SEPTEMBER 2016 M.Sc. THESIS IN CIVIL ENGINEERING NOUR ABUHEMEIDA

UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF
NATURAL & APPLIED SCIENCES

DESIGN AND IMPROVE FIRE TRUCK TURNTABLE LADDER

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IN
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BY

NOUR ABUHEMEIDA

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DESIGN AND IMPROVE FIRE TRUCK TURNTABLE LADDER

University of Gaziantep
M.Sc. Thesis
in
Civil Engineering

Supervisor
Prof. Dr. Mustafa ÖZAKÇA

By
Nour ABUHEMEIDA
September 2016

REPUBLIC OF TURKEY
UNIVERSITY OF GAZİANTEP
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ABSTRACT

DESIGN AND IMPROVE FIRE TRUCK TURNTABLE LADDER

ABUHEMEIDA, Nour
M.Sc. in Civil Engineering
Supervisor: Prof. Dr. Mustafa ÖZAKÇA
September 2016
53 pages

In getting a better model for aerial ladder, the need to check for possible failure in the model of the equipment is paramount, as failure in the components might result due to fatigue in the material of the ladder, or as a result of poor failure of the truss due to over loading and poor design. The need to check for possible failure in the equipment calls for an approach that will analyse the model and optimize the existing parameters of the proposed model, or creating a new approach in the design of the model based on the Turkish and European standards TS EN 14044+A1 "for High rise aerial appliances for fire service use – Turntable ladders with sequential movements". This approach will bring about checking the figures and the design of the model in terms of the failure and the model design for the system.

The data from the initial model was analysed and checked through the finite element method adopted in SAP 2000 software. This approach is used because it brings about a total check of possible failures in the model, and it comes up with a possible attainable terms and conditions for the optimum utilization of the model. Upon finalizing the initial model, a couple of changes and improvements was applied as an effort to get more efficient design and gain wider working range for the aerial ladder.

Keywords: turntable ladder; platform; working range; SAP2000; curve fitting.

ÖZET

DESIGN AND IMPROVE FIRE TRUCK TURNTABLE LADDER

ABUHEMEIDA, Nour
Yüksek Lisans, İnşaat Mühendisliği
Danışman: Prof. Dr. Mustafa ÖZAKÇA
Eylül 2016
53 sayfa

Hava merdiveni için daha iyi bir örnek alabilmek için, ekipman modelinde muhtemel arıza olup olmadığını kontrol etmek son derecede önem taşımakta, bileşenlerde olası arıza merdiven malzemesinin aşınmasından meydana gelebilir, veya sonuç olarak kafeste düşük başarısızlık aşırı yükleme ve kötü tasarım sebeblerinden oluşabilir.
Ekipmanda olası başarısızlığı kontrol etme ihtiyacı, model analizini ve önerilen modelin mevcut parametrelerini uygun hale getirilmesinin yaklaşımını, veya TS EN 14044+A1 Türk ve Avrupa standartlarına dayalı modelin tasarımında yeni bir yaklaşımın itfaiye kullanımı için yüksek artış hava aletleri - sıralı hareketlerle döner merdivenler oluşturulmasını çağrıstırıyor. Bu yaklaşım, rakamların denetimini ve model tasarımının başarısızlık durumunda ve model tasarımını beraberinde getirecektir.

Başlangıç modelinde elde edilen veriler analiz edilmiş ve SAP 2000 yazılımında benimsenen sonlu unsur metodu ile kontrol edildi. Bu yaklaşım, modelde olası arızaların tümünün kontrolünü sağliyor ve bunun yanında bu modelin optimum kullanımı için olası ulaşılabilir şartları ve koşulları meydana getiriyor.

İlk modelin sonuçlandırılması üzerine, hava merdiveni ile ilgili daha verimli tasarım ve geniş çalışma aralığı kazanmak için bir kaç değişiklik ve iyileştirmeler uygulanmıştır.
Keywords: turntable ladder; platform; working range; SAP2000; curve fitting.

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LIST OF ABBREVIATIONS

NIST	National Institute of Standards and Technology
FM Global	Factory Mutual Global
UL	Underwriters Laboratories
FEA	Finite Element Analysis
FEM	Finite Element Method
FVM	Finite Volume Method

CHAPTER 1
INTRODUCTION

1.1 Background of Study

In today's world, the construction of an advance society in meeting the need of urbanization becomes often and more rapidly, with this development, the recurrent of fire disaster happening in the city are unruly. There is now more concern by the populace on the issue of fire disaster, particularly in high rise buildings, this concern ranges from what to use to fight the fire, the equipment and the likes, which has its own limitations [1]. Many countries have suffered a number of fire outbreaks and in particular when dealing with fire incidents in high rise buildings, the problem becomes more complicated. Fighting fire in high rise building encompass a complex process and procedure during the fire outbreak and required the use of targeted and key firefighting apparatus like the aerial fire truck ladder in order to control the situation and to reduce the effect on the surrounding properties and environment. In Wales and England there are building regulations which are requires of buildings that are higher than 18 meters in order to make certain provisions for firefighting occurrences [2].

Dubai in the United Arab Emirates is the home to hundreds of luxurious high-rise buildings; we can expect the impact of fire accidents to be high and more severe. To this reason fire safety has been considered as a crucial issue and many concerns are raise in relation to the building damage. In order to understand the situation better, a statistical study was conducted on information relating to fire incidents across the city between 2006 and 2013. As a result of this study, the total number of declared incidents relating to fire issues was about 5,490 fire incidents, with the highest number in 2008 followed by 2007 [3]. In fighting fire in tall or high rise buildings there is a need to develop standard structural requirements and an operating procedure that governed aerial ladder operations and firefighting departments for a safe and appropriate use of the apparatus [4]. It was reported that, when ladder is extended at a low incline angle, its will support a minimal weight at the tip, in order word the more vertical the ladder is the more weight its can support by the load being transferred down the beams of the ladder. The weight is calculated at the center point of the ladder and distributed over the ladder's entire length [5]. A pre-tensioned hose reel is usually attached to the turntable ladder during firefighting in order to supply the basket/cage, and this reel is also attached with a hose and nozzle pipe. The hose reel in the basket is usually an automatic reel that independently recoils the hose following use. The equipment is attached to the ladder platform and is thus able to execute all ladder movements with ease, providing the fire brigade with initial fire-fighting equipment even whilst the ladder is being extended and the water supply established [6]. The aerial ladder trucks used in fighting fire have been around since the 1930s. Currently, manufacturers offer fire departments and various stakeholders several techniques to securely deliver the high master stream in fighting fire in high rise buildings, including a platform attached to the end of the aerial or the traditional aerial ladder with the pre piped waterway and remote-controlled nozzle. Modern technology has made transitioning from an interior offensive attack to an exterior defensive attack into a smooth efficient process [7].

Fire-rescue turntable ladders can be considered as a large scale automated appliance with two rotatory axes and one translational axis all mounted on a fire truck. This special purpose apparatus is the best known form nowadays, and is used to access fires at high story buildings. The telescopic ladder is mounted on the back of the fire-rescue truck chassis and it is allowable to pivot around a stable base, and has the ability of being extendable using either a hydraulic or pneumatic system [8]. In the design of a mobile aerial ladder in fighting fire in high rise buildings or skyscrapers there are various kinds of mobile truck that can be used base on their purpose of usage [9]. Many individuals and professionals use the term fire apparatus or "fire truck" to describe such means of fire transportation, as the term fire engine also can be used to denote a specific type of fire truck, a motor vehicle which is designed to carry personnel and equipment which can be used to fight fires. In many instances, a fire truck performs this key function of transporting water or chemical fire suppressant to the site of a fire along with the fire fighter personnel as they are equipped with ladders or hydraulic platforms for reaching high raise buildings [10].

1.2 Significance of Study

In getting a better model for aerial ladder truck the need to check for possible failure in the model of the equipment is paramount, as failure in the components might result due to fatigue in the material of the ladder or as a result of poor failure of the truss due to over loading and poor design. The need to analytical check for possible failure in the equipment, my checking the model failure through stress distribution on the aerial ladder and perfecting the design of the total aerial ladder when place on the truck, calls for an approach that will analyses the model and optimize the existing parameters of the proposed model or creating a new approach in the design of the model base of standard and previous research. This approach will bring about checking the figures and the design of the model in terms of the failure and the model design for the system. Figure 1.1 shows typical aerial ladder components.

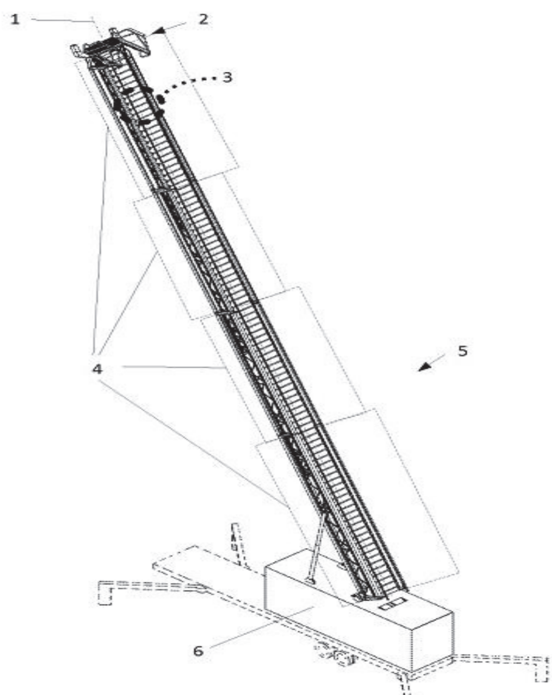


Figure 1.1. Perspective view of an aerial ladder

Key:

1. Longitudinal Axis
2. Top Edge

3. Rails and Rungs
4. Ladder Units
5. Ladder
6. Rotational Base

The above perspective view of an aerial ladder that can be lengthen, which is expected to be placed on a vehicle in order to be used for lifting and taking down during rescue operations.

The data from the model is analysed and checked through a finite element method and optimize through SAP 2000 for authentication. This approach is used because it will bring about a total check of possible failures and faults in the model and comes up with a possible attainable terms and conditions for the optimum utilization of the model. Upon finalizing the base model, a couple of changes and improvements will be applied as an effort to get more efficient design and gain wider working range for the aerial ladder

1.3 Objectives of Study

The scope of this research is to conduct, check and do an optimization on an aerial ladder frame model. The aerial ladder is modeled to achieve the following objectives.

I. To design an aerial ladder self-weight model that will withstand working loads and diverse forces in its static mode.
II. To determine the dynamic and mechanical aspects of the turntable or turntable articulated aerial ladder.
III. To check and optimize the basic failure mechanism of the fire-rescue turntable ladder model.

1.4 Outlines of Study

In chapter 1- Introduction: The first chapter of the thesis gives an overview of the research work. This chapter focuses on the background of study, the aim and object, the research significant and the outline

In chapter 2- Literature Review: This part of the thesis derived and processed information relating to this study through work done by other researchers in journals, articles, facts from text books, case studies, manuals etc.

In chapter 3- Methodology: This chapter of the research work present and described the method that will be used on the proposed model for the complete analysis and optimization of the proposed aerials ladder truck model as mentioned in the literature review in chapter 2.

In chapter 4- Model Data Result and Discussions: The information derived from the analysis of the model is assessed. The proposed designed model is checked, evaluated, optimized and discussed base on key features of the study.

In Chapter 5- Conclusion and Recommendation: In this section the results obtained from the studies of the proposed model is drawn and key recommendation on the models are made for further studies.

CHAPTER 2
LITERATURE REVIEW

2.1 General

For some few decades now, immerse effort has been devoted on researching and understanding the science of fire and combustion. A great amount of these studies have been committed to the area of combustion engines and power generation, while other efforts have directed to open fires and flame features. Some of the advanced type of research has centered on the area of fire-fighting, largely targeting fire prevention and enhancing understanding of phenomena involved in flame spread and propagation. Substantial steps have been made in outlining and analyzing the factors involved in open fires. As mentioned earlier, only a rare case studies have dealt with fire-fighter, apparatus, safety and protection, although some of the results delivered useful insight to the environmental situations to which fire-fighters are opened to [11].

2.2 Fire Dynamics

The study of fire by considering how the fire start, spread, develop, and extinguish is termed “Fire Dynamics”. To describe fire behavior expressively, fire dynamics must combine the interaction of chemistry and material science and the engineering disciplines of fluid mechanics and heat transfer. Furthermore, one must also consider the dealings of fire with structures, materials, and people in order to fully comprehend the fire dynamics of a certain fire incident. The research paper on the “Microstratigraphic evidence of in situ fire in the Acheulean strata of Wonderwork Cave, Northern Cape province, South Africa” this article was published at April of 2012 [12], showing how fire was used productively for thousands of years ago and how recently the use and research by the hunters, farmers, cooks, scientists, chemists, engineers, and firefighters have studied one aspect of fire or another. Each cluster focused on its specific area of concern and interest in or the use of fire. For instance, some studied the use of fire to form metal while others investigated the combustion of fuel as a means to optimize the use of fuel in boilers, automobiles, aircraft, etc. For more than 100 years, National Institute of Standards and Technology (NIST) in America, Factory Mutual Global (FM Global) and the Underwriters Laboratories (UL) and other establishments have studied how to protect buildings from fire by investigating the fire resistance of columns and walls with furnace tests [13]. However it was not until 1985 that the first textbook on fire dynamics was published [14].As the result of U.S.-based research programs led and sustained by NIST in the 1970s and 1980s, as well as a substantial level of fire-research activity in Canada, Japan, and the United Kingdom, a body of knowledge established the fire chemistry, fire plumes, compartment fires, and simple models of fire phenomena. This information created a foundation for fire-protection engineers to ponder on fire dynamics when designing buildings and preventing fires [15].

2.3 Fire Behavior

Naturally, firefighters have been taught about the behavior of fire in structures with drawings and a simple graph as seen in Figure 2.1 describe its better. The figure described qualitatively through the graph by showing and telling us, that fire begins with ignition. The fire is then in the growth phase, where the heat-release rate escalates until the fire is fully advanced. In a compartment fire, the changes from the growth stage to the entirely developed stage may involve a flashover. Flashover is a transition that occurred in the development of a confined fire. In the case of flashover, surfaces exposed to thermal radiation from fire gases in excess of 600°C (1,100°F) reach ignition temperature more or less simultaneously. Fire spreads quickly through the sections of compartment, with burning from ground to the ceiling. Without interference, the fire transitions to the decay stage as the fuel is exhausted. The ideal curve best suited for describing a fuel-controlled fire, in other words, a fire that has all of the oxygen can sustain the heat-generating chemical reaction [15].

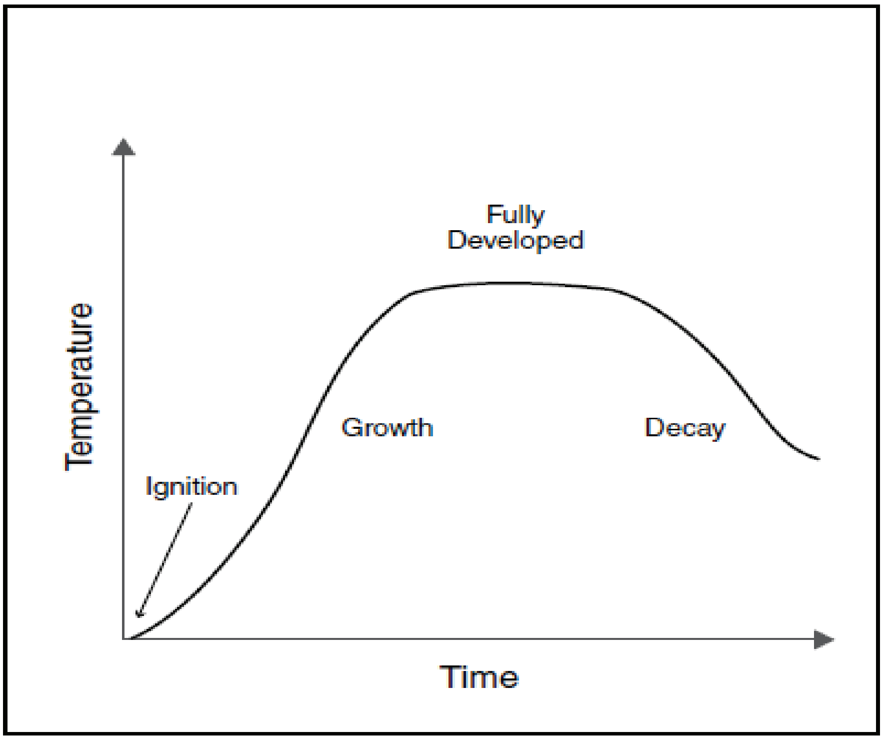


Figure 2.1. Traditional idealized fire-behavior graphs showing a typical fuel-controlled fire. [15].

In such cases, the peak heat-release rate is partial to the amount of fuel available for combustion, and the decay stage is typically related to the reduced amount of fuel available for burning. Heat-release-rate curves from free-burn sofa fires with no compartmentation effects are shown in Figure 2.2 for a typical, residential-scale room with 2.01 m high, the minimum heat-release rate required to flashover the room is about 2,000 kW. Figure 2.2 shows that a sofa has twice the peak heat-release rate needed to flashover the room.

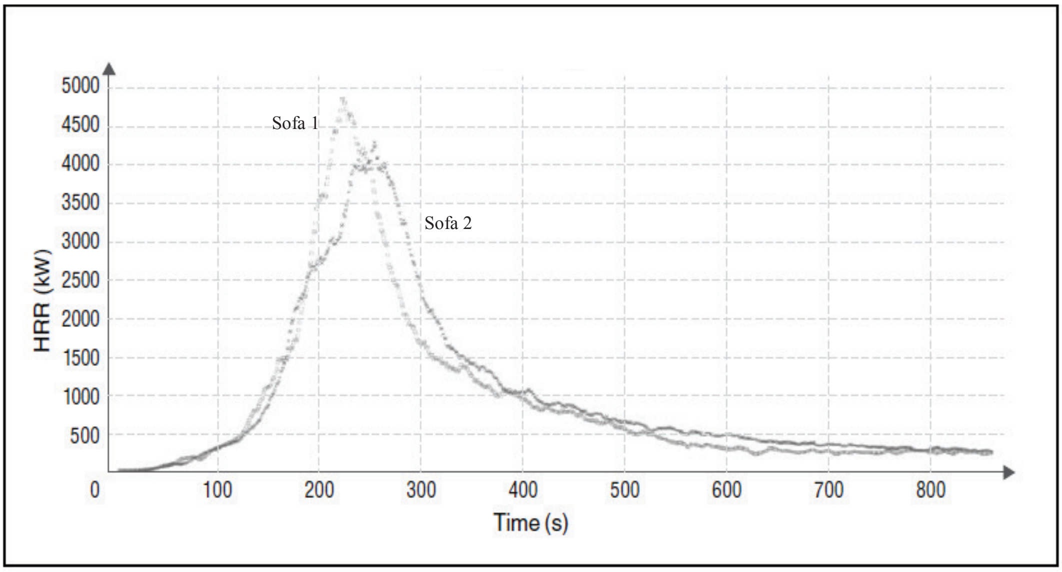


Figure 2.2. Heat-release rate time history from sofa "free burns." [15].

The Figure 2.3 in the cause of the fire dynamics is a graph of temperature vs. time-history curves shown from a sofa fire in a compartment with an open doorway, which allows for the continuous flow of oxygen from the outside of the compartment to the fire. From the figure we are going to see that in each case, the free burn and the open-room burn, the fuel-controlled pattern pertaining to the basic growth, fully developed, and decay.

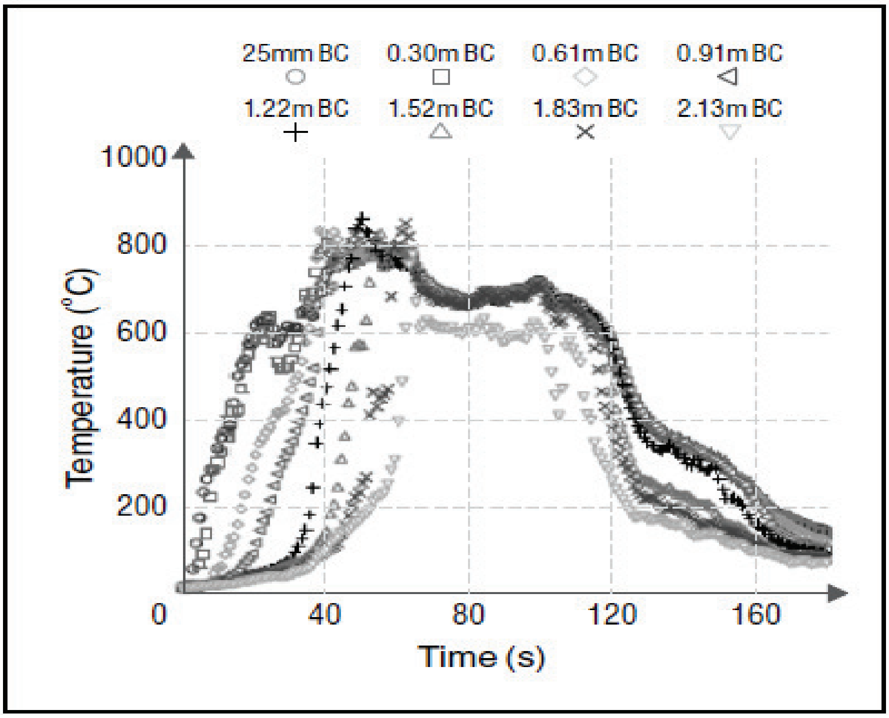


Figure 2.3. Temperature time-history curves from a furnished room fire with an open doorway [15].

Fire scholars have determined experimentally that heat transfer from open combustion is controlled by radiation for fires larger than 0.3m, this radiation is primarily energizes by the radiating soot particles. While peak mean temperatures in fires are on the order of 977 Celsius, the radiating soot typically models as radiating at a temperature near 1127 Celsius [16]. Radiant heat flux formed by such fires is often demonstrated in magnitude as 2.0 W/cm^2, corresponding unevenly to the level of heat flux at floor level. This level of heat flux also corresponds unevenly to the level which would cause fast pyrolysis of cellulosic materials and generate ignition of a flammable floor covering with pilot flame present [16].

2.4 Firefighting Apparatus

During firefighting operation different types of vehicles are used, depending on the need and duty that will be performed. The duties might include: firefighting, investigation of dangerous goods, search and rescue vehicle extrication, medical emergency, plane crashes and swift water rescue. Thus the firefighting apparatus are label vehicles that have been tailored for usage during firefighting tasks. The common types of these vehicles are the aerial fire apparatus, fireboat, hazardous materials apparatus, heavy rescue vehicle etc. [17]

2.4.1 Aerial Fire Apparatus

The aerial fire apparatus is basically used in combating wildfire from above be enhancing articulate aerial resources like aircrafts in fighting the wildfire. The aircrafts used in this operation of wildfire ranges from helicopters, fixed-wings aircraft, rappellers, and somkejumpers. This apparatus carries Along with them additional chemicals to combat fires such as plain water, water enhancers (gels and foams) and most importantly the formulated fire retardants [3]**.** Helicopters may be provided with water tanks or they can carry buckets which are usually be dipped in any water source such as rivers, lakes, or even portable tanks.

Also another common type of aerial apparatus is the Air tankers known as water bombers, use the same principle of helicopters in skimming water from rivers, lakes etc. Over the years, various aircraft have been used for firefighting. The largest firefighter ever used that could carry 90,800 litres of water is the Boeing 747 aerial firefighter, the next largest one which is currently in use, can carry up to 56,800 litres is the Russian IL-76 air tankers [20].

2.4.2. Fire Boat

When you have fires happening on shipboard or shoreline the best choice is to fight it using a fireboat which is a specialized firefighting appliance with nozzles and pumps designed for this specific purpose in fire combatting [22]. Providing water for these boats is not a thing to worry about as they are pump water directly from the below the hull, the modern models of fire boats are able to pump thousands of gallons of water per minute, for example The Warner L. Lawrence (commonly called Fireboat 2) is capable to pump approximately 2.4 m^3 /sec to a high of 122 m in the air [23].

2.4.3 Hazardous Materials Apparatus

Fires could be caused by several different things, one of them are the hazardous materials, which might be toxic, flammable, corrosive, explosive, etc. Therefore, a special arrangement should be taking into consideration when dealing with such substances. Due to the nature of the fire to be combatted a special appliance for fighting dangerous fire is deplored like the Hamzat Vehicle [24].

These specialized firefighting vehicles are provided with televisions, computers, radios, as well as a portable lab in order to do needed experiments and analyses on substances samples collected which enable the firefighter to know exactly what kind of response they need to provide in this site. [24]

2.4.4 Heavy Rescue Vehicle

This special vehicle is designed to provide specialized and necessary equipment for technical rescue situation during firefighting. They carry a variety of needed heavy equipment such as generators, winches, cutting torches, etc. The size of the heavy rescue vehicle and the equipment carried by it can be classified in to these categories: Light rescue, Medium rescue, Heavy rescue, Technical rescue [25].

The National Fire Protection Association in the U.S (NFPA) have standards for the operation of the heavy fire rescue vehicles, under the heavy rescue category, these standards indicate that before holding any rescue operation, the rescuers should have medical training which is equivalent to the Basic standard of EMT. [26]

2.4.5 Fire Rehabilitation Unit

In the case of fire emergency during fire outbreak, not only the people trapped in the fire will need help but also all the rescuers that is exposed to the heat, the mental and physical stress of the fire emergency, the risk of panting as a result of high level of carbon monoxide intake into the body system. Duo to these facts a fire rehabilitation unit need to accompany the firefighting crew to provide any needed medical support and monitoring to all emergency personnel [27].

2.4.6 Water Tender

The specific purpose of this vehicle is to transport sufficient amount of water from water source to the scene of the fire incident. It is not expected to be provided with a high capacity pump, it was founded to supply other appliances such as fire engine with water. The vast majority of water tenders are designed to carry up to 3800 liters, and others can be filled with approximately 19,000 liters. [28]

2.4.7 Fire Engine

This vehicle which is known as fire truck, fire appliance, or fire apparatus is designed specifically to fight fires including of course carrying the needed supplies as well as the fire fighters themselves to the scene. The common equipment carried by the fire engine might contain ventilating equipment, hydraulic rescue tools, self-contained breathing apparatus, and first aid kits. As mentioned above this vehicle depends on other sources to get the sufficient amount of water such as water tenders or even a natural water source such as lacks or rivers [29]. When talking about challenging access to some high narrow places then we need the fire engine to be mounted by a turntable ladder, this kind of aerial apparatus is helpful in gaining access to high occurring fires. This turntable ladder is telescopic which means it can be increased in length as it consists of sections slide into each other.

The essential functions of the turntable ladder are [30]:

- providing access at height for fire victims and firefighters
- providing water from a high level point
- with a platform some extra tasks can be executed

The turntable ladders have a platform mounted at the top of it, which is termed the basket or the cage, this aerial ladder is the mounted on a vehicle platform called the truck. On this platform tagged the basket or cage, the firefighters can operate more stably and safely. In the Figure 2.4 shows the turntable ladder with a platform**.**

Figure 2.4. Fire engine with turntable ladder and platform [29]

2.5 Fire Truck History

The first vehicle used in firefighting apparatus was not more than a water pump on wheels and this was back in the 1700s [32].

Humans were the first propulsion means for this kind of vehicle with hand or steamed powered pumps. As the apparatus had little room for personnel, the whole system was moving slowly and when they got to scene the pullers who were the firefighters at the same time were often too tired to do their main job. Towards mid 1800s horses were largely used to pull the fire pumps, which were improved as time passes by through the fire brigades, but still the problem was not completely solved [32].

The first fire engine which was self-propelled and steam powered in the US came in 1841 and was built in New York. The increasing size of buildings in 1930s and the main certain way to reach upper floors of building raise cause for concern in the case of accidents. At this time, ladders were initiated and installed on trucks directly, but the interesting part of this discovery is making the ladders reaching desirable heights of more than 30 meters, which lead to the further developments of turntable ladders [31].

The modern fire truck we know today was defined and attained in 1960s and it can perform the desired tasks of firefighting from a distance height and it is provided with modern water pumps, ladders and basket/bucket. [31]

The tallest firefighting aerial device known till now which was launched in 2010 is the Bronto S-112 HLA (High Level Articulated). This device can go up to 112m, with a safe working load of 700 kg. Figure 2.5 gives a clearer view of the Bronto S-112 HLA fire truck with turntable ladder attached to it and in operation [33].

Figure 2.5. Bronto S-112 HLA, [33]

The four driven and five steered axles of the Bronto S-122 HLA, provides the incredible stable base that will enable the basket to reach high safely. The structure is made up of high tensile steel, and the crane arm can be bent at a 90 degrees which enables this system to reach the highest length of the system, It also come along with an automatic leveling function sets up, that will enable the turntable ladder to reach the desired length of operations with a minute with the aid of a full hydraulic smooth system, making the emergency rescue process more easy and effective [33].

Some of the main operating limits are stated below [33]:

- Maximum working height 112 m
- Maximum outreach 33 m
- Working load 700 kg
- Transport length 19 m
- Transport width 2.7 m
- Typical weight (standard with chassis) 75 t

2.6 Materials for Turntable Ladders

The most popular materials used in building turntable ladders structure are Steel and Aluminum. Each one of them has its special characteristics with pros and cons; there is a need to be aware of all the properties in order to determine which material is suitable for the final product [34].

For turntable ladders, most of manufacturers prefer steel and its alloys basically due to the fact of its properties are more favorable for most of the designed.

The most important characteristics to be check when considering the materials to be used is the cost, strength and malleability, corrosion resistance, weight, and electrical conductivity.

When talking about cost which is the key factor to be considered before making decision about any product material to be used, usually the steel in general cheaper to Aluminum when comparing the prices. Basically when comparing these two materials, the result looks more like these [34].

I. In raw material, steel is 3 times cheaper in cost than aluminum.
II. In shaping, steel is 2 times cheaper in cost than aluminum.
III. In assembly, steel is approximately 25% cheaper than aluminum.

Bearing in mind that the prices are fluctuating continuously based on global demand, availability of raw materials and fuel cost [34].

When talking about elasticity and malleability, aluminum is more elastic and more malleable than steel, while steel is a very resilient material and very tough. Therefore, steel can't be formed in a shape of limited dimension as aluminum. On the other hand, when you need a big metal element with high strength, steel would be the right choice. Coming to the corrosion resistance, one of the best characteristics of aluminum is that this metal doesn't need any further painting or coating as it doesn't rust and it is fully corrosion resistance, whereas steel is subjected to corrosion and needs to be coated after spinning to avoid the element being rusted specially if it is applied in a moist environment. Steel is harder and denser and less likely to be scratched or bent easily comparing to aluminum and it is denser than aluminum with typically 3 times [34].

The above mentioned information can be translated into numbers and stress strain curve in Table 2.1 and Figure 2.6.

Table 2.1. Material properties for aluminum and steel [35]

	Unit	Aluminum	Steel
Density, ρ	kg m^{-3}	2,700	7,800
Young modulus, E	N mm^{-2}	70,000	210,000
Shear modulus, G	N mm^{-2}	27,000	81,000
Poisson ratio, ν		0.33	0.3
Coefficient of linear thermal expansion, α	K^{-1}	23 x 10^{-6}	12 x 10^{-6}

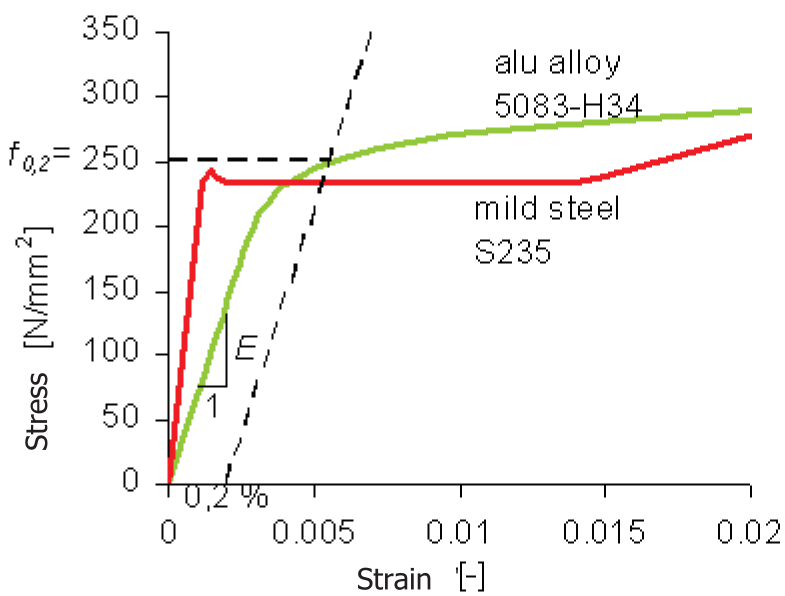


Figure 2.6. Stress-Strain behavior for aluminum alloy and mild steel [35]

For turntable telescopic ladders it is important to design them resistant to buckling, for this purpose we need high tensile strength material which can resist buckling and twisting better. Even though the steel is serving this goal but it is more brittle and less flexible than aluminum, which means it is more eligible to cracking under high levels of stress. On the other hand, the steel costs less and manufacturers are more familiar working with it, this resulted into having more aerial ladders built form steel than those from aluminum. However, as long as the design meets the specifications for structural and stability factors of safety, it those not matter which one of these materials is used [36]

2.7 Structure of Turntable Ladder

Turntable ladders are big scale machines with two rotatory axes and one translational axis mounted on a truck. The manipulator motion potentials are distinct by spherical coordinates, as seen in Figure 2.7. The translational coordinate is equal to telescoping the ladder and designated by the variable *l*. Raising the height of the ladder set, is shaped by the angle variable *ΦR*, which will turn the ladder at the variable *ΦT* [39].

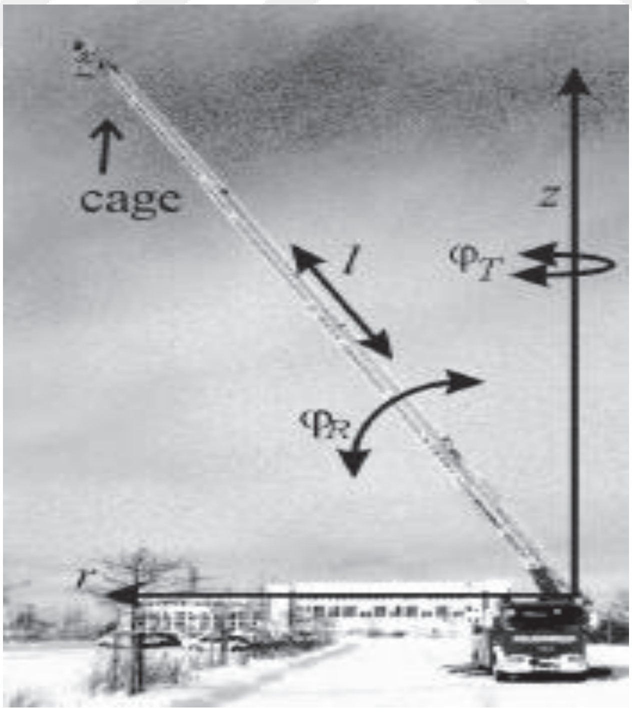


Figure 2.7. Fire-rescue turntable ladders as flexible link robot [39].

The ideal control system of turntable ladders is a combined electronic and hydraulic switch with rate limiters without feedback loop, reason been that the ladder weight should be minimized in respect of attaining a better workspace, especially at steady raising angles, the stiffness of the ladder is restricted with the swaying of the ladder in circumstance of long ladder lengths. Recently, the swaying is being avoided by reducing the practicable velocity which is dependent on the ladder length and the angle of rising with the purpose of increase the velocities meaningfully which is significant and superior in the use for fire turntable ladders as emergency vehicles [40]. Furthermore, for fast evacuation of people in large numbers with fully mechanized operation model should be established. The idea will bring about an integrated trajectory tracking regulator with capabilities to damp the imminent oscillations into the electronic and hydraulic vehicle control as seen in Figure 2.8.

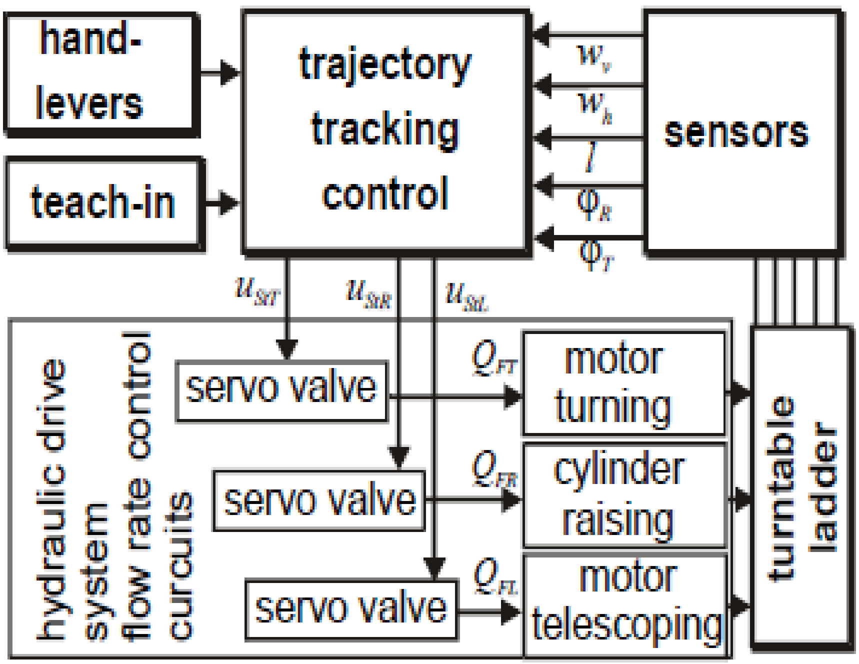


Figure 2.8. Trajectory control embedded in the vehicle [39].

2.7.1 Dynamic Model of Turntable Ladder

In deriving and describing the dynamic model for raising a ladder, the position variable of the angle of raising is introduced at the angle Φ_R with Figure 2.9. The vertical flexion of the ladder is represented by the variable w_v. As the control variable with the raising angle is given as Φ_{CR} with respect to the cage position can be stated as [39],

$$\varphi_{CR} = \varphi_R - \frac{w_v}{l} \qquad \text{.............(2.1)}$$

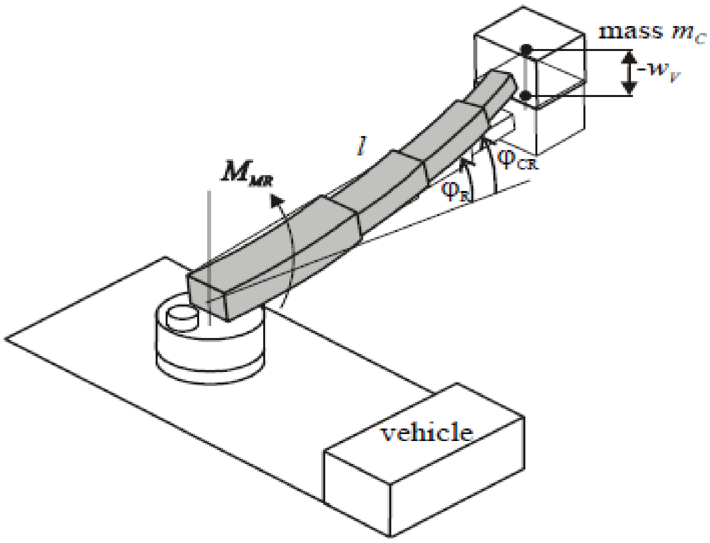


Figure 2.9. Modeling the mechanical structure of the ladder [39].

For proper description raising ladder in relations to its dynamic behavior, a malleable multibody system is selected. The flexibility of the ladder is modeled by flexion of the lines of the four ladder parts through superposition as described in figure 2.17 and repatriated to a corresponding stiffness. Hence, the flexion of the ladder has to be considered and determined by [41],

$$\frac{d^2 w_v}{dl^2} = -\frac{F \cdot l}{E \cdot I_{l-l}} \qquad \text{.................(2.2)}$$

F the force interaction, E the modulus for tension and 2.2 is the geometrical moment of inertia relating to the direction l of the ladder. Because of the four parts of the ladder, the diverse moment of inertia of each ladder will be considered, which will eventually lead to polynomial function of third order with conditional on the ladder length l.

$$w_v = f(l) \cdot F \qquad \text{.................(2.3)}$$

This revenues, the equivalent stiffness then can be assumed as,

$$c_{RL}(l) = \frac{1}{f(l)} \qquad \text{..................(2.4)}$$

Next stage is to cut the ladder into two parts (Figure 2.10) and then introduce the corresponding masses for each of them. As a generalization the equivalent masses m are both set to half of the complete ladder set mass ml.

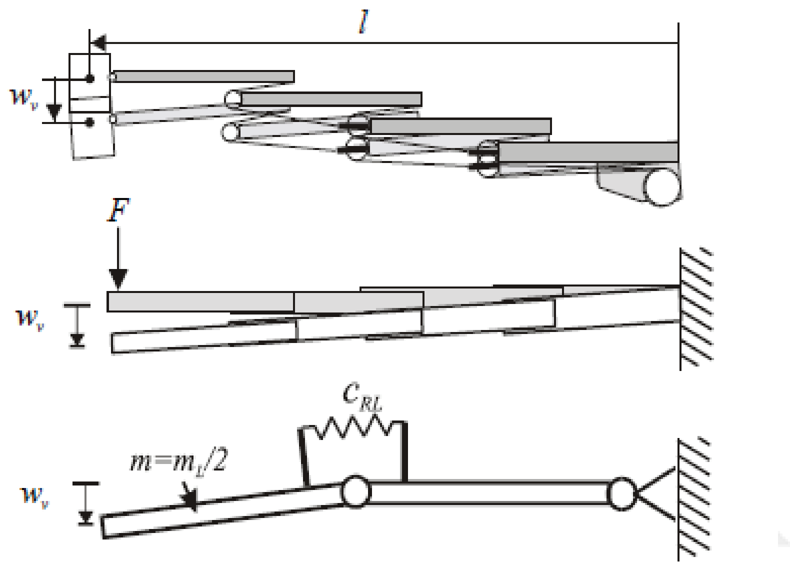


Figure 2.10. Ladder set and flexible multibody representation.

The last stage before deriving the equations of motion is the evaluation of the mass moment of inertia for the ladder. Therefore, the ladder is presumed to be a beam with definite cross sectional dimensions. Result will be a function $J_R(l)$ depending on the ladder length l for the mass moment of inertia of the ladder. In conclusion the equations of motion derived by the Lagrange formalism of the given system with the movement direction of defiance of gravity the ladder is given as

$$(J_R(l) + m_C l^2)\ddot{\varphi}_R - ml \cdot \ddot{w}_v - ml \cdot g\cos\varphi_R = M_{MR} - b_R\dot{\varphi}_R$$

$$-ml \cdot \ddot{\varphi}_R + m \cdot \ddot{w}_v + b_{RL} \cdot \dot{w}_v + c_{RL}(l) \cdot w_v = 0 \qquad \text{............(2.5)}$$

The first equation in the above equation 5 describes mainly the raising kinematics concerning the lower ladder part, whereas the reaction due to the flexion of the ladder is considered. The second equation of the equation is the equation of motion describing the ladder oscillations due to the ladder flexion. In the second equation beside the equivalent stiffness c_{RL} a damping coefficient b_{RL} for the ladder oscillation is introduced. As hydraulic drive two hydraulic cylinders are mounted in the ladder gear. The reacting torque on the ladder can be described by the following equations [41]

$$
\begin{gathered}
M_{MR} = F_{cyl} d_b \cos\varphi_p(\varphi_R) \\
F_{cyl} = p_{cyl} A_{cyl} \\
\dot{p}_{cyl} = \frac{2}{\beta V_{cyl}} (Q_{FR} - A_{cyl} \dot{z}_{cyl}(\varphi_R, \dot{\varphi}_R)) \\
Q_{FR} = K_{PR} u_{StR}
\end{gathered}
\qquad \text{………………(2.6)}
$$

F_{cyl} is the force of the hydraulic cylinders on the piston rod, p_{cyl} is the pressure in the cylinder, Acyl the cross sectional area of the cylinder, þ the compressibility of the oil, V_{cyl} the volume of the cylinder, Q_{FR} the flow rate, and K_{PR} the constant which describes the connection between flow rate and input voltage of the valve. The dynamical effects of the underlying flow rate control are neglected [42].

The hydraulic cylinders are mounted in the ladder gear. The piston rods of the cylinders are fixed at the ladder set. The distances d_a and d_b can be evaluated out of technical data of the ladder. This results then in the following equation describing the dependency between the piston rod position z_{cyl} and the raising angle Φ_R [42].

$$
z_{cyl} = \sqrt{d_a^2 + d_b^2 - 2 d_b d_a \cos(\varphi_R + \varphi_0)} \qquad \text{…………(2.7)}
$$

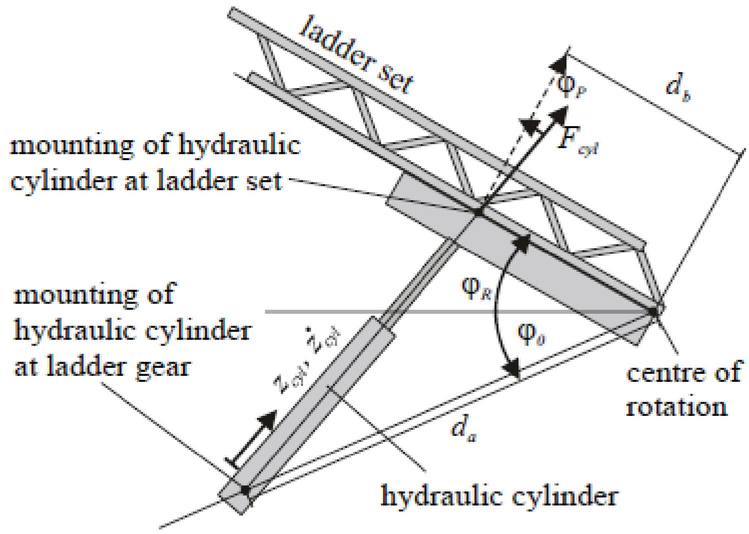


Figure 2.11. A typical kinematic structure of raising the ladder via hydraulic cylinders [42].

2.7.2 Standardization in Turntable Ladder

Turntable Ladders are a simple tool for gaining access to higher levels. When properly used and cared for, they will provide many years of useful service. This Ladder are built of several and different materials with various designs and standard. The association of the European Union and the United Kingdom created a ladder certification system that involves grouping of ladder in to classes for any of the ladders manufactured or will be traded in Europe. The accreditation of the certificate for classes of these ladders will solely be applicable to ladders that are portable i.e. the stepladders and the extension ladders, all categorizes into these three types of certification classes. Each of the ladder certification class is color-coded to designate the extent of weight the ladder is intended to hold, also the certification class category and its usage. The safety label color specifies the class and use of the ladder. The classifications are as follows [38].

- The Class One ladder: Heavy duty, industrial uses with a maximum load of about 175 kg.The Color-code of the ladder is “blue” to identify.
- The Class EN131 ladders: Commercial uses, with an approximate maximum load of about 150 kg. No exact color code is given for this kind of ladder.

- Class three ladders: This is ideal for light and domestic use, with a maximum load of 125 kg. The color-code is “red” to recognition.

In the United Kingdom there are quite a few numbers of British standards involved in the three main ladder certifications, which are comparative to the specific ladder type. The applicable orderings include BS 1129:1990 (British) which is applicable to Timber Ladders and Steps; BS 2037:1994 (British) which is applicable to Metal and Aluminum Ladders and Steps and BS EN 131:1993 (European) which is applicable to both Timber and Aluminum Ladders and Steps [38].

2. 8. Failure in Aerial Turntable Ladder

Whereas many aerials ladders are similar in appearance, there can be subtle and significant differences in their individual specifications that can have a critical effect on their performance abilities. The main concern that goes into any aerial ladder design like the turntable ladder is the safety, with the goal to design an apparatus that will meets a series of performance objectives, while resisting catastrophic failures through proper integration of safety factors along the design process. The engineer to needs design an apparatus that will resist failure of the ladder, using knowledge of how materials fail, how columns fail, and how stresses are transferred through the structure [43].

2.8.1 The Forces Causing Failure Turntable Aerial Ladders

The turntable aerial ladder is an arranged and complicated assembly of trusses which telescope together. Each larger section of the ladder is significantly stronger than the individual sections that telescope into it, and the assembly is particularly strong where the sections overlap. In a cantilever configuration as seen in Figure 2.12, bending stress creates tension forces in the top chord (the handrails) and compression forces in the bottom chord (lower beams), which increase in magnitude from top to bottom. When the tip of the ladder is supported the top chord is in compression and the bottom chord is in tension [44]. A cantilever configuration creates greater bending stresses in a ladder than a supported configuration. Simple bending failures often occur at the point where the first section extends out of the bed ladder, as shown in several of the incidents discussed in this report. At this location the ladder is subjected to the greatest bending forces in any of the telescoping sections, just prior to the point where the load is transferred to the bed ladder. The bending forces continue to increase in magnitude down to the bottom of the ladder; however, the bed ladder has a much greater capacity to resist bending stresses than the telescoping sections. Failures that occur at this location often involve elongation of the handrails when their tensile capacity is exceeded, or buckling of the lower beams due to compression forces, allowing the upper portion of the ladder to droop. Twisting actions can be extremely damaging to aerial ladders. Any action that twists a ladder creates complex forces that may overload individual members or cause the ladder sections to become disengaged, leading to catastrophic failure [45].

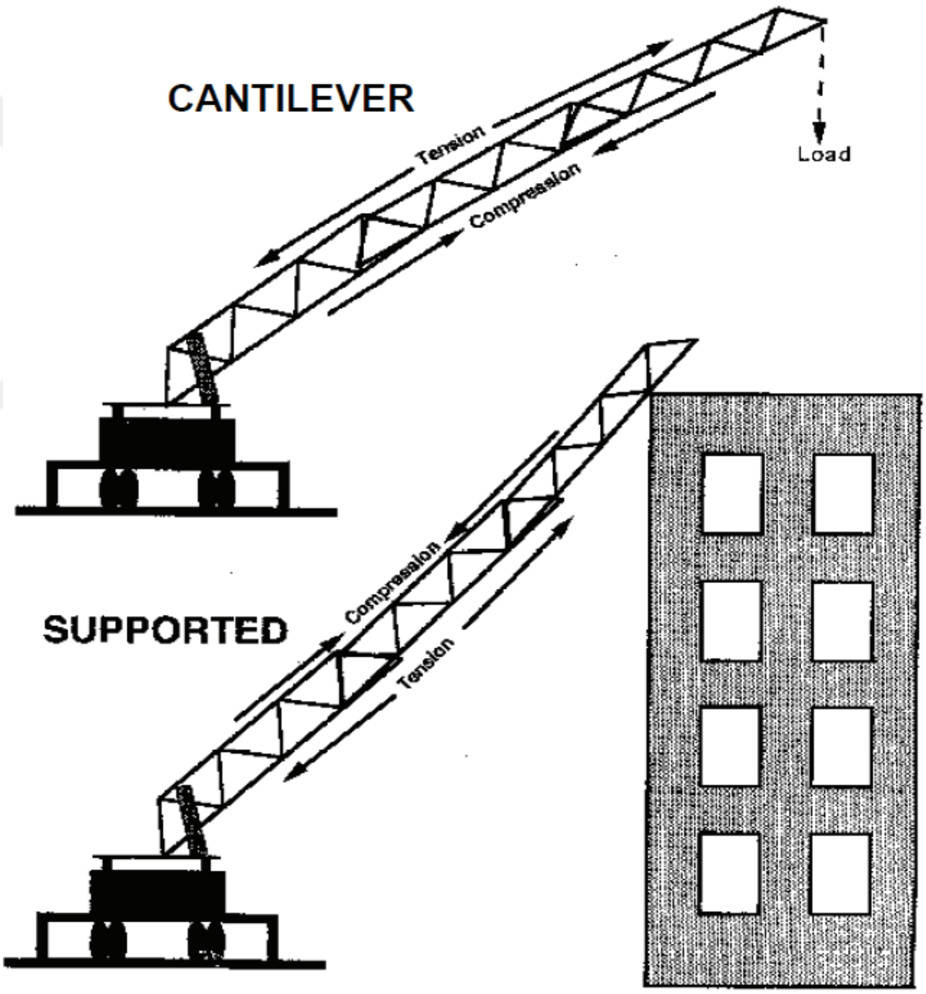


Figure 2.12. Forces in ladder in cantilever and supported operating modes [45]

A twisting failure can occur at any point in a ladder where the stress in a particular member or at a connection exceeds its capacity. However, the failure is most likely to occur at a point. Most aerial ladder failures, which happens as a result of overloading, over extension at low elevation angles, this result into overturning or structural failure of the ladder. Aerial turntable ladders are vulnerable to catastrophic failure when the ultimate capabilities of one or more critical members or connections in the ladder assembly are surpassed. These states of the member or the connection of the ladder may undergo bending stresses, twisting stresses or a combination of bending and twisting [44].

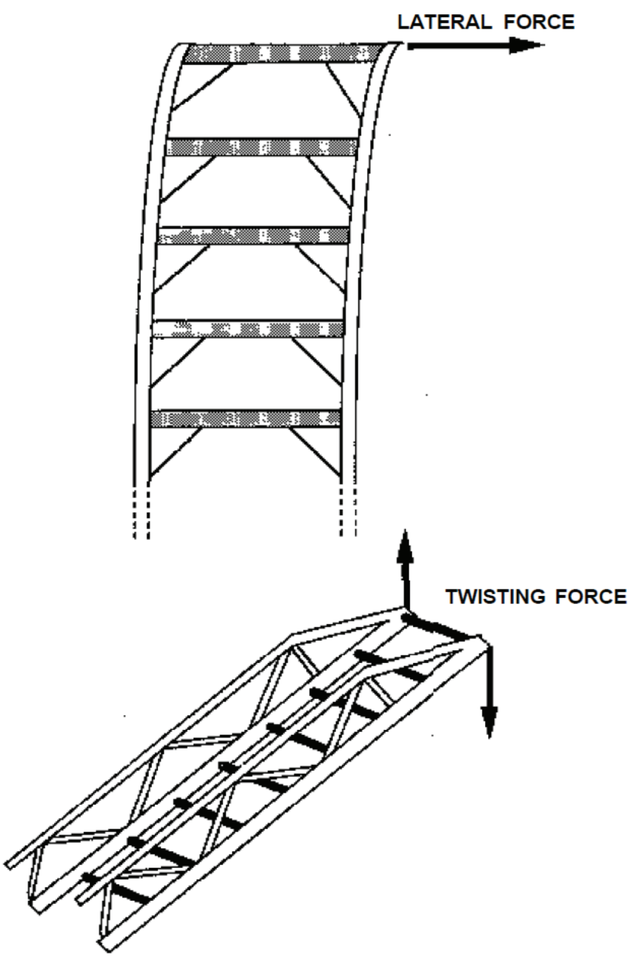


Figure 2.13. Lateral forces and twisting forces in aerial ladders [44].

In the earlier days of ladder designs, the turntable ladders are prone to susceptible structural failure that the newer ladders because they were not designed to provide the needed load capabilities that are vital and meet the real standards. The first set of turntable ladders have proven to be free of structural failure and dependable when operated within their design limits; nevertheless, they were not designed for low angle procedures. The developments in aerial ladder technology have made the newer ladders widely available and safe [44].

2.8.2. How Failure Occur in Turntable Aerial Ladders

The Statement below simplifies failure in aerial ladders [46].

The Euler Buckling is of the ladder is dependent on the material used, the cross-sectional area and the length.

Where:

*Stiffness of material equals the tensile strength.

* Cross-sectional area equals the moment of inertia which evaluates the resistance to twisting for a column which depends on the dimensions and wall thickness of individual structural members.

*Length is simply the length of the aerial.

Take note of the fact that as the aerials become lengthier, they become less resistant to buckling, regardless of what they are made of or their cross-sectional area. The length of the aerial becomes its greatest liability when it comes to strength. If a column is doubled in length, the column now has only ¼ the resistance to buckling, ¼ as strong. The opposite is also true, not only does the column become stronger, but the center of gravity comes closer to the rotation axis [43 44]. The higher tensile strength metals resist twisting and buckling better than the lower tensile metals. When comparing steel to aluminum, steel has a greater tensile strength, however, the steel weighs more. There are a variety of steels with different tensile strengths and the higher tensile steels are more brittle. More brittle means less flexible and more susceptible to cracking when suffering an impact. Steel has three times the tensile strength of aluminum when comparing exact same size columns, length, physical cross-section, and wall thickness. Aluminum has 1/3 the density of steel, that means for equal volumes of material, aluminum weighs 1/3 as much as steel. This result indicates why more aerials are built from steel than aluminum, along with the fact that people are more conversant working with steel than aluminum [43-46].

2.9. Finite Element Method

The term Finite Element Analysis (FEA) is a numerical method for solving engineering problems.

When the problem consists of complex geometries and loadings without the likelihoods of deriving analytical solution, this method is suggested. FEA is piloted by basically following three important steps: preprocessing, analysis and post processing, as explained below [47].

The preprocessing of FEA: This involves constructing a model of the component that is to be analyzed. This is usually carried out by first dividing the geometric shape into different discrete elements which are connected with various nodes. Some of the nodes in the model can have fixed displacements, while others can have recommended for loading. Usually the graphical preprocessor software was used to superimpose a mesh on preexisting computer with the help of design file and finite element analysis was conducted with computerized drafting and design process. The process was carried out in this way if not it would be a tedious process [49].

The analysis in FEA: This process entails, making use of the dataset prepared by the preprocessor is served into the finite element code for processing. The process of solving the problem might require using a linear and nonlinear algebraic expression or equations [47-49].

FEA Post-processing: In the process of the analysis, graphical displays are produced to visualize the results relation to the trends, displacement, stresses and factors. The FEA postprocessor software can display varying levels of stress in the model in colored contours to show the experimental results. Consequently, the numerical solutions of difficult stress problems can be created easily by using FEA. Regardless of the use and approval of this commercially available software, the main drawback is that the codes are invisible and perplexing to the user and makes it hard for the user to understand the underlying mechanisms in generating results [48]. The other disadvantage is that although the stress results are shown, FEA analysis might not certainly explain the relationship of stress with other significant factors such as other material and geometrical features of the components. It is also likely that results obtained can easily be incorrect due to error in entering data into the system. To this end the usage of FEA should be done with absolute care by the designer and should enhancement the result obtain with other possible closed applications and experimental analysis [48].

2.9.1 Relation of Finite Element Method to Design of Experiments

Since numerical approaches provide a universal tool to analyze illogical geometries and loading conditions. One of the numerical methods is the FEA which has been widely used with great success recorded; though, this analysis involves the generation of a large set of data in order to acquire reasonably and correct results, thou its consumes large investment in engineering time and computer assets [51]. The Finite Element Method (FEM) is a good choice for the analysis of aerials ladder structural stability and for checking optimization at it helps in eliminating the need for tedious experiments work to improve the process of determining the parameters [50]. The FEM simulations are progressively used for examining and optimizing the structural strength. Many time occupying experiments can be swapped by the computer simulations. The finite element method gives a rough solution with an accurate data that depends mainly on the type of component and the fine quality of the finite element mesh. In the manufacturing sector, design of experiments is establish to be an effective statistical technique that can be used for various experimental examinations. The design of experiments is one of the influential tools used to examine deep and hidden causes of process in variation [52]. It is a methodical, demanding approach to engineering problem solving, which apply the principles and techniques of data collection techniques to ensure the generation of true, secure, and acceptable conclusions. In the optimization of aerial ladder for better performance and maximum benefit, the experimental design is considered a powerful approach for process development, and for improving the stability of the ongoing process. Hambli et al., [53] found that the design of experiments technique is an effective and an economical way to model and analyze the interactions that describe process deviations.

2.9.2 Advantages of Finite Element Method over Other Methods

The merit of FEM over other method of numerical analysis method as stated below [51-54].

i. The FEM can be used on arbitrary domains (in contrast to finite difference methods)
ii. It is an enormously computational method that is applicable to a large number of different applications.
iii. The fact that you can change functions and the FEM scales betters makes your calculation more correct without altering your mesh.
iv. FEM tends to detect small information in solutions better than finite volume methods because of the way that the solution is efficiently interpolated over each element in the FEM. This gives a tradeoff for the person performing the model over Finite Volume Method (FVM), as it can be more computationally efficient for many applications.
v. The ability of FEM to resolve fine details in the solution of the model to be designed as it often superior for Multiphysics problems, giving rise to a high degree of coupling and non-linearity, as well as the peed benefit when compared to FVM .

CHAPTER 3
THE METHODOLOGY FOR AERIAL LADDER DESIGN AND MODELLING

3. 1 Introduction

The first and most important part of the process of acquiring new fire apparatus is to determine the operational needs. It is important to recognize the intended uses of specific ladders and the proper techniques to deploy them. There are many factors involved in deploying and choosing appropriate ladders. Considerations include the mode in which you are operating, building type, occupancy type, incident type, complexities, and time management.

3.2 Aerial Turntable Ladder and Parts According to Standard

The Aerial Ladder Platform shall be designed explicitly for the purpose of firefighting and rescue to enable fireman or the rescuer to go up over and above the other side of any barrier. It shall encompass of main body with Telescopic sections and a cage mounted at the top of ladder and the entire unit shall be mounted onto a chassis cabin with suitable capacity.

- ✓ The aerial ladder platform shall be designed for the operational stability and structural strength based on the criteria laid in **TS EN 14044+A1** and other related European standard and the standards appropriate for elevated raised platforms used for firefighting and rescue operations.

- ✓ The aerial platform shall be capable of use at any angle of elevation without any reduction of load capacity of the cage. It shall also rotate 360 degrees at any angle of elevation as well as below ground level.

- ✓ The apparatus shall be compact and fast on the road and easily controllable in the crowded streets and around sharp corners. The overall dimensions shall not exceed the limits specified for this kind of operation.

- ✓ The working height of the Aerial Ladder Platform shall not be less than the specified standard in **TS EN 14044+A1** for the Ground and the Horizontal.

- ✓ A telescopic rescue ladder shall be attached. The ladders shall be provided with enough width and handrails for rescue of the people at any height during rescue operation.

- ✓ The aerial ladder platform shall be electro hydraulically controlled, allowing easy operations under the most challenging conditions, with sufficient backup strength and stability.

- ✓ An adequate safety links shall be unified in the design so as to ensure complete safety procedures and long years of dependable service.

3.3 The Aerial Ladder Construction Material

The aerial ladder on the apparatus shall be of good and strong construction; the materials used in construction shall be cautiously nominated for lightness and durability. The use of timber shall be restricted in the bodywork and use of rubber shall be avoided as far as possible. The ferrous metal parts for the construction of the ladder shall be treated for any anti-corrosion effect by a technique other than electro-plating. The following material properties were used in this research models for the proposed aerial ladder.

- Material type: Steel
- Weight per unit volume: 7849.8 kgf/m^3
- Mass per unit volume: 800.5 kg/m^3
- Modulus of Elasticity: 2.102×10^{10} kgf/m^2
- Poisson's ratio: 0.3
- Effective Yield stress F_{ye}: 23963331 kgf/m^2

- Effective Tensile stress F_{ue}: 36709783 kgf/m^2

3.4 A Typical Aerial Ladder Description

As shown in Figure 1.1, the perspective view of an aerial ladder that can be lengthen, which is expected to be placed on a vehicle in order to be used for lifting and taking down during rescue operations [56].

The parts of the ladder set are [55]:

1. Longitudinal Axis
2. Top Edge
3. Rails and Rungs
4. Ladder Units
5. Ladder
6. Rotational Base

3.5 The Structural Model of the Aerial Ladder.

The proposed aerial ladder to be model was checked and builds using the SAP 2000. Full length of the ladder is 23.85 m and it consists of 4 sections, 3 of them are able to slide inside each other as you can see in the Figure 3.2

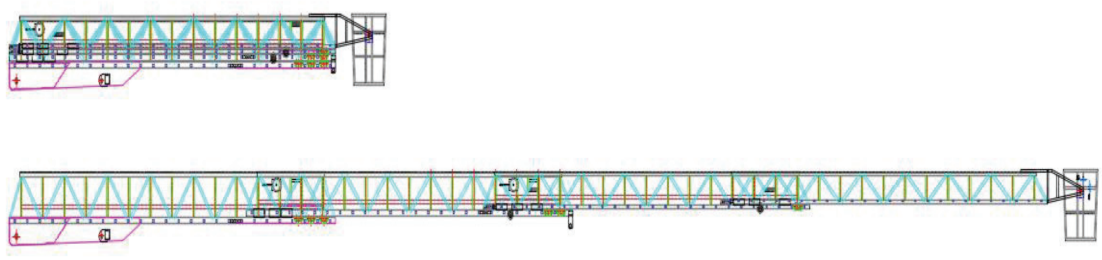


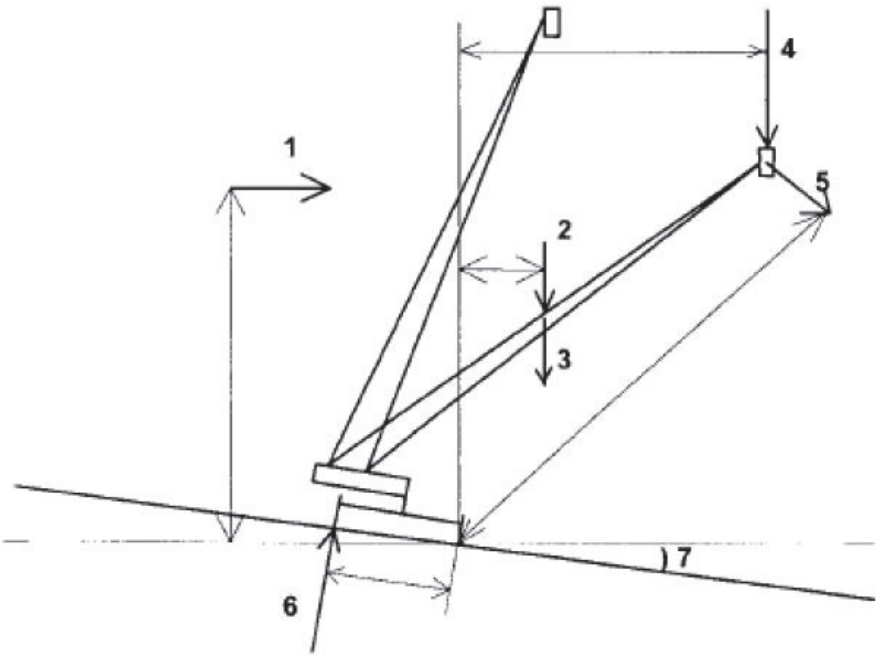
Figure 3.1. The designed ladder in full length and minimum length

The study aimed to obtain the optimum length when rotating the ladder down for each 5 degrees starting from 75 degrees. I.e. optimum length for 75, 60, 65, etc. and out of these values to identify the work range for each model.

Loads and safety factors:

We have the following forces applied on the ladder that needed to be taken into consideration while checking and designing the model:

- Forces engendered by gravity (F_G and F_E) which generate a tilting moment and/or righting moment, are multiplied by the factor of 1.0. They are assumed to be acting vertically downwards.
- Forces engendered by the gravity of the maximum working load (F_L), which create a tilting moment and/or righting moment are multiplied by the factor of 1.25. They are assumed to be acting vertically downwards.
- Inertial forces engendered by masses in motion (F_N) are multiplied by a factor of 0.1 for $V \leq 0.7$ m/s and by the factor of 0.2 for $V > 0.7$ m/s. They are assumed to act tangentially to the direction of movement which generates the maximum tilting moment and applied to the center of gravity of the structure in motion.
- Diverse forces (F_S) (e.g. manual forces, reaction to a water jet ...) are multiplied by the factor of 1.1 and assumed to act in the direction of movement which generates the maximum tilting moment.
- Wind forces (F_W) having an influence on stability are multiplied by the factor of 1.1. They are assumed to act horizontally.
- The absolute velocity at the head of the extended ladder set under normal working conditions shall be taken as the speed of movement V. [57]



Key

1 Force resulting from wind load, F_w

2 Force resulting from dead weight load, F_G and F_E

3 Force resulting from inertial forces tangential to direction of movement, F_N

4 Force resulting from the working load, F_L

5 Force resulting from diverse forces (e.g. jet reaction), F_S

6 Force resulting from residual forces, F_R

7 Angle being the combination of camber angle and gradient angle

Figure 3.2. Example of forces acting on turntable ladder

CHAPTER 4
MODEL ANALYSIS AND DISCUSSION

4.1 Model Analysis

In this section the initial design analysis and results will be discuss and a possible suggestion on improvement will be made according to the analysis and result obtained, in relation to the working range for the models.

4.2 General Information

4.2.1 Software Used

SAP2000 software was used to build and check all models in this study.

4.2.2 Material Properties

As explained in chapter 3, the following material properties were used in all models:

- Material type: Steel
- Weight per unit volume: 7849.8 kgf/m3
- Mass per unit volume: 800.5 kg/ m3
- Modulus of Elasticity: 2.102 x 1010 kgf/m2
- Poisson's ratio: 0.3
- Effective Yield stress Fye: 23963331 kgf/m2
- Effective Tensile stress Fue: 36709783 kgf/m2

4.2.3 Geometry

Full length of the ladder is 23.85m and it consists of 4 sections, 3 of them are able to slide inside each other and the one at the base (first section) is fixed as what shown in Figure 3.1

The study aimed to obtain the optimum length when rotating the ladder down for each 5 degrees starting from 75 degrees. I.e. optimum length for 75, 60, 65, etc. and out of these values to identify the work range for each model. All cross sections used in the models are tube kind, and are increased in cross section size as we go down to base.

4.2.4 Joint Definition

All joint between elements of the ladder truss are modeled as pinned joints, and the attaching area between the ladder and the plate of the mechanical base are defined as 3D fixed joints.

4.2.5 Load and Load Combinations

Were identified according to Turkish and European standards for turntable ladders with sequential movements **TS EN 14044+A1**. The safety factors for each kind of load are listed in table1.

Table 4.1. Turkish and European standards TS EN 14044+A1, safety factors.

	Symbol	Unit	Direction of action	Factors for use in calculations	
Speed of movement	V	m/s	-	≤ 0,7	> 0,7
Forces engendered by gravity (dead weight)	F_G	Kgf	vertical	1,0 × F_G	
Forces engendered by working load (applied load)	F_L	Kgf	vertical	1,25 × F_L	
Inertial forces	F_N	Kgf	Tangential to direction of movement	0,1 × F_E + 0,1 × F_L	0,2 × F_E + 0,2 × F_L
Wind forces	F_W	Kgf	horizontal	1,1 × F_W	
Diverse forces	F_S	Kgf	Selected angle	1,1 × F_S	

According to the load combination, which was set as a combination of all listed forces multiplied by corresponding factor, in addition to one or two wind loads that might acting together (wind speed in area the ladder will be used in equals to 28 mph):

- All factored forces + 1.1 × wind load in 0^0 direction
- All factored forces + 1.1 × wind load in 90^0 direction
- All factored forces + 1.1 × wind load in 180^0 direction
- All factored forces + 1.1 × wind load in 270^0 direction
- All factored forces + 1.1 × wind load in 0^0 direction + 1.1 × wind load in 90^0 direction
- All factored forces + 1.1 × wind load in 90^0 direction + 1.1 × wind load in 180^0 direction
- All factored forces + 1.1 × wind load in 180^0 direction + 1.1 × wind load in 270^0 direction
- All factored forces + 1.1 × wind load in 270^0 direction + 1.1 × wind load in 0^0 direction

4.3 Designing the Model for the Aerial Ladder

4.3.1 First Model (Base Model)

With a regular case of having two persons in cage, this model was designed using AutoCAD 3D and then imported to SAP 2000. The Sections and loads were assigned, and loads combinations were identified according to the adopted Turkish and European code.

The model was stable in full length at 75^0, and as mentioned above, the model was analyzed at each 5 degrees starting from 75 downwards. The Table 4.2 represents each degree of the value obtained with maximum length in correlation with the Figure 4. 2, that shows the cubic curve fitting of the results, a derivation can then be consider for the inner area as working range for this model.

Table 4.2. Angle vs length of ladder in Model 1, two persons in cage.

Angle (Degree)	75	70	65	60	55	50	45	40
Length (meter)	23.85	23.85	23.85	23.55	22.35	20.55	20.55	19.95

Angle (Degree)	35	30	25	20	15	10	5	0
Length (meter)	19.35	18.15	17.85	17.25	17.25	17.25	17.25	17.25

As shown in Figure 4.2, the length of ladder in Model 1 with two persons in the cage, is changing between 65^0 and 20^0 and out of this range, the length is remaining the same.

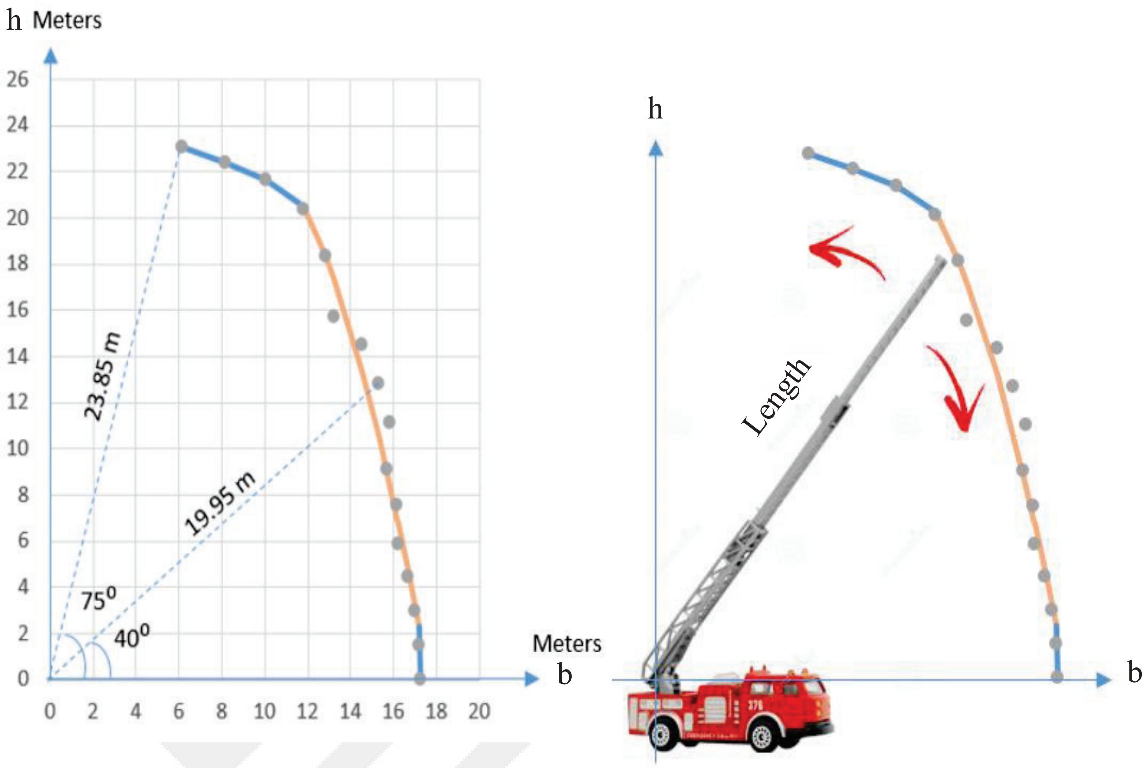


Figure 4.1. Angle vs length of ladder in Model 1, two persons in cage

The ladder can't go beyond the drawn limit drown in Figure 4. 2, otherwise it will fail. By using the same structure but decreasing live load in cage from two persons into one person only, the working range will expand more according to Table 4.3.

Table 4.3. Angle vs length of ladder in Model 1, one person in cage.

Angle (Degree)	75	70	65	60	55	50	45	40
Length (meter)	23.85	23.85	23.85	23.85	23.25	22.35	21.15	20.85

Angle (Degree)	35	30	25	20	15	10	5	0
Length (meter)	20.85	19.95	19.95	19.65	19.65	19.65	19.65	19.65

The Table 4.3 in comparing with the working range with one person VS two persons is represented in Figure 4.3.

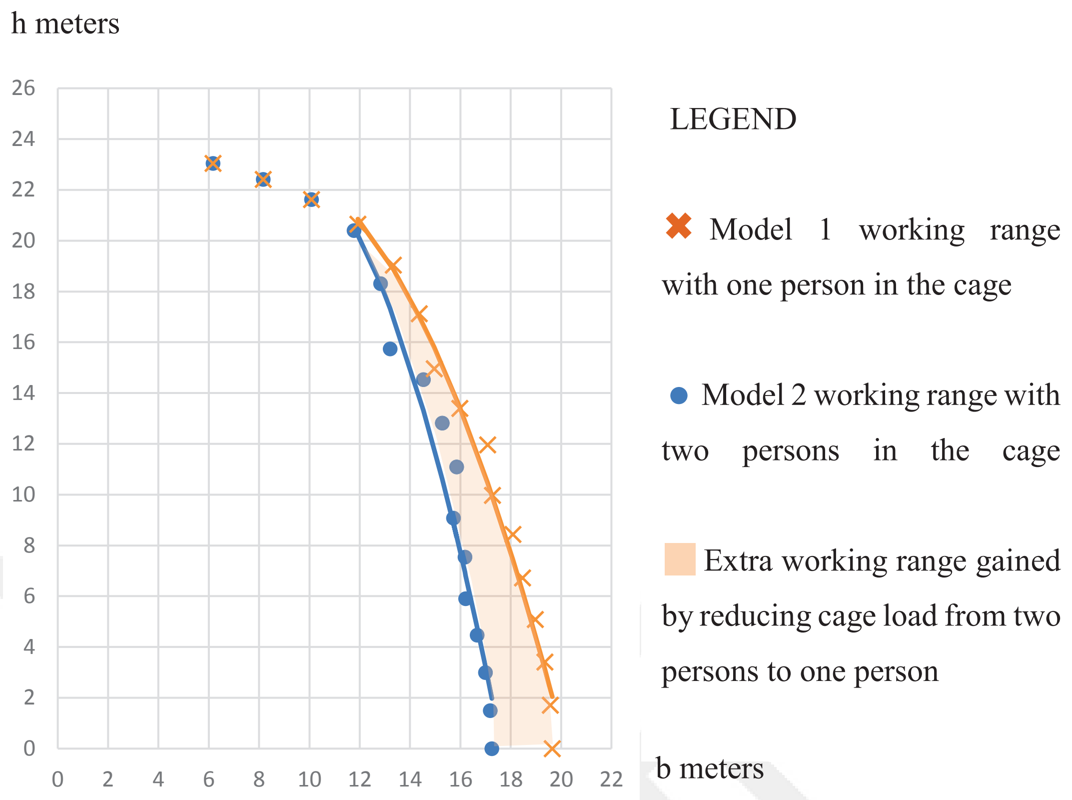


Figure 4.2. Angle vs length of ladder in Model 1, one person vs two persons in cage.

The cage with one person is visualized by the green series, whereas with the cage two people in it, the case is visualized by blue series. The highlighted area between two is the extra space in work range we can gain when only one person is working in the ladder cage.

4.3.2 Second Model

After checking the stability for the previous model with one and two people in the cage for each 5 degrees, the analysis shows that the most vulnerable frames in the ladder structure is in the upper tensioned frames, especially those located in the middle of each ladder section, as seen in Figure 4.4.

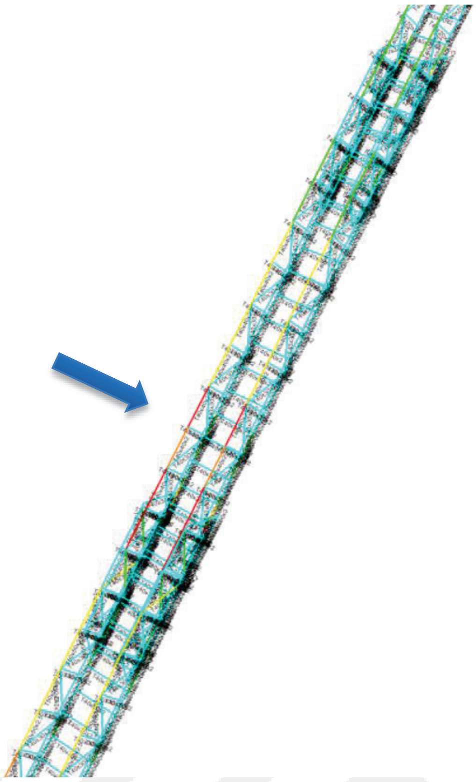


Figure 4.3. Weakest members' location in the ladder

After running the design and checking the structure in SAP 2000, the program shows the structure members in different colors indicating the stability status. The more the close color to the red, the more critical the member stands. The Red color is assigned to the failed members.

Analysis results of Model 2 in a comparison with Model 1 are shown in Table 4.2, According to the upper recognized behavior of the system, all sections in the upper section were increased as following:

60X60X2.5 was increased to 80X80X3

50X50X2.5 was increased to 60X60X2.5

40X40X2 was increased to 50X50X2.5

Table 4.2. Comparison between angle vs length for Model 1 and Model 2.

Angle (Degree)	75	70	65	60	55	50	45	40
Length (meter) for Model 1	23.85	23.85	23.85	23.55	22.35	20.55	20.55	19.95
Length (meter) for Model 2	23.85	23.85	23.85	23.85	23.55	20.85	20.85	20.55

Angle (Degree)	35	30	25	20	15	10	5	0
Length (meter) for Model 1	19.35	18.15	17.85	17.25	17.25	17.25	17.25	17.25
Length (meter) for Model 2	19.35	18.15	17.85	17.25	17.25	17.25	17.25	17.25

The highlighted cells show the slight improvement happened between two models. By using the mentioned increased section, extra 30 cm length was gained between 60^0 and 40^0.

4.3.3 Third Model

In the model stage all square sections in the ladder in Model 1 were changed to rectangle, taking into consideration and maintaining the same area for each section as shown in Figure 4.5.

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Figure 4.4. Cross sections transformation in Model 3

The new cross sections were changed to the following:

From 80x80x3 to 160x40x3

From 60x60x3 to 120x30x3

From 60x60x2.5 to 120x30x2.5

From 50x50x2.5 to 100x25x2.5

From 40x40x2 to 80x20x2

The main reason behind this change is to have a higher value for Moment of Inertia for sections **$I = b.d^3/12$**

The extra length is derived by applying this method, which is less than 30 cm. Also by checking the figure 4.6 for the comparison between Model 1 and Model 3 at the same degree.

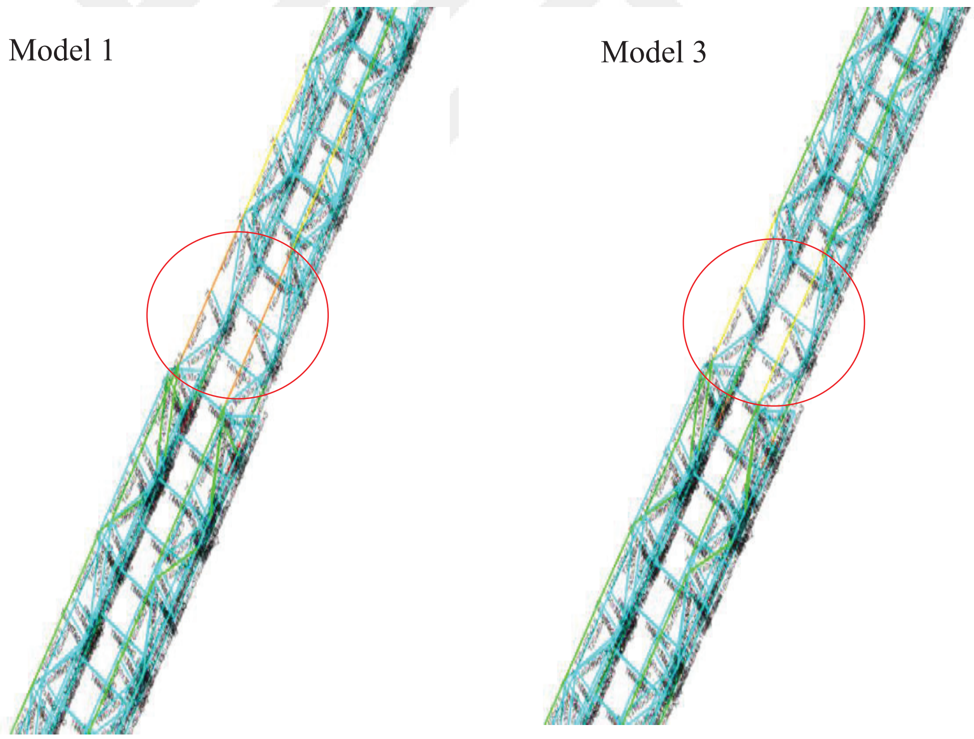

Figure 4.5. Comparison between hand rails member in Model 1 and Model 3 at 35^0 and 19.65m

As shown in Figure 4.6 above, the upper members in hand rails in Model 1 are more critical than the members in the same location in Model 3, which uses the same cross sectional areas but the rearrangement is taken into consideration as more effective section to resist the moment of inertia.

4.2.4. Fourth model

The design of handrail way in all previous models was in a shape of rectangles with diagonal elements (vertical bars and diagonal bars between the upper and lower rails, with different spaces in-between from one ladder section to another). In Model 4 this system of hand rail was changed to a shape of equilateral triangles as shown in Figure 4.7.

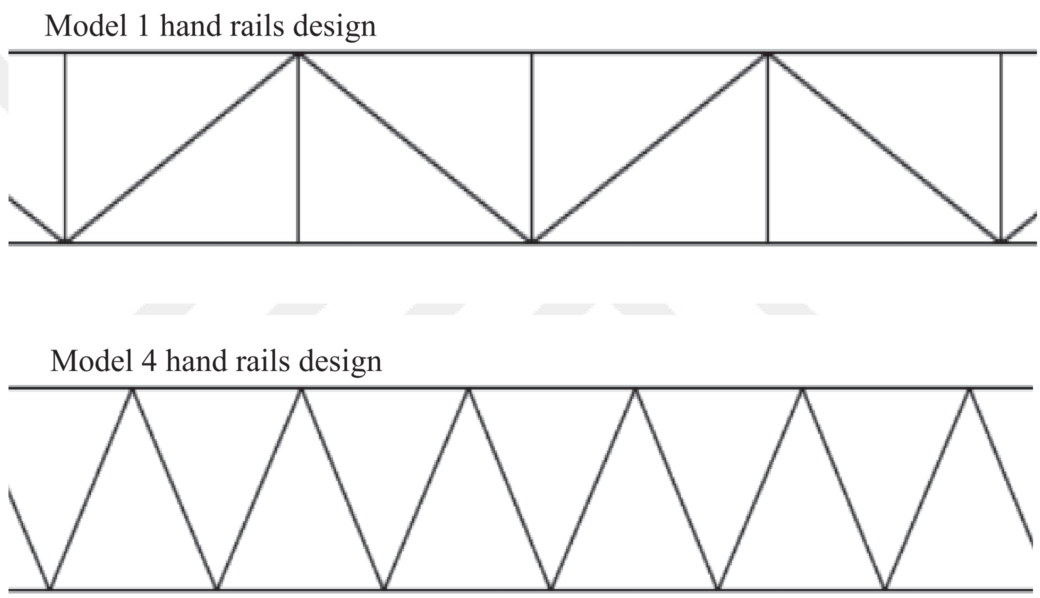

Figure 4.6. Comparison between lateral truss's (hand rails) design in Model 1 and Model 4.

The self-weight for both models is almost the same, only 1 kg less in Model 4 (1293 kg in Model 1 and 1292 kg in Model 4) and the work range remained the same as well in the new model stage four.

4.2.5. Reducing Cross Sections for Low-Load Bearing Elements of the Model

In a try to decrease the overall self-weight of the structure, the bars in the middle, which act as the ladder steps were replaced in all sections with 40x20x2 channel instead of 40x40x2 tube in the first section, 40x30x2 tube in the second and the third ones, 40x20x2 tube in the fourth section. All of them became 40x20x2 channel. As a result of this replacement the self-weight was decreased to 59 kg, even though, the functionality of the models remained the same. See figure 4.8. for illustration.

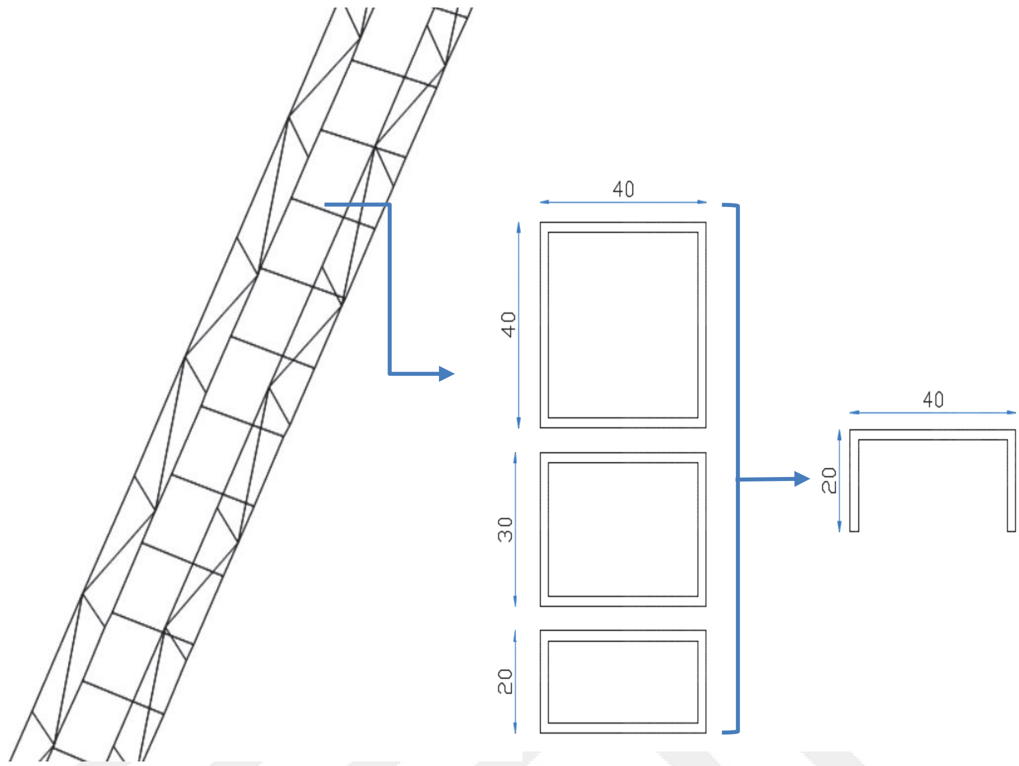

Figure 4.7. Comparison between original and decreased ladder steps' cross sections.

After running analysis and designing the modified model, the entire element remained intact as indicated by the blue color in the view, which remains the same as the previous model models. The result shows that the model is still safe and never affected by the cause of decreasing the sections. This support the assumption that they are not the main load-bearing members but the lateral trusses therein.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This thesis presented the checking and designing of a fire truck turntable ladder which was conducted according to the Turkish and European standards, in addition to changes to the structure which were implemented and checked in order to improve the functionality of this system. The aim was centered around basically represented and gaining more working range as well as reducing extra useful weight.

- The initial design was met the Turkish and European standards and the working range were visualized accordingly.

- The lesser the people on the cage the more area could be reached by the ladder.

- Upper hand rails are the most vulnerable elements in the turntable ladder, increasing cross sections of them will definitely lead to expanding working range.

- Using vertical-rectangular cross sections instead of square cross sections with same area is more efficient.

- The lateral truss design in a shape of rectangles with diagonal bars and the design in a shape of equilateral triangles were acting exactly the same.

- Step bars of the ladder could be reduced to a minimum cross section and should not be increased in section towards the base (as in the lateral truss

By doing so with the studied ladder, the overall self-weight was decreased by 59 kg and the whole structure remained functional.

5.2 Further Study and Recommendations

- The use of composite elements for the improvement might be useful, which cause for the further studying in this regards instead of steel bars only, such as injecting cement mortar strengthened with fiberglass and/or steel bars inside the tubes of upper and lower rail's elements. This method might help in improving any existing ladder without having to replace small cross-sectional frames with bigger ones.

- Analyze the model taking into consideration the dynamic effect of the rotational and vertical movements. In addition to further analysis of the model in composite movement (rotational and vertical together).

- Find out the ratio between ladder's wide and length to keep buckling under control, and how this ration might be different for ladders made of different materials.

REFERENCES

[1] Zhu, G. (2009). *The Research Based on Higher Efficiency and Lower Cost for Salvation Equipment of Fire Disaster Site.* Master's Thesis, Jilin University, National University in Changchun, China.

[2] TSO publication (2008). *Generic Risk Assessments GRAs 3.2, Fighting fires in high rise buildings*. ISBN 9780113413256

[3] Mohammad A., A, Niamh N., D. (2014). Fires and related incidents in Dubai, United Arab Emirates (2006–2013), *Journal on Case Studies in Fire Safety*, Volume 2, , Pages 28–32.

[4]. NFPA (2009). NFPA 1002 *Standard for Fire Apparatus Driver/Operator Professional Qualifications*, 2009 edition. Quincy, MA: National Fire Protection Association.

[5] FEMA (1996). *Aerial Ladder Collapse Incidents*, U.S. Fire Administration/Technical Report Series, USFA-TR-081

[6] USP. United States Patent, (1989), *Aerial ladder tower with pretension truss members*.

[7] TSO. publication (2008). *Generic Risk Assessments GRAs 3.2*, Fighting fires in high rise buildings. ISBN 9780113413256

[8] Mohammad A., A, Niamh N., D. (2014), Fires and related incidents in Dubai, United Arab Emirates (2006–2013), *journal on Case Studies in Fire Safety*, Volume 2, Pages 33–36.

[9] Al Hom (1997). *Detachable Ladder Pipe Operations*, San Francisco Fire Department Truck & Ladder Manual, revised March 4.10-4.13.

[10] Mary M., Bronwyn H. (2016).*WiseGEEK article on what is fire engine*. http://www.wisegeek.com/what-is-a-fire-engine.htm

[11] National Fire Protection Association, (2000), "*NFPA 1971-2000: Protective Ensemble for Structural Fire Fighting*", National Fire Protection Association, Quincy, Massachusetts.

[12] Berna, F. (2012). *Microstratigraphic evidence of in situ fire in the Acheulean strata of Wonderwerk Cave*, Northern Cape province, South Africa. Proceedings of the National Academy of Sciences of the United States of America.

[13] Gross, D. (1991). *Fire research at NBS: The first 75 years*. Third International Symposium, conducted at the meeting of the International Association for Fire Safety Science, Fire Safety Science Proceedings. Edinburgh, Scotland.

[14] Drysdale, D. (1985). *An introduction to fire dynamics.* West Sussex, England: John Wiley & Sons Ltd.

[15] Daniel Madrzykowski,(2013). Fire Dynamics: *The Science of Fire Fighting*. International Fire Service Journal of Leadership and Management, Volume 7, Fire Protection Publications/IFSTA.

[16] Cox, Geoffrey, "*Combustion Fundamentals of Fire*", Academic Press, San Diego, CA, 1995, p. 4. Ibid, p. 276.

[17] Butler, B.W and Alexander, M.E. (2005). *Eighth International Wildland Firefighter Safety Summit-Human Factors* - 10 Years Later; Missoula, MT. The International Association of Wildland Fire, Hot Springs, SD.USA.

[18] U.S. Department of Agriculture (USDA), (2005), Forest Service Wildland Fire Chemicals, *The Standard Test Procedures for the Evaluation of Wildland Fire Chemical Products*, Missoula Technology and Development Center, Missoula, Montana 59804. pp. 10-55.

[19] Oleg, Belyakov, (2016). *The State emergency service of Ukraine* Mil Mi-m8MTV picking up water near Nezhin, UW uploads using a custom license, CC-BY-SA-3.0,GFDL-1.2,
https://commons.wikimedia.org/wiki/File:Ukrainian_MChS_Mil_Mi8_Belyakov.jpg

[20] JASON PAUR, (2009). *Fahrenheit 747: World's Biggest Fire Extinguisher* Douses L.A. County, Wired magazine,
http://www.wired.com/2009/09/evergreen-supertanker/.

[21] Gabbert, B. (2010). *Evergreen's 747 Supertanker deployed to fight fires in Israel*, Wildfiretoday.com,
http://wildfiretoday.com/2010/12/03/evergreens-747-supertanker-deployed-to-fight-fires-in-israel.

[22] James Delgado (1988). *Duwamish Fireboat: National Historic Landmark Study*, National Park Service.

[23] Gauvin, Brian, (2009). *Los Angeles Fireboat 2 is No. 1 in the world*, Professional Mariner. No. 127.

[24] Petrillo, Alan, (2012). *Hazmat Vehicle Designs Reflect Unique Requirement*. Fire Apparatus & Emergency Equipment 17 (8).

[25] Pelastustoimen, yleisopas. (2007). *A general guide for rescue vehicles: rescue vehicle*, Ministry of the Interior, Finland .http://www.pelastustoimi.fi/raportit/pelastusajoneuvojen-yleisopas/raivausauto,

[26] National Fire Protection Association in the U.S.A (NFPA), (2003). *1006 Standard for Rescue Technician Professional Qualifications*. 2003 Edition of the National Fire Protection Association Publications.

[27] Dickinson, E., T., Wieder, Michael A. (2003). *Emergency Incident Rehabilitation*. Brady/Pearson/Prentice Hall. ISBN 0131142798.

[28] National Fire Protection. Association (NFPA), (2003). *The 1901 Standard for Automotive Fire Apparatus*, Chapter 7: Mobile Water Supply Fire Apparatus. 2003 edition. National Fire Protection. Association. http://www.firecom.com/pdf/NFPA_1901.pdf

[29] Leihbacher, D. (2000). *Preconnects and the Basics of fire engine*, Fire Engineering Magazine. 153 (4). http://www.fireengineering.com/articles/print/volume-153/issue4/features/features /preconnects-the-basics.html

[30] Hines, C. (2015). *Fire Apparatus Utilized on Emergency Responses - Benefits of a Tiller*, City of San Luis Obispo. USA. http://www.slocity.org/Home/ShowDocument?id=66

[31] Daniel, P. (2009). *The Fire Truck History*, http://www.autoevolution.com/ news/fire-truck-history-7249.html

[32] Cowart, John, W. (2006). Heroes all: *a history of firefighting in Jacksonville*. Published by Bluefish Books, ISBN-1411683005, 9781411683006, pp. 25.35.

[33] Bronto, Skylift, (2007). Bronto Skylift brochure, S 112 HLA: *The World's Highest Truck Mounted Access Platform, Industrial applications*. http://www.rothlehner.de/wp-content/uploads/2013/02/Datenblatt-S112HLA.pdf

[34] Adam H. (2011). Wenzel Metal Spinning, *Steel versus Aluminum Steel versus Aluminum – the Weight, Strength, Cost, Malleability Comparison*, Version 2 ME, IIT Kharagpur, www.wenzelmetalspinning.com/steel-vs-aluminum.html.

[35] Sanne, L., Benson, P., Höglund, T., (1992). *Lateral Torsional Buckling of Aluminium Beam Columns – Test and Design*. The Royal Institute of Technology, Department of Structural Engineering, Stockholm, Sweden, Report 1992:6.

[36] National Fire Protection Association (NFPA), (2009). *Apparatus Specification standards for automotive mfire apparatus 1901*. ed. Annex E Pg. 179/201. https://en.wikipedia.org/wiki/NFPA_1901#cite_ref-2

[37] Simeonov, Peter; Hsiao, H., Powers, J. (2013). *"Ladder Safety: There's an App for That*".

[38] Cyr, Dawna, L., Steven, B., J. (2006). Ladders, Lifting and Falls. *National Ag Safety Database*.
http://www.ladders-direct.com/acatalog/ladder-certification.html.

[39] Sawodny, o., H. Aschemann, Bulach, A., (2002). *Mechatronical Designed Control of Fire-Rescue Turntable-Ladders As Flexible Link Robots*, 15th Triennial World Congress, Barcelona, Spain, IFAC (International federation of automatic control).

[40] Sawodny, O., H. Aschemann, S. Lahres and E.P. Hofer (1999), *Tracking Control for Automated Bridge Cranes in: Advances in Manufacturing* (S. Tzafestas (Ed.)), pp. 309-320. Springer Verlag, London.

[41] Maier, T. and C. Wörnle (2000). *Simulationsgestützter Entwurf der Bahnsteuerung eines seilgeführten Handhabungssystems*. In: Proceedings of Simulation im Maschinenbau. pp. 501-518. University of Dresden, Dresden.

[42] Wey, T., M. Lemmen and W. Bernzen (1999). *Hydraulic Actuators for Flexible Robots: A Flatness Based Approach for Tracking and Vibration Control*. In: CD-ROM Proceedings of European Control Conference 1999, Karlsruhe.

[43] James, B. (2006). *Physics of Aerials for Operators*. Research term paper, http://s64f1250de3627ffc.jimcontent.com/download/version/1404834452/module/7811893769/name/Physics%20of%20Aerial%20Ladders%20PPT.pdf

[44] Arthur D. Little, (1995). Failure Analysis of a 100 ft Aerial Ladder, Technical Report to Fire Dept. New York. Arthur D. Little, Inc. Acorn Park Cambridge, Massachusetts, 02140-2390, Reference 48260.

[45] Gordon, Routley, J., Reade, B. (1996), *Aerial Ladder Collapse Incidents*,Technical report series, Varley-Campbell and Associates, Inc./TriData Corporation under the contract EMW-94-C-4423 to the United States Fire Administration, Federal Emergency Management Agency.

[46] Ralph C., James S. (1996). *The contributing Causes to Aerial Failures*, Online Article of fire engineering Magazine and Editorial. PennWell Corporation, 21-00 Route 208 South, Fair Lawn, NJ07410.
http://www.fireengineering.com/articles/print/volume-149/issue-7/features/the-contributing-causes-to-aerial-failures.html

[47] Sameer K. (2015). *Chassis frame design of a mobile platform equipped with robotic arms*. Master Thesis, Lappeenranta University of Technology, School of Technology, LUT Mechanical Engineering. Lappeenranta, Finland.

[48] Roylance, D. (2001). *Finite Element Analysis* [web document]. Cambridge: Massachusetts Institute of Technology. 16 p. Available in PDF-file:
http://ocw.mit.edu/courses/materials-science-and-engineering/3-11-mechanics-ofmaterials- fall-1999/modules/fea.pdf

[49] Martins, J., A., Kövesdy, I. (2012). INTECH [Web database].*Overview in the Application of FEM in Mining and the Study of Case: Stress Analysis in Pulleys of Stacker-Reclaimers*: FEM vs. Analytical Available:
http://www.intechopen.com/books/finite-element-analysis-applications-in-mechanicalengineering/overview-in-the-application-of-fem-in-mining-and-the-study-of-case-stressanalysis- in-pulleys-of-sta

[50] S. Maiti, A. Ambekar, U. Singh, P. Date, and K. Narasimhan, (2000). Assessment of influence of some process parameters on sheet metal blanking. *Materials Processing Technology*, Vol. 102, 249-256.

[51] H. Andruet, (1998). *Special 2-D and 3-D Geometrically Nonlinear Finite Elements for Analysis of Adhesively Bonded Joints*, Unpublished Doctoral Dissertation, Virginia Polytechnic Institute, USA.

[52] I., Rawabdeh, H. Hilwa, M. Abu Hammad, (2003). *Minimizing Necking Defects in Aluminum Beverage Cans Using Experimental Design Techniques*. Dirasat, No.1, 84-97.

[53] R., Hambli, S., Richir, P., Crubleau, B., Taravel, (2003). *Prediction of optimum clearance in sheet metal blankingprocesses*. International Journal of Advanced Manufacturing Technology, Vol. 22, 2003, 20-25.

[54] Mukunda M., N. (2014). *Mathematics behind the Finite Element Method*, Indian Institute of Science, Bangalore (IISc) and National Institute of Technology Silchar
https://www.quora.com/What-exactly-is-Finite-element-analysis

[55] Orville, D., D.(2012). *Aerial ladder system with powered rungs*, Patent N0.: US 8,074,767 B1, http://www.google.ch/patents/US8074767.
[56] Hirst, Ben, A. (2004). *Fire Apparatus Driver and Operator*. Sudbury, MA: Jones and Bartlett Publishers, Inc. ISBN 0763728454
[57] *Turkish and European standards TS EN 14044+A1*. High rise aerial appliances for fire service use – Turntable ladders with sequential movements.