Sudan University of Science and Technology

College of Engineering

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Design model of vertical farm structure supported by mechanical system

A Project Submitted in Partial Fulfillment for the Requirements of the Degree of B.S.C (Honor) in Mechanical Engineering (Production)

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بسم الله الرحمن الرحيم

قال تعالى :-

{ أَوَلَمْ يَرَوْا أَنَّا نَسُوقُ الْمَاءَ إِلَى الْأَرْضِ الْجُرُزِ فَنُخْرِجُ بِهِ زَرْعًا تَأْكُلُ مِنْهُ أَنْعَامُهُمْ وَأَنفُسُهُمْ ۖ أَفَلَا يُبْصِرُونَ }

السجدة الآية (27)

Courtesy

To our **professors** who paved our way of science and knowledge, inspired us and open our eyes to new ways of thinking we have never known before.

To our dear **parents** who lit our way to reach this summit.

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To all I express my gratitude for their support.

Abstract

The research aims to study vertical farming technique which is one of modern techniques, and so with its great potential in contributing to meet the need for various agricultural products by amounts of productivity exceeds the traditional agriculture, also it aims to increase strawberry productivity besides facilitating agricultural operations, and that through design dedicated system for cultivate in vertical layers providing them by a mechanical system for movement and rotation of these layers to be able to cultivate and harvest on all layers, besides provide ventilation and light needed for plants, also the layers are provided by an irrigation system for watering crops, and the necessary design calculations has been done besides using Solidworks software to assist in design and analysis of the system.

The results show by using the principle of vertical farming the maximum cultivable area can be exploited a total of more than doubled compared to conventional agriculture, also the productivity of strawberry using vertical farm has increased at a rate of 126% compared with traditional agriculture of strawberry. In addition to facilitating agricultural operations for operators such as cultivation, irrigation and harvest besides facilitate censorship for products, by replacing large horizontal spaces in traditional farms by going towards cultivate vertically allowing limited agricultural area, besides the mechanical system which rotates the tiers from top height to the bottom.

المستخلص

يهدف البحث الى دراسة تقنية الزراعة العمودية التي تعتبر من التقنيات الحديثة ، وذلك بما لها من امكانيات كبيرة في المساهمة بتلبية الحوجة للمنتجات الزراعية المختلفة بكميات انتاجية تفوق الزراعة التقليدية، ايضا يهدف البحث الى زيادة انتاجية الفراولة بالاضافة الى تسهيل العمليات الزراعية، وذلك من خلال تصميم منظومة مخصصة للزراعة في طبقات عمودية وتزويدها بنظام ميكانيكي لحركة و دوران هذه الطبقات للتمكن من اجراء عملية الزراعة والحصاد بكافة الطبقات وتوفير التهوية والضوء اللازمين للنباتات بالاضافة الى تزويد المنظومة بنظام للقيام بعملية الري، ولقد تم اجراء الحسابات التصميمة اللازمة و استخدام برنامج (Solidworks) للمساعدة في تصميم وتحليل المنظومة.

وقد اظهرت النتائج انه باستخدام مبدأ الزراعة العمودية يمكن استغلال المساحة القصوى للزراعة والتي تصل الى اكثر من الضعف مقارنة بالزراعة التقليدية، ايضا بالزراعة عموديا زادت انتاجية الفراولة بمعدل 126 % بالمقارنة بالزراعة التقليدية للفراولة، بالاضافة الى تسهيل العمليات الزراعية من زراعة و ري و حصاد على العمال وتسهيل عملية الرقابة على المنتجات، وذلك باستبدال المساحات الافقية الكبيرة في المزارع التقليدية بالتوجه نحوالزراعة رأسيا مما يتيح حصر منطقة الزراعة، بالاضافة الى النظام الميكانيكي الذي يعمل على دوران الطبقات من الارتفاع الاغلى الى الادنى.

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VF	**Vertical Farm**
HDVG	**High Density Vertical Growth**
LED	**Light-Emitting Diode**
PVC	**Polyvinyl chloride**
ANSI	**American National Standards Institute**
D_s	**Density of Soil**
m	**Mass of soil**
V	**Volume**
W	**Weight**

D	**Diameter**
HP	**Horse Power**
T_g	**Number of teeth in gear**
P_t	**Pitch**
P	**Power**
RPM	**Revolution Per Minute**
T_r	**Torque**
F	**Force**
F_r	**Coefficient of Friction**
N	**Rotational Speed**
S_s	**Allowable Torsional Shearing Stress**
α	**Angular Deflection of Shaft**
USS	**Ultimate Shear Strength**
TYS	**Tensile Yield Strength**
N_t	**Number of Teeth**
PD	**Pitch Diameter**
P_c	**Pitch Circular**
L	**Length**
d	**Nominal Diameter of the Thread**

S	Size of Hex Head
K	Height of Bolt head
b	Thread Length
ME	Major Equipment
SP	Selling Price
FC	Fixed Cost
VC	Variable Cost

Appendix

Chapter One

Introduction

Chapter One

Introduction

1.1 Introduction

According to the United Nations World Food Program nearly 1 billion people worldwide are undernourished. This already unacceptable situation is going to compound with growing population and therefore requires new approaches towards food production in the coming decades. Transition economies must further adapt to the fast changing dietary pattern towards high protein, vitamin and mineral rich diets demanded by a growing population with gradually increasing purchasing power. By 2050, the growing global population will require an estimated 60% more food than produced today.

All this while 1.3 billion tons of global food production is lost or wasted annually, until 2050 the number of people living in urban areas is expected to rise to more than 6 billion, 90% of them in developing countries. This unprecedented explosion and growth of mega-cities worldwide may prove unsustainable and ecologically disastrous. In 2000, the world's mega-cities took up just 2% of the Earth's land surface, but they already accounted for roughly 75% of the industrial wood use, 60% of human water use, and nearly 80% of all human produced carbon emissions. It is clear that the human population is not only growing but also concentrating in social agglomerates. This has mixed effects on the environment. From a macro perspective, it means concentration of service industry and less distance to be covered to deliver goods and services, thus cutting on emissions. Arable land is also finite, with agricultural land covering 38% and arable land covering 11% of the total land area. The global projections show that up to 2040 agricultural land can only be increased by another 2%. Water is a scarce resource too.

From this, the need to minimize the negative environmental effects of agriculture, particularly with regard to greenhouse gas emissions, soil degradation and the protection of already dwindling water supplies and biodiversity arises. Therefore we need to find agricultural technologies that have a neutral or positive impact on our environment.

Vertical Farming holds the promise of addressing these issues by enabling more food to be produced with less resources use. However, its economic as well as environmental feasibility requires in-depth scientific investigation. Vertical Farming is steadily becoming a subject discussed broadly in industrial and scientific communities. It is an agricultural technique involving large-scale food production in high-rises. Using cutting-edge greenhouse methods and technologies, like High Density Vertical Growth (HDVG), these buildings would be able to produce fruits, vegetables and other consumables throughout the year. The concept involves growing and harvesting of a wide range of plants in high density urban areas (mega cities) and the sale of these crops directly within the city community, reducing transportation as opposed to the standard rural farming model. The advantages of this method are the multiplication of agriculturally productive land (by growing in vertically mounted stacks), the increase in crop yields (by using optimized production methods, such as light exposure variations, or additional CO_2 supply), the protection of the crops from weather-related problems as well as pest and diseases (as opposed to outdoor farming), and the minimization of water requirements (through water recycling).

1.2 Project Problem

The problem is about increasing food productivity (High quantity) of agriculture products, to ensure food security for the future, through design vertical farm structure supported by mechanical system.

1.3 Project importance

The research contribute to food security by encouraging the idea of local producing and consuming food in addition to the idea of productive families, besides the Possibility of farming products in non-arable areas. Also the protection of agricultural products from contamination and environmental disasters, by growing agricultural products under controlled conditions.

1.4 Project Objectives

1- Increase strawberry productivity by applying vertical farm technique.

2- Facilitating agricultural operations by design a model of vertical farm structure supported by mechanical system.

1.5 Project Scope

Design vertical farm system (A-shaped tower) for growing Strawberry on tiers and focus on tiers transmission system and irrigation system design.

1.6 Project Layout

The project consists of five chapters, in the first chapter the project addresses an introduction to the concept of vertical farm and it is importance and need for it, due to food shortage in the world, besides the massive increase of population in the world and Concentration of population in urban areas. In addition to some Statistics which show the need to apply the concept of vertical farming. The chapter also includes the project problem, importance, objectives and scope.

In chapter two the literature review is addressed, the chapter contains a background of vertical farm in addition to the relation between vertical farm and weather problems. Also the chapter contains the concept of vertical farm in developing countries besides an explanation of the types of vertical farm, also advantages and limitation of vertical farming.

The methodology of the project is explained in chapter three, it contains a detailed explanation of the farming system and each component of the system is presented with its function.

In chapter four the design results are presented and discussed. The chapter deals with a detailed explanation of design calculations, also it contains analysis results which emphasizes that each part of the system confirm the design specifications and configuration. Also the chapter contains a cost estimation of the system.

The conclusion and recommendations are presented in chapter five. The chapter presents results obtained from chapter four in addition to recommendations for researchers in the future.

Chapter Two

Literature Review

Chapter Two

Literature Review

2.1 Vertical Farming background

Vertical farming is one promising solution to the drawbacks of traditional agriculture. Compared to traditional agriculture, vertical farming uses 70 to 95 percent less water and over 90 percent less land, while harvesting 80 percent more per unit of area. The Association for Vertical Farming, a two-year-old nonprofit focused on advancing the industry, says that vertical farming allows farmers to produce crops all year round because all environmental factors are controlled. It produces healthier and higher yields faster than traditional agriculture, and is resilient to climate change. Moreover as the global population becomes more urbanized, vertical farms can help meet the rising demand for fresh local produce[1].

2.1.1 Vertical Farming history

The concept of Vertical Farms (VF) as it is understood nowadays is very different as the first intents or ideas of this concept. Nowadays defenders of VF argue that, by allowing traditional outdoor farms to revert to a natural state and reducing the energy costs needed to transport foods to consumers, vertical farms could significantly alleviate climate change produced by excess atmospheric carbon.

Critics have noted that the costs of the additional energy needed for artificial lighting, heating and other vertical farming operations would outweigh the benefit of the building's close proximity to the areas of consumption. One of the first's ideas of Vertical Farms was published at the Life Magazine in 1909 where a tall building that cultivates food for the purposes of consumption.

Architects as Le Corbusier in the Immeubles-Villas (1922) reproduce some ideas related to the Vertical Farm concept.

1909 Life Magazine idea placing houses with gardens in a vertical way.

Many built examples in high buildings using hydroponics are documented in the canonical text of The Glass House by John Hix. Some of them are the Vertical Farms at the School of Gardeners in Langenlois, Austria, and the glass tower at the Vienna International Horticulture Exhibition (1964). This shows that the VF concept already existed more than forty years before the currently debate about the sustainability and viability of Vertical Farms.

Despite the architectural precedents, nowadays technology is many steps upper than the one used before. The development of Hydroponic technology in greenhouses has experimented a large evolution in the last decades. These horticultural building systems evolved from greenhouse technology, and paved the way for the modern concept of the Vertical Farm.

The British Interplanetary Society developed a hydroponic for lunar conditions and other building prototypes where developed during the early days of space exploration. During this era of expansion and experimentation the first Tower Hydroponic Units where developed in Armenia in 1951[2].

2.1.2 Vertical Farming and weather problems

Crops grown in traditional outdoor farming suffer from the often suboptimal and sometimes extreme nature of geological and meteorological events such as undesirable temperatures or rainfall amounts, monsoons, hailstorms, tornadoes, flooding, wildfires, earthquakes and severe droughts. The protection of crops from weather is increasingly important as global climate change occurs. “Three recent floods (in 1993, 2007 and 2008) cost the United States billions of dollars in lost crops, with even more devastating losses in topsoil. Changes in rain patterns and temperature could diminish India’s agricultural output by 30 percent by the end of the century.

Because vertical plant farming provides a controlled environment, the productivity of vertical farms would be mostly independent of weather and protected from extreme weather events[3].

2.1.3 Vertical farming in developing countries

As previously stated, Despommier claims locating vertical farms near human hot spots can alleviate hunger and starvation as well as a lot of the sanitary issues seen in developing countries due to human feces being used as fertilizers. However if someone cannot pay for artificial fertilizers and is suffering starvation and disease because they cannot afford proper nutrition and health care, how are they going to pay for vertical farms, a single building of which is probably worth millions of dollars in construction and operational costs.

Unless extensive financial aid was given to the establishment of vertical farms in developing countries and "human hot spots" it´s unlikely that we will see any of these in the aforementioned regions in the near future. Although vertical farms might initially only be available to people with a strong economy, technology gets cheaper. The IPhone might not initially have been developed with third world markets in mind but eventually it reaches these areas as well. So maybe we just have to withstand that vertical farms, initially become the toys of the richer westernized world, keeping in mind that eventually the technology will be available in the countries where it will benefit the most[4].

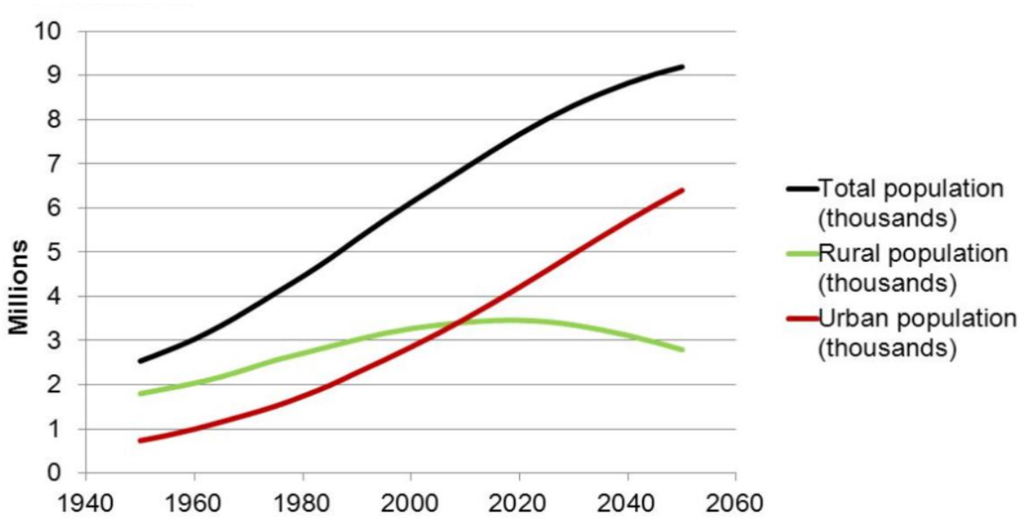


Fig 2.1: Population Trends

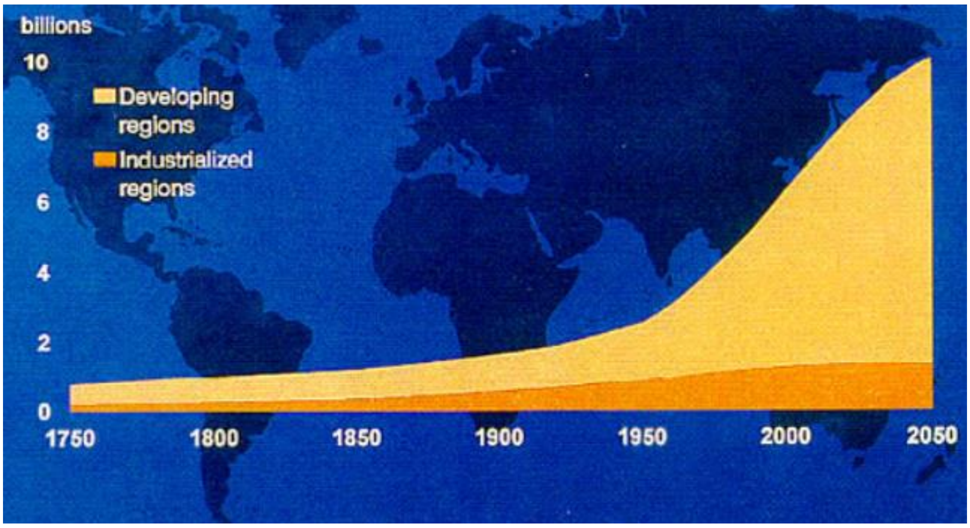


Fig 2.2: World Population Growth

2.1.4 Types of vertical farm

The term "vertical farming" was coined by Gilbert Ellis Bailey in 1915 in his book Vertical Farming. His use of the term differs from the current meaning he wrote about farming with a special interest in soil origin, its nutrient content and the view of plant life as "vertical" life forms, specifically relating to root structures underground. Modern usage refers to skyscrapers using some degree of natural light[5].

2.1.4.1 Mixed-use skyscrapers

Mixed-use skyscrapers were proposed and built by architect Ken Yeang which combines living units and opportunities for food production. Yeang proposes that instead of hermetically sealed mass-produced agriculture that plant life should be cultivated within open air, mixed-use skyscrapers for climate control and consumption (i.e. a personal or communal planting space as per the needs of the individual). This version of vertical farming is based upon personal or community use rather than the wholesale production and distribution plant life that aspires to feed an entire city.

Despommier's concept of "The Vertical Farm" emerged in 1999 at Columbia University. It promotes the mass cultivation of plant life for commercial purposes in skyscrapers[5].

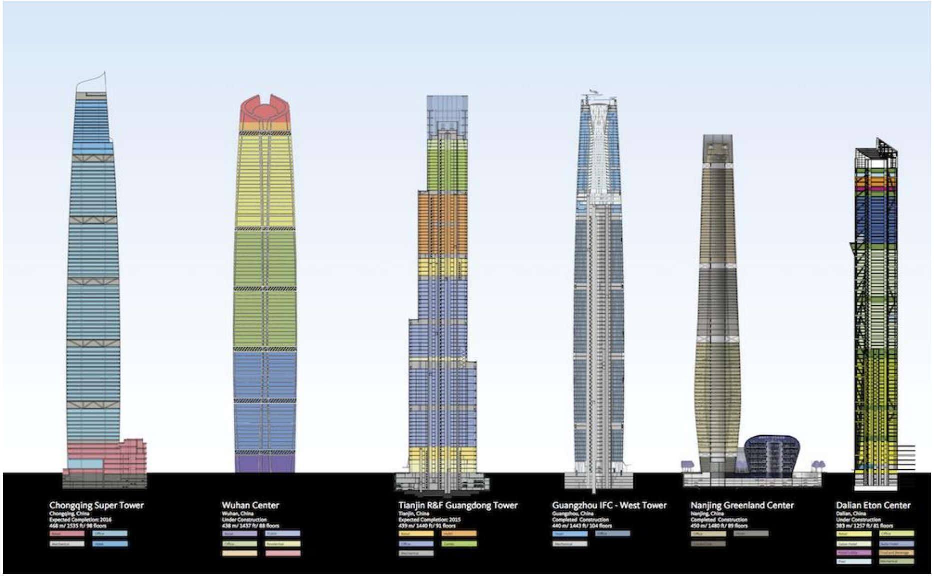


Fig 2.3: Mixed-use skyscrapers

2.1.4.2 Stackable shipping containers

Several companies have brought forth the concept of stacking recycled shipping containers in urban settings. Freight Farms produces a “leafy green machine” that is a complete farm-to-table system outfitted with vertical hydroponics, LED lighting and intuitive climate controls built within a 40’x8’ shipping container. Podponics has built a large scale vertical farm in Atlanta consisting of over 100 stacked grow pods. A similar farm is currently under construction in Oman**[5]**.

Fig 2.4: Stackable shipping containers

2.1.4.3 Despommier’s skyscrapers

Ecologist Dickson Despommier argues that vertical farming is legitimate for environmental reasons. He claims that the cultivation of plant life within skyscrapers will produce less embedded energy and toxicity than plant life produced on natural landscapes. He moreover claims that natural landscapes are too toxic for natural, agricultural production, despite the ecological and environmental costs of extracting materials to build skyscrapers for the simple purpose of agricultural production[5].

2.2 Modern Agriculture

The modernity of agricultural systems is a characteristic well understood by farmers but not easily defined with specificity. Still, the distinctions between modern and traditional systems have powerful implications for the future development of the global food system even though it is important to recognize that few, if any, systems fall entirely into either the modern or traditional categories. Traditional systems. Perhaps the most important difference between the categories is the way farmers see themselves and their roles. Traditional farmers, for example, often say that they seek to work effectively with resources at hand. That is, they use the land, rainfall, seeds, tillage methods and power sources they have to produce what nature offers. Conventional processes are used to till the land, select and plant seeds, protect plants from competing plants and animals and gather the harvest. Surpluses are marketed through nearby outlets. Such producers frequently report only limited capacity to change these processes and some seek to avoid change.

The productivity of such systems depends primarily on the natural fertility of the soils enhanced by skillful care and on the climate. The technology and management systems involved are often characterized by lack of access to, or reluctance to use new information about production and/or management, or public or commercial assistance. Their productivity tends to grow slowly, often in response to outside developments that reduce producer isolation, increase access to markets or support investment in water and land. Modern agriculture. In modern agricultural systems farmers believe they have much more central roles and are eager to apply technology and information to control most components of the system, a very different view from that of traditional farmers. In contrast to the isolation inherent in traditional arrangements, modern agriculture tends to see its success as dependent on linkages access to resources, technology, management, investment, markets and supportive government policies. As a result, much of the success of modern systems depends on the development and maintenance of soil fertility through the specific provision of nutrients when they are depleted; of machine power and technology to create soil conditions necessary to promote plant growth with minimal disturbance and minimal soil loss; of the use of improved genetics for crops and livestock to enhance yields, quality and reliability; and, on modern genetic and other techniques to protect plants and livestock from losses to competing plants, diseases, drought insects and other threats. This success also depends on access to efficient, effective irrigation to supplement rainfall in many climates; on advanced harvesting, handling and storage equipment and techniques to prevent losses and to market commodities efficiently. It depends, in turn, on both public and private investment to provide access to technology, equipment, information and physical facilities throughout the production-marketing system. And, it depends on well supported commercial and financial systems and broad public policies that support effective commercial markets at all levels that generate economic returns throughout the system[6].

2.3 Economics

Opponents question the potential profitability of vertical farming. A detailed cost analysis of start-up costs, operation costs, and revenue has not been done. The extra cost of lighting, heating, and powering the vertical farm may negate any of the cost benefits received by the decrease in transportation expenses. The economic and environmental benefits of vertical farming rest partly on the concept of minimizing food miles, the distance that food travels from farm to consumer. However, a recent analysis suggests that transportation is only a minor contributor to the economic and environmental costs of supplying food to urban populations. The author of the report, University of Toronto professor Pierre Desrochers, concluded that "food miles are, at best, a marketing fad." Thus the facility would have to produce a considerable profit to justify remaining in the city. A simpler concept rather than trying to stack farms on multiple stories would be to just cultivate crops on the roofs of existing building. Rooftop farming is a growing urban trend, requires little construction (other than fortifying the roof to hold the weight of the growing medium), still takes advantage of sunlight and doesn't require investment in machinery, growing lights or irrigation. Similarly, if the power needs of the vertical farm are met by fossil fuels, the environmental effect may be a net loss; even building low-carbon capacity to power the farms may not make as much sense as simply leaving the traditional farms in place, and burning less coal.

The initial building costs will be easily over $100 million, for a 60 hectare vertical farm. Office occupancy costs can be very high in major cities, with cities such as Tokyo, Moscow, Mumbai, Dubai, Milan, Zurich, and Sao Paulo ranging from $1850 to $880 per square meter, respectively[1].

2.4 Increased crop production

Unlike traditional farming in non-tropical areas, indoor farming can produce crops year-round. All-season farming multiplies the productivity of the farmed surface by a factor of 4 to 6 depending on the crop. With some crops, such as strawberries, the factor may be as high as 30. Furthermore, as the crops would be sold in the same infrastructures in which they are grown, they will not need to be transported between production and sale, resulting in less spoilage, infestation, and energy required than conventional farming encounters. Research has shown that 30% of harvested crops are wasted due to spoilage and infestation, though this number is much lower in developed nations. Despommier suggests that, if dwarf versions of certain crops are used (e.g. dwarf wheat, which has been grown in space by NASA, is smaller in size but richer in nutrients), year-round crops, and "stacker" plant holders are accounted for, a 30-story building with a base of a building block (2 hectares (5 acres)) would yield a yearly crop analogous to that of 1,000 hectares (2,400 acres) of traditional farming[7].

Table 2.1: Estimated yield of a Vertical Farm compared to traditional agriculture

Crops	Yield in VF due to	Field Yield (tons/ha)	Factor increase	Factor increase due to
Carrots	58	30	1,9	347
Radish	23	15	1,5	829
Potatoes	150	28	5,4	552
Tomatoes	155	45	3,4	548
Pepper	133	30	4,4	704
Strawberry	69	30	2,3	368
Peas	9	6	1,5	283
Cabbage	67	50	1,3	215
Lettuce	37	25	1,5	709
Spinach	22	12	1,8	820
Total (average)	71	28	2,5	516

2.5 Advantages of vertical farming

1. In an enclosed building, optimum temperatures can be controlled and maintained allowing for healthier, faster growing plants and additionally, a year round production schedule[8].

2. Every 1 acre indoors is equal to an average 4-6 outdoor acres depending upon the species. This is due to the fact that many layers of plants can be stacked on top of each other as well as other considerations of crop failures caused by the outside environment[8].

3. There are no crop failures due to the environment whether it be droughts, floods, pests, etc[8].

4. Every crop grown is able to receive its special defined diet concerning nutrient balance. No fertilizers, pesticides, or herbicides would be needed. All crops would be healthy and organic[8].

5. Vertical farming eliminates runoff of these chemicals into the environment and water supplies[8].

6. Massive amounts of forests needing to be cleared for farmland would no longer be necessary. The landscape can finally be returned back to nature and ecosystems restored[8].

7. There would be an elimination of infectious diseases that are started at the agricultural level due to the usage of feces as fertilizer[8].

8. The usage of fossil fuels would be greatly reduced, therefore global warming. Currently, 1/5th of all fossil fuel is used for agriculture. This fuel is used for plowing fields, harvesting, storing and refrigerating the goods, shipping either by boat or by tractor-trailer, or in some cases shipping to other processing plants. An unbelievable 1500 miles is the average distance that any given piece of produce travels until it finally reaches the grocery store[8].

9. The importation of foods would be lessened[8].

10. Urban centers can now be considered sustainable environments[8].

11. Without first testing an indoor farm on earth, we will not be able to live on the moon, Mars, or beyond. "At present a lot of research is being carried out to develop hydroponic systems for the growing of vegetables on the space station to be constructed in the future. Closed-loop re-circulating systems are being designed and tested to operate under micro-gravity environments. Hydroponic systems will grow food to nourish astronauts on long space missions." The best way to test these systems would be to have them realized in industry use[8].

Dickson Despommier feels that there is a great need for inner city blocks to have their own immediate source of food where plants will be grown without soil, by means of aeroponics and hydroponics within buildings already known as farmscrapers[8].

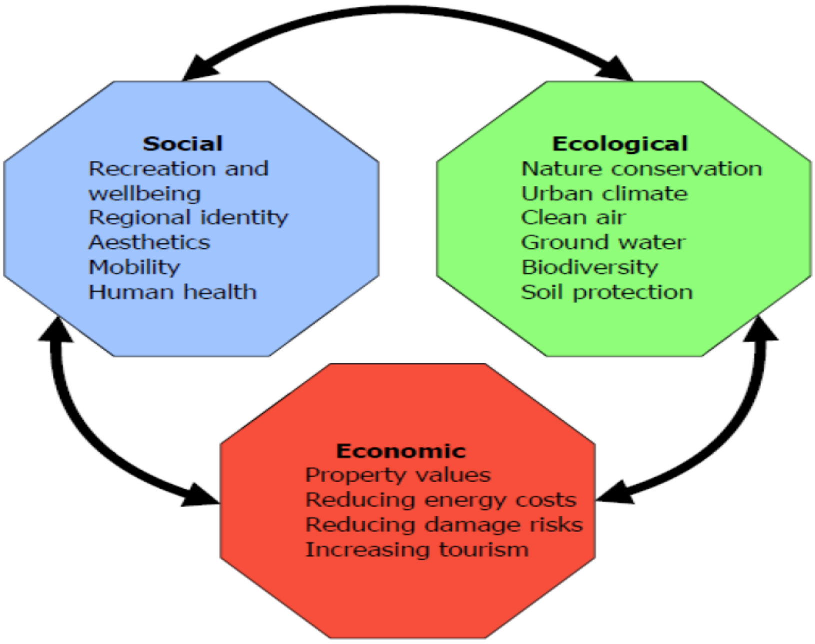


Fig 2.5: Social, Ecological and Economic benefits of VF

2.6 Limitation of vertical farming

However, those are the benefits, what are some of the negative aspects that haven't been mentioned in vertical farming? Well, pollination is something that needs serious consideration. Insects are crucial to this process. So if this is going to be an insect-free environment, pollination will have to be done by hand, which is labor-intensive, and will this result in the produce costing more?

And talking about costs, we all know that urban land is far more expensive that farm land, and the cost of creating such a concept and powering up a farmscraper for lights, controlling ambient temperatures and the like, will not be a cheap exercise. So just how much this produce will cost the consumer? It sounds as if it would cost them far more than what they could expect to pay for conventionally grown food.

Controlling the environment within these buildings with regards to lighting, temperature, pollination and the arrangement of plants will all be important factors for success[8].

2.7 Vertical farming products

Fruits, vegetables and other consumables can be grown vertically some examples are below:-

Table 2.2: Vertical Farm products

Tomatoes	Radish	Potatoes
Pepper	Strawberry	Peas
Cabbage	Lettuce	Spinach

2.8 The Future for Vertical Farming

Will vertical farming ever take off? We are at least 5 - 10 years away from such a concept. We still have enough land to feed the masses in most countries around the world, and we haven't reached crunch point just yet. However, I certainly think that the concept needs to be given serious consideration, especially as what is being proposed is not outlandish. With cost factors being the major drawback, once cheaper solutions can be found in the construction of these farmscrapers, traditional farming may one day be revolutionized. We may see traditional farmers working in conjunction with inner city farmers in a supporting capacity, to farm organically some of the few crops that perhaps cannot feasibly be grown in a farmscraper environment[7].

2.9 Understanding Hydroponics

Hydroponics originating from the Greek words hydro -water and ponos labor, is a way of growing plants utilizing nutrient solutions rather than soil. Plants can be grown with their roots in either a mineral nutrient solution only or have an additional component such as gravel or mineral wool.

In the late 19th century, plant physiology researchers discovered that plants absorb their essential mineral nutrients as inorganic ions in water. Naturally, soil acts as a nutrient reservoir and is not itself in any way essential to plant growth. When these nutrients absorb into the soil, plants are able to extract them. When nutrients are artificially introduced into the plant's water supply, soil is no longer needed for the plant to develop.

Today, hydroponics is an established branch of science. There has been rapid progress and results from many countries proving it very practical over traditional methods of horticulture[7].

2.10 Strawberry background

Strawberries were cultivated by the Romans as early as 234 BC and in mediaeval times strawberries were regarded as an aphrodisiac. Native American Indians were already eating strawberries when the Colonists arrived and it is believed that in 1780, the first strawberry hybrid was developed in the USA. In South Africa strawberries were introduced in 1656[7].

2.10.1 Climatic and soil requirements

Berries prefer to grow in areas were the winters are very cold followed by mild summers. They need full sun for the highest yields at least 6 (six) hours a day. The soil requirement differs according to variety. Avoid soils with a high clay content. Strawberries grow well in soils that are well drained and high in organic matter[7].

2.10.2 Fertilization

Soil sampling levels are important and differ according to variety. No lime or phosphorus should be applied after planting as it has already been applied during soil preparation. However, regular applications of nitrogen (N) and potassium (K) throughout the season are essential. Potassium is vital for the formation of flowers and to ensure quality fruit. Sufficient quantities of potassium will also ensure a good yield and quality fruit. Potassium should be applied monthly, starting from the date on which the first flowers appear. Strawberries also need a constant supply of nitrogen, especially after planting. Any source of nitrogen can be used[7].

2.10.3 Irrigation

Irrigation is necessary to produce quality fruit. Certain factors should be considered in deciding on the time and frequency of irrigation. Such factors include soil type, water quality, weather conditions, season, type of fruit, the type of irrigation system used as well as mulching. Strawberries require 15 mm to 25 mm of irrigation per week and this will depend on the time of year and the stage of production. Sandy soils have low water-holding capacities. It is therefore essential to apply small volumes of water at relatively short intervals, i.e. 2 to 3 days between irrigations. Loamy and clayey soils, on the other hand, have higher water-holding capacities. Larger volumes of water should therefore be applied with longer intervals between irrigations such as once every 4 to 5 days between irrigations[7].

2.10.4 Weed control

Grass and weeds absorb considerable quantities of nitrogen and water to the detriment of trees. Weeds can be controlled either mechanically or chemically. However, hand hoeing is labor intensive and time consuming. Hoeing can also damage the roots or fruit of the strawberry plants. Caution should be taken when herbicides are used for weed control. The herbicide must not come into contact with the strawberry plants. User instructions, as supplied by the manufacturer of the herbicide, should be adhered to[7].

2.10.5 Pest and disease control

Regular monitoring of pests is of the utmost importance. This will ensure timely intervention in order to control the pests before the infestations reach critical levels. There are several insecticides which are registered for strawberries in order to control specific pests. It is important to adhere to the user instructions as supplied by the manufacturers. Red spider mite, leaf spot and botrytis could be problems on strawberries. Spray with Ludwig's Insect Spray to deal with adult mites followed a week later by 5 ml Ludwig's Rose Spider Mite Spray, which kills the eggs and immature mites. The key to good control of leaf spot is good sanitation. Botrytis is a grey mould which is most probably the biggest enemy of strawberries and can be controlled by fungicides[7].

2.11 Peat Moss (Potting Soil)

A growing medium that provides a healthy environment for roots is essential for successful container gardening, and for propagating many plants from seed or cuttings. Good drainage and adequate water-holding capacity are important characteristics to consider. Weight is another; the medium should have enough weight to support the plant without its toppling over, but should not be too heavy if the plan to lug the container from place to place[7].

Fig 2.6: Potting Soil illustration

Chapter Three
Methodology

Chapter Three

Methodology

This vertical farming system, grows vegetables in A-shaped towers, each of six meters tall. These modular A-frames are quick to install and easy to maintain. Each tower consists of 17 tiers of growing troughs, which are rotated around the tower frame a rate of 10 mm per second to ensure uniform distribution of sunlight, good air flow and irrigation for all the plants. The whole system occupies an area of only .about 6 square meters.

The rotation system need a motor, which rotates the transmission shaft that transfers the rotational motion to the tiers through roller chain and chain sprockets.

The vertical farming system is housed in a protected environment of PVC roofing and netted walls to enable cultivation of strawberry under natural sunlight, all year round, all these efficiencies ensure that production costs are kept low.

The designed model as a solution is consist of 2 subsystems, Irrigation system and Transmission system in addition to the A-shaped tower. The model will produce 599.7 Ton of strawberry in the year in one acre as the constant for all calculations Process.

This research will focus on design of the transmission system and irrigation system to get an integrated agricultural system which is totally different from traditional agricultural operations.

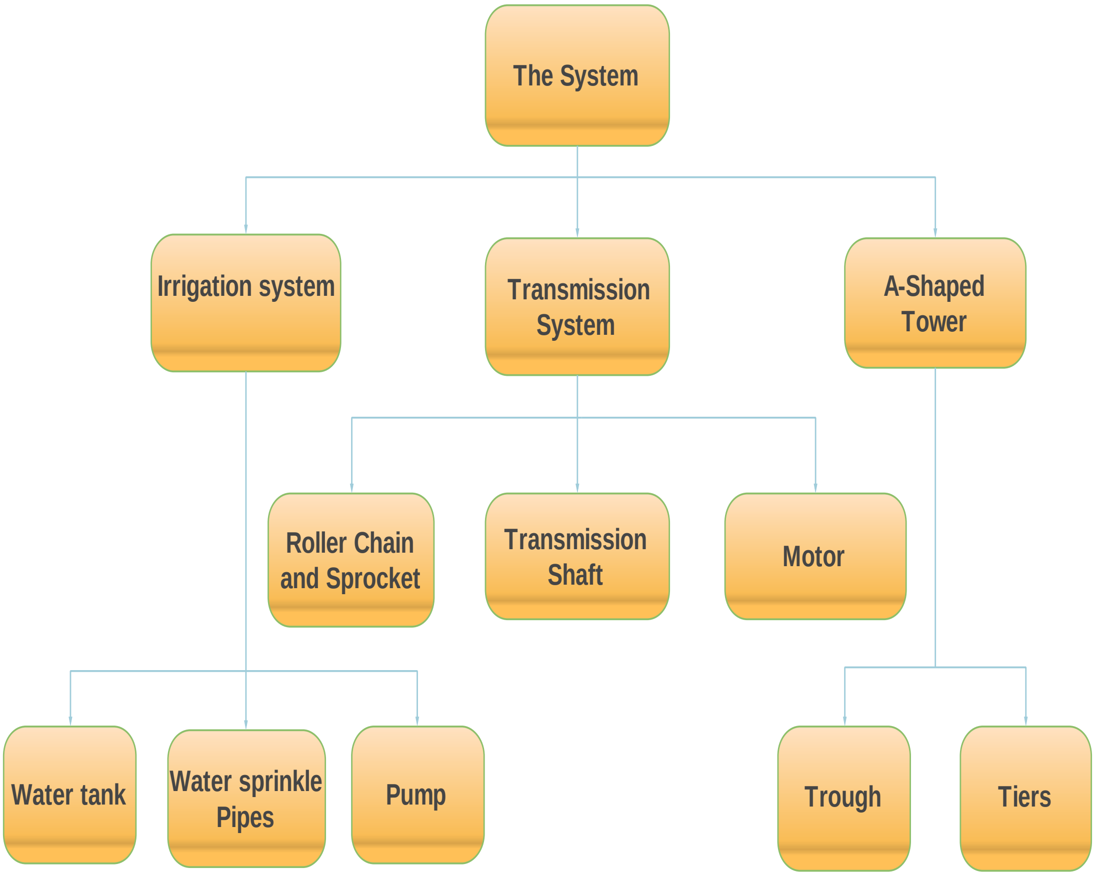


Fig 3.1: Vertical farm main components

3.1 A-shaped tower

Is a stainless steel structure in A-shaped which contains tiers, transmission and irrigation system components.

To establish the right size of A-shaped tower, design must consider:-

- Total number of tiers
- Material selection
- Height of tower
- Total load carried by tower

A-shaped tower design type Selection

The tower design selected for the system is A-shaped. Because it provides comparative advantage which is optimum utilization of space with facilitating tires rotation also it provides optimum rigidity for the system. And the selected material is stainless steel to protect the system from corrosion which can occur due to frequent use of water.

The A-shaped tower contains tiers which carrying growing troughs.

3.1.1 Growing troughs

The growing troughs is the part which carry the soil and plants and where farming operation take place.

To establish the right size of troughs, design must consider:-

- Material selection
- Volume of trough
- Total load carried by trough

Troughs design type selection

The trough selected for the system is PVC square trough. Because it provides suitable area for strawberry growing requirement, the material selected PVC because it is inexpensive and has a good resistant to environmental factors.

3.1.2 Tiers

The tier is the part which carry the growing troughs and it is suspended in the A-shaped tower through pins.

To establish the right size of tiers, design must consider:-

- Material selection
- Total load carried by tiers
- Number of troughs on one tier

Tiers design type selection

The tier design selected for the system is hollow rectangular frame. Because it provides good support for trough with minimum load fulfillment. And the selected material is stainless steel to protect the system from corrosion which can occur due to frequent use of water.

3.2 Transmission system

This system transfer rotational motion to the tier to rotate around A-shaped tower, to ensure uniform distribution of sunlight, good air flow to the plants, also the system facilitates agricultural operations (Planting, harvesting, irrigation) because of the high elevation of the structure.

Transmission System Main Components are Roller chain, Sprocket wheel, Transmission shaft and Electrical motor.

3.2.1 Chain and Sprocket selection procedures

1- Determine class of driven load.

2-Select service factor.

3- Calculate design horsepower.

4- Select chain pitch.

5- Select number of teeth in small sprocket.

6- Determine number of teeth in larger sprocket.

7- Calculate chain length.

3.2.2 Roller chain

Is the type of chain drive most commonly used for transmission of mechanical power it consists of a series of short cylindrical rollers held together by side links. It is driven by a toothed wheel called a sprocket.

Chain type Selection

The chain design selected for the system is roller chain. Because the outstanding advantage of this type of chain is the ability of the rollers to rotate when contacting the teeth of the sprocket, also it has ability to carry the specified loads, additionally it has the suitable pitch which allows appropriate installation of the tires.

3.2.3 Sprocket-wheel

Is a profiled wheel with teeth, cogs, or even sprockets that mesh with a chain.

3.2.4 Motor

The system needs a motor to rotate the sprocket-wheel to convey rotational motion through roller chain to rotate tiers which are installed on the structure.

To select the right motor, selection must consider:-

- Load Characteristics
- Horsepower to be transmitted
- Torque to be transmitted
- Speed

Motor type Selection

The motor selected is a spool valve T Series (158) according to Eaton cooperation and it is suitable to run the system because of this reasons:-

- High efficiency.
- Smooth low-speed operation.
- Extended motor life (especially at low speed conditions).
- Design flexibility.
- Provides low speed, high torque.

3.2.5 Transmission shaft

Is mechanical component for transmitting torque and rotation which used to connect motor with sprocket-wheel.

3.3 Irrigation system

This system is the method in which water is supplied to plants at regular intervals for agriculture.

Irrigation system contain

- Water tank
- Pump
- Water sprinkle Pipes

3.3.1 Water tank

The water tank is a container for storing water, the need for a water tank is to provide storage of water for use in irrigation process.

3.3.2 Water sprinkle pipes

Water sprinkle pipes are Tubes located downstream, or after the zone control on/off valve. They are not pressurized all the time, but are only pressurized when the sprinkler or drip irrigation zone's on/off valve is "on." The function of these sprinkle pipes is equal distribution of water through tiers.

3.3.3 Pump

The system needs a pump to carry water from the tank to Water sprinkle pipes.

To select the right pump, pump selection must consider:-

- Water pressure
- Water flow rate

3.4 Other proposed idea of vertical farm

This proposed idea of vertical farm consist of the following components:-

- Vertical layers

The growing layers is the part which carry the soil and plants and where farming operation take place.

- Movement Tower

The tower is a part which carry the agriculture tools they are, the soil leveling tool which used for soil settlement, and plowing tool which used for plowing the soil, besides a tool for setting seeds in the soil.

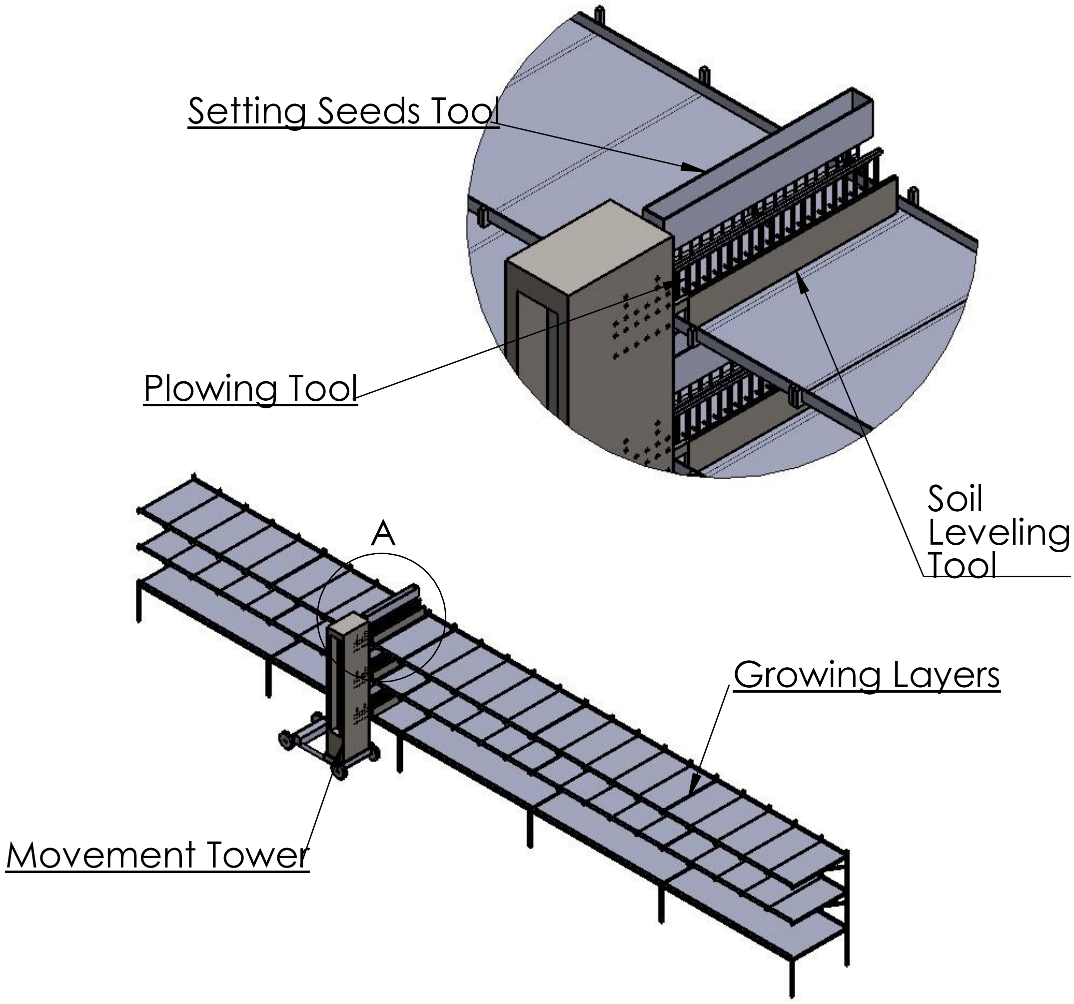


Fig 3.2: proposed idea of vertical farm

Chapter Four
Results and Discussion

Chapter Four

Results and Discussion

4.1 A-shaped tower calculations

To establish the right size of A-shaped tower the calculation as follow:

<u>A-shaped tower design constrains</u>

- Total number of tiers =17 tiers
- Distance between tiers = 70 cm

<u>A-shaped tower design Assumptions</u>

- Height of tower = 600 cm
- Bottom distance between two beams of A-shape = 200 cm
- Top distance between two beams of A-shape = 100 cm
- Distance between two A sides = 300 cm

4.2 Growing troughs calculations

To establish the right size of troughs the calculation as follow:

<u>Troughs design constrains</u>

- Depth of roots = 15 cm
- Distance between plants = 25 cm
- Weight of plant = 2 kg
- Height of plant = 20 cm
- Number of plants on one trough = 4 plants

- Every one meter needs 2.4 L of water per day

Troughs design Assumptions

- Trough length = 50 cm
- Trough Width = 50 cm
- Trough height = 20 cm
- Trough thickness = 0.5 cm

Troughs Design Calculations

Weight of soil can be calculated by the following formula:-

- $D_s = \frac{m}{v}$

$D_s = 0.15\ g/cm^3$

$v = 50 \times 50 \times 15 = 37500\ cm^3$

$m = 0.15 \times 37500 \times 10^{-3} = 5.625\ kg$

Weight of material can be calculated by the following formula:-

$D_s = 1.160\ g/cm^3$

$v = (50 \times 20 \times 0.5 \times 4) + (50 \times 50 \times 0.5) = 3250\ cm^3$

$m = 1.160 \times 3250 \times 10^{-3} = 3.77\ kg$

Weight of plants can be calculated by the following formula:-

- Number of plant on one trough × Number of troughs × weight of one plant =

$4 \times 2 = 8\ kg$

Weight of water can be calculated by the following formula:-

Trough area × Water needed for 1m per kg

$$W= (0.5 \times 0.5) \times (2.4 \times 0.225) = 0.135 \text{ kg}$$

The total weight of one trough = Sum of all weights above

= 5.625 + 3.77 + 8 + 0.135 = 17.53 kg

4.3 Tiers calculations

To establish the right size of tiers the calculation as follow:

<u>Tiers design constrains</u>

- Total number of troughs on one tier = 5

<u>Tiers design Assumptions</u>

- Tier length = 270 cm
- Tier width = 60 cm
- Tier thickness = 5 cm

Tiers Design Calculations:-

- V = 3609.60 cm^3
- Density of stainless steel = 7.80 g/m^3

Weight of rectangle frame = 7.80 × 3609.60 × 10^{-3} = 28.155 Kg

Total weight of one tier = Weight of rectangle frame + (Weight of one trough × Number of troughs) =

28.155 + (17.53 × 5) = 115.805 kg

Total weight of all tiers = Total weight of one tier × Number of tiers = 115.805 × 17 = 1968.685 kg

4.4 Transmission system calculations

To establish the suitable transmission system calculation as follow:

Determine class of driven load:

The class of driven load is (uniform load) according to ANSI standard (from appendix table1: Service Classification)

The total load to be transmitted = total weight of tiers + chain weight + sprockets weight

= 4340.21 + 301.568 + 59

= 4700.78 lb

Select service factor:

The service factor considerations is service classification, type of input power and unfavorable operating conditions.

Unfavorable Operating Conditions which may be present should be compensated for by adding 0.2 to the Service Factor for each unfavorable condition. So the service factor = 1.2 (from appendix table 2: Service Factor).

Calculate design horsepower:

$$\text{HP} = \frac{\text{Service Factor} \times \text{working load} \times \text{Tg} \times \text{Pt} \times \text{RPM}}{396000}$$

$$\frac{1.2 \times 4700.78 \times 50 \times 2 \times 2.4}{396000} = 3.42 \text{ HP}$$

4.4.1 Roller chain calculations

To select the suitable roller chain the calculation as follow:

Chain selection constrains

- Carried load
- Pin dimension

Chain specifications (from appendix table 3: ANSI Roller Chain Dimensions ASME/ANSI B29.1M-1986).

- Standard chain number = 160
- Pitch = 2 in
- Max roller diameter = 1.125 in
- Nominal width = 1.25 in
- Nominal pin diameter = 0.562 in
- Type of series = Heavy
- Link plate thickness = 0.281 in
- Length tolerance = 0.015 in/ft
- Measuring load = 500 Ib
- Minimum ultimate tensile strength = 50000 Ib
- Minimum dynamic strength = 7820 Ib
- Extended pin diameter = 0.562 in
- Extended pin length = 1.5 in

4.4.2 Sprocket-wheel calculations

To select the suitable sprocket-wheel the calculation as follow:

Sprocket selection constrains:-

- Chain type
- Pitch diameter = 31.5 in

- Pitch = 2 in

Chain sprocket specifications (from appendix table 5: Standard and Heavy Series Chain Sprockets).

- Chain Number 160H
- Pitch = 2 in
- Width = 1.250 in
- Roller diameter = 1.125 in
- Single strand t1 = 1.156 in

Chain sprocket calculations

$N_t = PD \times P_C$

$P_c = \frac{\pi}{Pt}$

$P_C = \frac{\pi}{2} = 1.57$ in

$N_t = 31.5 \times 1.75$

$= 49.455 \approx 50$ teeth

4.4.3 Motor calculations

To select the suitable motor the calculation as follow:

Motor selection constrains

- Total load to be transmitted = 4700.78 lb
- $T_r = F \times P_t \times F_r$

  $= 4700.78 \times 2 \times 0.14 = 1316.218$ lb-in

Motor specifications (from appendix table 6: Specification Data-T Motors).

- Max speed = 694 r.p.m

- Torque = 1541 lb-in

Driving Sprockets specifications

- Number of teeth = 25
- Pitch = 0.998 in
- Pitch diameter = 7.9787 in
- Outside diameter = 8.516 in
- Caliper factor = 7.9630

Driven Sprockets specifications (from appendix table 7: ANSI Roller chain Sprocket Diameters ANSI/ASME B29.1M-1993).

- Number of teeth = 50
- Pitch = 0.998 in
- Pitch diameter = 15.9260 in
- Outside diameter = 16.459 in
- Caliper factor = 15.5999 in

Driven Sprockets calculations

$$\frac{N1}{N2} = \frac{T2}{T1}$$

N_2 = 2.4 RPM

T_1 = 25 Teeth

T_2 = 50 Teeth

$N_1 = 2.4 \times \frac{50}{25} = 4.8$ RPM

So the speed of motor must be 4.8 RPM to obtain the required speed for the system which equal 2.4 RPM.

4.4.4 Transmission shaft calculations

To select the suitable transmission shaft the calculation as follow:

<u>Shaft selection constrains</u>

- Distance between A-shape sides = 300 cm
- Motor Torque = 1541 lb-in

<u>Shaft calculations</u>

- Twisting moment

$T_r = \frac{63000 \times P}{N}$

$\frac{63000 \times 3.42}{2.4}$ = 89775 Ib-inch

- Shaft diameter

$$D = \sqrt[3]{\frac{5.1T}{Ss}} = \sqrt[3]{\frac{5.1 \times 89775}{4000}} = 4.86 \text{ in}$$

- Horse power transmitted

$P = \frac{D^3 \times N}{80}$

$\frac{4.86^3 \times 2.4}{80} = 3.44$ HP

- Torsional deflection of shaft

$\alpha = \frac{584TL}{D^4G}$

$\frac{584 \times 44534.5 \times 118.111}{4.86^4 \times 115 \times 10^5}$ = 0.965 degree

Keyway specifications (from appendix table 8: Key size versus shaft diameter ANSI B17.1-1967 (R1998)).

Nominal shaft diameter = 4.86 in

Width = $1\frac{1}{4}$ in

Height = $1\frac{1}{4}$ in

Normal Keyseat Depth = $\frac{5}{8}$ in

Bearings constrains

- Dynamic load
- Static load
- Inside diameter

Bearing specifications

- Bearing name: Spherical Roller
- Dynamic load = 9300 KN
- Static load = 22500 KN
- Inside diameter = 420 mm
- Outside diameter = 730 mm
- Thickness = 272 mm

4.5 Irrigation system calculations

To establish the suitable irrigation system calculation as follow:

Sprinkle selection constrains

- Height of pipes = 1.2 m
- Amount of water to be delivered for 1 tier / day = 1 gpm
- Field area = 1.5 m^2
- Irrigation frequency = 2 Times/day

- Irrigation run time = 2 min/day

Sprinkle calculations

- Water velocity inside pipes

$V = 0.408 \times Q / D^2$

$= 0.408 \times \frac{0.475}{0.75^2} = 0.345$ ft/s

- Amount of water delivered from sprinkle

$Q_{ns} = 28.9 \times D^2 \sqrt{P}$

D = 0.1 in

Q_{ns} 0.024 gpm

P = 0.29 Psi

- Pressure inside main pipes

$$(\frac{P1}{p1*g} + \frac{V1^2}{2g} + Z_1) = (\frac{P2}{p2*g} + \frac{V2^2}{2g} + Z_2)$$

$$= (\frac{P1}{1000*9.81} + \frac{0.2^2}{2*9.81} + 1.6) = (\frac{0.29}{1000*9.81} + \frac{0.345^2}{2*9.8} + 1.6)$$

$= P_1 + 0.2^2 = 0.29 + 0.345^2$

P1 = 0.37 psi

Pump calculations

- Flow rate = 10 gpm

- Static head = 20 ft

- Factor of friction head = 0.69
- Friction head = 20 × 0.69 = 13.8 ft

- Total head = Friction head + Static head

= 13.8 + 20 = 33.8 ft

<u>Pump specifications</u>

- Pump name: SP25
- Body construction: Cast Iron
- Horsepower = $\frac{1}{4}$ HP
- Maximum head = 22 ft
- Maximum capacity = 32 gpm
- Flow at 10 ft Lift = 22 gmp
- Switch type: SP25A1
- Voltage = 115v AC, 60HZ

4.6 Fixtures for A-shaped tower calculations

The main fixtures necessary for A-shaped tower are bolts and nuts

<u>Bolt selection constrains</u>

- Total load = 2132.24 kg

<u>Fixtures calculations</u>

USS = 0.85 × TYS

0.85 × 172.34 = 146.489 N/mm^2

$$USS = \frac{4 \times F}{\pi \times D^2}$$

F= Effects of applied forces on bolt

D = Bolt diameter

$$F = \frac{\text{Total load} \times \text{Factor of safety}}{\text{Number of bolts}}$$

$$\frac{2132.24 \times 3 \times 9.81}{24} = 2614.66\ N$$

$$D = \sqrt{\frac{4 \times F}{USS \times \pi}} = \sqrt{\frac{4 \times 2614.66}{146.489 \times \pi}} = 4.76 \text{ mm}$$

The calculated diameter is the minimum diameter which needed for design, but the selected bolt diameter is 10 mm to ensure good fixture and it is available in standard.

<u>Bolts for sprocket set calculations</u>

$$F = \frac{2132.24 \times 3 \times 9.81}{8} = 7843.98 \text{ N}$$

$$D = \sqrt{\frac{4 \times 7843.98}{146.489 \times \pi}} = 8.2 \text{ mm}$$

The calculated diameter is the minimum diameter which needed for design, but the selected bolt diameter is 24 mm to ensure good fixture and it is available in standard.

<u>Specifications of bolts for structure connections</u>

- Bolt type : Hexagon Head Screw
- D × L = 10 × 30 mm
- d = M10
- S = 16 mm
- K = 6.4 mm

<u>Specifications of bolts for shaft set</u>

- Bolt type : Hexagon Head Screw
- D × L = 10 × 50 mm

- d = M10
- S = 16 mm
- K = 6.4 mm

Nuts Specifications

- Nut type : Hexagon Nut
- d = M10
- m = 8.4 mm
- s = 16 mm

Specifications of bolts for upper sprocket set

- Bolt type: Hexagon Head Half Thread
- D × L = 24 × 140 mm
- d = M24
- S = 36 mm
- K = 15mm
- b = 60 mm

Nuts Specifications

- Nut type : Hexagon Nut
- d = M24
- m = 21.5 mm
- s = 36 mm

4.7 Analysis of Design

At this point, after the model design is finished, testing process is carried out to analyze the model components and parts. The analysis aim to evaluate and confirm the design configuration, using SolidWorks version (2015) the analysis has been done and reported through the program simulation functions. The component to be analyzed are:-

1- Component to be analyzed:-

2- Growing trough

3- Tier

4- Transmission shaft

5- Chain pin

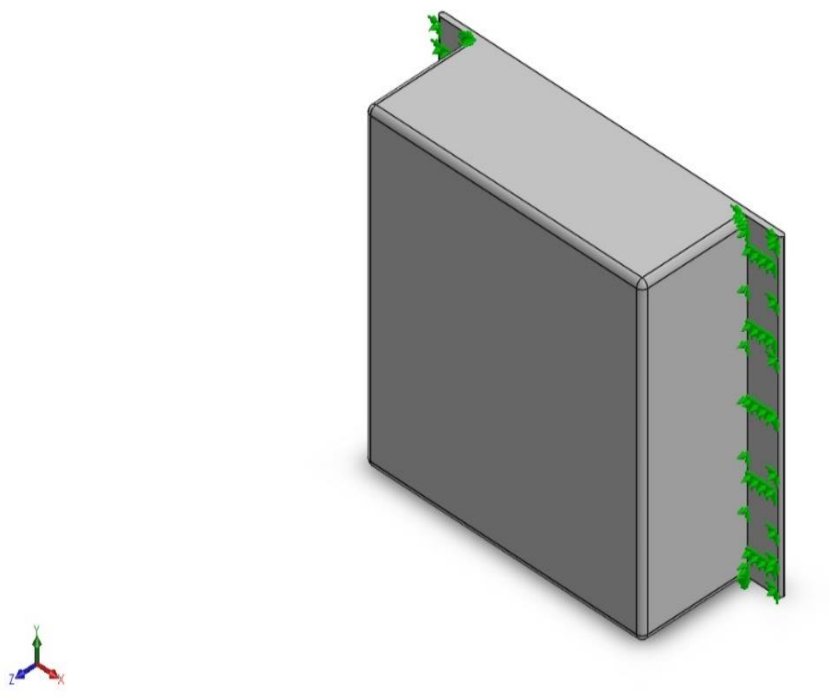
4.7.1 Growing trough analysis

The growing trough carry soil and plants a total load of 13.76 kg, the material of the trough is PVC plasticized. The analyze process has been made and the result shows that the part is working proper, the properties of component is shown in fig 4.1.

The maximum stress in part is =172979 N/m^2 which appear to be at the corners of the trough sides as shown in fig 4.2 and it is less than the yield strength.

The maximum displacement in part is = 43.4213 mm which appear to be at the bottom of the trough as shown in fig 4.3.

The maximum strain in part is = 0.0209453 which appear to be at the corners of the trough sides as shown in fig 4.4.



Model name: Trough
Current Configuration: Default

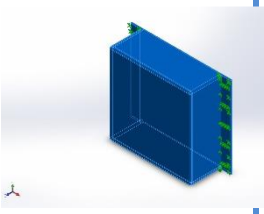
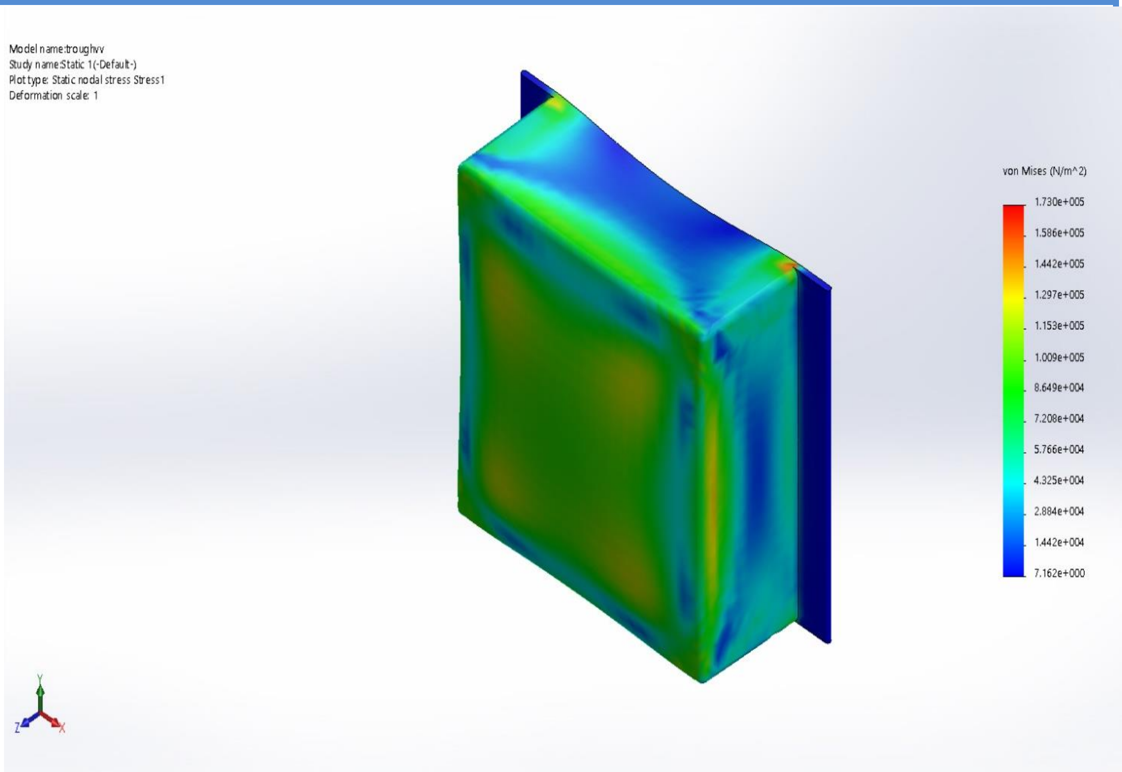
Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Fillet10 	Solid Body	**Mass:6.41054 kg** **Volume:0.00496941 m^3** **Density:1290 kg/m^3** **Weight:62.8233 N**	**C:\Users\Mustafa\Documents\SolidWorks\Design\tier square\troughvv.SLDPRT** Sep 11 18:18:22 2016

Fig 4.1: Trough properties

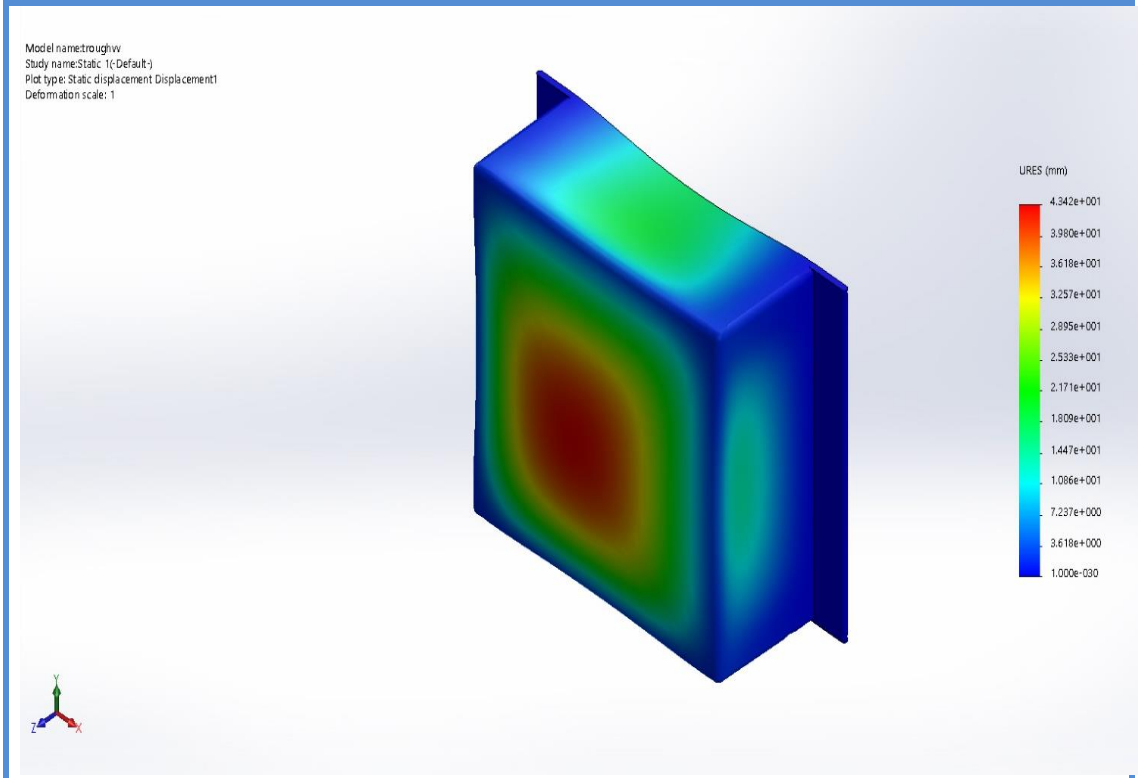
Name	Type	Min	Max
Stress1	VON: von Mises Stress	7.16198 N/m^2 Node: 2767	172979 N/m^2 Node: 1622



Trough-Static 1-Stress-Stress1

Fig 4.2: Trough Stress Analysis

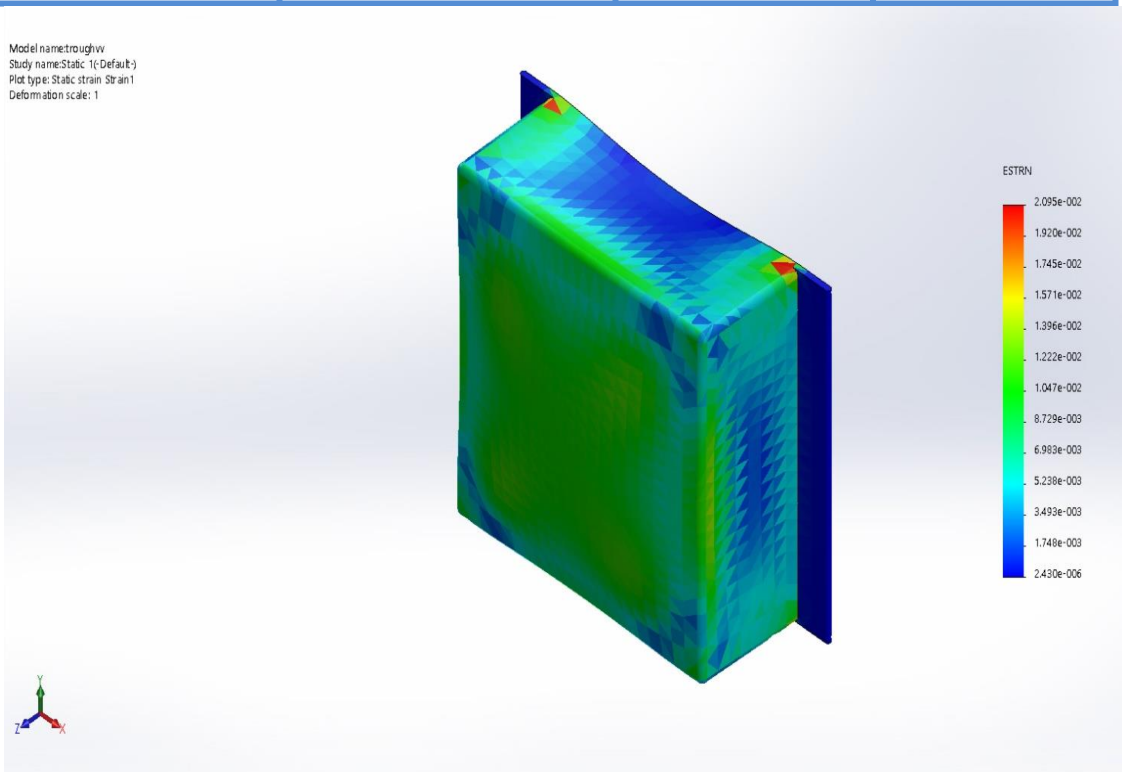
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 1	43.4213 mm Node: 2216



Trough-Static 1-Displacement-Displacement1

Fig 4.3: Trough Displacement Analysis

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	2.42954e-006 Element: 5598	0.0209453 Element: 4962



Trough-Static 1-Strain-Strain1

Fig 4.4: Trough Strain Analysis

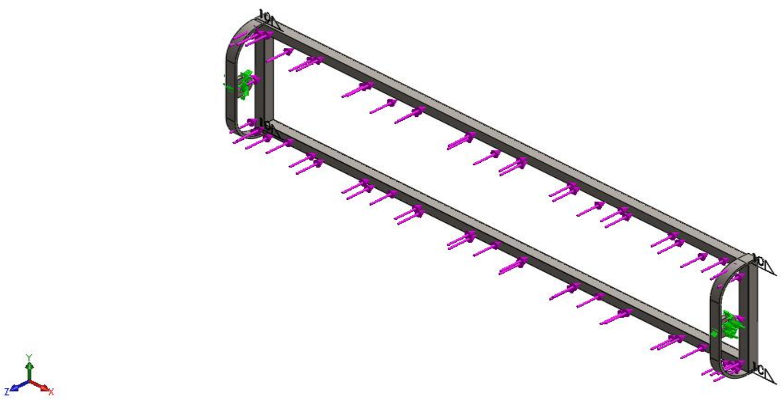
4.7.2 Tier analysis

The tier carry the growing troughs a total load of 87.65 kg, the material of the tier is Stainless steel. The analyze process has been made and the result shows that the part is working proper, the properties of component is shown in fig 4.5.

The maximum stress in part is = 2.9228e+007 N/m^2 which appear to be at the holder of the tier as shown in fig 4.6.

The maximum displacement in part is = 0.987837 mm which appear to be at the center of the tier section as shown in fig 4.7.

The maximum strain in part is = 7.16631e-005 which appear to be at the holder of the tier as shown in fig 4.8.



Model name: Tier
Current Configuration: Default

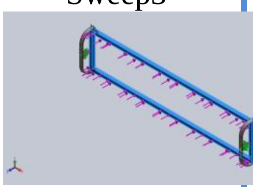
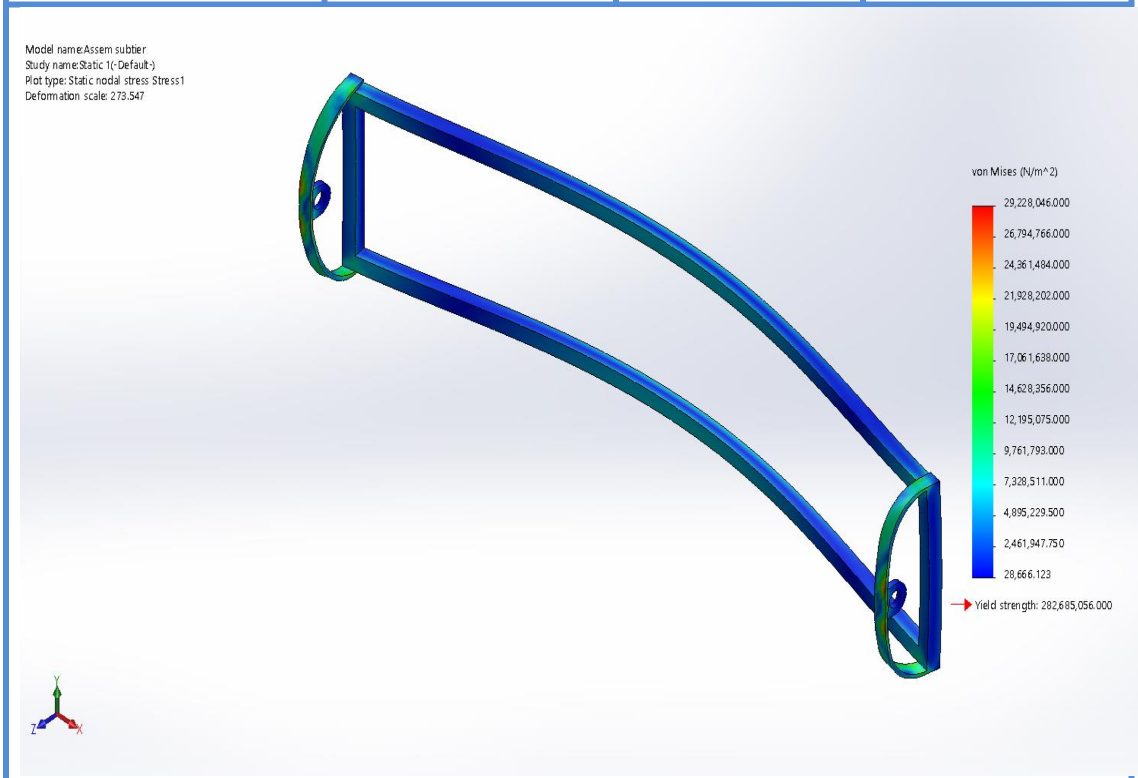
Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Sweep3 	Solid Body	**Mass:28.3642 kg** **Volume:0.0036096 m^3** **Density:7858 kg/m^3** **Weight:277.97 N**	**C:\Users\Moayed\Desktop\Design\tier square\Part3.SLDPRT** Aug 27 23:29:40 2016

Fig (4.5): Tier properties

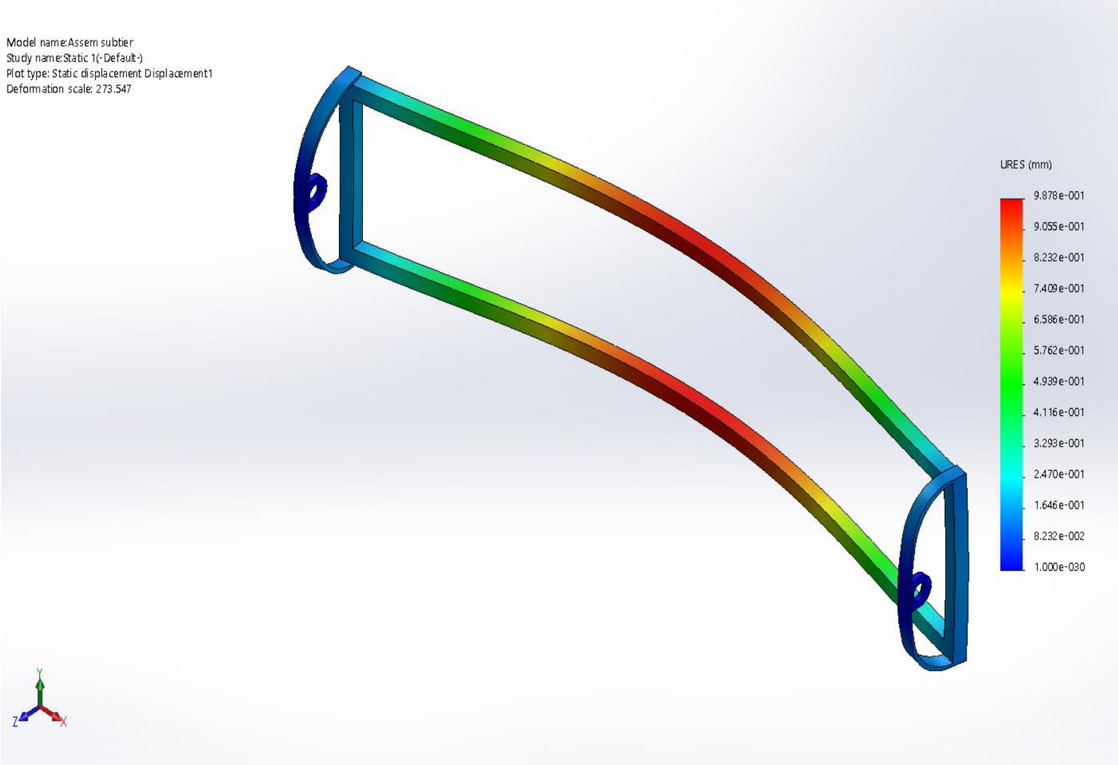
Name	Type	Min	Max
Stress1	VON: von Mises Stress	28666.1 N/m^2 Node: 16180	2.9228e+007 N/m^2 Node: 14052



Tier-Static 1-Stress-Stress1

Fig 4.6: Tier Stress Analysis

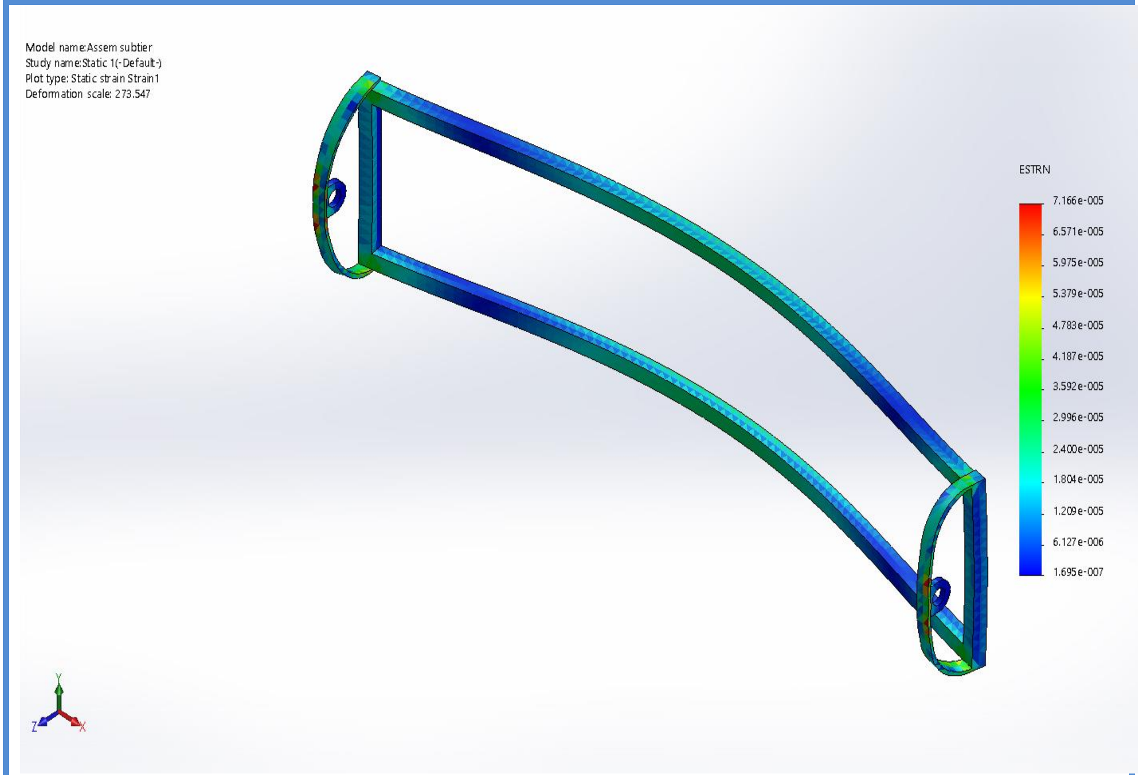
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 13919	0.987837 mm Node: 1196



Tier-Static 1-Displacement-Displacement1

Fig 4.7: Tier Displacement Analysis

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.69492e-007 Element: 7424	7.16631e-005 Element: 7397



Tier-Static 1-Strain-Strain1

Fig 4.8: Tier Strain Analysis

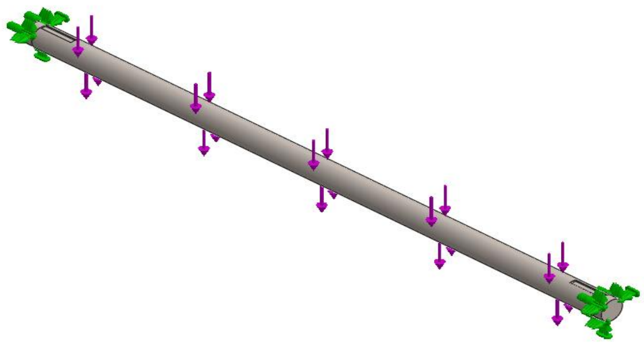
4.7.3 Transmission shaft analysis

The Transmission shaft carry the sprockets a total load of 53.5 kg, the material of the shaft is Stainless steel. The analyze process has been made and the result shows that the part is working proper, the properties of component is shown in fig 4.9.

The maximum stress in part is = 2.09015e+006 which appear to be at the bearings position as shown in fig 4.10.

The maximum displacement in part is = 0.00540297 mm which appear to be at the center of the shaft as shown in fig 4.11.

The maximum strain in part is = 6.55802e-006 which appear to be at the bearings position as shown in fig 4.12.



Model name: Shaft
Current Configuration: Default

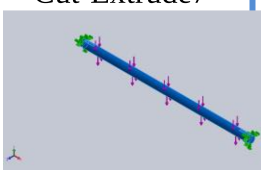
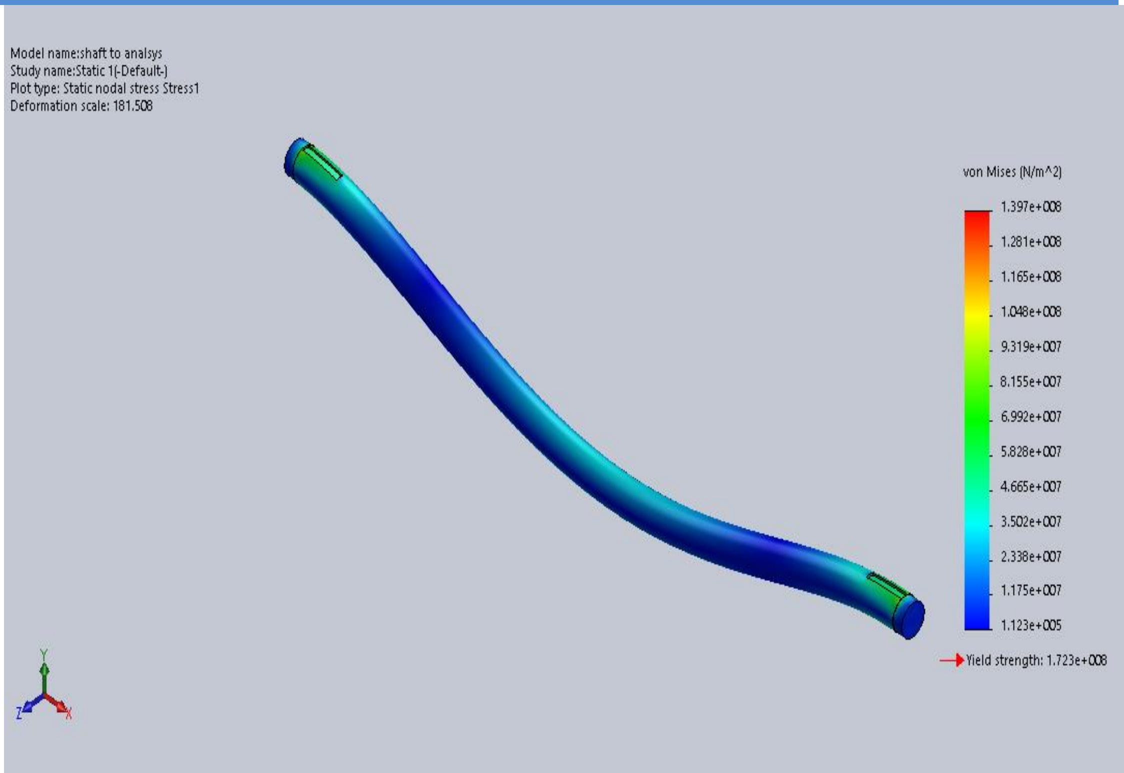
Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Cut-Extrude7 	Solid Body	**Mass:305.53 kg** **Volume:0.0391705 m^3** **Density:7800 kg/m^3** **Weight:2994.19 N**	**C:\Users\Moayed\Desktop\tier square\structure \shaft to analsys.SLDPRT** Oct 18 14:36:48 2016

Fig 4.9: Shaft properties

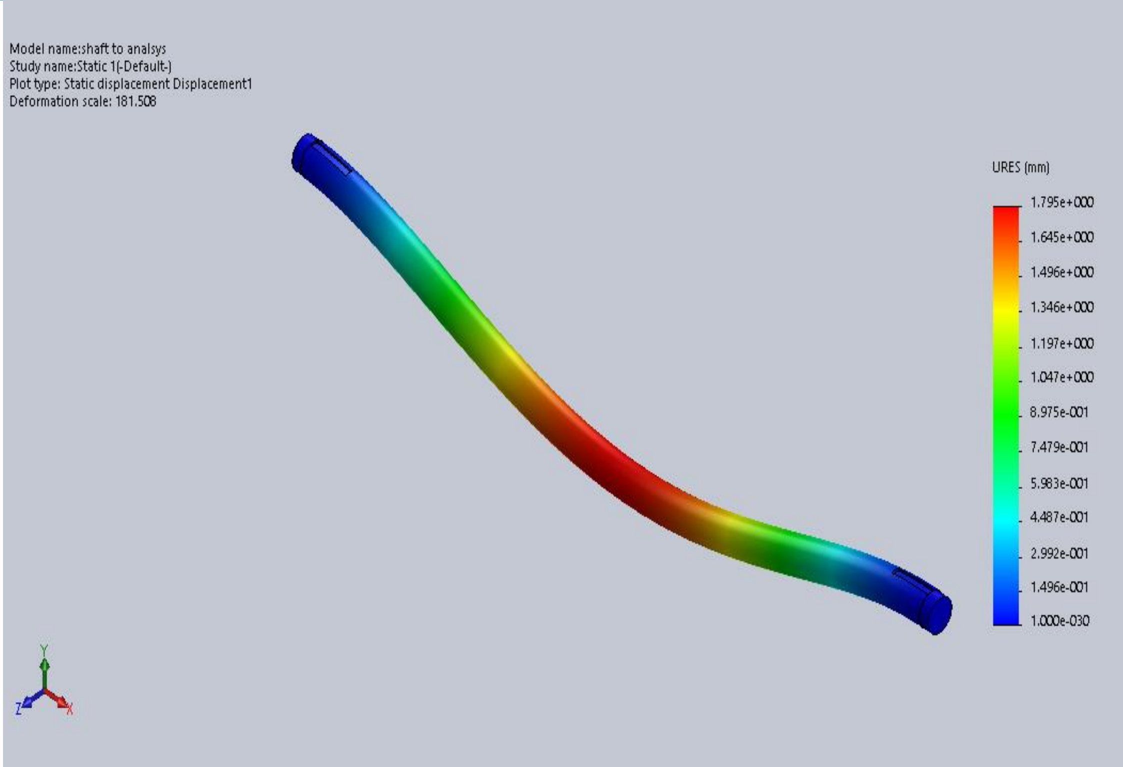
Name	Type	Min	Max
Stress1	VON: von Mises Stress	112282 N/m^2 Node: 3796	1.39727e+008 N/m^2 Node: 12632



Shaft-Static 1-Stress-Stress1

Fig 4.10: Shaft Stress Analysis

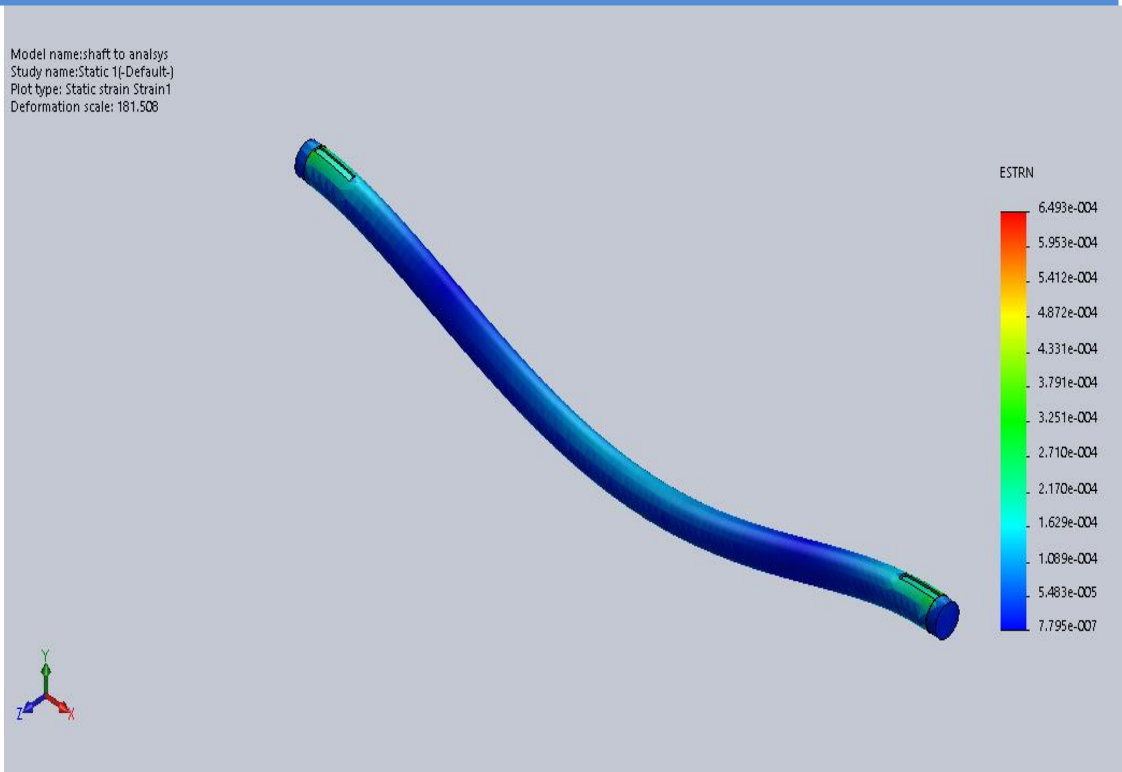
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 1	1.79497 mm Node: 583



Shaft-Static 1-Displacement-Displacement1

Fig 4.11: Shaft Displacement Analysis

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	7.79482e-007 Element: 4377	0.000649328 Element: 378



Shaft-Static 1-Strain-Strain1

Fig 4.12: Shaft Strain Analysis

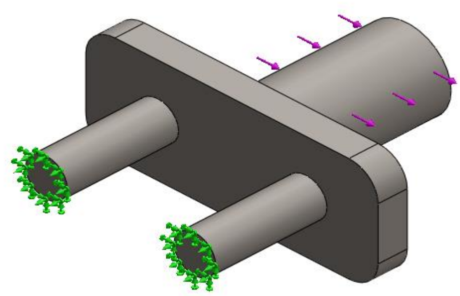
4.7.4 Chain Pin analysis

The chain pin carry the tiers a total load of 115 kg, the material of the chain is Stainless steel. The analyze process has been made and the result shows that the part is working proper, the properties of component is shown in fig 4.13.

The maximum stress in part is = 4.5559e+007 N/m^2 which appear to be at the Tier fixing position as shown in fig 4.14.

The maximum displacement in part is = 0.0184923 mm which appear to be at the bearing position as shown in fig 4.15.

Maximum strain in part is = 0.0000161961 which appear to be at the Tier position as shown in fig 4.16



Model name: Chain Pin
Current Configuration: Default

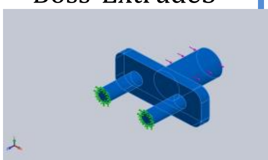
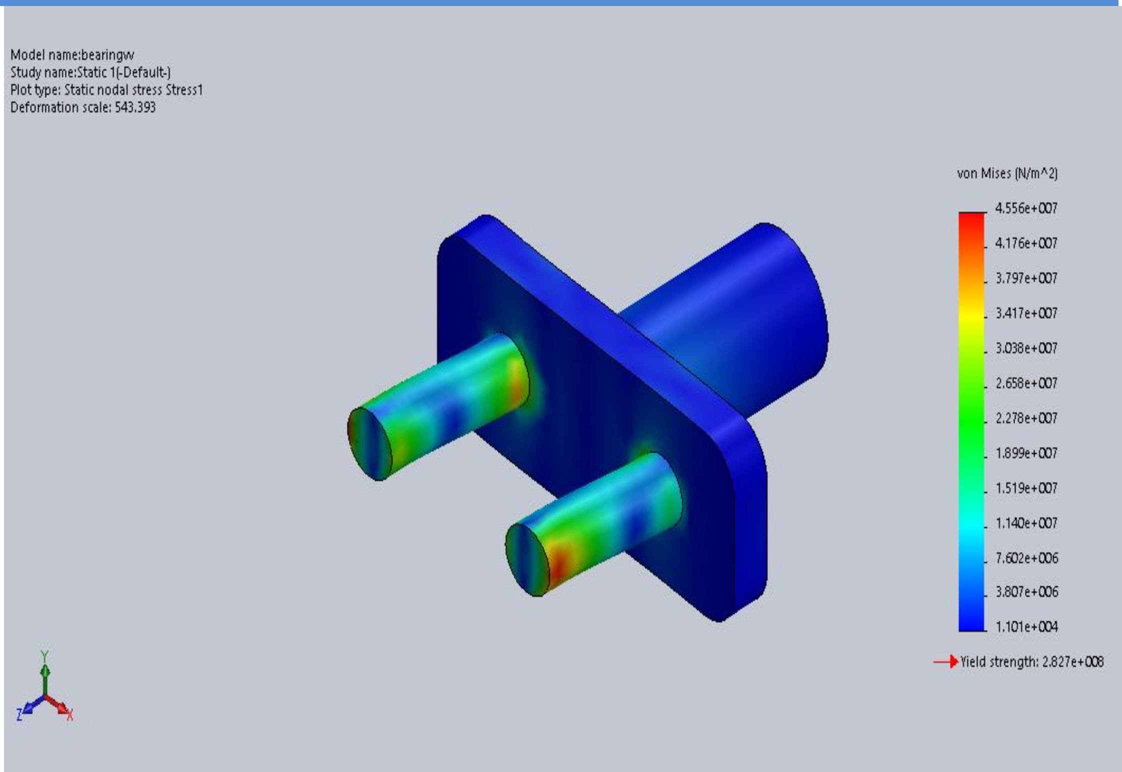
Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Boss-Extrude3 	Solid Body	**Mass:0.681064 kg Volume:8.66714e-005 m^3 Density:7858 kg/m^3 Weight:6.67443 N**	**C:\Users\Moayed \Desktop\tier square\bearingv v.SLDPRT** Aug 30 21:51:05 2016

Fig 4.13: Chain Pin properties

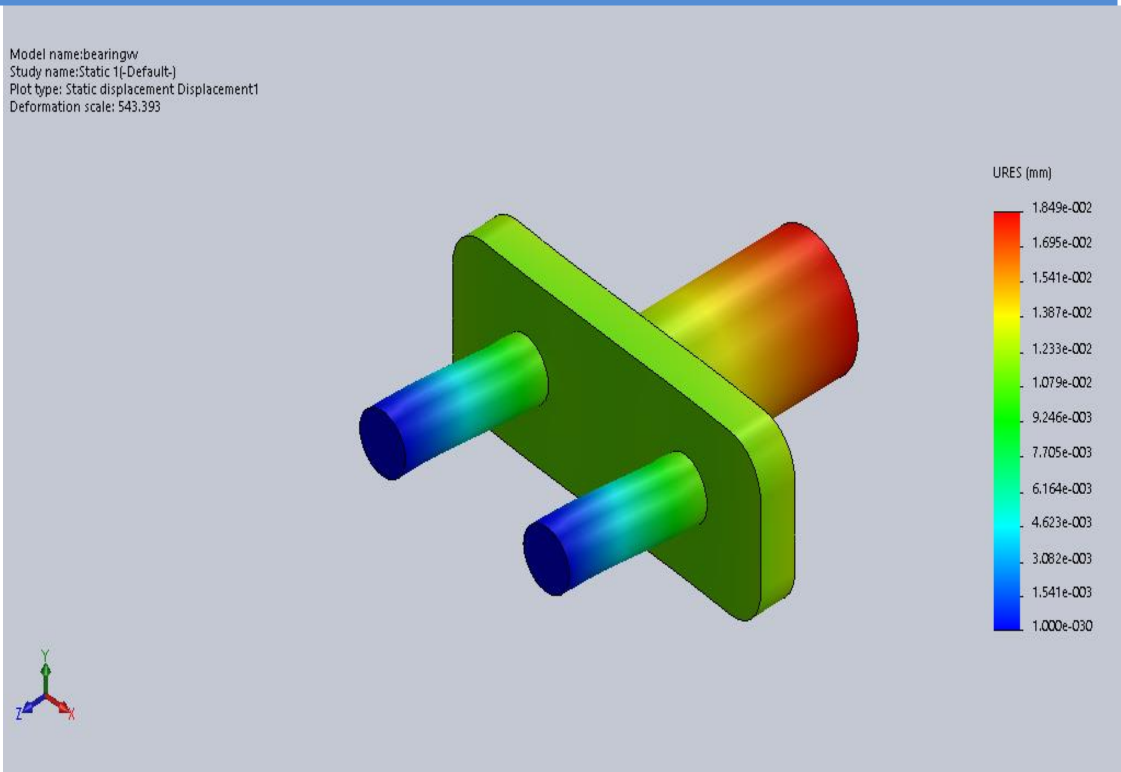
Name	Type	Min	Max
Stress1	VON: von Mises Stress	11012.3 N/m^2 Node: 5433	4.5559e+007 N/m^2 Node: 325



Chain Pin-Static 1-Stress-Stress1

Fig 4.14: Chain Pin Stress Analysis

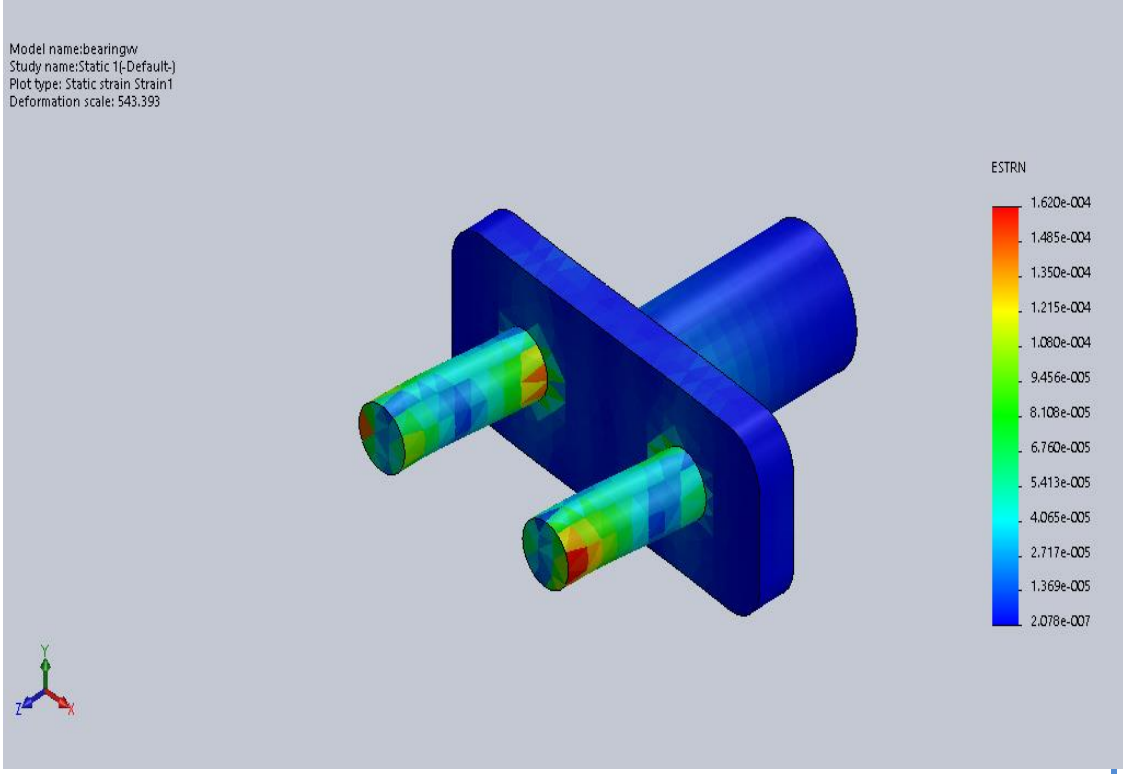
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 200	0.0184923 mm Node: 107



Chain Pin-Static 1-Displacement-Displacement1

Fig 4.15: Chain Pin Displacement Analysis

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	2.0782e-007 Element: 4426	0.000161961 Element: 2219



Chain Pin-Static 1-Strain-Strain1

Fig 4.16: Chain Pin Strain Analysis

4.8 Cost Estimation:-

The cost estimation for installation and running of 1 acer vertical farm that has 441 structure by using cost breakdown structure for the major systems of the farm

The cost of main systems to be estimated are:-

- Transmission system costs
- Irrigation system costs
- Structure costs

<u>Transmission system:</u>

No	Item	Cost/unit	Quantity	Fixed cost
1	Motor	750$	441	330750 $
2	Sprocket	50$	2646	132300 $
3	Shaft	50$	441	22050 $
4	Chain	200$	882	176400 $
5	Bearing	10$	15876	158760 $
6	Key	1$	882	882 $
Total				**821142 $**

<u>Irrigation system:</u>

No	item	Cost/unit	Quantity	Fixed cost
1	Pump	50$	8	400 $
2	Tank	40$	8	320 $
3	Sprinkle	5$	441	2205 $
Total				**2925 $**

Structure:

No	item	Cost/unit	Quantity	Fixed cost	Variable costs
1	Beams	2000	176.4 Ton	352800 $	
2	Trough	4$	37485	149940 $	
3	Fixture	0.83$	15876	13230 $	
4	Plants	1$	149940/Year	-	149940 $/year
5	Soil	11.2$	6174 Bag/year	-	69678 $/year
6	Labor		-	-	36000 $/year
7	Controllable Environment		-		15720 $
Total				**515970 $**	**271338 $/year**

4.9 Cost Calculations

• Total Major Equipment = ME (transmission system) + ME (irrigation system) + ME (structure)

• Total ME = 821142 + 2925 + 515970 = 1340037 $

• Insurance (I) = 1.5% (ME) = 1.5% × 1340037 = 20100.56 $

• Port Duties (PD) = 2% (ME + I) = 2% × 1360137.56 = 27202.76 $

• Custom Duties (CD) = 15% (ME+I) + PD = (15% × 1360137.56) + 27202.67 = 231223.39 $

• In Land Transportation (ILT) = 2.5% (CD) = 2.5% × 231223.39 = 5780.58 $

• Installation (Ins) = 30% (ME) = 30% × 1340037 = 402011.1 $

• Cost of install equipment (IL) = ME + I + PD + CD + ILT + INS
= 1340037 + 20100.56 + 27202.76 + 231223.39 + 5780.58 + 402011.1 = 2026355.39 $

• Land cost = 10000 $

• Work capital cost (WC) = civil work + furniture

• WC = 2000 + 700 = 2700 $

• Total capital investment = IL + LC + CW + FC

•Total Investment = 2026355.39 + 10000 + 2700 = 2039055.39 $

• Total cost (TC) = Total revenue (TR)

• TR(X) = SPX

•SP × X = $F_c + V_c (X)$

• Selling pries = 3 $/Kg

• Total variable cost = 271338 $/year

$= \frac{271338\ \$/year}{599760\ Kg/year} = 0.45\ \$/kilo$

• Fixed cost = 2039055.39 $

$X = \frac{2039055.39}{3 - 0.45} = 799629.56\ Kilo$

• From result it's appear that after we sell 799629.56 Kg of Strawberry all revenues become profits (after 15 month).

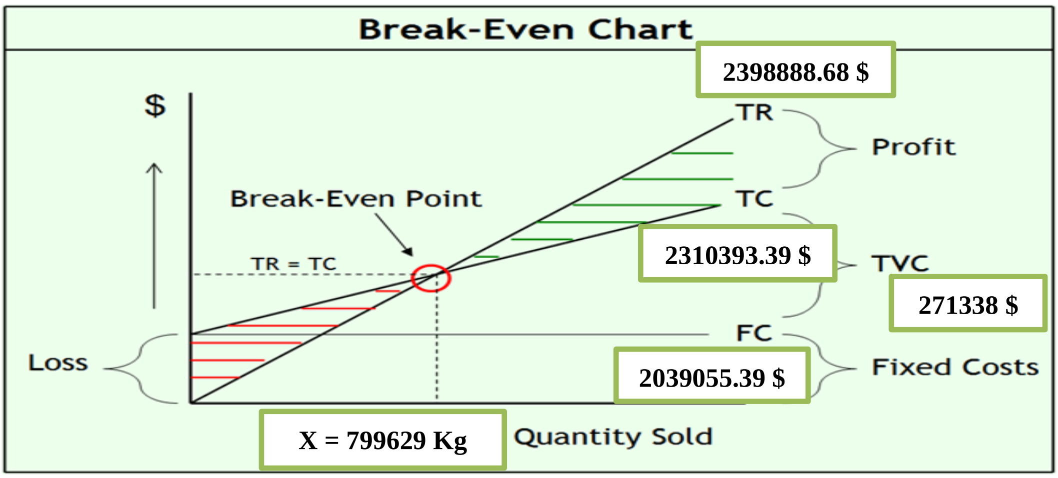


Fig (5.1): Break event point

Chapter Five
Conclusion and Recommendations

Chapter Five

Conclusion and Recommendations

5.1 Conclusion

The intent of this research was to investigate the vertical farming technique, also to Increase strawberry productivity besides facilitate agricultural operations. A model has been designed and discussed.

1–The floor space occupied by the vertical farm equals 7.5m^2 while the total space that can be grown vertically equals 21.25m^2, so by comparing the space that can be grown horizontally to the one can be grown vertically the gain in floor space is 3 times

2–The productivity of strawberry using vertical farm has increased at a rate of 126% compared with traditional agriculture of strawberry.

3–The farming and harvesting have been facilitated, the operator does not need to move over long distances by decrease the farming floor space compared to traditional farming besides the mechanical system which rotates the tiers from top height to the bottom.

5.2 Recommendations

To improve the design one can recommend that:-

1–Design an automation system for planting, harvesting and irrigation for the vertical farm.

2–Establish a controllable environment system (air conditioning units and ventilation system).

3–Increase flexibility of the farm system to allow the possibility of cultivate different products.

4–Implement the other proposed idea of vertical farm in chapter two.

References

[1] C. Banerjee and L. Adenaeuer, "Up, up and away! The economics of vertical farming," Journal of Agricultural Studies, vol. 2, pp. 40-60, 2014.

[2] M. Prades Villanova, "Vertical farm façade: first approach to the energetic savings applied to the Seagram Building in New York," 2013.

[3] M. Pollan, "Big food vs. big insurance," The New York Times, 2009.

[4] P. Möller Voss, "Vertical Farming: An agricultural revolution on the rise," 2013.

[5] B. Venkataraman, "Country, the city version: farms in the sky gain new interest," New York Times, vol. 15, 2008.

[6] W. C. Motes, "Modern Agriculture and Its Benefits–Trends, Implications and Outlook," Global Harvest Initiative, vol. 12, 2011.

[7] D. Despommier, "The rise of vertical farms," Scientific American, vol. 301, pp. 80-87, 2009.

[8] D. Despommier, The vertical farm: feeding the world in the 21st century: Macmillan, 2010.

[9] E. Oberg, Machinery's Handbook 29th Edition-Full Book: Industrial Press, 2012.

[10] R. Khurmi and J. Gupta, "A text book of Machine Design. Eurasia Publishing house (PVT.) Ltd," *First multi color edition,* pp. 576-586, 2005.

[11] E. J. Hearn, Mechanics of materials 1: an introduction to the mechanics of elastic and plastic deformation of solids and structural components: Butterworth-Heinemann, 1997.

Appendix

Table 1: Service Classification

Service Classification — Table I	
Uniform Load	
Agitators, Liquid	Generators
Blowers, Centrifugal	Line Shafts, Even Load
Conveyors, Even Load	Machines, Even Load, Non-reversing
Elevators, Even Load	Pumps, Centrifugal
Fans, Centrifugal	
Moderate Shock Load	
Beaters	Laundry - Washers and Tumblers
Compressors, Centrifugal	Line Shafts, Uneven Load
Conveyors, Uneven Load	Machines, Pulsating Load, Non-reversing
Elevators, Uneven Load	Pumps, Reciprocating, Triplex
Grinders, Pulp	Screens, Rotary, Even Load
Kilns and Dryers	Woodworking Machinery
Heavy Shock Load	
Brick Machines	Mills, Hammer, Rolling or Drawing
Compressors Reciprocating	Presses
Crushers	Pumps, Reciprocating, Simplex or Duplex
Machines, Reversing or Impact Loads	

Table 2: Service Factor

SERVICE CLASSIFICATION	TYPE OF INPUT POWER		
	Internal Combustion Engine with Hydraulic Drive	Electric Motor or Turbine	Internal Combustion Engine with Mechanical Drive
Uniform Load	1.0	1.0	1.2
Moderate Shock Load	1.2	1.3	1.4
Heavy Shock Load	1.4	1.5	1.7

Table 3: ANSI Roller Chain Dimensions ASME/ANSI B29.1M-1986

Standard chain N°	Pitch P (in.)	Max. Roller Ø Dr (in.)	Nominal Width W (in.)	Nominal pin Ø Dp (in.)	Type of series	Link plate thickness (in.)	Length tolerance, in./ft	Measuring load (lb)	M.U.T.S. (lb)	Min. Dyn. Strength (lb)
240	3	1.875	1.875	0.937	Standard	0.375	0.015	1000	112500	15800
60	0.75	0.469	0.5	0.234	Heavy	0.125	0.017	70	7030	1230
80	1	0.625	0.625	0.312	Heavy	0.156	0.016	125	12500	2150
100	1.25	0.75	0.75	0.375	Heavy	0.187	0.016	195	19530	3280
120	1.5	0.875	1	0.437	Heavy	0.219	0.015	281	28125	4620
140	1.75	1	1	0.5	Heavy	0.25	0.015	383	38280	6140
160	2	1.125	1.25	0.562	Heavy	0.281	0.015	500	50000	7820
180	2.25	1.406	1.406	0.687	Heavy	0.312	0.015	633	63280	9650
200	2.5	1.562	1.5	0.781	Heavy	0.375	0.015	781	78125	11600

Table 4: Straight and Bent Link Plate Extensions and Extended Pin Dimensions ANSI/ASME B29.1M-1993

Chain No.	Straight Link Plate Extension			Bent Link Plate Extension				Extended Pin	
	B min.	*D*	*F*	*B* min.	*C*	*D*	*F*	D_p Nominal	*L*
35	0.102	0.375	0.050	0.102	0.250	0.375	0.050	0.141	0.375
40	0.131	0.500	0.060	0.131	0.312	0.500	0.060	0.156	0.375
50	0.200	0.625	0.080	0.200	0.406	0.625	0.080	0.200	0.469
60	0.200	0.719	0.094	0.200	0.469	0.750	0.094	0.234	0.562
80	0.261	0.969	0.125	0.261	0.625	1.000	0.125	0.312	0.750
100	0.323	1.250	0.156	0.323	0.781	1.250	0.156	0.375	0.938
120	0.386	1.438	0.188	0.386	0.906	1.500	0.188	0.437	1.125
140	0.448	1.750	0.219	0.448	1.125	1.750	0.219	0.500	1.312
160	0.516	2.000	0.250	0.516	1.250	2.000	0.250	0.562	1.500
200	0.641	2.500	0.312	0.641	1.688	2.500	0.312	0.781	1.875

Table 5: Standard and Heavy Series Chain Sprockets

Chain Data For All Sprockets				Single Strand	Double and Triple Strand			For 4 or more Strands									Minus			
A.S.A. Chain No.	Pitch P	Roller Width W	Roller Diameter	t1 and T_{HR}	t_2	M_2	M_3	t_4	M_2	M_3	M_4	M_5	M_6	M_8	M_{10}	M_{12}	M_{16}	K	Tolerance on "t" and "M" Machined	Minus Tolerance on T_{HR}
HEAVY SERIES CHAIN SPROCKETS																				
60H	.750	.500	.469	.459	.444	1.472	2.500	.418	1.446	2.474	3.502	4.530	5.558	7.614				1.028	-.011	-.036
80H	1.000	.625	.625	.575	.557	1.840	3.123	.526	1.809	3.092	4.375	5.568	6.941	9.507				1.283	-.012	-.040
100H	1.250	.750	.750	.692	.669	2.208	3.747	.633	2.172	3.711	5.250	6.789	8.328	11.406				1.539	-.014	-.046
120H	1.500	1.000	.875	.924	.894	2.818	4.742	.848	2.772	4.696	6.620	8.544	10.468	14.316				1.924	-.016	-.057
140H	1.750	1.000	1.000	.924	.894	2.949	5.004	.848	2.903	4.958	7.013	9.068	11.123	15.233				2.055	-.016	-.057
160H	2.000	1.250	1.125	1.156	1.119	3.555	5.991	1.063	3.499	5.935	8.371	10.807	13.243	18.115				2.436	-.019	-.062
180H	2.250	1.406	1.406	1.301	1.259	3.982	6.705	1.197	3.920	6.643	9.366	12.089	14.812	20.258				2.723	-.020	-.068
200H	2.500	1.500	1.562	1.389	1.344	4.427	7.510	1.278	4.361	7.444	10.527	13.610	16.693	22.859				3.083	-.021	-.072

Table 6: Specification Data-T Motors

SPECIFICATION DATA – T MOTORS

Displ. cm^3/r [in^3/r]		36 [2.2]	49 [3.0]	66 [4.0]	80 [4.9]	102 [6.2]	131 [8.0]	157 [9.6]	195 [11.9]	244 [14.9]	306 [18.7]	370 [22.6]
Max. Speed (RPM) @ Continuous Flow		1021	906	849	694	550	426	355	287	229	183	152
Flow LPM [GPM]	Continuous	38 [10]	45 [12]	57 [15]	57 [15]	57 [15]	57 [15]	57 [15]	57 [15]	57 [15]	57 [15]	57 [15]
	Intermittent	38 [10]	57 [15]	68 [18]	76 [20]	76 [20]	76 [20]	76 [20]	76 [20]	76 [20]	76 [20]	76 [20]
Torque Nm [lb-in]	Continuous	76 [672]	105 [928]	138 [1222]	174 [1541]	219 [1936]	251 [2226]	297 [2628]	359 [3178]	410 [3633]	441 [3905]	430 [3811]
	Intermittent **	93 [824]	118 [1131]	168 [1488]	212 [1872]	264 [2339]	307 [2718]	359 [3178]	437 [3864]	485 [4290]	483 [4275]	486 [4300]
Pressure Δ Bar Δ PSI]	Continuous*	155 [2250]	155 [2250]	155 [2250]	155 [2250]	155 [2250]	138 [2000]	138 [2000]	138 [2000]	127 [1850]	110 [1600]	90 [1300]
	Intermittent**	190 [2750]	190 [2750]	190 [2750]	190 [2750]	190 [2750]	172 [2500]	172 [2500]	172 [2500]	155 [2250]	124 [1800]	103 [1500]

Table 7: ANSI Roller chain Sprocket Diameters ANSI/ASME B29.1M-1993

No. Teeth[a]	Pitch Diameter	Outside Diameter		Caliper Factor	No. Teeth[a]	Pitch Diameter	Outside Diameter		Caliper Factor
		Turned	Topping Hob Cut				Turned	Topping Hob Cut	
45	14.3355	14.901	14.908	14.3269	95	30.2449	30.828	30.817	30.2408
46	14.6535	15.219	15.226		96	30.5632	31.147	31.135	
47	14.9717	15.538	15.544	14.9634	97	30.8815	31.465	31.454	30.8774
48	15.2898	15.857	15.862		98	31.1997	31.784	31.772	
49	15.6079	16.176	16.180	15.5999	99	31.5180	32.102	32.090	31.5140
50	15.9260	16.495	16.498		100	31.8362	32.421	32.408	
51	16.2441	16.813	16.816	16.2364	101	32.1545	32.739	32.727	32.1506
52	16.5622	17.132	17.134		102	32.4727	33.057	33.045	
53	16.8803	17.451	17.452	16.8729	103	32.7910	33.376	33.363	32.7872
54	17.1984	17.769	17.770		104	33.1093	33.694	33.681	
55	17.5165	18.088	18.089	17.5094	105	33.4275	34.013	34.000	33.4238
56	17.8347	18.407	18.407		106	33.7458	34.331	34.318	
57	18.1528	18.725	18.725	18.1459	107	34.0641	34.649	34.636	34.0604
58	18.4710	19.044	19.043		108	34.3823	34.968	34.954	

Table 8: Key size versus shaft diameter ANSI B17.1-1967 (R1998)

Nominal Shaft Diameter		Nominal Key Size			Normal Keyseat Depth	
			Height, *H*		*H*/2	
Over	To (Incl.)	Width, *W*	Square	Rectangular	Square	Rectangular
2¾	3¼	¾	¾	½	⅜	¼
3¼	3¾	⅞	⅞	⅝	7/16	5/16
3¾	4½	1	1	¾	½	⅜
4½	5½	1¼	1¼	⅞	⅝	7/16
5½	6½	1½	1½	1	¾	½