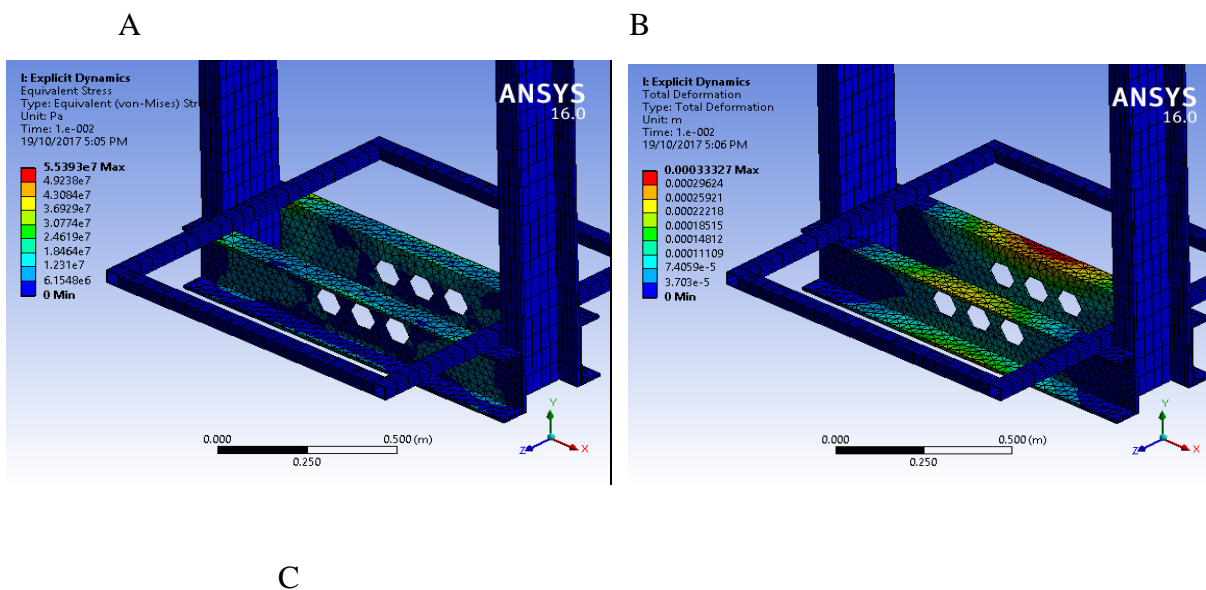


Figure 17 Three web opening hexagonal C channel supporting beam with 0.5D at maximum load condition A) Equivalent Von- Mises Stress B) total deformation C) Equivalent Elastic strain



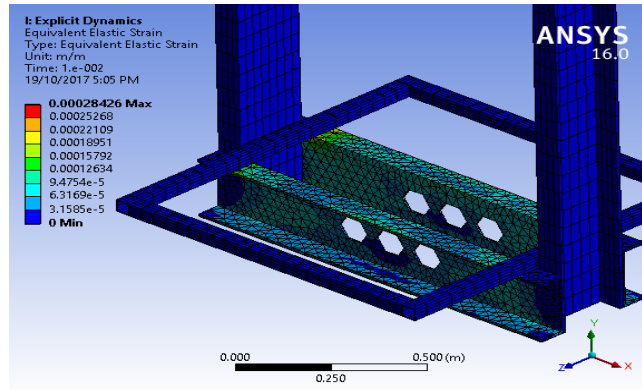
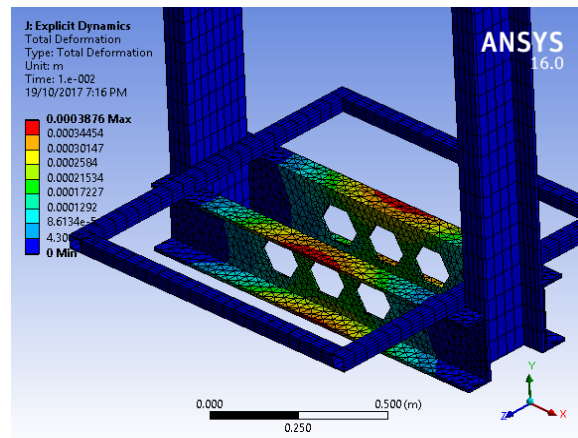
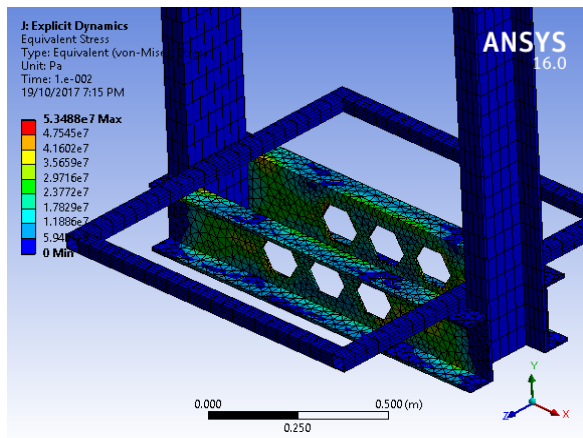


Figure 18 Three web opening hexagonal C channel supporting beam with 0.6D at maximum load condition A) Equivalent Von- Mises Stress B) total deformation C) Equivalent Elastic strain

A

B



C

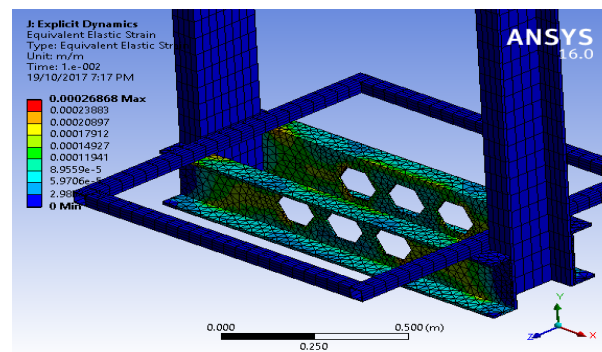


Figure 19 Three web opening hexagonal C channel supporting beam with 0.8D at maximum load condition A) Equivalent Von- Mises Stress B) total deformation C) Equivalent Elastic strain

A

B

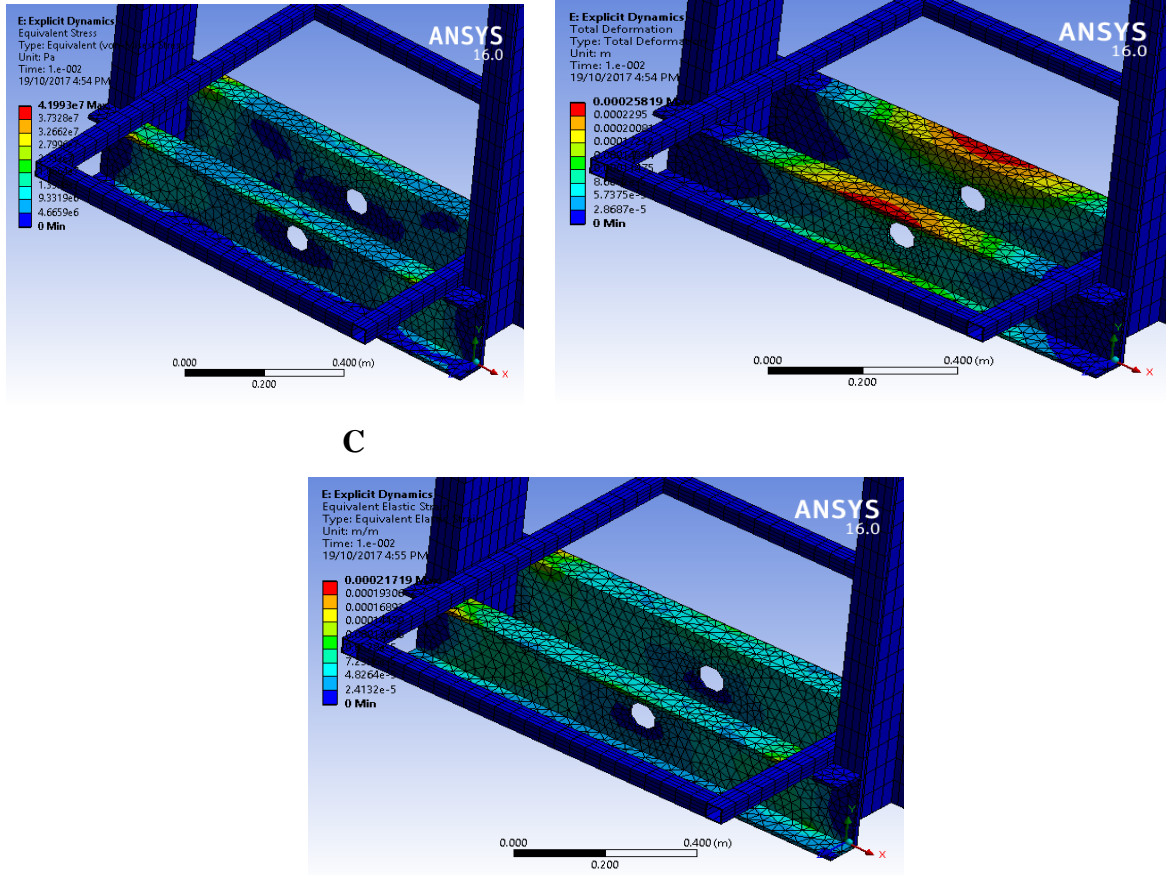
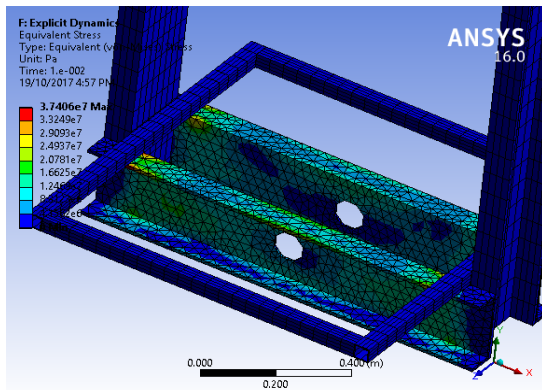
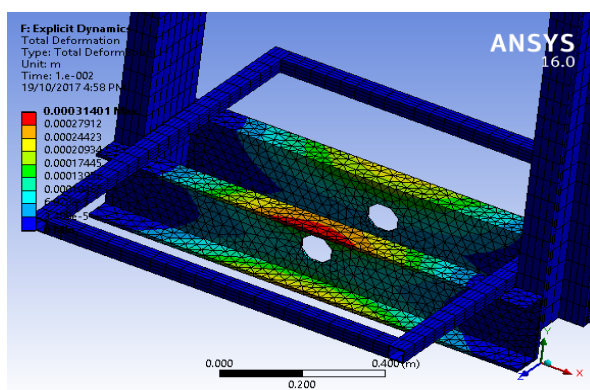


Figure 20 one web opening octagonal C channel supporting beam with 0.5D at maximum load condition A) Equivalent Von- Mises Stress B) total deformation C) Equivalent Elastic strain

A



B



C

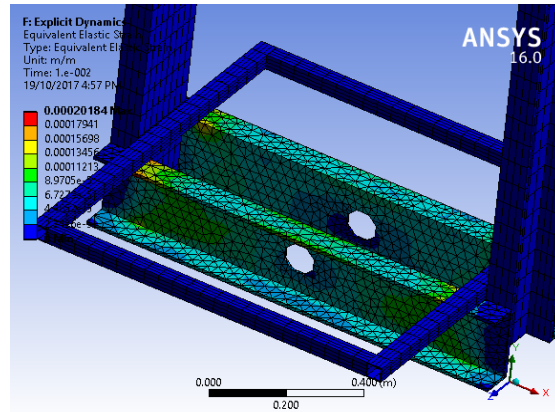
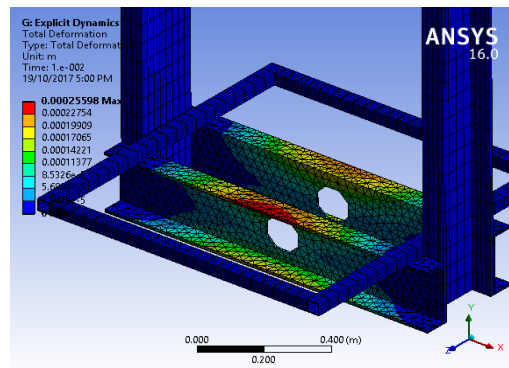
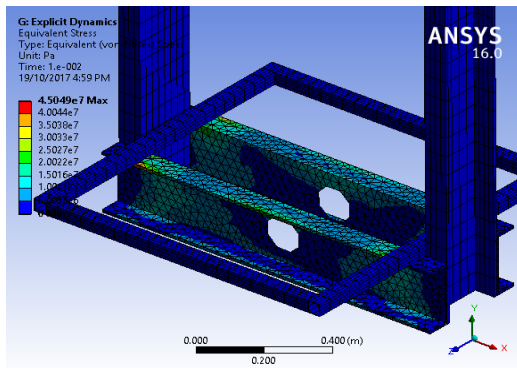


Figure 21 one web opening octagonal C channel supporting beam with 0.6D at maximum load condition A) Equivalent Von- Mises Stress B) total deformation C) Equivalent Elastic strain

A

B



C

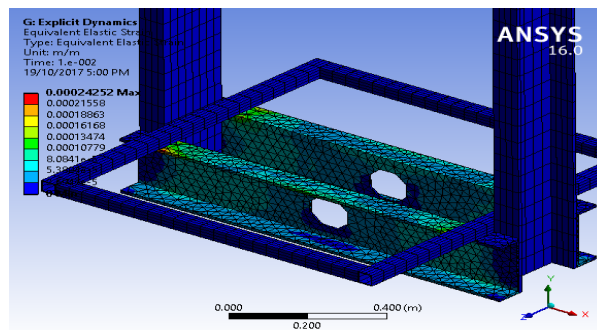
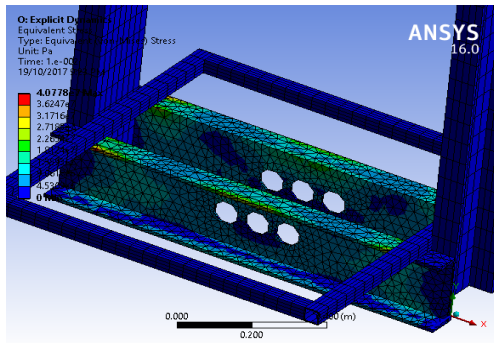
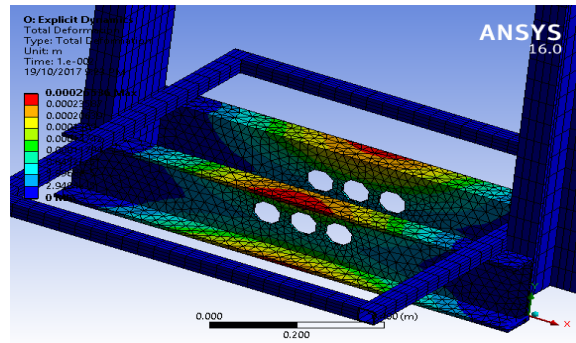


Figure 22 one web opening octagonal C channel supporting beam with 0.8D at maximum load condition A) Equivalent Von- Mises Stress B) total deformation C) Equivalent Elastic strain

A



B



C

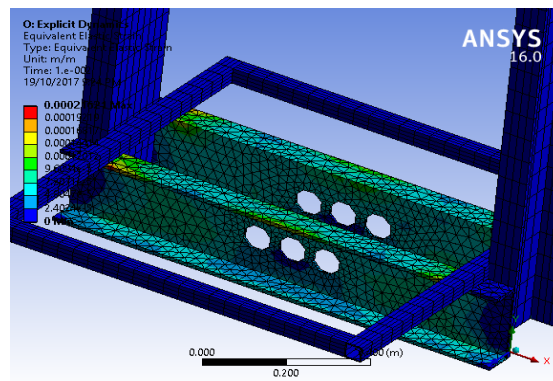
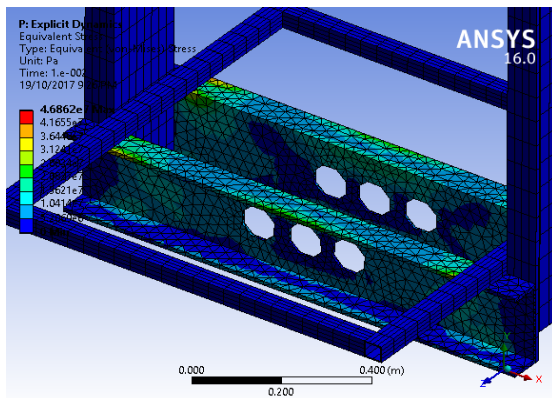
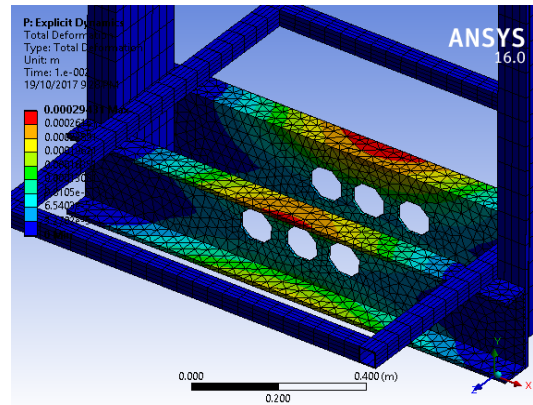


Figure 23 Three web opening octagonal C channel supporting beam with 0.5D at maximum load condition A) Equivalent Von- Mises Stress B) total deformation C) Equivalent Elastic strain.

A



B



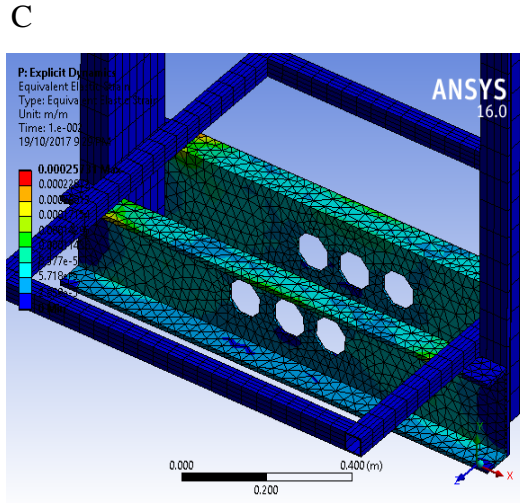
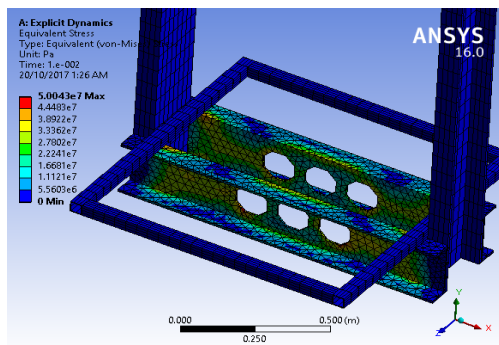
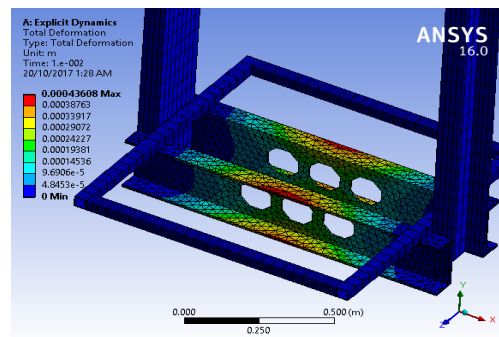


Figure 24 Three web opening octagonal C channel supporting beam with 0.6D at maximum load condition A) Equivalent Von- Mises Stress B) total deformation C) Equivalent Elastic strain

A



B



C

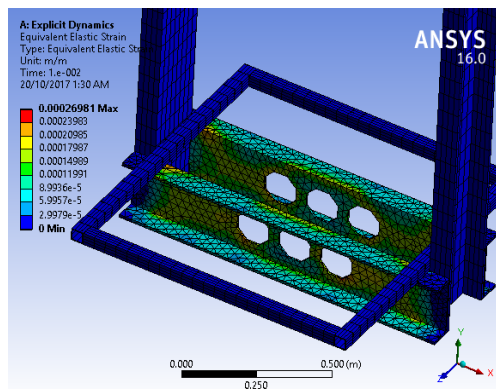


Figure 25 Three web opening octagonal C channel supporting beam with 0.8D at maximum load condition A) Equivalent Von- Mises Stress B) total deformation C) Equivalent Elastic strain

4.2 Discussion

This section of paper specifies the result obtained from the ANSYS software. The above result shows the different failure criteria due to the vertical applied load on the bottom of the horizontal beam supporter. In this paper, analysis of C channel support beam is done by changing various parameters like the shape, size and location of the openings provided on the web are always an important issue of concern considering the structural performance of the beam. It also leads to a considerable decrease in the load carrying capacity of the beam. Therefore, the shape, size and location of the openings provided on the web are always an important issue of concern considering the structural performance of the beam. In this work a comparative analysis of steel beams having different cross section has been done in which different loading conditions are considered. For this study ANSYS software have been used. Analysis showed that the steel beams have no significant effect on deflection due to the depth opening and number of opening. It is concluded that as the depth of opening increases, stress concentrations increases at the opening boundaries and Perforations caused an increased Von-Mises stress in the web above the opening due to the reduced Section moduli and shear area.

Table 9 The final results compare von-mises stress, weight in different shape at 0.5D

Parameter	Two C channel elevator car support beam		
	Solid C channel beam (without web opening)	hexagonal web opening C channel beam	octagonal web opening C channel beam
		One opening	One opening
Von-mises stress(MPa)	35.35	42.26	41.99
Total Mass (kg)	61.8	60.67	60.7
%weight reduction		1.83	1.78

Table 10 showing the analysis ANSYS result of solid C channel beam without web opening (Appendix I)

Failure theories	(solid C channel support beam(without web opening))
	Maximum load condition (over loaded car)
Max-equivalent Von-mises stress(MPa)	35.91
Max-Total deformation (mm)	0.166
Max-equivalent elastic strain (mm/mm)	0.000192

Table 11 showing the analysis ANSYS result of web opening C channel support beam with 0.5D depth of opening and number of opening

Failure theories	Web opening C channel support beam			
	Maximum load conation (over loaded car)			
	Hexagonal		Octagonal	
	0.5D		0.5D	
	One opening	Three opening	One opening	Three opening
Max-equivalent Von-mises stress(MPa)	42.26	56.75	41.99	45.18
Max-Total deformation (mm)	0.257	0.334	0.258	0.266
Max- equivalent elastic strain (mm/mm)	0.000218	0.000291	0.000217	0.000216

Table 12 showing the analysis ANSYS result of web opening C channel support beam with 0.6D depth of opening and number of opening

Failure theories	Web opening C channel support beam			
	Maximum load condition (over loaded car)			
	Hexagonal		Octagonal	
	0.6D		0.6D	
	One opening	Three opening	One opening	Three opening
Max-equivalent Von-mises stress(MPa)	44.74	55.39	37.85	46.84
Max-Total deformation (mm)	0.308	0.333	0.314	0.294
Max- equivalent elastic strain (mm/mm)	0.000216	0.000284	0.000202	0.000257

Table 13 showing the analysis ANSYS result of web opening C channel support beam with 0.8D depth of opening and number of opening

Failure theories	Web opening C channel support beam			
	Maximum load condition (over loaded car)			
	Hexagonal shape		Octagonal shape	
	0.8D		0.8D	
	One opening	Three opening	One opening	Three opening
Max-equivalent Von-mises stress(MPa)	44.19	53.48	45.01	50.46
Max-Total deformation (mm)	0.26	0.387	0.255	0.436
Max- equivalent elastic strain (mm/mm)	0.000212	0.000268	0.000242	0.000269

Note where 0.5D, 0.6D and 0.8D the depth opening from the overall depth

Table 14 showing the analysis ANSYS result of web opening C channel support beam with space plate reinforcement (Appendix I)

Failure theories	web opening C channel support beams (with space plate reinforcement in web opening)	
	Maximum load condition (over loaded car)	
	Hexagonal	Octagonal
Max-equivalent Von-mises stress(MPa)	40.61	41.64
Max-Total deformation (mm)	0.344	0.343
Max-equivalent elastic strain (mm/mm)	0.000201	0.0199

The above result are includes both cases for the reason of the analysis performed with different loaded condition. This paper mainly focus on the over loaded car condition for that matter The maximum parameter is used to perform the stress analysis and also to change the channel support beam geometry of elevator car frame structure for the simplicity of the stress analysis

As shown from the ANSYS dynamic analysis result the value of stress is vary for one case to other case. The maximum stress position also varying for case to case. In case one web opening C channel beam as shown in the figure 15,16 and 17, the maximum equivalent stress 42.26vMPa, 44.74 MPa and 44.19 MPa and also in case three web opening C channel beam as shown in the figure the maximum Equivalent stress 56.75 MPa, 55.39 MPa and 53.43 Mpa

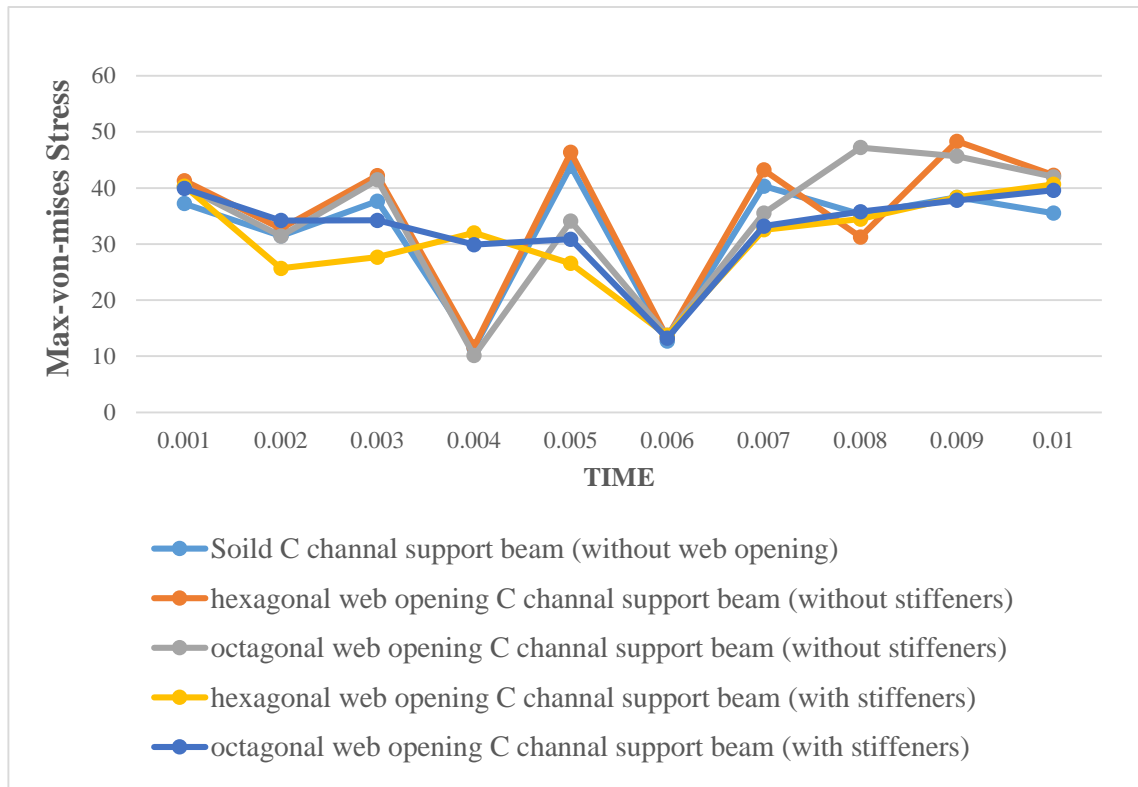


Figure 25 stress vs time graply with and without beam stiffeners C channel support beam

As shown in the above figure it is clear that the web opening C channel support steel beam having stiffeners along with spacer plates carries more load before failure. The stiffeners provided in the open web causes smooth flow of the shear forces leading to lesser deflection. In order to shift the stress concentration point occurs near the corners and web portion which may leads to local failures. The web opening longitudinal stiffeners enable a better stress redistribution around the opening region contributing for an increase of the beams ultimate load carrying capacity. As the opening shape provided is Hexagonal and octagonal, it is very effective as it shows stress concentrations at the boundaries of the web openings. As in case of octagonal shaped openings more shear transfer area is available so there is minimum effects of local failure. Therefore, castellated beam with octagonal shaped openings proves to be better than the other shaped openings in respect reliable strength requirement. By comparing castellated beam with solid beam it is concluded that solid beam required higher section than castellated beam for same loading and geometric condition. It is also found that higher section required in solid beam is due to the deflection only, because solid beam is safe in all checks like shear, bending, web buckling and

web crippling but it is not safe in deflection. To minimize the deflection in solid beam higher section is required. By changing shape of opening in castellated beam (Hexagonal, octagonal) it is concluded that there is no effect of shape of opening on deflection but shape of opening effect on stress concentration. Maximum stress concentration occur in Hexagonal shape of opening.

From the previous discussions of stress concentration, influences in different geometry with different parameter consider compared and discussed. Now the whole result of maximum stress on each geometry and their perspective parameter could be summarized as shown in the next column graph.

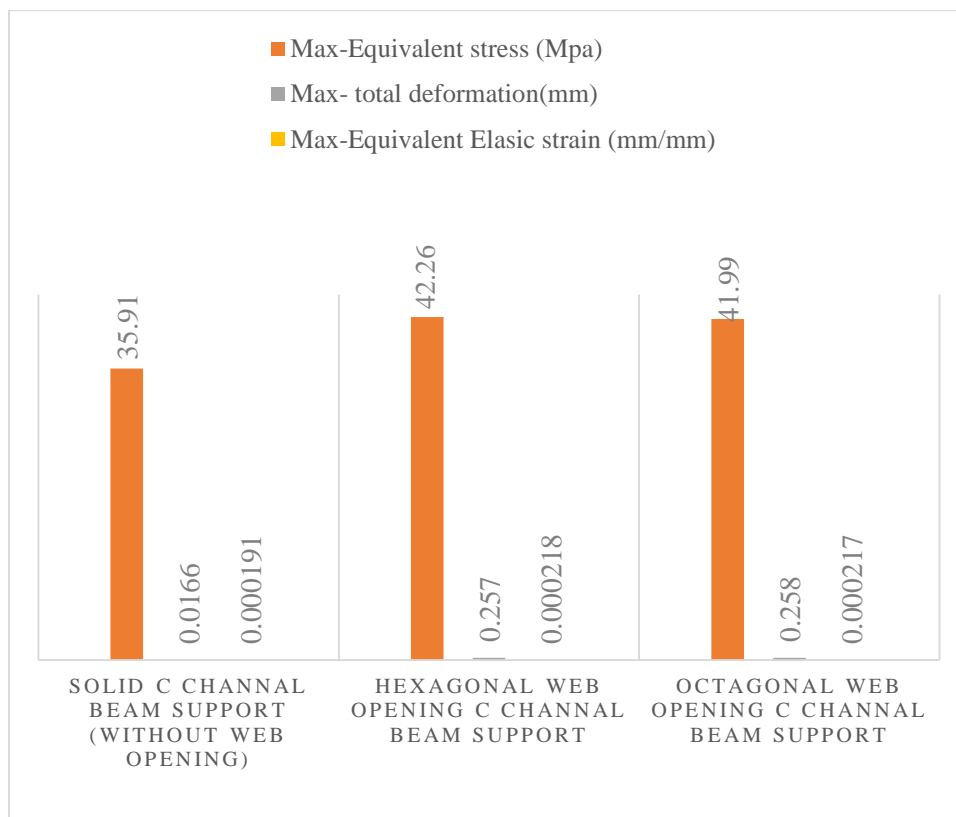


Figure 26 comparison stress in the solid channel beam (without web opening) and different shape of web opening

From the previous discussions of strength weight ratio, influences in different cross section area of geometry compared and discussed. Now the whole result of on each cross section area of geometry and their perspective weight could be summarized as shown in the next column graph

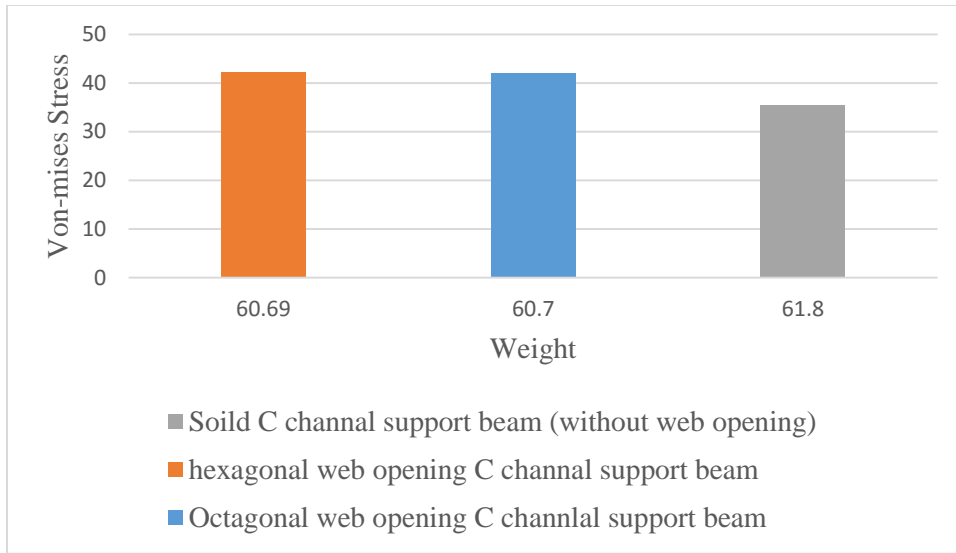


Figure 27 Comparison of von mises stress vs weight in solid channel without web opening and with opening

From the previous discussions due to increased depth of section without any additional weight, high strength to weight ratio, influences in different cross section area of geometry compared and discussed. Now the whole result of on each cross section area of geometry and their perspective weight could be summarized as shown in the next column grapy

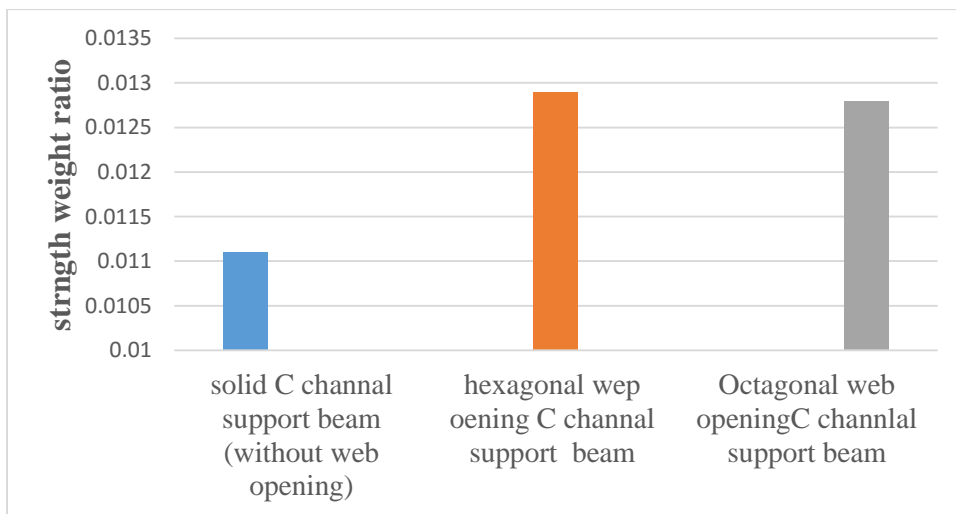


Figure 28 show the strength weight ratio in different shape of C channal support beam

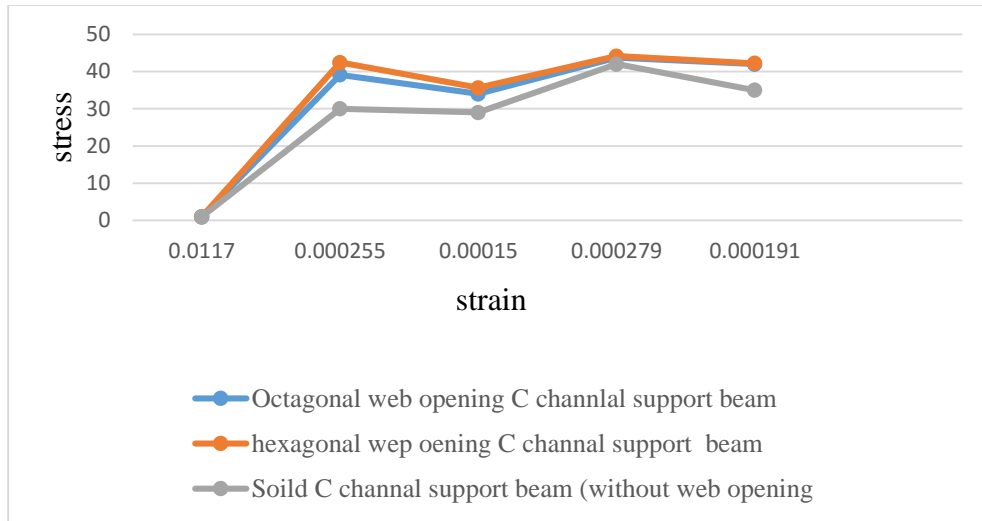


Figure 29 stress-strain behavior of different structure

As shown in the above figure the structure of channel support beam (without web opening) indicates that the structural deflections will be small as long as the material is elastic at the web opening condition at yield stress point is higher than solid beam so less structural deflection

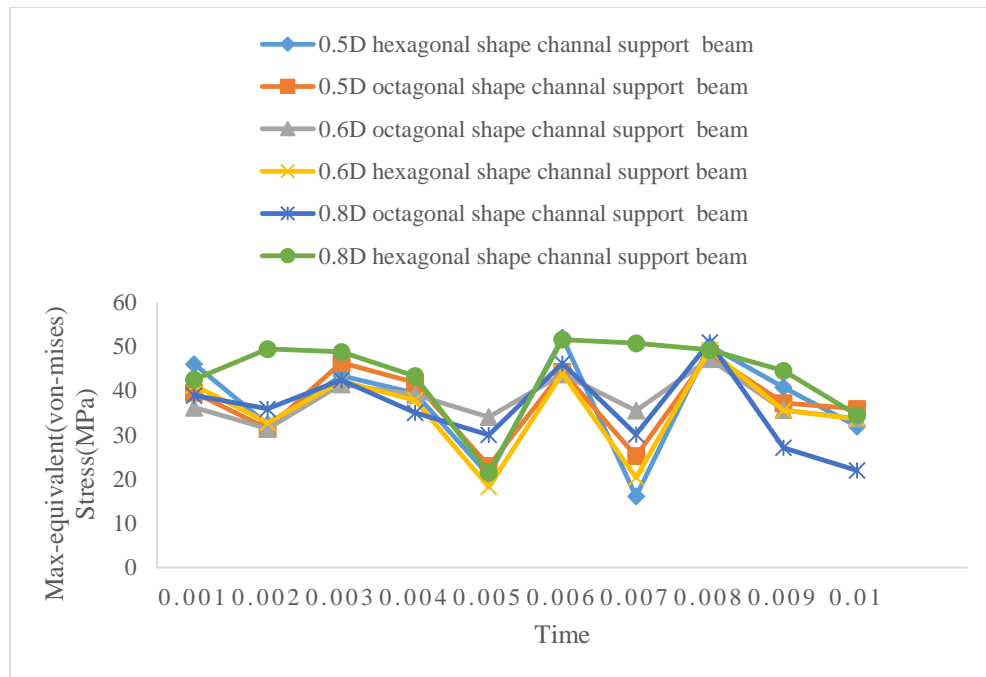


Figure 30 stress vs time graph with different depth opening of C channel support beam

As shown in above figure the depth of the opening is the most important parameter which affects the C channel support beams overall capacity as the Section module and Shear area gets reduced.

By changing ratio of depth of opening to total depth, it is concluded that as ratio increases stresses are also increases. Maximum stresses occur at ratio 0.8D and minimum at 0.5D. The depth of the opening should not exceed 50% of the overall beam depth (0.5D), as in almost all cases the effect suddenly increases as the depth of opening increases to 0.6D and 0.8D. Castellated beams have holes in its web, which lead to local effects in the beams. This causes the beams to fail in different local failure modes, which reduces their virgin load carrying capacity. Hence, it is irrational to compare the structural behavior of beams having different modes of failure, based only on strength criteria. The finite element analysis effectively captured the different failure modes of all the beams. From this analysis, it was observed that as the depth of opening increases, stress concentrations increases at the hole corners (Vierendeel effect) and at load application point. The results also confirm that the flexural stiffness of castellated beams decrease as the depth of opening increases. So by taking corrective measures, i.e. by rounding hole corners, providing reinforcement at critical section, providing plate below point load, etc.

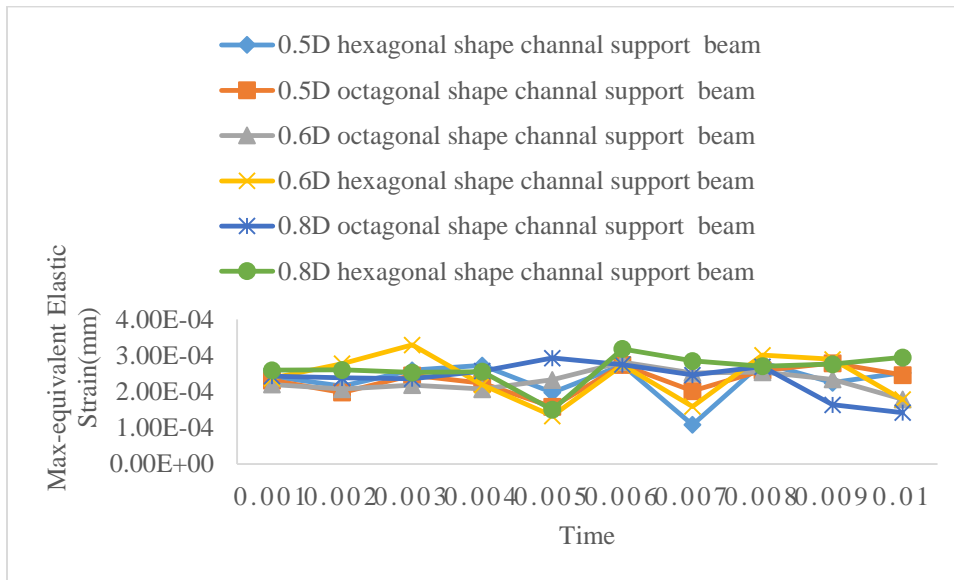


Figure 31 strain vs time graph with different depth opening of c channel support beam

As shown the above figure Strain variation according to the depth opening is seen in Fig. 3. Strain rates increase at the depth of opening 0.5D, 0.6D, 0.8, respectively. While maximum strain occurs at the 0.8D and lowest strain occurs at the 0.5D

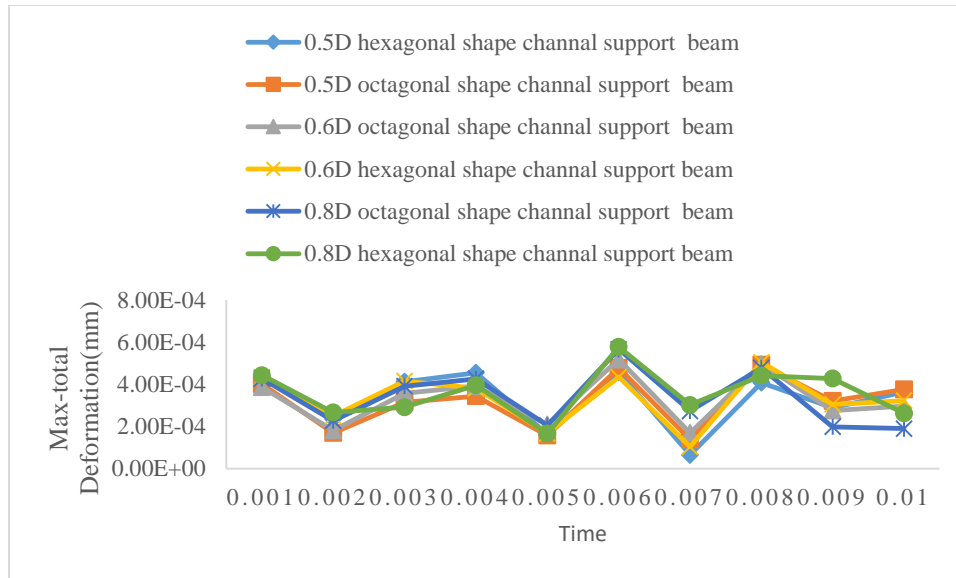


Figure 32 deformation vs time graph with different depth opening of C channel support beam

As shown in the above figure by changing shape of opening in castellated beam (i.e. Hexagonal, octagonal), it is concluded that there is no effect of shape of opening on deflection but shape of opening effect on stress concentration. It is seen that value of deflection is not depend on different parameters of hole. Different parameters of hole are affecting to stresses only.

From the previous discussions of the depth of opening, influences in changing ratio of depth opening of different geometry compared and discussed. Now the whole result of on each depth opening parameter of geometry and their perspective shape of channel beam could be summarized as shown in the next column graph

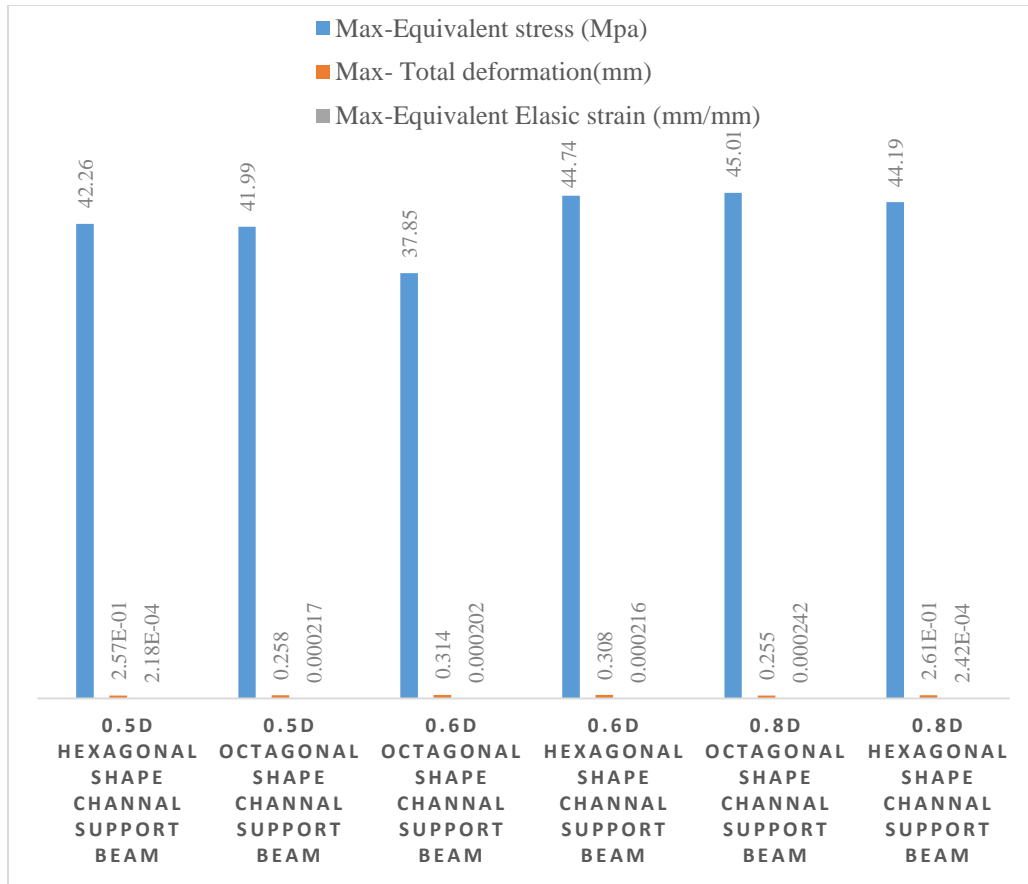


Figure 33 Comparison between different depth of opening and shapes of opening (hexagonal and octagonal)

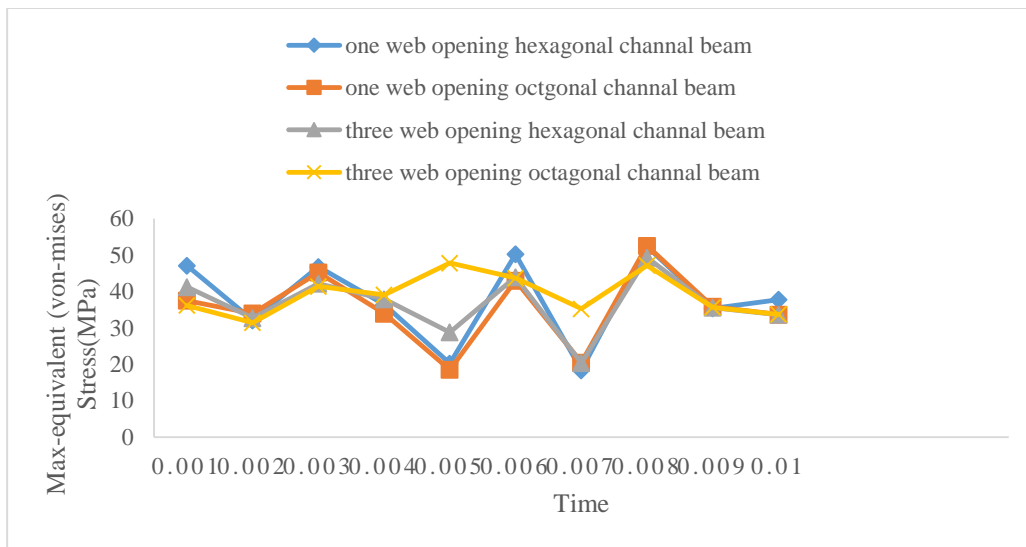


Figure 34 stress vs time graph with number of opening of C channel support beam

From the above figure by changing number of opening of Channel support beam. It is also concluded that maximum stresses occur at three web opening hexagonal C channel beam. By increasing the number of opening the stress increase. Generally from the analysis three web opening is better to shift the stress concentration point at the opening region.

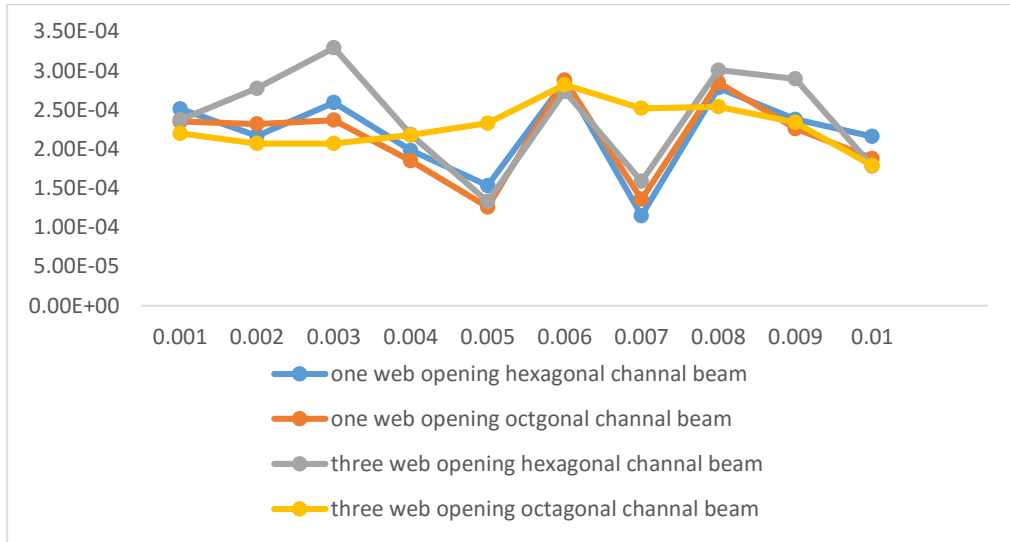


Figure 35 Strain vs time with different number of opening of channel beam

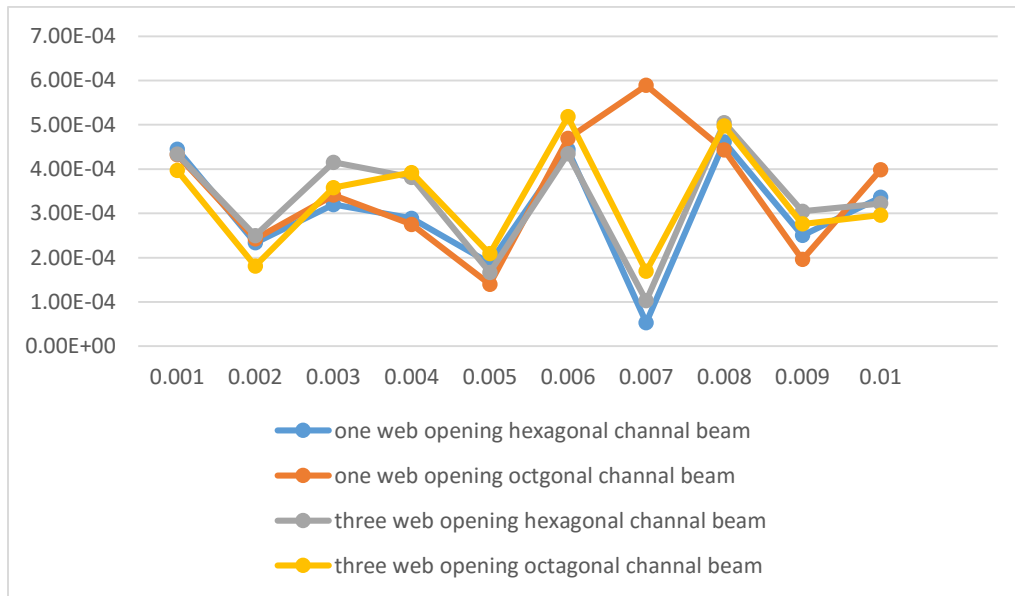


Figure 36 Deformation vs time with different number of opening of channel beam

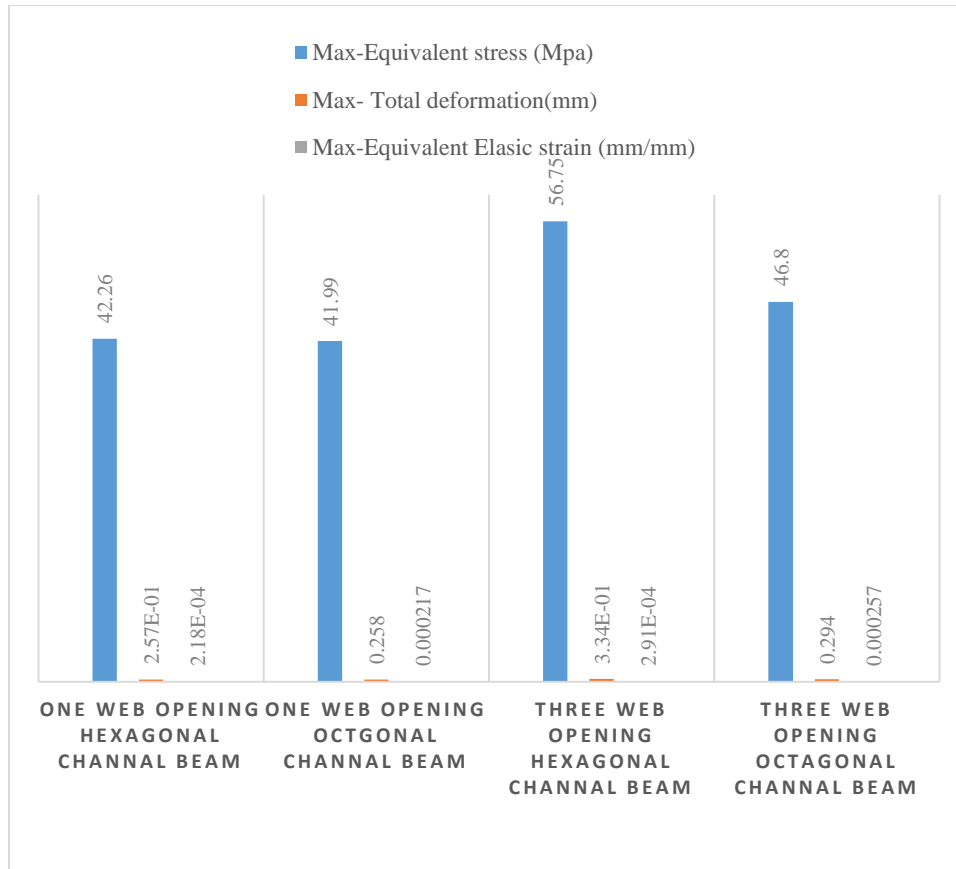


Figure 37 Comparison between different shapes of number of opening (hexagonal and octagona

CHAPTER FIVE

5. CONCLUSION RECOMMENDATION AND FUTURE WORK

5.1 Conclusion

The study focus on the stress analysis of the supporting elevator car frame structure and dynamic load condition. The analysis considers for the case of when the elevator in running condition considering loaded car, fully loaded car and over loaded car capacity loading condition. Stress Analysis is also conducted by varying the shape of web opening and different parameter like depth opening and number of opening are considered in the analysis.

The stress value of the bottom support C channel beam due to force applied after stress analysis ANSYS result shifting the stress concentration point and optimize the strength weight ratio. The web opening longitudinal stiffeners enable a better stress redistribution around the opening region contributing for an increase of the beams ultimate load carrying capacity. The C channel support beam should have enough stiffness to use different shape web opening with different parameter like depth of opening and number of opening. The material removed to reduce the weight of lower horizontal C channel beam so as to improve the efficiency. In this thesis, the modeling of bottom support elevator car frame and finite element analysis has been presented. The stress analyses has been done in this thesis work. Firstly, minimize the weight of the C channel support beam under the effect of equivalent stress by gradually reducing the area of solid channel beam with different shape web opening (hexagonal and octagonal) within the limit of allowable stress. The bottom channel web opening supporter beam is 2 % weight reduction in total mass channel beam and from analytical result to improve 13.2% strength weight ratio than the current solid channel beam for the same materiel. The main objective of the present work to optimize the strength to weight ratio and weight reduction in C channel support beam and to perform stress analysis at varying the depth opening, number of opening and stress conditions and different shape like hexagonal and octagonal.

5.2. Recommendation

The bottom supporting elevator car frame component needed more attention than other parts, to reduce the problem related to vertical beam and cross head beam. This paper recommends using shape like hexagonal and octagonal on C channel support beam with considering depth opening and number of web opening during the mechanical break loading condition. This paper is also recommended using C channel web opening in hexagonal and octagonal shape in stress analysis dispensable weight, material Expenditure and stress level are reduced for bottom beam of elevator structure and also improve the strength to weight ratio and weight reduction in C channel support beam and to perform stress analysis at varying the depth opening.

5.3 Future Work

In this thesis work total deformation, von misses stress and maximum Equivalent elastic strain are studied for different shape web opening and parameters like depth of opening on the bottom support C channel beam. Other influence factors are not studied. So this work is restricted to specified cases. However, this paper can be extended to other situation listed below

- Applying of different parts on other parts of the elevator such as, cross head vertical member
- Using the analysis by using other forms fiber composite in space plate of stiffener of web opening to increase its performance
- Do the analysis by assessing other cause of failure of the elevator, such as the impact

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APPENDIX I

A) FEM Result on solid C channel support beam

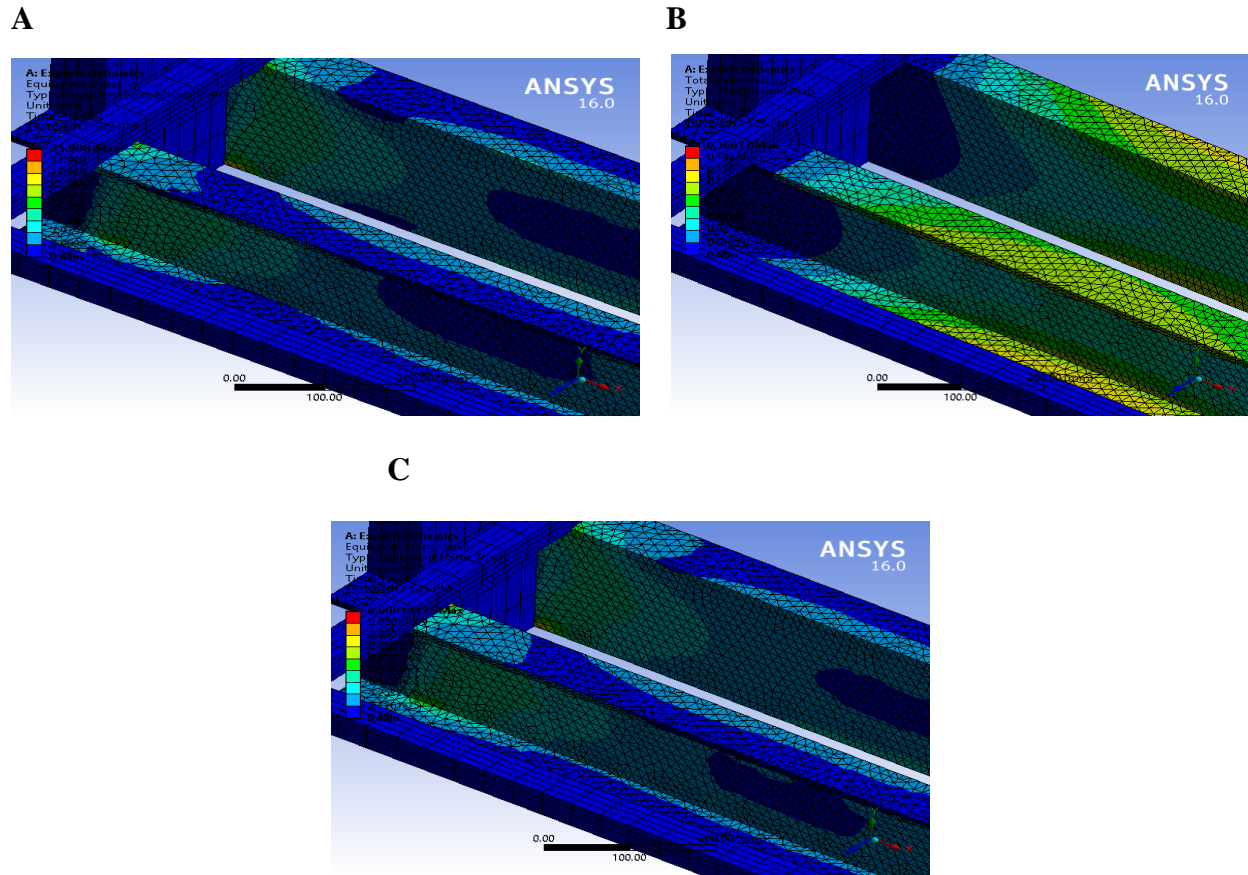
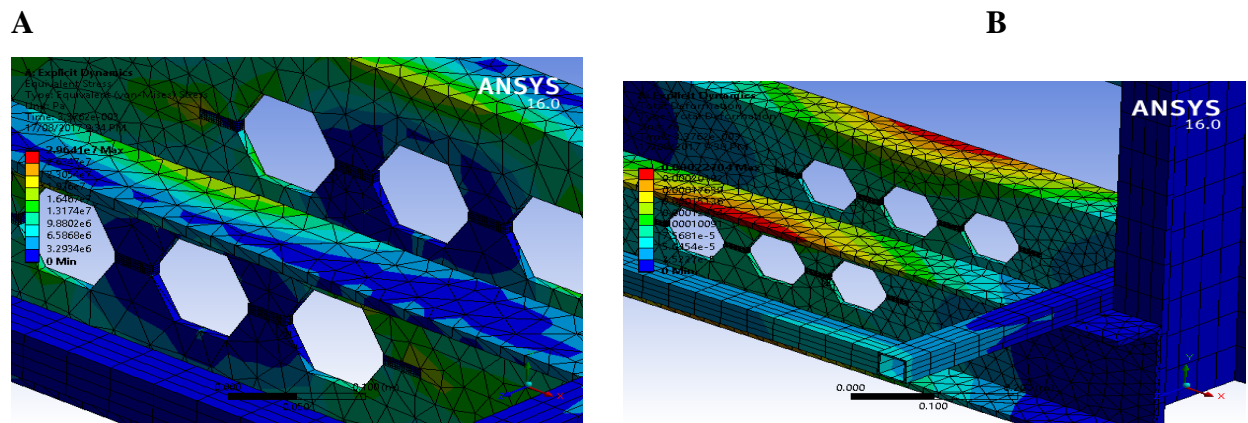


Figure38 Solid C channel support beam (without web opening) at maximum load condition A) Equivalent Von- Mises Stress B) total deformation C) Equivalent Elastic strain
 B) FEM result on web opening C channel support beam (with space plate reinforcement)



C

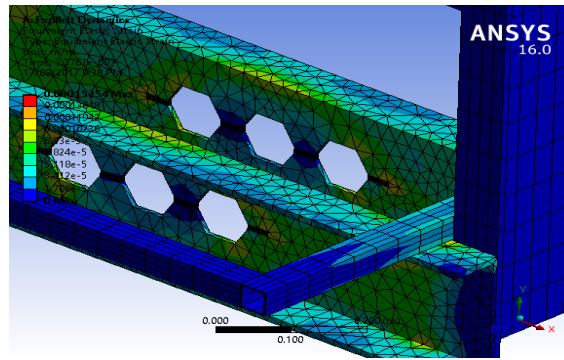
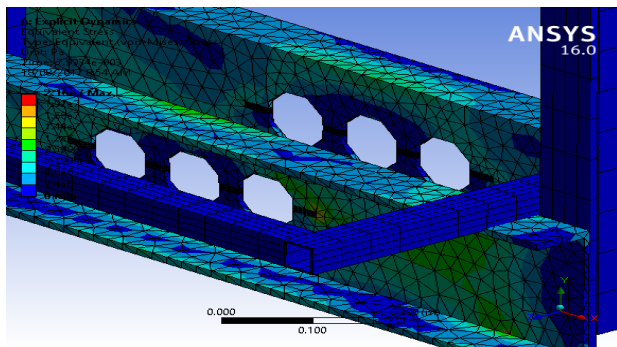
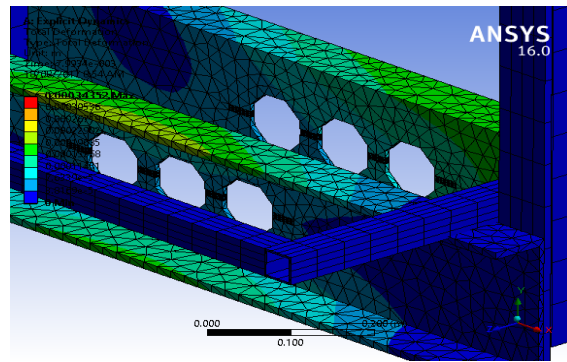


Figure.39 Hexagonal web opening C channel support beam (with space plate reinforcement) at maximum load condition A) Equivalent Von- Mises Stress B) total deformation C) Equivalent Elastic strain.

A



B



C

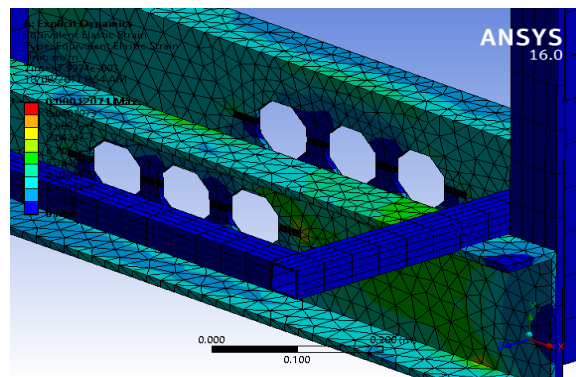
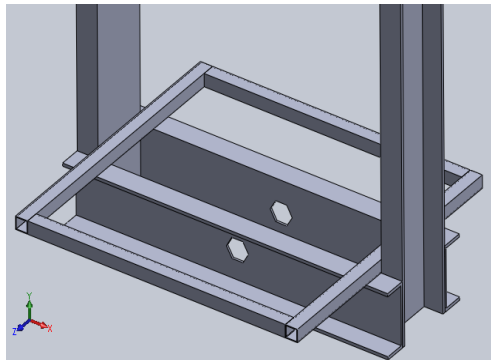


Figure.40 octagonal web opening C channel support beam (with space plate reinforcement) at maximum load condition A) Equivalent Von- Mises Stress B) total deformation C) Equivalent Elastic strain.

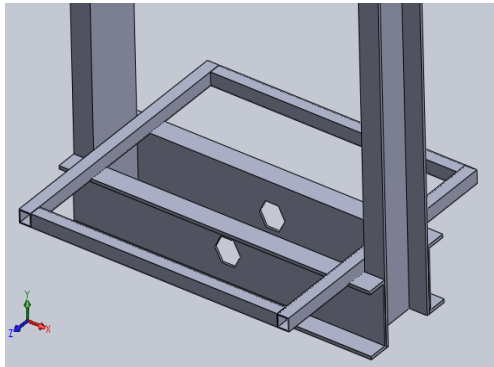
APPENDIX II

Analysis Model

A



B



C

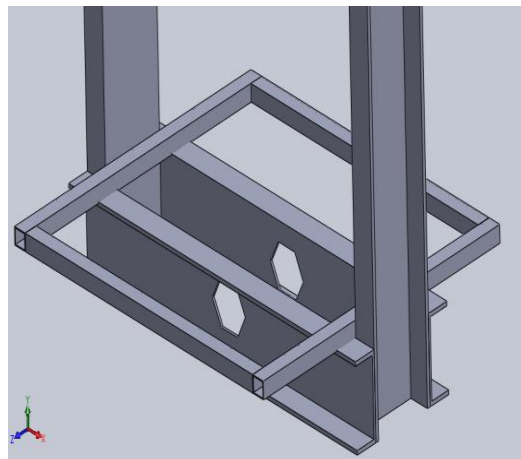
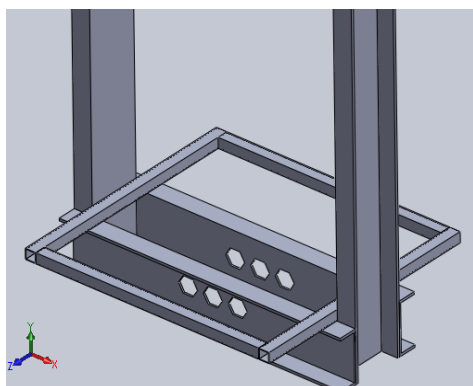
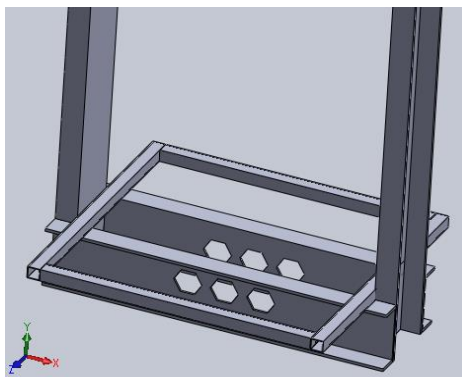


Figure 41 the solid model of C channel one opening hexagonal shape A) 0.5D B) 0.6D C) 0.8D

A



B



C

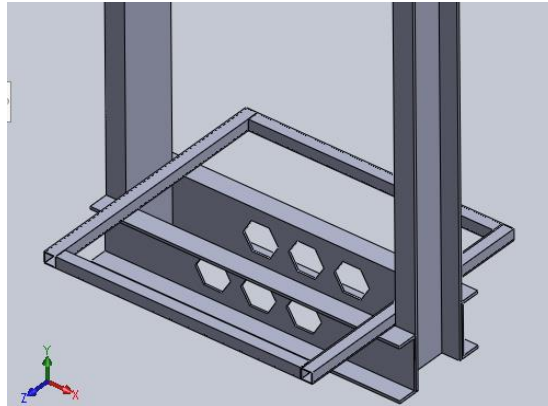
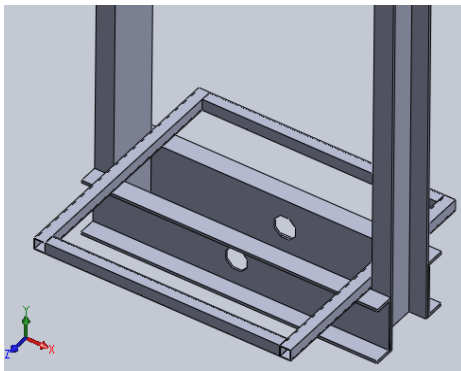
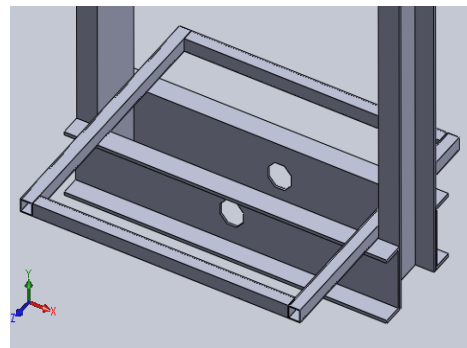


Figure 42 The solid model of C channel three opening hexagonal shape A) 0.5D B) 0.6D C) 0.8D

A



B



C

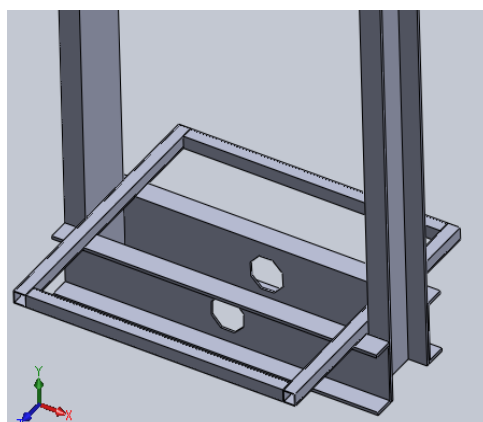


Figure 43 the solid model of C channel one opening octagonal shape A) 0.5D B) 0.6D C) 0.8D

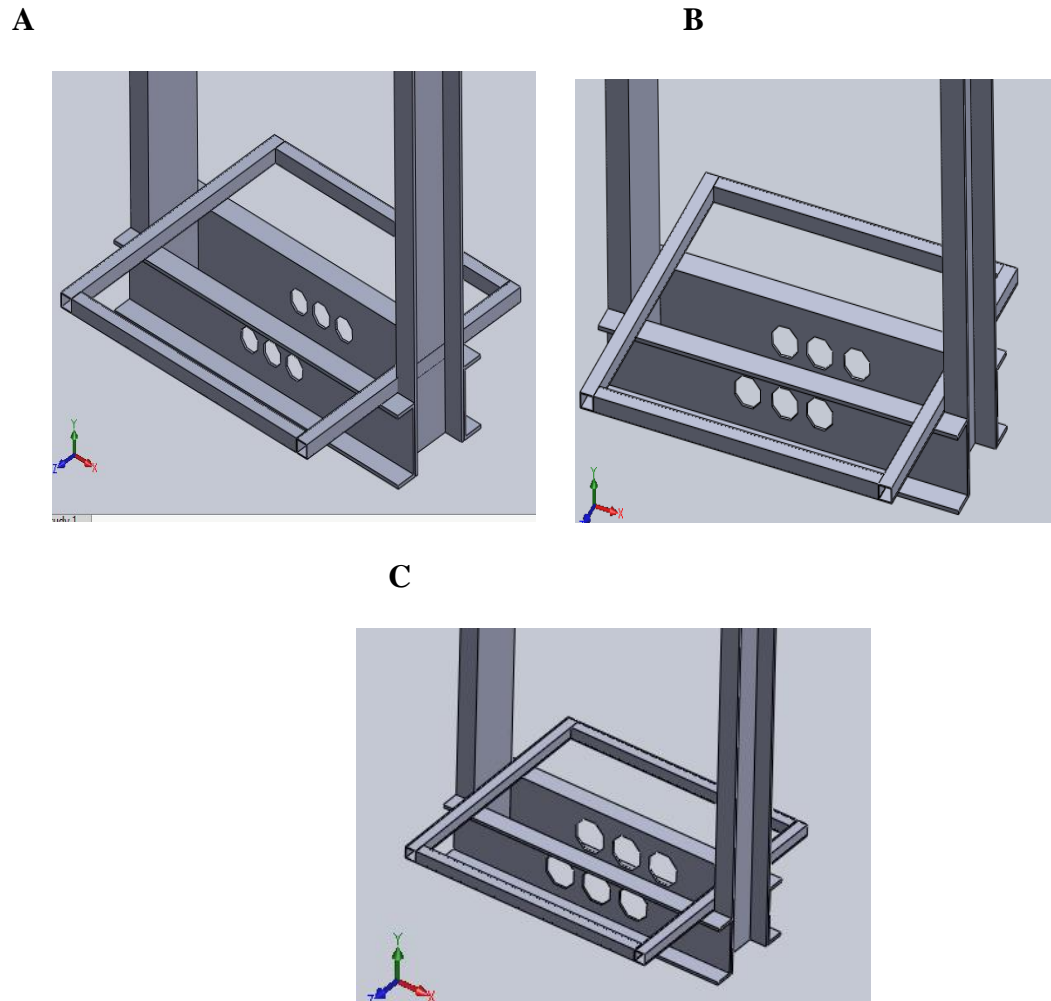


Figure 44 the solid model of C channel three opening octagonal shape A) 0.5D B) 0.6D C) 0.8D

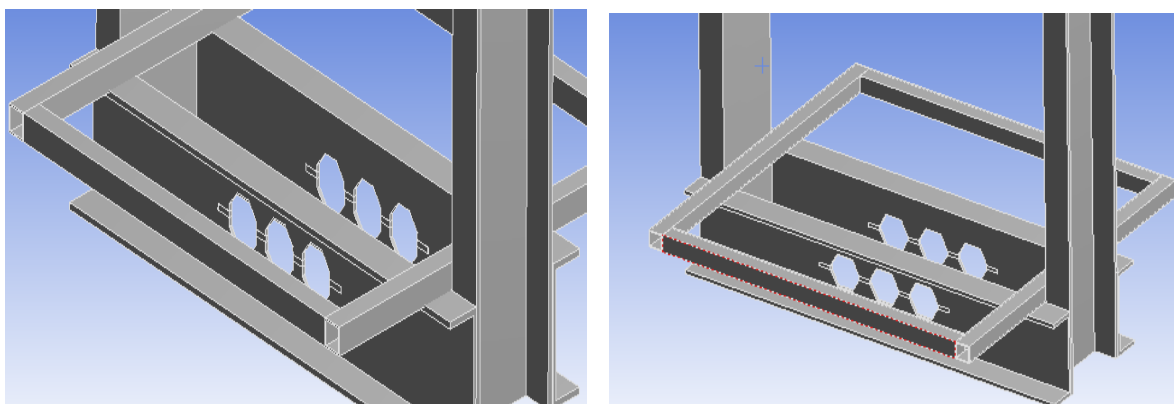


Figure 45 The ANSYS geometry model of C channel beam (with space plates reinforcement)



Figure 46 The ANSYS geometry model of space plates reinforcement)

2 ANSYS Procedure

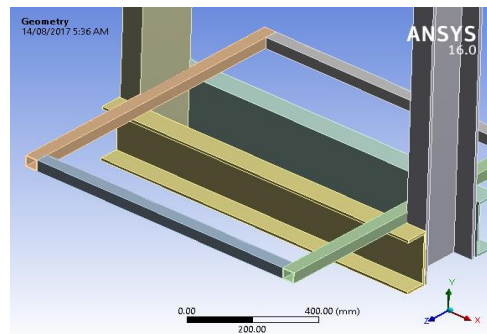


Figure.47 The geometry of solid C channel beam

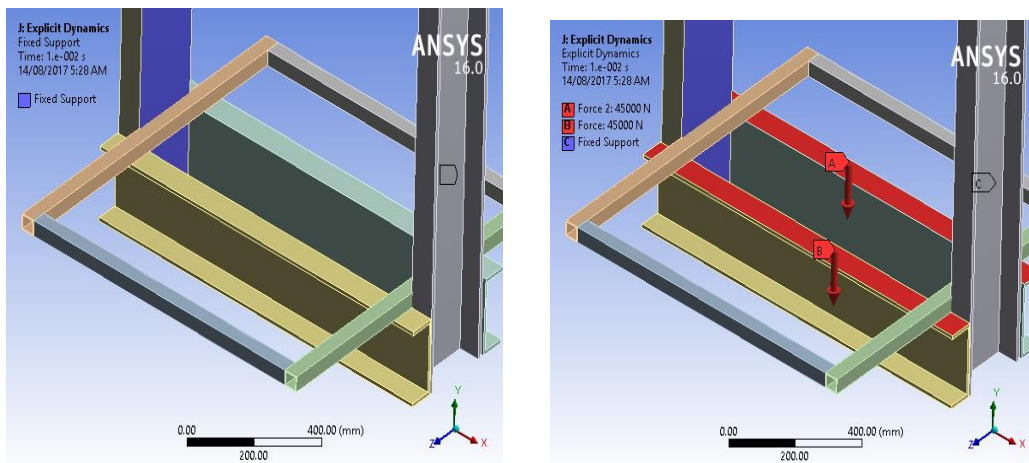


Figure 48 Applying boundary conditions on ANSYS Workbench on elevator car frame structure

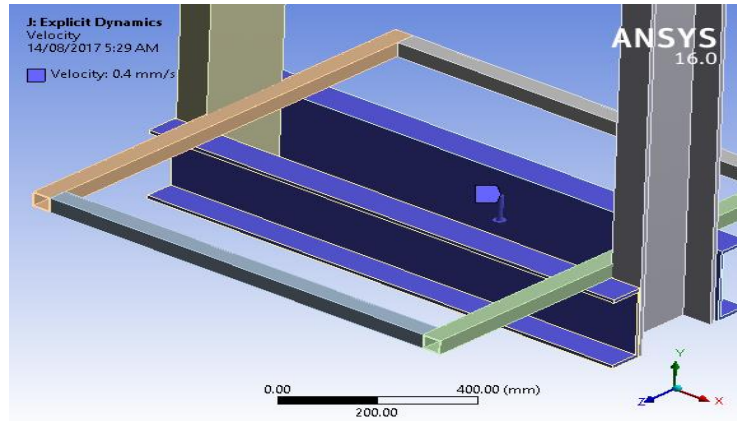


Figure 49 Applying velocity field due to inertial load on ANSYS Workbench

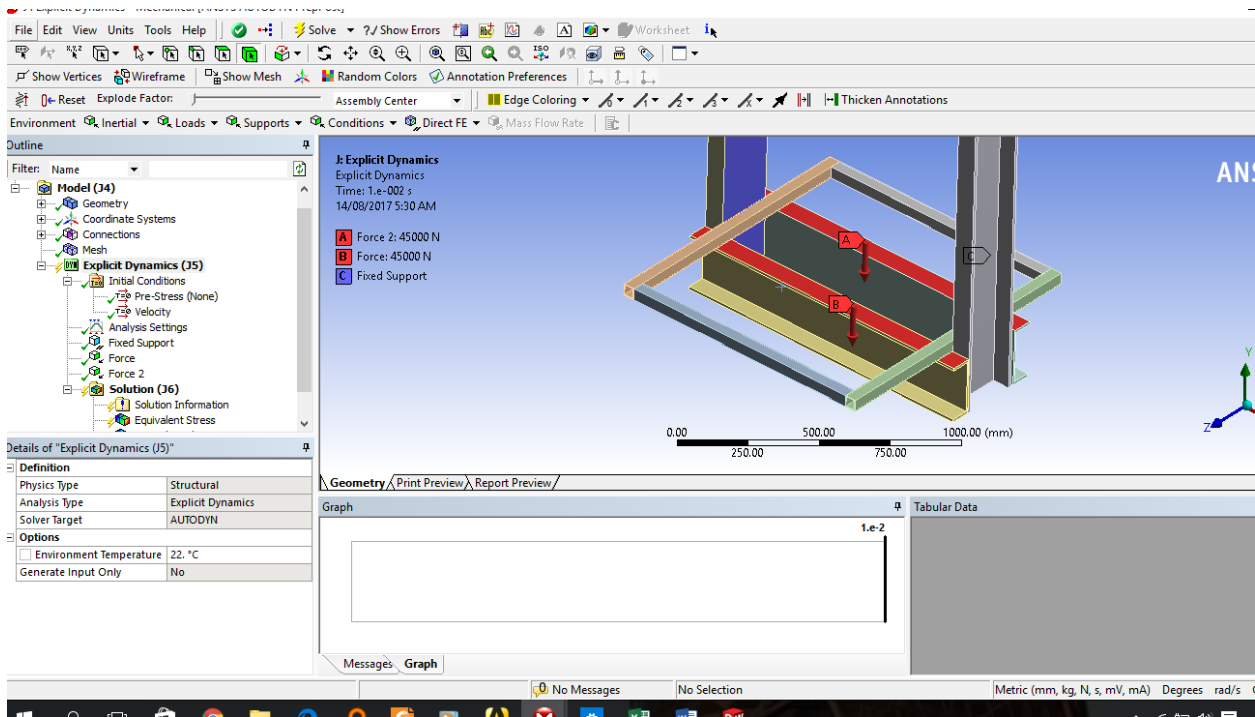


Figure 50 Generating the solution the above input parameter