FEASIBILITY STUDY OF USE OF HEMP ROPE AS REINFORCEMENT IN STRUCTURAL ELEMENTS

FINAL YEAR PROJECT UG-2014

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This is to certify that the Final Year Project Titled

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has been accepted towards the requirements
for the undergraduate degree

in

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DEDICATED TO OUR PARENTS
& TEACHERS

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We would like to thank the Almighty Allah for giving us the strength to successfully complete our project. It would not have been possible without the kind help and solid support of our instructors, parents and friends.

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ABSTRACT

This was an industrial project, with the main emphasis on the evaluation of various properties of Hemp rope to verify its suitability for use as a replacement of steel reinforcement in structural elements. Steel has long been used as a reinforcement in structural elements but it has certain drawbacks. This quest for a sustainable and a green alternative lead us to Hemp rope.

A Hemp rope is made from fibers of Hemp plant. Hemp fibre is one of the longest and strongest of the natural fibers. The long fibers of the Hemp plants are twisted, braided or wound together to form a long rope of various thickness. For thousands of years Hemp was traditionally used as an industrial fiber. Sailors relied upon Hemp cordage for strength to hold their ships and sails. One of the most significant characteristic of the Hemp ropes is their strength. Besides the production of Hemp rope being environmentally friendly and a rather convenient process, it exhibits high tensile strength.

In this study, we assessed different properties of the Hemp rope to verify its suitability for usage as a replacement of steel reinforcement in structural elements in single-story residential buildings. Tests for its tensile strength, modulus of elasticity, water absorption, effect of water absorption on its properties, and flexural strength were conducted using ropes of 3 different diameters. Results from these tests suggest that Hemp rope of diameter 1 in or more can be used as a reinforcement in place of steel rebars in single-story structures.

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Chapter 1

INTRODUCTION

1.1 Introduction

This chapter offers an insight into the current materials being used and practices in construction industry, and the need for alternate, green, renewable and sustainable materials. It also covers the background study of these materials, the problem at hand and the objective, scope and significance of this research to resolve the problem.

1.2 Background Study

Concrete is the single most widely used material in construction today. Humans have been using concrete in their ground-breaking architectural feats for centuries. The basic ingredients – sand and gravel (aggregate), a cement-like binder, and water – were being mixed at least as far back as Egyptian times. The Romans are well-documented masters of this material, using it to create wonders of Roman architecture. Modern concrete was born in the early nineteenth century, with the discovery of Portland cement, the key ingredient used in concretes today (Crow, 2008).

The mix of a conventional concrete consists of cement, fine aggregate, coarse aggregate and water. In addition to its high strength, durability and its initial ability to adapt to virtually any form, concrete is fire resistant (The Editors of Encyclopædia Britannica, 2016). These characteristics account for concrete's wide usage as a construction material today.

In most countries, concrete is widely used as the foundation for the infrastructure. Concrete is used largely because it is economical, readily available and has suitable building properties such as its ability to support large compressive loads. However, plain concrete cannot easily bear stresses produced due to wind, earthquakes and other bending forces. Its high density results in the increase of the dead load of the building, making it unsuitable for many structural applications such as roof slabs. So, the use of concrete is limited because it has low tensile strength. For this reason, it is reinforced, and one of the more popular reinforcing bars (rebar) is steel.

Steel has a relatively high tensile strength, as high as 115 ksi (792 N/mm2), complementing the low tensile strength of concrete. It is available and affordable in most developed countries but unfortunately not all parts of the world. In many countries, none or very little steel reinforcement is used in construction.

It is thus reinforced with steel bars to provide considerable tensile strength to it. In reinforced concrete, the tensile strength of steel and the compressional strength of concrete render a member capable of sustaining heavy stresses of all kinds over considerable spans (The Editors of Encyclopædia Britannica, 2014). In conclusion, reducing the dead load of building would leave us with so much advantages and lead us towards efficient construction.

Introduction of lightweight aggregate to make concrete lighter has been a major breakthrough in the construction industry. Lightweight concretes can be produced using a variety of lightweight aggregates such as volcanic pumice, clay, Leca, Lytag, Pellite, natural fibers etc. It can be used for structural applications with strengths equivalent to normal weight concrete (The Concrete Centre, 2012).

Another lightweight material recently embraced is the Hempcrete. Hempcrete is a material that uses part of a Hemp plant as bio-aggregate. Hemp fibers instead of coarse aggregate are incorporated in a binder typically hydraulic lime and Pozzolana - a cementitious additive instead of cement. This greatly reduces its density which is about 15% of the conventional concrete (Sandin *et al.*, 2009). This reduction in dead load due to reduced self-weight reduces load on foundations and saves material used in construction as well as the reinforcement used in it (Elie Awwad, Bilal Hamad, Mounir Mabsout, 2014).

Similarly, alternatives for steel reinforcement are gaining popularity because they offer advantages over steel (Ghavami, 2005). Steel reinforcement has a low strength to weight ratio which means that it adds up to the dead load of the structural element. Different lightweight fibers both natural and synthetic with high tensile strength have been in use such as glass fibers, carbon and basalt fibers, nylon ropes, ropes, bamboo etc.

Ropes made from Hemp fibre are called Hemp ropes. One of the most significant characteristic of the Hemp ropes is their strength. Besides the production of Hemp rope being environmentally friendly and a rather convenient process, it exhibits high tensile strength (Shahzad, 2013; Vadivambal *et al.*, 2015). It has been extensively used in history for various purposes.

This makes Hemp rope an attractive alternative to steel in tensile loading applications. This is due to the fact that the ratio of tensile strength to specific weight of Hemp rope is greater than that of steel (Vadivambal *et al.*, 2015).

This study will focus on the evaluation of various physical and mechanical properties of Hemp fibre ropes to assess its suitability for use as reinforcement in composite materials in place of steel reinforcement.

1.3 Problem Statement

It is a fact that the construction industry is the main consumer of energy and materials in most countries of the world. The pursuit of sustainable development has become a major issue when trying to meet the challenges in providing proper and low cost housing for the ever-increasing world population (Ghavami, 2005). The present energy crisis due to increasing industrial growth has caused serious concerns about managing the energy resources still available and about environmental degradation. There is an intense on-going search for non-polluting materials and manufacturing processes, which require less energy.

In this era of industrialization, the selection of materials is based mainly on the price and the type of facility used for production or processing. Industrialized materials, such as ordinary Portland cement (OPC) and steel, find applications in all sectors. In consequence of the consumers choosing industrialized products, renewable materials are wasted causing permanent pollution. In this sense, it becomes obvious that ecological materials satisfy such fundamental requirements. Use of biodegradable materials such as rice husk, coconut fibers, sisal, Hemp fibers and bamboo in construction minimizes energy consumption, conserving non-renewable natural resources, reducing pollution and maintaining a healthy environment. Another disadvantage of manufactured steel reinforcement is the cost of haulage of the reinforcement from production site to the construction site.

Steel reinforcement at some point may also be no longer be available as it is manufactured using raw materials that are a natural resource which are depleting day by day. Even today there exists a need for more economical and readily available substitute reinforcements for concrete. In some parts of the world many buildings are constructed only with concrete or mud-bricks. This is dangerous in case of seismic activity. These buildings have little hope of standing in the case of an earthquake. Steel reinforcement would be an ideal solution, but cost is a considerable problem. Scientists and engineers are constantly seeking for new materials for structural systems; the idea of using natural and synthetic fibers, and bamboo etc. as possible reinforcement has gained popularity.

Natural fibre reinforced composites are gaining popularity as the solution to aforementioned problems. Besides offering significant durability, they also offer advantages over steel such as higher strength to weight ratio, they are not electrically or magnetically conductive, and most importantly they do not corrode. They are also renewable, environment friendly, readily available, cost-effective and truly sustainable.

1.4 Aim and Scope of the Study

The need for better, economical, healthy, environmentally friendly and sustainable construction materials and processes has led to the discovery of new renewable and sustainable materials. Hemp Rope, formed from the Hemp plant, is one such material.

The main objective of this study is to determine the feasibility of Hemp rope reinforcement for concrete beams and slabs. While, the mechanical properties and behavior of steel reinforced concrete have been extensively studied and well documented, there exists no comprehensive data describing Hemp rope reinforced concrete.

Therefore, the aim of this study is to provide a preliminary contribution toward the collection of the mechanical properties and behaviors of Hemp rope reinforced beams. In concrete, reinforcement is put in place to provide tensile strength, a property that concrete lacks. Therefore, if Hemp rope is to be used as concrete reinforcement, it is necessary to understand how Hemp rope behaves in tension.

This study will consider Hemp rope of three diameters – 1 in, 1.25 in and 1.5 in. These were tested for tensile strength without waterproofing agents. Once all the data is collected, it was analyzed to determine the tensile properties of Hemp rope. The effect of water absorption will also be examined by submerging the ropes in water for 24 hours and determining the mechanical properties afterwards. To examine the behavior of Hemp rope in concrete, three-point loading tests of Hemp rope reinforced concrete beams were conducted for all three diameters. When the tests were completed, the results were compared with steel reinforced balanced section and plain concrete beams to compare their performances.

The study is focused to inspect the properties of Hemp fibre rope to assess its suitability for use as reinforcement in composite materials. Hemp rope will form a sustainable, healthy and affordable building material.

1.5 Significance of the study

Hemp fibers are found in the stem of the Hemp plant which makes them strong and stiff, a primary requirement for the reinforcement of composite materials. The mechanical properties of Hemp fibers are comparable to those of glass fibers (Shahzad, 2013).

Hemp fibre rope is one material which will have a tremendous economic advantage over the current materials in use. The Hemp plant reaches its full growth in just a few months and can be harvested 3-4 times annually. Moreover, it exists in abundance in tropical and subtropical regions of the globe and can be grown with little to no effort.

The use of Hemp fibre rope as reinforcement in composite materials is a response to the increasing demand for developing biodegradable, sustainable, and recyclable materials. Its use will not only cut down the major expenditures on the production and haulage of steel in construction, but also help us to take down the environmental problems and issues contributed by the manufacturing process because significantly less energy is required for the production of Hemp fibre rope than production of steel. Reduction of weight will reduce the dead load of building and would leave us with so much advantages and lead us towards efficient construction. Provision of cheap housing has been a goal for many governments around the world. This be a big leap towards achieving it.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This section presents a literature review spanning the range of the history and complex structure of Hemp rope for understanding to prior research conducted on its properties and mechanical behavior and different applications of the Hemp rope. It is aimed to identify and fill potential gaps in the current knowledge and point out needs for more detailed studies. For this purpose we consulted relevant books, research papers and journal articles extensively.

2.2 Hemp

The hemp plant, thanks to its many uses and in particular its most famous one, as a widely popular recreational drug, is one of the most easily recognizable plants in the world.

Figure 1: Hemp Plant

Hemp is the English name (from the old English *haenep*) for the cannabis plant. The words *haenep* and cannabis are both thought to derive from the Ancient Greek *kánnabis*, which in turn evolved from an older word in an ancient Iranian language from around 2,500 years ago.

Three varieties of the cannabis plant exist: Cannabis sativa, Cannabis indica and Cannabis ruderalis. Cannabis sativa and Cannabis indica are seen as the more closely related species. Cannabis ruderalis differs from them in that its flowering happens after a predetermined number of days, rather than being dependent on the seasons, and it contains very little tetrahydrocannabinol (THC), the psychoactive substance that gives the drug cannabis its active ingredient.

Hemp is a fast-growing erect annual plant which produces only a few branches, usually at the top of the plant, and grows to a height of between 1.5m and 4m. Its stem is thin and hollow, with a diameter of 4mm to 20mm, depending on the conditions and the specific variety grown. The ‘bast’ fibres of the hemp plant, which are contained in the bark of the woody stem, range from about 1.2m to 2.1m in length and are extremely strong. Their quality varies depending on the timing of harvesting, and the fibres are graded in terms of their fineness, length, colour, uniformity and strength (Stanwix and Sparrow, 2014).

Figure 2: Hemp Plant

The inner woody stem, the ‘shiv’ (or ‘shive’, or ‘hurds’), historically has not been used intensively, but this is changing rapidly in the modern world, with new uses being developed all the time: packaging filler and animal bedding, for example. It is hemp shiv that is used in the production of hempcrete.

The seeds of the Hemp plant are used as a food source, and ground to produce oils for a wide range of purposes, including technical and industrial applications. The Hemp plant in its whole state can be used as a biofuel, and even the cell fluid of the Hemp plant is now used in the manufacture of abrasive fluids (Bevan and Woolley, 2008).

Hemp is an incredibly sustainable renewable resource that can be grown in many climates and conditions around the world. Hemp can be harvested after about 4 months. So theoretically grown twice or three times a year. With an average yield of 10-12 tones/ha (Rehman and Qadir, 2016). With that being said, there are many environmental benefits by using this sustainable plant. For one, the use of hemp to create a better quality and longer-lasting paper is extremely environmentally friendly. It would only take one acre of hemp compared to destroying 4.1 acres of trees to create the same amount of paper (Robinson, 1996). This would help deforestation exponentially.

One acre of hemp is not only a beneficial alternative for paper, but also for the production of cotton as well. Just one acre of hemp could produce as much fibre as two to three acres of cotton. The difference is that hemp fibre lasts longer, will not mildew, and is much stronger and softer than cotton. In addition, cotton requires large quantities of dangerous pesticides and herbicides. Hemp is relatively easy to grow with low demand on inputs (pesticides, herbicides, fertilizers). Modern applications of Hemp includes insulation, paper, cloth, biofuel, cosmetics, food, bioremediation of contaminated soils, and bio-composite materials.

These environmental benefits of using hemp, in addition to its usage, puts into question why hemp still has not been produced as a major crop in most parts of the world including Pakistan.

2.2.1 History of Hemp

The common hemp plant, Cannabis sativa, is one of the earliest recorded domestically grown plants, with evidence of its cultivation by humans since Neolithic times (Stanwix and Sparrow, 2014). Hemp is found across the world, and has a long history of widespread use for a range of important products: hemp seeds for oils and resin, food, fuel, medicines and cosmetics; hemp fibre for hard-wearing clothing, rope and tough fabrics such as sailcloth (the word canvas derives from cannabis: literally – originally – 'a fabric made from hemp'), and as a pulp from which to make paper.

It is thought that the plant originated in China, and that its cultivation gradually spread westwards through India and into the Middle East, Africa and the Mediterranean, where it formed an essential part of the livelihood and culture of each people who grew it. Surviving writings from the

Egyptian, Greek and Roman records show how important the hemp plant was to the lifestyle, trade and expansion of these great civilizations. The cultivation of hemp in Europe continued throughout modern history, with evidence that its use in Britain, introduced by the Romans, continued thereafter, with the Saxons incorporating it into their medical treatments. Later kings of England promoted the cultivation of hemp, not only for its everyday uses for linen and rope but also for the vital part it played in the military supremacy of

Britain as an island nation: Henry VIII passed a law making it compulsory for farmers to grow hemp, such was its importance to the defense of the realm through its use for sailcloth and rigging. Later still, the hemp plant played a not-insignificant part in Napoleon Bonaparte's downfall, since his ill-fated incursion into Russia had as its aim the destruction of Russian hemp plantations. Russia had been supplying the English with hemp, and thus equipping the navy of Napoleon's enemy (Robinson, 1996).

Up until the arrival of cheap imported cotton, sisal and jute, towards the end of the nineteenth century, hemp and flax were still widely used for clothing, other textile products, rope and netting. In fact, these two plants are the only fibre crops that are commercially viable in our temperate maritime climate. The earliest recorded evidence of this is a "payment for a large quantity of sails and cordage in 1211", which was followed by "an order from King John for Bridport rope and cloth to supply the navy in 1213 (Williams, 2006).

Another of the main uses of the plant throughout history has been in religious ceremonies, and more recently as a recreational drug, due to its relaxing and mildly psychoactive effect. This use of cannabis, or marijuana, as a narcotic eventually led to the growing and possession of the hemp plant being outlawed in most Western countries in the early decades of the twentieth century. The prohibition of cannabis remains in force widely today, in the West at least, with some notable exceptions, such as the Netherlands (Stanwix and Sparrow, 2014).

2.3 Hemp Rope

A Hemp rope is made from fibers of Hemp plant. Hemp fibre is one of the longest and strongest of the natural fibers. The long fibers of the Hemp plants are twisted, braided or wound together to form a long rope of various thickness. For thousands of years Hemp was traditionally used as an industrial fiber. Sailors relied upon Hemp cordage for strength to hold their ships and sails, and the coarseness of the fibre made Hemp useful for canvas, sailcloth, sacks, rope, and paper (Hemp Traders, 2013).

Figure 3: Hemp Twine

Hemp rope had been around for several centuries and was once the main ingredient used to make rope. Unfortunately in recent years other fibers have become more popular, mainly because of their affordability. Today, cotton is more likely to be used for making products such as rope and clothing but it is not an ecofriendly choice. Unlike hemp, cotton is not produced without the use of chemicals, pesticides, and synthetics. These ingredients are harmful to both the environment and our overall health. Also, there are very few fibers that provide the strength and durability offered by hemp. Rope made from hemp is not only sturdy but also resistant to damage from water. It can withstand sun and rain for many years without damage.

Hemp rope is a popular product for people who are environmentally conscious. The rope is being used for a wide variety of household purposes both indoors and out. As people become more aware of the importance of protecting our environment, hemp is more likely to become popular again.

Hemp rope has been used for millennia and is known for its strength and durability. Unlike cotton which has short fibers, hemp has long fibers, making it very sturdy. Hemp cord is available in a number of different colors and sizes. Durable and strong, hemp cord is also quite affordable. Historically, Hemp ropes were used for climbing, shipping, fishing, horsemanship and construction. They are less widely used now due to the decline in industrial Hemp production due to prohibition on its production and wider availability of alternative rope fibers.

Figure 4: Hemp ropes used to tie sails of a ship

One of the most significant characteristic of the Hemp ropes is their strength. Besides the production of Hemp rope being environmentally friendly and a rather convenient process, it exhibits high tensile strength (Vadivambal et al., 2015).

2.3.1 Rope making

A Hemp rope is made from fibers of Hemp plant. Hemp fibre is one of the longest and strongest of the natural fibers. The long fibers of the Hemp plants are twisted, braided or wound together to form a long rope of various thickness. Following process is followed to make a rope out of the hemp fibres:

- Separate the Hemp fibers or unwind the Hemp yarn and cut into lengths approximately twice as long as the desired length of the rope. Continue cutting until you have a bundle of fibers approximately half the size of the diameter of rope you'd like to make.

- Grab the bundle of fibers and fold it in half, securing the fold by placing a dowel rod through the resultant loop and into the ground. Smooth the fibers of this bundle down by running your hand along the length of the cord.
- Divide the bundle in two, holding half the fibers in your left hand and half the fibers in your right.
- Twist each bundle clockwise until the cord you are creating begins to kink and loop. Pull as hard as you can while twisting.
- Twist the two cords together, wrapping one over the other in a counterclockwise motion, to form a rope.
- Secure the ends with overhand knots beginning with the end in your hands. Once the first end is tightly tied, slip the rope off the dowel rod and tie it as well.

This process can be repeated as many times as required (Hunker, 2014).

2.3.2 Properties of Hemp Rope

The literature suggests that the Hemp rope is known for its high strength, low cost, flexibility, low density and durability.

Hemp can be easily grown and harvested in almost every region of the world. This lowers the cost of Hemp rope production as compared to steel, and hence the construction using it. It also increases the strength of the buildings that would otherwise be unreinforced.

Hemp rope is, at the same time, very flexible and hence, can take any shape during construction. Flexibility is one of the most attractive attributes Hemp rope possesses against steel reinforcement.

One of the properties that would make Hemp rope a good substitute to steel in reinforced concrete is its strength. The strength of Hemp rope is greater than most natural fibre products which are advantageous. Breaking load of 8 and 10 mm diameter Hemp ropes are comparable to the breaking load of 2 mm diameter steel cable (Vadivambal et al., 2015).

The yield strength of the steel bar is around 250 MPa (MatWeb, 2012), while that of Hemp rope of diameter 1 inch is 71 MPa (The Engineering Toolbox, 2014).

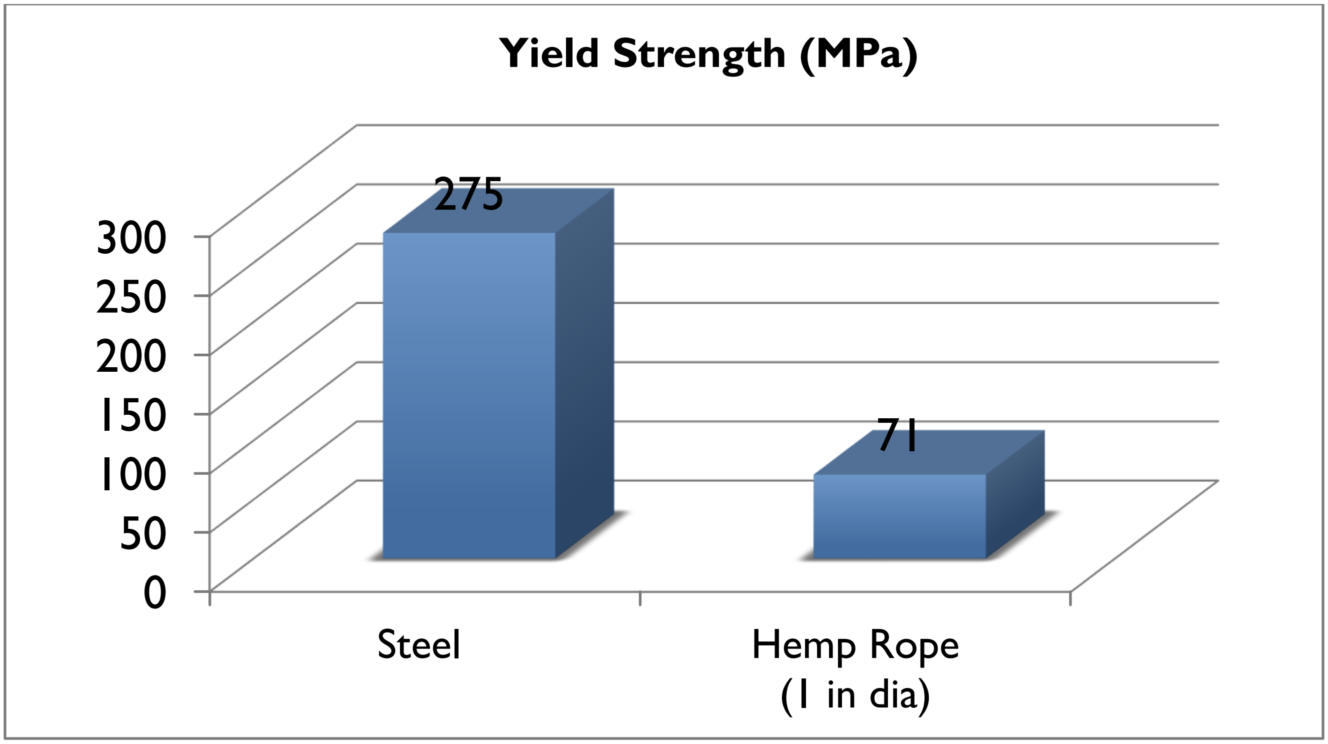

Figure 5: Comparison between tensile strength of steel and 1 in. dia. Hemp rope

Hemp rope is very light in weight as compared to steel. Due to its low modulus of elasticity, Hemp rope can crack and deflect more than steel reinforcement under the same conditions. These aspects put Hemp rope on the list of viable construction materials.

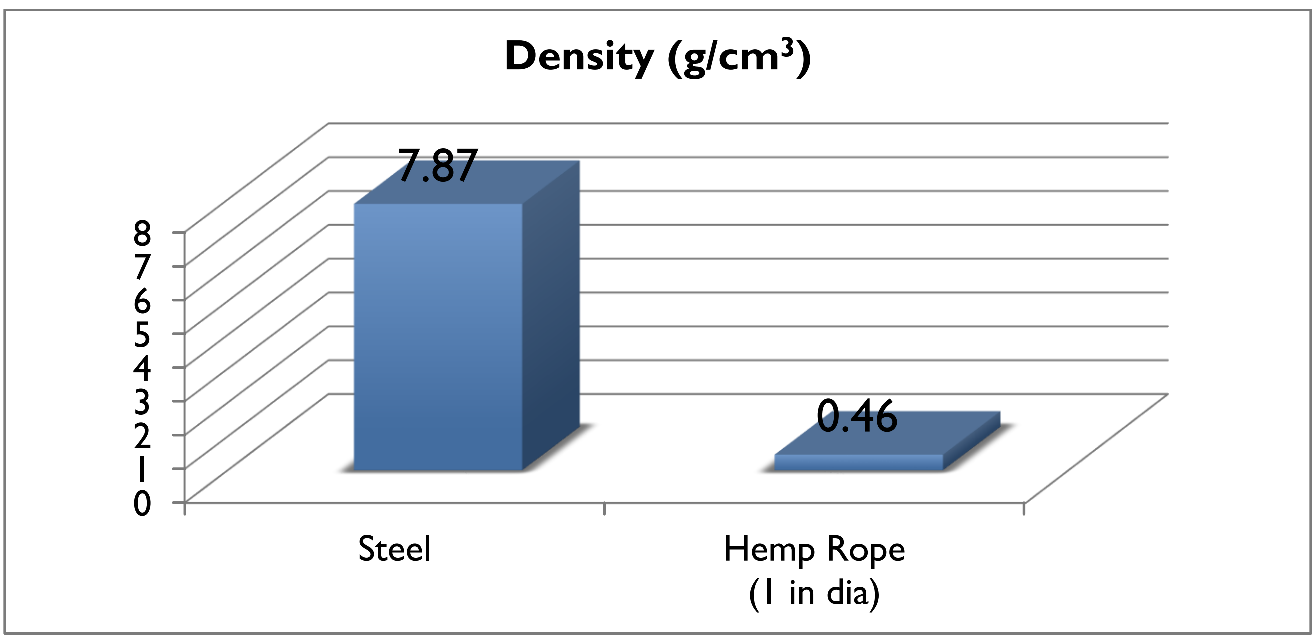

Figure 6: Comparison between density of Steel and 1 in. dia. Hemp rope

The density of the steel bar is around 7.87 g/cm^3 (MatWeb, 2012), while that of Hemp rope of diameter 1 inch is 0.46 g/cm^3 (The Engineering Toolbox, 2014).

The specific strength of the steel bar is around 34.94 MPa cm^3/g (MatWeb, 2012), while that of Hemp rope of diameter 1 inch is 154.34 MPa cm^3/g (The Engineering Toolbox, 2014).

These values go to show that the hemp rope has a very high strength to weight ratio unlike steel. This is a very positive attribute considering that the weight of the steel adds up on the dead load of the building during construction.

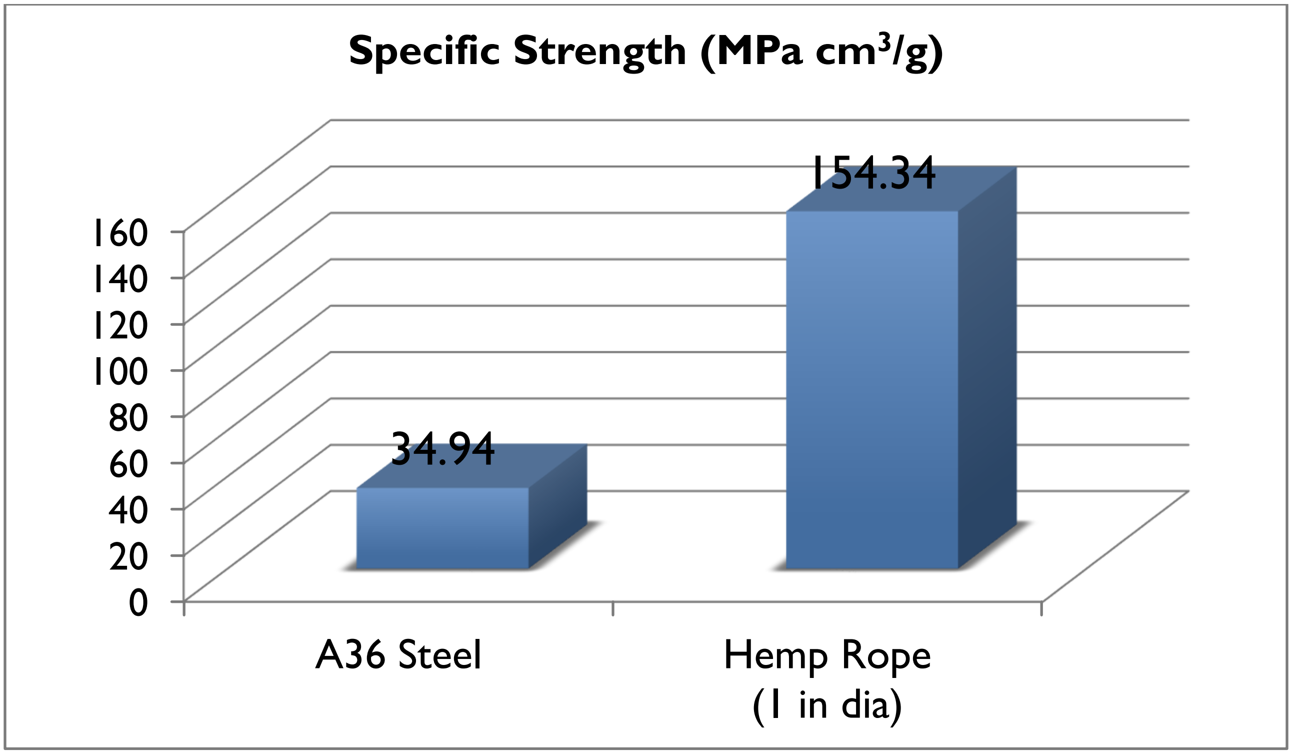

Figure 7: Comparison between specific strength of Steel and 1 in. dia. Hemp rope

Another attractive property of Hemp rope is that it has a very low thermal conductivity of 0.040 W/m-K (Benfratello *et al.*, 2013), while that of A46 Steel bar is 50 W/m-K (MakeItFrom.com, 2011). The increase in the temperature causes reduction in the strength of steel which is a huge drawback of using steel as a reinforcement.

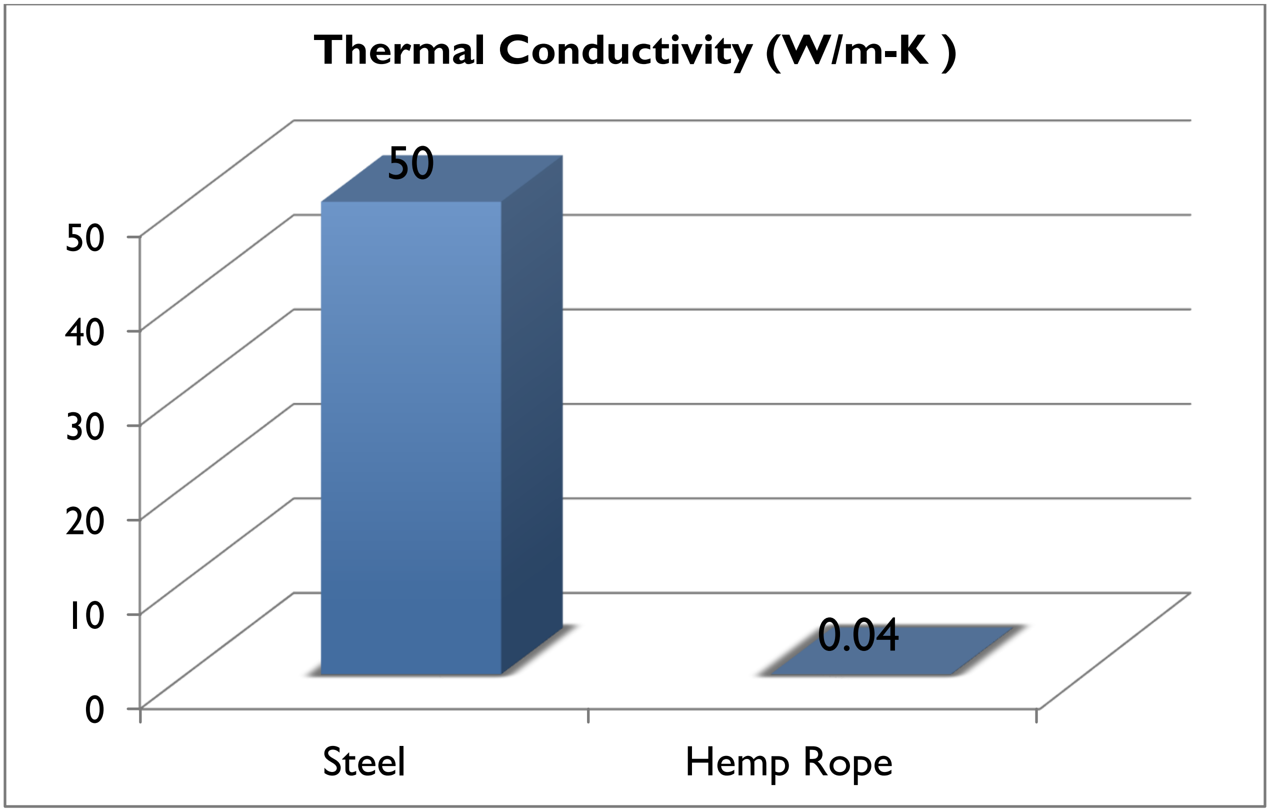

Figure 8: Comparison between thermal conductivity Steel and. Hemp rope

While the aforementioned mechanical properties and behavior of Hemp rope have been studied and documented, some aspects still need to be studied. Therefore, the aim of this study is to provide a preliminary contribution toward the collection of the mechanical properties and behaviors of Hemp rope reinforced concrete.

Chapter 3

METHODOLGY

3.1 Introduction

This chapter includes the details of the procedure and methodology that was adopted in order to attain the objectives of this study. Detailed description of the experimental setup, and the testing methods are also provided in this chapter.

3.2 Calculation of Required Amount of Rope

The first step towards achieving the objectives of this study was to arrange for the required material and equipment. The total amount of rope required was calculated.

The following were the results of the calculations made after considering prior information gathered from the literature and research papers consulted in literature review:

Rope type = 3 strand Hemp rope

Rope diameter = 1 in, 1.25 in and 1.5 in

Rope lengths = 20 ft each

3.3 Acquisition of Materials

The second step was to acquire the materials required for experimentation. Significant amount of Hemp was acquired from the H-13 sector. The plants would then have been used to extract the fibres and convert it into twine and then finally into rope. But due to non-availability of such a processing plant in Pakistan, we had to switch to acquiring material from China.

Figure 9: Hemp Plant acquired from H-13

Later on, due to unavailability of Hemp rope in a small quantity such as required by us, we had to opt for Hemp twine which was readily available. Hemp twine was imported from China and processed and converted into ropes of required diameters at Sootar Gali, Rawalpindi.

Figure 10: Hemp rope of 1 in. diameter

3.4 Tests on Hemp Rope

The experimental program of this research consists of tensile testing of Hemp ropes, ability of water absorption of Hemp rope, effect of the water absorbed on the properties of Hemp rope and the three point loading tests of Hemp rope reinforced concrete beams. Following test were conducted.

3.4.1 Tensile Strength

Tensile strength is the maximum amount of tensile stress that it can take before failure. Reinforcements need to have high tensile strength because concrete cannot bear tensile load.

Since the information given in literature is limited with regards to the Hemp rope's tensile strength, it was desired to investigate this property. Thus, some specimen were prepared to measure its tensile strength. Tensile tests involved specimen preparation, test set-up and instrumentation.

Tensile strength of the Hemp ropes were determined by clamping both sides of the samples in the standard tensile test machine and stretching the rope by applying a gradually increasing force till it yielded. The test method was performed as per ASTM standards at room temperature.

Figure 11: Tensile Strength Test being conducted

3.4.2 Modulus of Elasticity

It measures the ability of an object to resist the elastic deformation when stress is applied on it. It is determined by dividing the stress applied on the object by strain produced in the object due to that stress. The higher the modulus of elasticity, the stiffer the material.

The test method and apparatus for Modulus of elasticity is the same as that used for tensile strength test. The stress applied and strain produced corresponding to that stress will be noted down after regular intervals. This will give us a stress-strain graph and subsequently modulus of elasticity can be calculated.

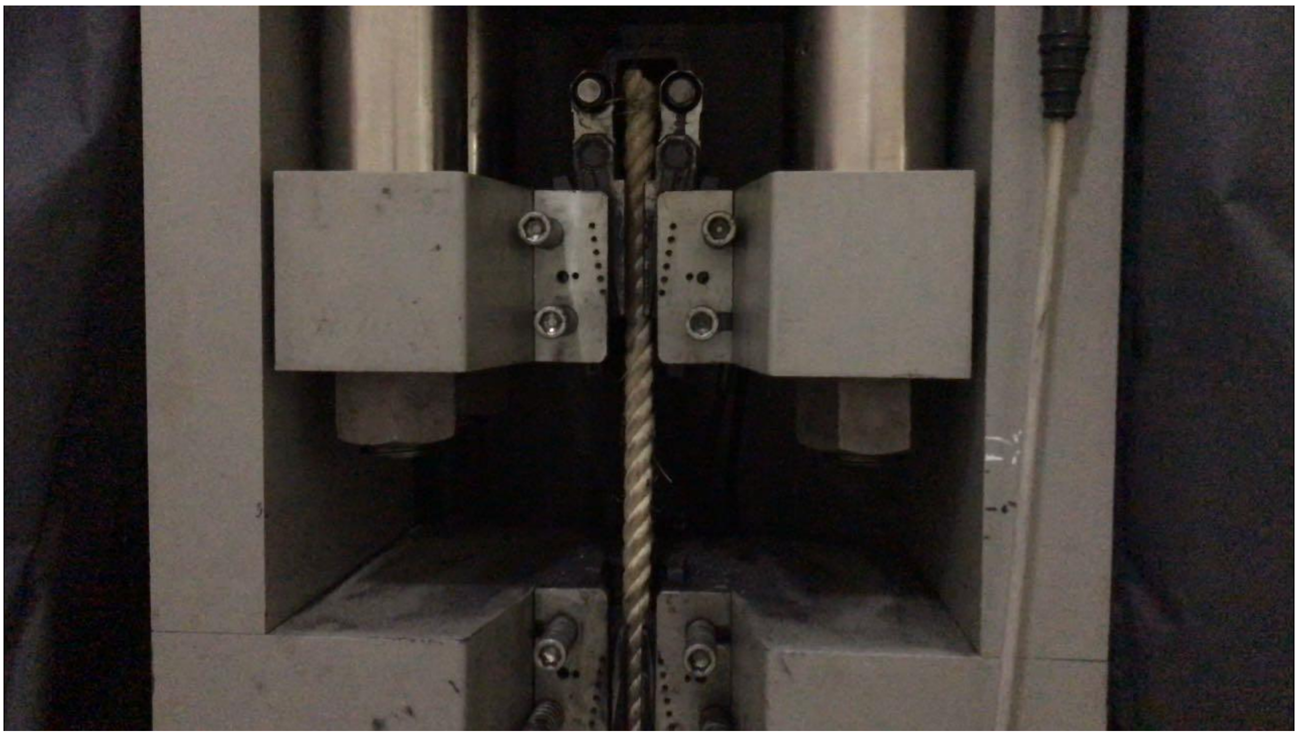

Figure 12: Tensile Strength Test

3.4.3 Effect of Water Absorption

Natural Fibers such as Hemp rope are hydrophilic and readily absorb moisture. They susceptible to alterations in their properties due to water or moisture absorption. This is because of their structure, which consists of cellulose, hemicellulose, lignin, and pectin (Shahzad, 2012).

To determine the changes that occur in the mechanical properties of the Hemp rope due to water absorption, we weighed the Hemp rope in dry condition and then immersed a rope sample for 24 hours in water. The sample was then be weighed to determine the amount of moisture absorbed. It was then tested for tensile strength and modulus of elasticity in wet condition and compared to that of dry condition.

Figure 13: Water absorption tests

3.4.4 Flexural Strength

Flexural strength is a material property, defined as the stress in a material just before it yields in a flexure test (Wikipedia, 2011). Flexural testing is used to determine the flex or bending properties of a material. It involves placing a sample between two points or supports and initiating a load using a third point or with two points.

To determine if the Hemp rope can be used in a structural element or not, we will cast a standard rectangular beam of lightweight concrete reinforced with Hemp rope. The beam will be then tested for flexure using Three Point flexural test. The flexural strength will then be calculated by the formula given below.

$S = 3FL/2bd^2$

Where

F = the load (force) at the fracture point

L = the length of the support span

b = width

d = thickness

Figure 14: Three point loading test of Hemp rope reinforced beams

Beam testing includes beam design, concrete mix design, specimen preparation, reinforcement preparation, form preparation, concrete casting, curing and the conduction of the tests.

Concrete Mix Designs

The concrete to be used in the beams was calculated through trials on 18 samples. Three mix designs i.e., 1:2:4, 1:4:8 and 1:4:6 were selected for testing. 6 cubes of each mix designs were casted. Cubes were of dimension 6x6x6 inches. 3 samples of cubes for each mix were then tested after curing of 7 and 28 days.

Tests on Beams

Beams of dimensions 70x15x15 cm were casted with ropes of each diameter as reinforcement. Concrete of mix design 1:2:4 was used. Four beams were casted. 3 out of which were with ropes of diameters 1 inch, 1.25 inch and 1.5 inch. 1 beam was a control beam which had no reinforcement. Beams were cured for 7 days and tests for flexure strength were conducted on three point loading apparatus.

Figure 15: Rope reinforced beam being tested on three point loading testing machine

3.4.5 Modelling on E Tabs

A slab for a single story was modelled using 1 inches diameter rope. Slabs dimension was of 20’x15’x 6”. Columns are of 15”x15”. Strength of rope from prior tests was used.

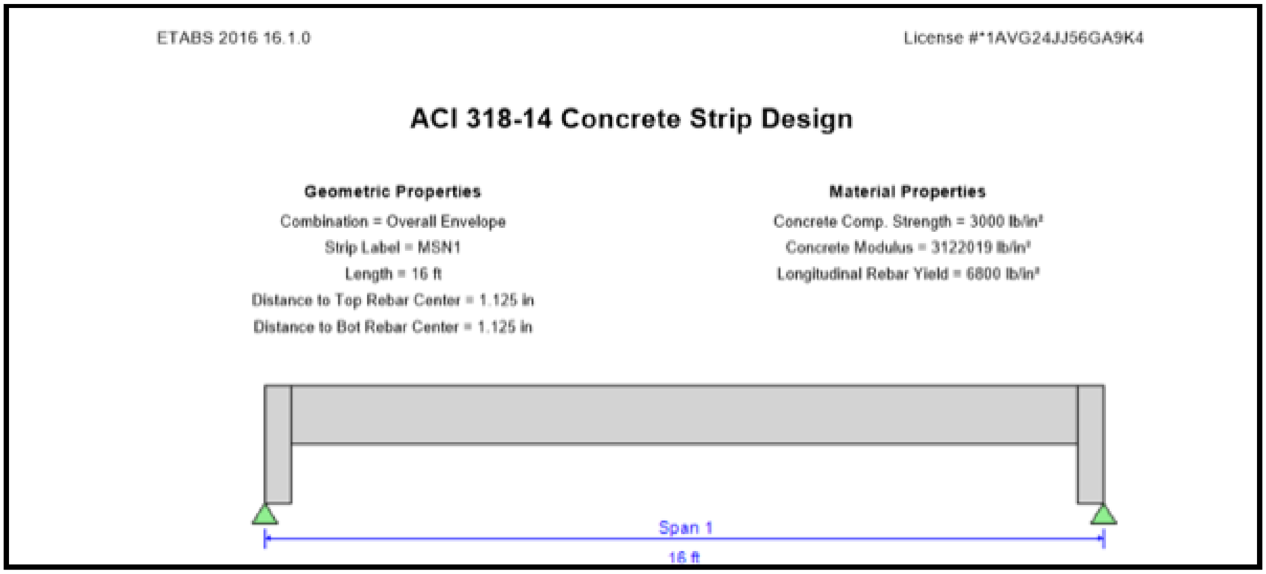

Figure 16: Slab designed in E Tabs

Chapter 4

RESULTS

4.1 Introduction

This chapter presents the results of the tensile testing of Hemp ropes, ability of water absorption of Hemp rope, effect of the water absorbed on the properties of Hemp rope and the three point loading tests of Hemp rope reinforced concrete beams.

4.2 Tensile Strength and Modulus of Elasticity

The results of the tensile strength of the ropes tested are as follows:

Table 1: Tensile Strength and Modulus of Elasticity

Rope Dia (in)	Breaking Load (lb)	Tensile Strength (Psi)	Elasticity Modulus (psi)
1	5239	7210	4641
1.25	8751	7840	4532
1.5	12337	8530	4768
Average		7860	4617

The values differ a bit from those acquired from the prior researches which can be due to the poor rope making practice and unavailability of proper hemp rope making machinery.

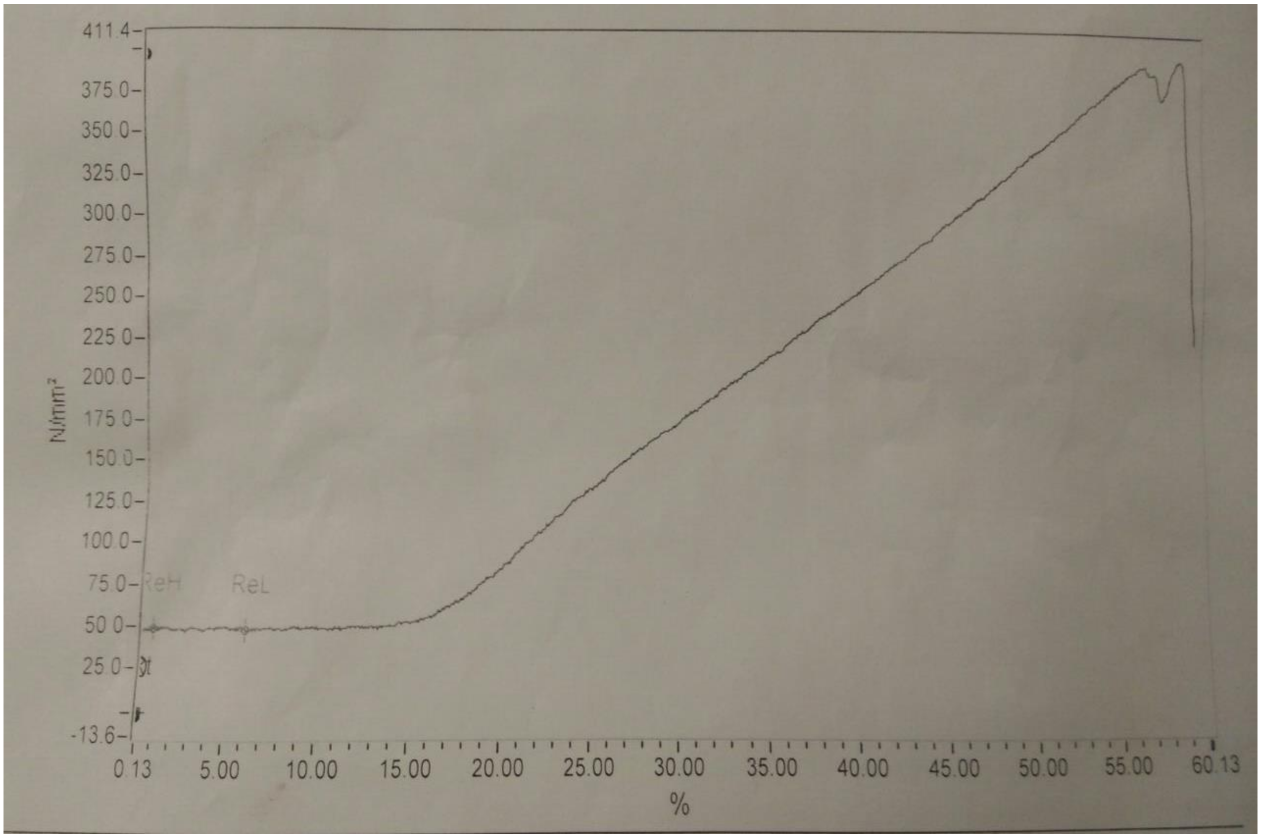

Figure 17: Stress-strain curve for 1 inch dia. Hemp rope

4.3 Effect of Water absorption

The following was observed by immersion of rope specimen in water for 24 hours.

Table 2: Water absorption of rope

Rope Dia (in)	Dry Weight	Wet Weight	Water Absorption (%)
1	87	136	56%
1.25	145	209	44%
1.5	189	291	54%
Average			51.3%

The following results were shown when wet rope was tested for tensile strength.

Table 3: Comparison of tensile strengths of wet and dry ropes

Rope Dia (in)	Wet Tensile Strength (Psi)	Dry Tensile Strength (Psi)
1	6670	7210
1.25	7130	7840
1.5	7980	8530

4.4 Flexural Strength

The following results were obtained for the mix proportions casted for beams.

Table 4: Comparison of compressive strengths of different mix proportions at 7 and 28 days

Mix Design	Strength (MPa) (7 days)	Strength (MPa) (28 days)
1:2:4	14.3	**20.8**
1:2:6	12.1	18.7
1:2:8	10.9	16.8

So the mix design of 1:2:4 was selected for beams. The following is the result of the three pont loading test.

Table 5: Comparison of Flexural Strengths of Hemp rope and steel reinforced beams

Reinforcement Dia (in)	Flexural strength (Psi)
1 (Hemp rope)	984
1.25 (Hemp rope)	1290
1.5 (Hemp rope)	1570
Control beam	281
#2 Steel bar	1227

The results show that the introduction of ropes significantly increased the flexural strength of the beams. It also indicates that the flexural strength provided by Hemp rope of 1.25 inches diameter is comparable to that of #2 steel bar.

It can also be observed that the flexural strength of the beam increases as the diameter of the rope is increased.

4.5 3-D Modelling

A 3-D model of a single-story single room frame structure was modelled. The slabs of dimensions 20'x15' x 6" were used. Columns of 15'x15' dimensions were used. The equations and standards used for finding the steel reinforcement were assumed for the calculation of rope. The resultant values for 1 inches diameter rope were:

9 inches centre to centre distance along the length and 5 inches centre to centre distance along the width. Total Rope required came out to be 805'.

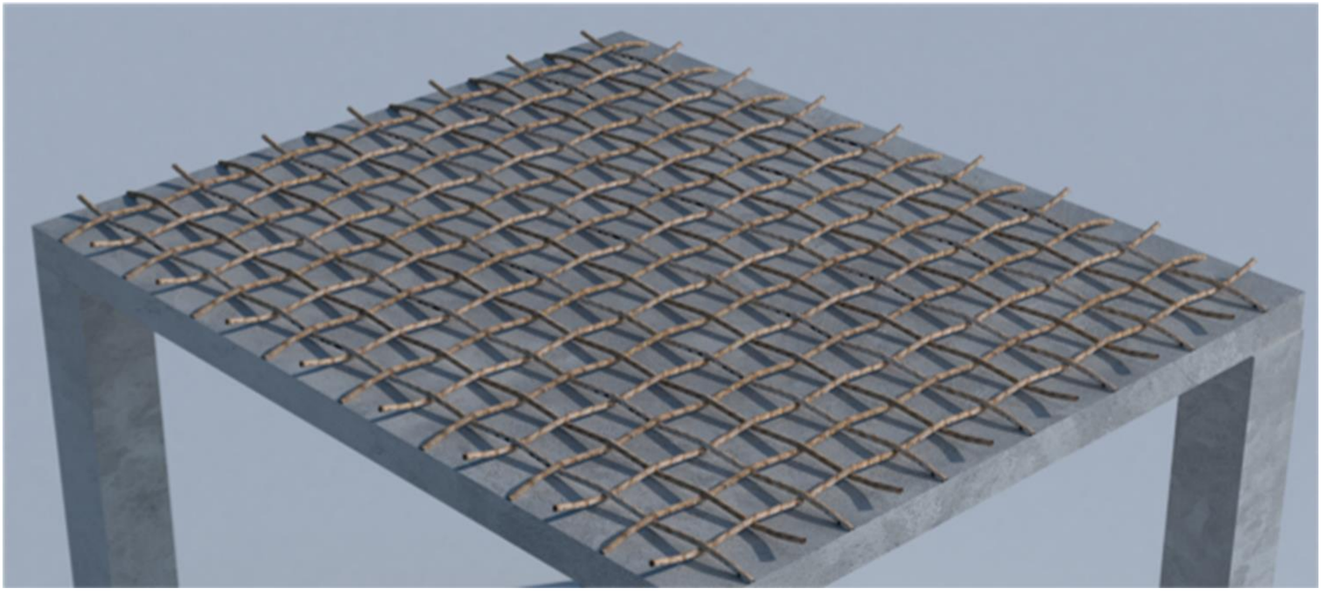

Figure 18: 3-D model of the rope reinforced slab

4.6 ETabs

The same values were again used to model the slab on the software ETabs. On ETabs we found out the comparative shear force and bending moment diagrams of steel and rope reinforced slabs.

The results are as shown below.

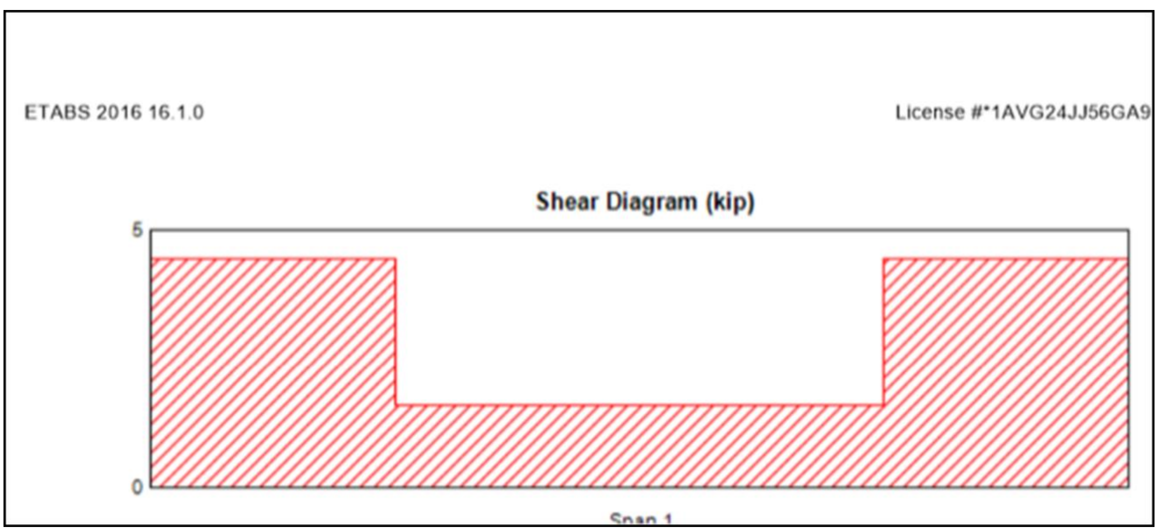

Figure 19: Shear force diagram of rope reinforced slab

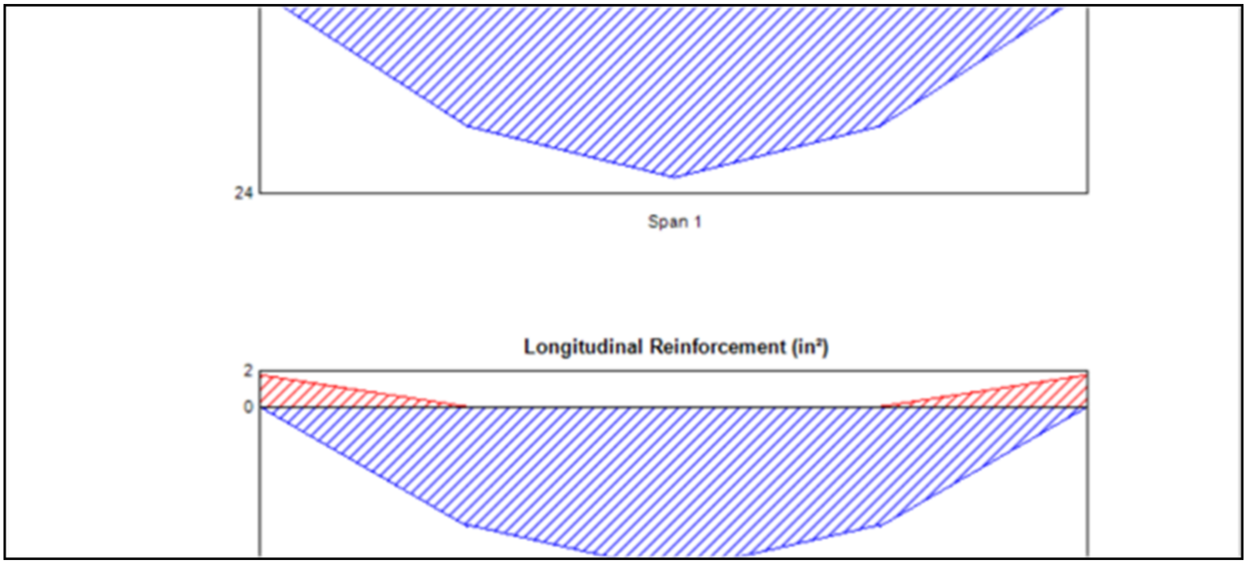

Figure 20: Bending moment diagram of rope reinforced slab

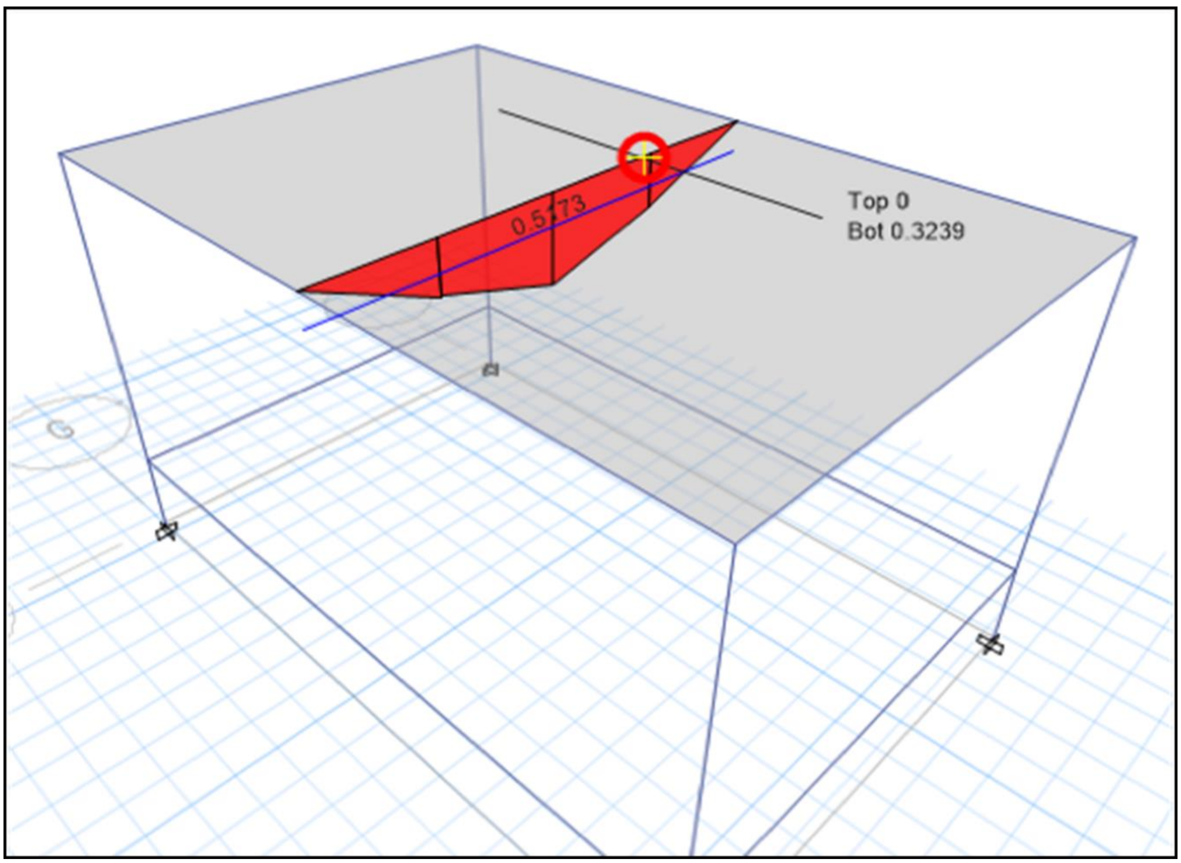

Figure 21: Deflection caused in rope reinforced slab

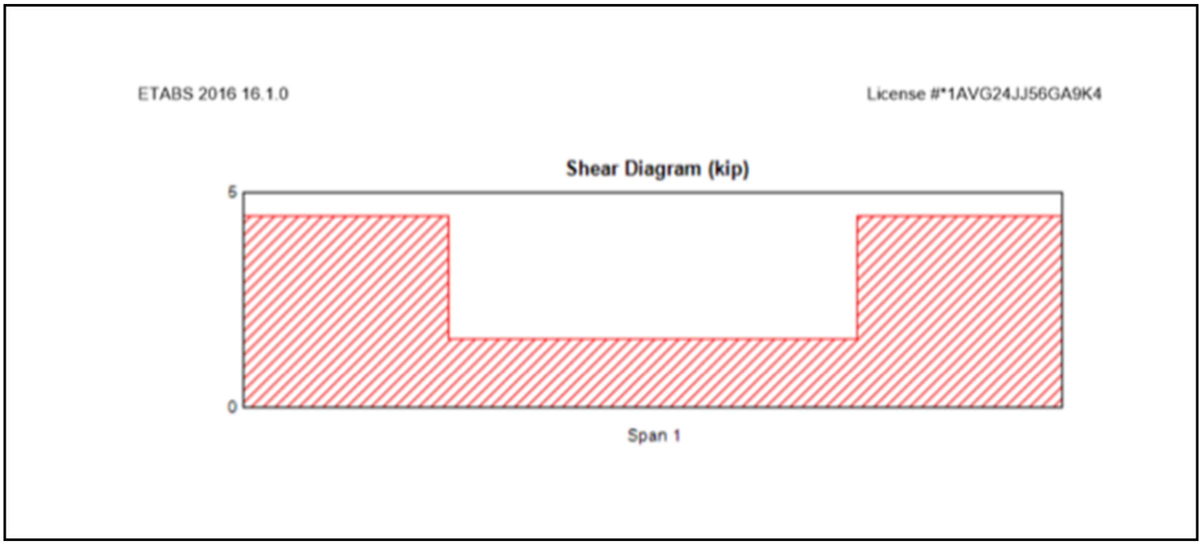

Figure 22: Shear force diagram of steel reinforced slab

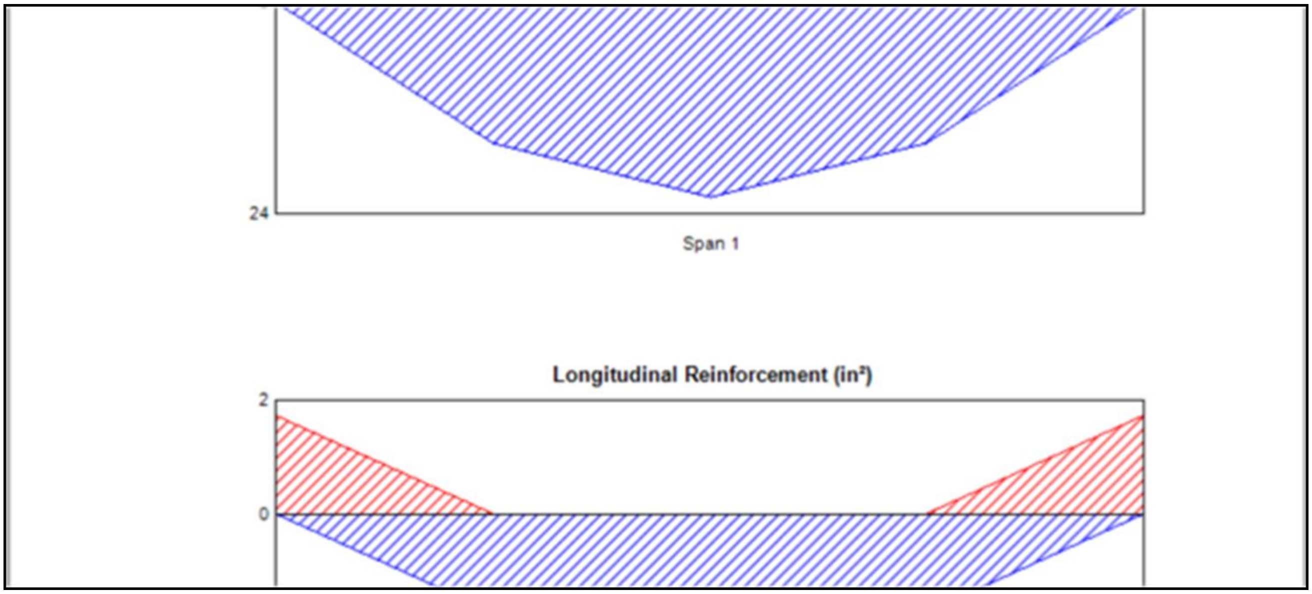

Figure 23: Bending moment diagram of steel reinforced slab

The results thus indicate that the rope reinforced slabs are feasible for single-story structures.

4.7 Cost Benefit Analysis

For the same structure, using our prior knowledge of structural engineering, we calculated the amount of steel that would be required. Then using the amount, we found out the costs and compared it with that of the Hemp rope.

Total steel required 1250’

Cost of steel = approx. Rs. 18000/-

Hemp Rope required 805’

Hemp Rope Cost = approx. Rs. 6000/-

This shows that the cost of Hemp rope is 3 times lower than that of steel and in a same structure the amount of steel is more than that of Hemp rope thus giving the disadvantage of increased dead load of the slabs.

Chapter 5

CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

From the conducted tests, the following can be conclude:

1. The tensile strength of the Hemp rope increases as the diameter increases.

2. The absorption of water slightly affects the tensile strength of the Hemp rope.

3. The flexural strength of a beam reinforced with 1.25” Hemp rope and #2 bar were comparable.

4. From the restricted number of tests conducted, it can be concluded that Hemp rope can possibly be used as a replacement of steel reinforcement. For areas where availability of steel is limited and plain concrete members are commonly being used, the use of Hemp rope reinforced concrete is highly recommended for single-story buildings particularly low cost housing and temporary structures.

5. Hemp ropes decreases the cost of the structure by more than 3 times when used as a replacement of steel.

5.2 Recommendations

Following recommendations are made on the basis of the research conducted.

1. More detailed research is suggested to further approve the feasibility of Hemp ropes use as a replacement for steel reinforcement.

2. A wide-ranging research to assess the performance of different qualities of Hemp rope is suggested as the Hemp ropes used in this research were of low quality due to poor rope making practices in Pakistan.

3. Bonding strength and its interaction with concrete should be studied. This research couldn’t cover this part due to unavailability of equipment.

4. The same tests ought to be carried out after the application of a hydrophobic agent on the ropes to avoid water absorption and asses the effect of the agent on its performance.

5. The lack of Hemp ropes in Pakistani market was a huge hindrance in our research. This in turn was due to non-availability of Hemp at the first place because of the ban on its cultivation. Although wild Hemp plants grow sporadically in Islamabad and other regions of Pakistan but the quality of its fibre is very low. Thus it is recommended that government must take steps to encourage the cultivation of this resourceful plant of industrial Hemp which is mistaken for the drug producing plant.

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