APPLICATIONS OF LIGHT WEIGHT FOAM CONCRETE IN COLD FORMED STEEL CONSTRUCTION

By

HASEEB TAJ

(NUST201463416MSCEE15214F)

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HASEEB TAJ

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Thesis Supervisor

____

Dr. Rao Arsalan Khushnood

NUST Institute of Civil Engineering (NICE)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST)

September 2018, Islamabad Pakistan

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS thesis written by **Mr. Haseeb Taj**, Registration No. **NUST201463416MSCEE15214F**, of MS Structural Engineering 2014 Batch (NICE) has been vetted by undersigned, found completed in all respects as per NUST Statutes/Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfilment for award of MS degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have been incorporated in the said thesis.

Signature____

Name of Supervisor Dr. Rao Arsalan Khushnood

Date: ____

Signature (HoD)__________________________________

Date: ____

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"in the name of Allah the most beneficent the most merciful"

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ABSTRACT

Foam concrete by definition is a cementitious material with a minimum of 20% entrained air in the shape of foam (Deijk, 1992). Foam concrete is a lightweight concrete in which coarse aggregate is replaced with air voids. In simple words it can also be considered an aerated mortar. The foam is generated separately before mixing with the help of a foam generator machine and then added to the cement slurry in order make the foam concrete. The foam is produced with a liquid chemical called the foaming agent that is added with water to make foam in the foam generator. This foaming agent makes a foam with tiny bubbles that are not easily broken during the mixing process and retain their shape.

The amount of foam and water cement ratio (w/c ratio) plays an important part in the strength and density of the foam. An increase in the amount of foam used means lower density and lower strength and an increase in the w/c ratio has the same effect on foam concrete samples. Typically the density of the foam concrete ranges from 300 kg/m^3 to 1850 kg/m^3 and the w/c ratio used ranges from 0.4 to 1.25. (Thakrele, 2014)

In this investigation a foam concrete with the density of around 1500 kg/m^3 is produced with a trial an error method using different w/c ratios and amount of foam in the mix. 18 cube specimens are prepared with different mixes, then their density is recorded and they are air cured to replicate the conditions at site. Then their compressive properties are investigated to select an option that is easy to make in the field. Then the selected formulation was used to make a cuboid of the size 4”x4”x1” to check its thermal conductivity against a cuboid made of mortar. The results showed that the foam concrete has exceptionally better thermal properties compared to mortar. Foam concrete is known for its excellent thermal and acoustic properties (R. Ramamurthy, 2009).

Finally windows of cold formed steel were made in order to check the structural value, if any, that is added by the foam concrete formulation. The formulation selected was then used to fill the windows and compressive tests were done on them with and without the foam concrete infill. The results showed that the windows with foam concrete showed an increased compressive strength compared to the windows without the foam concrete. Thus confirming that the foam concrete also gives a structural value to the system and can be used to compliment the structural strength of the cold formed steel structures.

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CHAPTER 1: INTRODUCTION

1.1. General

Foam concrete by definition is a cementitious material with a minimum of 20% entrained air in the shape of foam (Deijk, 1992). Foam concrete is a lightweight concrete in which coarse aggregate is replaced with air voids. In simple words it can also be considered an aerated mortar. The foam is generated separately before mixing with the help of a foam generator machine and then added to the cement slurry in order make the foam concrete. The foam is produced with a liquid chemical called the foaming agent that is added with water to make foam in the foam generator. This foaming agent makes a foam with tiny bubbles that are not easily broken during the mixing process and retain their shape.

1.2. Advantages of Foam Concrete

The main advantages of foam concrete are summarized below:

i) **Weight reduction:** One of the main advantage of the foam concrete is that it reduces the overall weight of the structure. In civil engineering terms it means that the dead load is drastically reduced which decreases the loads on a structure and this results in a lowering of reinforcement need for the structure which is not only economical for any project but is beneficial for our environment as well.

ii) **Excellent thermal properties:** Foam concrete has small pores with air in them that act as a buffer for the heat and is used as an insulator in many practical applications like roof or floor lining under tiles and wall filler in cold formed steel construction projects.

iii) **Good acoustic value:** In places like lecture halls, restaurants, coffee shops, libraries and even in residential buildings, the noise level has to be kept at a minimum. The only effective way of doing it to make the building as sound proof as well. In the modern world today, there are studies done to check for the acoustic value of different dwelling spaces. Foam concrete has exceptional acoustic properties as well. There it can be used for that purpose in a variety of buildings.

iv) **Fire resistant:** Foam concrete due to its excellent thermal properties is also fire resistant and resists fire much more than normal concrete.

v) **Reduced cost:** In a lot of applications, foam concrete has a lower price because of the added volume of air in the entire mix. The air increases the volume with a fraction of the cost. Similarly, foam concrete does not require specialized labour or equipment except for one machine.

vi) **Easy and affordable to produce:** This research aims to prove that the foam concrete is not an expensive thing to produce and can be easily produced anywhere. If the process is carefully planned it can be made quite affordable.

vii) **High flow:** Foam concrete typically uses a high water to cement ratio and has a lot of flow because of the air bubbles as well. This is particularly beneficial in its application as a filler material because is engulfs all the plumbing of anything that it is used in.

1.3. Applications of Foam Concrete

The main applications of foam concrete are summarized below:

i) **Precast block and wall elements:** One of the main application of foam concrete is that it is used to make light weight, fire resistant, blast resistant, water resistant, and well-built isolations blocks to be used in frame structures for non-load bearing walls. These blocks are available in Pakistan with a limited number of vendors.

ii) **Cast in situ/cast in place walls:** The cast in place/cast in situ wall elements are really easy to make with foam concrete because of its light weight behaviour and high flow. The flow enables the workers to work with it with ease and also makes it easier to transport.

iii) **Floor screeds/roof screeds for insulation:** Foam concrete is used due to its insulation properties and high flow in floor screeds and roof screeds to insulate the building against heat. Furthermore it also increased the acoustic value of the building because it becomes much less noisy because of foam concrete.

iv) **Sunken portion filling:** Sunken portions in the washrooms are full of plumbing and needs to be filled in a proper way. Foam concrete due to high flow engulfs all the plumbing pipes and seals them as well which makes it an ideal material to use for such works.

v) **Used as a base material for road:** As shown in the literature review of this research, foam concrete is used as a sub layer in the road construction as well. There are a lot of practical examples in United Kingdom and United States of American where foam concrete is used in road construction.

1.4. Research Objectives

i) To make a FC mix with a suitable density and compressive strength so that it can be used as a structural member in cold formed steel construction.

ii) To find a way of making a stable foam without the use of foam generator machine.

iii) To demonstrate that the mix is thermally efficient.

iv) To demonstrate that the mix can not only be used in cold formed steel construction but it adds to the structural value of the system.

v) To make a model on ETABS and compare a small unit with and without the use of foam concrete.

1.5. Scope of Research

There is a huge room for research in the field of light weight concrete but this research will be restricted to the foam concrete only. There are other ways to producing light weight concrete as well but this research aims to study the light weight concrete produced by foaming agent only.

Secondly, the research will be focused on the practical aspect of the foam concrete usage so it will take into account the steps that can be taken to make the process as easy as possible to achieve the same results on site in the presence of a lot of variables. In order to achieve this, some of the specific details regarding the laboratory usage is not included in the research and more emphasis is given to the field work.

Mainly the physical and thermal properties of foam concrete were investigated to check it effects in the usage of foam concrete. The main test was the compression test done on a strain controlled machine where the compressive strength and the stress-strain graph was made in order to check the behaviour of the material.

In the end an ETABS software analysis was done to model the things done in lab and confirm the trend of the results in order to the composite behaviour of the foam concrete mix that we made in the lab. A non-linear analysis was done in ETABS where the properties of the material was given manually to the system. There were the real values taken from the stress-stain graphs of the laboratory results of compression tests. Two models were compared: one with and one without the use of foam concrete to see a visible difference.

CHAPTER 2: LITERATURE REVIEW

2.1. Use of lightweight concrete in flexure members (2017 study)

In a paper called “Laboratory tests of foam concrete slabs reinforced with composite grid” presented by Jacek Hulimka et all in the “International Conference on Analytical Models and New Concepts in Concrete and Masonry Structures AMCM’ 2017” it is stated that due to low resistance to concentrated load, sufficient bonding is not achieved in foam concrete, however, with the use of reinforcing mesh the transverse fibres help anchor the main fibres resulting in a huge improvement in the capacity of the slabs (Jacek Hulimka, 2017). In this study, nine specimens were used, three specimens with no reinforcement, three with basalt mesh as reinforcement, and three with carbon grid as reinforcement. There was a marked difference in many aspects with the use of reinforcement in foam concrete. Primarily the strength and deflection measures were improved drastically as shown by the Fig below:

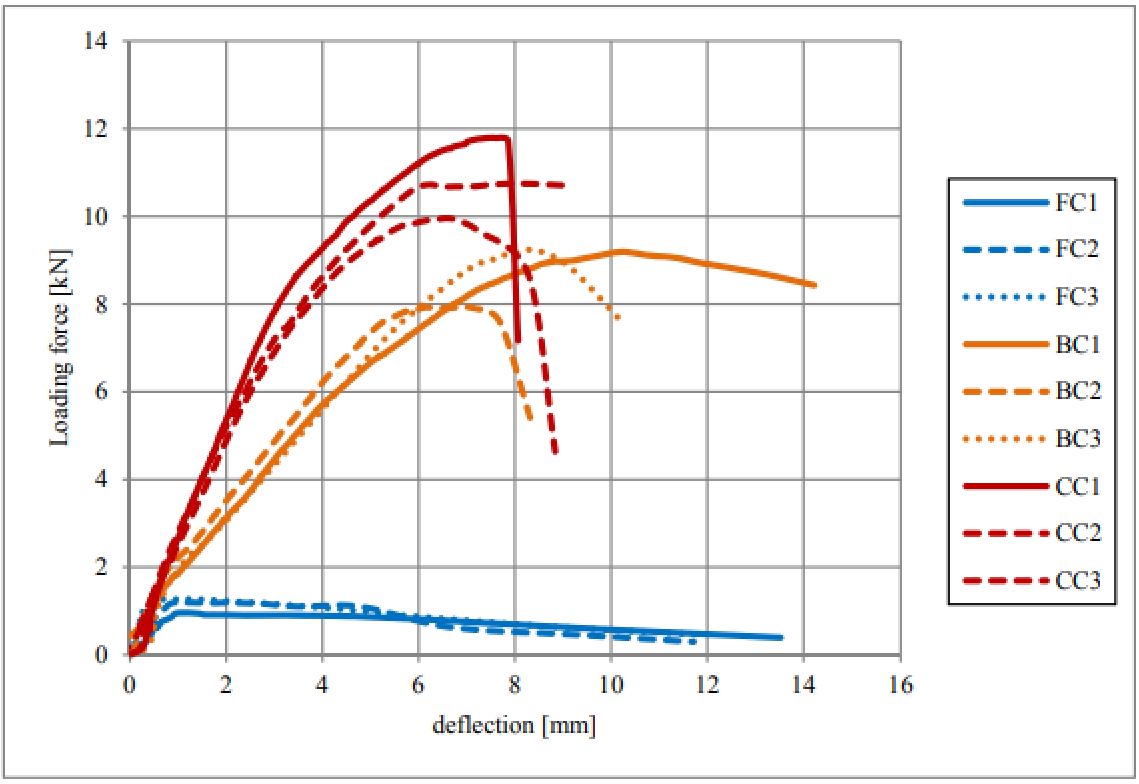


Fig 2.1: Deflection of tested samples of slabs (Jacek Hulimka, 2017).

The grid of Basalt mesh was 25 mm x 25 mm and carbon fibre mesh was 60 mm x 60 mm and the deflection was better in the smaller mesh design confirming the test results. Furthermore, the shrinkage was also decreased by use of this composite mesh. The shrinkage cracks were minimum on samples with the mesh. It also lead the report to conclude that the use of mesh made the transfer of tensile forces better and prevented brittle failure (Jacek Hulimka, 2017). The following figure was taken from the study to show the failure modes of the specimen with and without the mesh reinforcement.

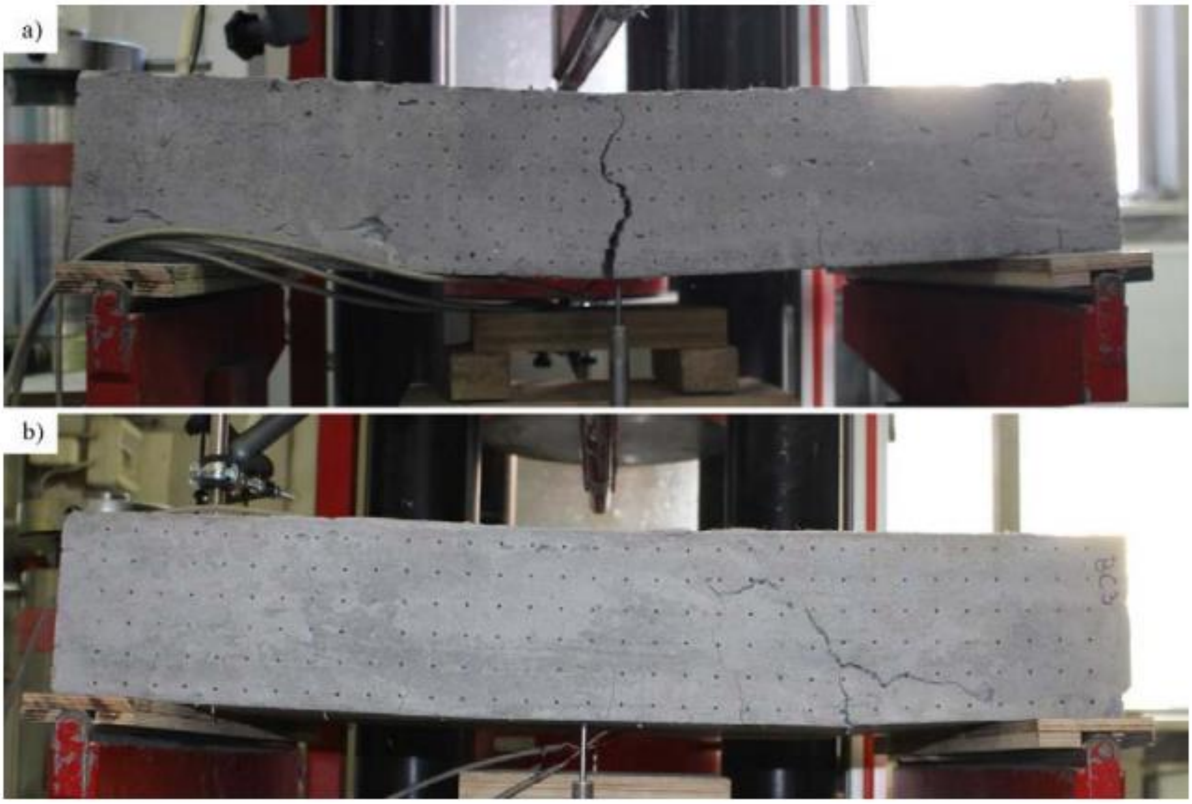


Fig 2.2: Failure modes of samples, a) without mesh, b) with mesh. (Jacek Hulimka, 2017)

2.2. General Uses of foam concrete.

In another study on light weight foam concrete in August 2017 by Assistant Professor Aswathy states that the light weight foam concrete can be used because of the following benefits:

i) It drastically reduces the dead load on the building.

ii) It does not require high workmanship or handling skill (like autoclave aerated concrete).

iii) It decreases the transport charges.

iv) It is environmentally friendly as compared to normal concrete blocks.

However, the study done by Aswathy also concludes that the density of the foam concrete can vary with the size of the sample. This aspect is not studies in this research as all the cubes were of similar size. This can have a huge impact on the result and is mentioned in the recommendation section of this report (Aswathy, 2017).

2.3. Use of lightweight concrete in road pavement

Lightweight foam concrete has been used as an insulation material for a long time. Similarly it is also used as a backfill material in excavated areas especially near retaining walls. However, with the increase in technology the use of foam concrete is also being studied as a structural member. In a research paper called "Application of foam concrete in road pavement – weak soil system" presented in the International Conference on Analytical Models and New Concepts in Concrete and Masonry Structures AMCM' 2017 the use of foam concrete is studied in a laboratory condition and then it is numerically studied in by simulation of road pavement (Marta Kadela, 2017).

The above mentioned study talks about the strengthening of weak soils and different ways that are currently being used. One of the most common ways is dynamic consolidation has a lot of vibrations which can damage existing buildings nearby. There is an increase in the engineering knowledge in the last few decades in which new solutions and alternative materials are being used to solve engineering problems. A good way to solve the problem of weak soils is to put a layer of foamed concrete on the ground to uniformly transfer the force from our structures to the weak soil below (Marta Kadela, 2017). The results were as follows:

i) Dry density of hardened concrete decreased with increase in the foaming agent content.

ii) Porosity of the foamed concrete increases with increase in the density of foaming agent.

iii) Compressive strength and flexure strength of foamed concrete increased with increase in the density of foamed concrete.

The following graphs show the results:

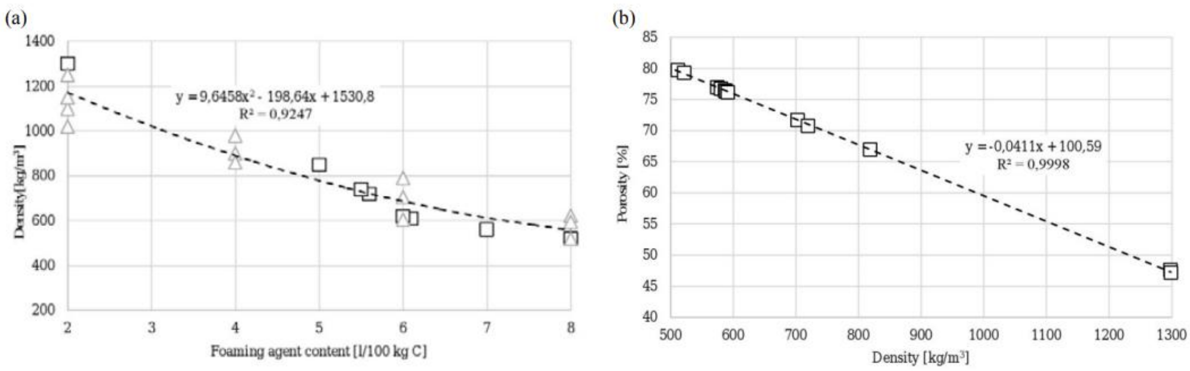


Fig 2.3: a) Density vs Foaming Agent Content, b) Porosity vs Density (Marta Kadela, 2017)

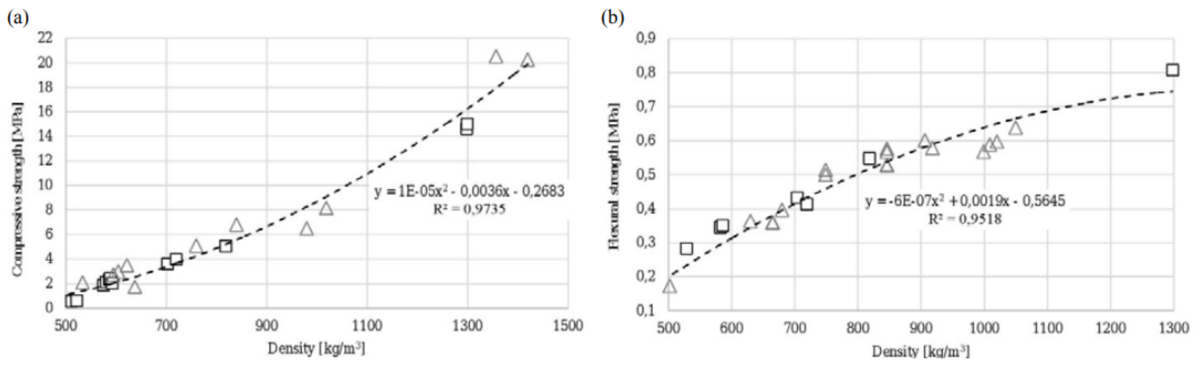


Fig 2.4: a) Compressive Strength vs Density, b) Flexural Strength vs Density (Marta Kadela, 2017)

In the numerical simulations the maximum tensile stresses in the lower part of the subbase layer were found to be 0.039 MPa and the flexural strength of the foamed concrete with the density range of 860 to 1060 kg/m^3 has the flexural strength of 0.55 to 0.67 MPa (Marta Kadela, 2017). These results clearly show that the foamed concrete can be used as a subbase material for roads. However, since the flexure strength of the subbase layer was calculated through a numerical approach there is a need to practically demonstrate these results with in-situ testing of the subbase layer made up of foamed concrete. The same study is taken by a new aspect to show that foam concrete can effectively be used in the industrial concrete floors in another study by M. Kadela in 2016 (M Kadela, 2016).

2.4. Real lift examples of the foam concrete usage

There are many projects in which foam concrete is being used these days and the engineering community has realized and acknowledges its use due to its low weight, quick pouring, and economical usage in many cases. Some of the examples are given below:

i) In the Hertfordshire Industrial Zone UK, foam concrete was used as a base material for the roads (Martin Decky, 2016).

ii) In the construction of Northwest Highway (route 14), Illinois USA, 13000 cubic meters of foam concrete was used with two densities: 590 kg/m^3 and 410 kg/m^3 (Martin Decky, 2016).

iii) In Schaumburg, Illinois the Central road of 3 km length was reconstructed that had a soft underlying soil. A 900 mm thick layer of 400 kg/m^3 and a 600 mm thick layer of 500 kg/m^3 was used that resulted in lower costs, lesser installation time and higher quality (Martin Decky, 2016).

iv) In South Africa, there is a deep-water port called the Richards Bay which handles around half of all the cargo ships passing through the country. It used a huge amount of foam concrete in 600 mm layers for filling and stabilisation of soil.

It can, therefore, be said that the use of foam concrete is very common in today's ever evolving world. The right range of density and attention to the design of the foam concrete can yield effective results in many situations where foam concrete proves itself to be more efficient and cost effective as compared to ordinary concrete.

2.5. Ultralight foamed concrete

In a study done by Xianjun Tan et all called the "Experimental Study of Ultralight (<300 kg/m^3) Foamed Concrete in 2014, the researchers have used fly ash in the foamed concrete mix of an ultralight specimen. They demonstrated that the use of fly ash increased the strength of the sample till 45% and after the amount of fly ash exceeds this value the strength shows a downward trend (Xianjun Tan, 2014). The image below shows the effect of using fly ash in foamed concrete:

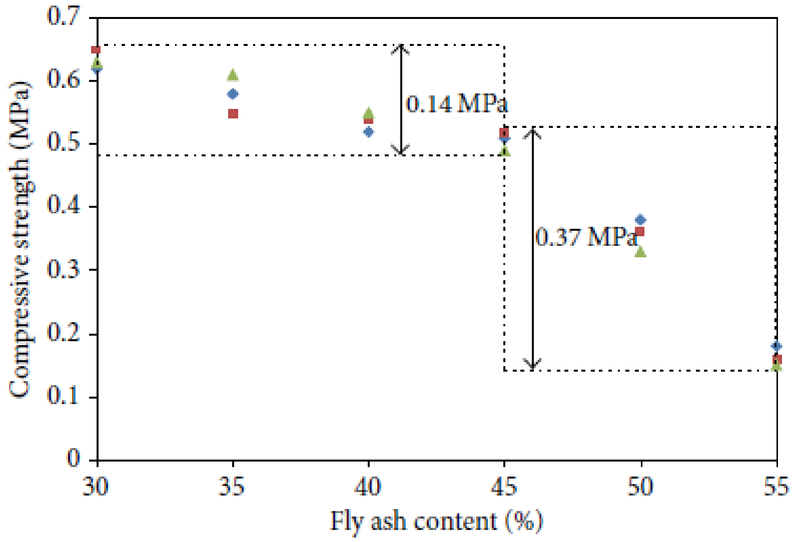


Fig 2.5: the effect of fly ash content on the compressive strength of foamed concrete.

2.6. Specification and Quality Control of light weight foamed concrete

In a study by Ashish Kurweti in 2017 the foam for the foamed concrete is also produced by mechanical stirring without using foam generator and foamed concrete of different densities is produced. There are three mixes produced with the help of this foam and their compressive strengths, water absorption, and densities are calculated (Ashish Kurweti, 2017). The table below summarizes the results:

1 specimen= 3samples	Density (in kg/m^3)	Compressive strength (in N/mm^2)	Water absorption (in %)
Sample1	1036	3.82	12.01
Sample2	1033	3.86	11.90
Sample2	1034	3.90	12.03
Average of above three	1034.33	3.86	11.98

Table.4. Mix-C

1 specimen= 3samples	Density	Compressive strength	Water absorption
Sample1	1228	6.81	10.9
Sample2	1230	6.85	10.11
Sample2	1231	6.88	10.3
Average of above three	1229.67	6.85	10.43

Table 2.1: Densities, Compressive Strengths, and Water Absorption results of the foamed concrete samples produced by mechanical stirring.

2.7. Thermal properties of foamed concrete

In a study by Shankar Ganesan et all in 2015 thermal properties of foamed concrete of various densities is investigated and analysed. It also concludes that various additives can be used to decrease or increase the dry density of foam concrete in order to cater for different needs (Shankar Ganesan, 2015). The following table shows the thermal properties of foamed concrete samples with different densities:

Sample	Density (kg/m^3)	Thermal conductivity (W/mK)	Thermal Diffusivity (mm^2/s)	Specific Heat Capacity (J/m^3k)	Percentage of Porosity (%)
Normal FC (NFC-1)	700	0.24	0.39	879	68
Normal FC (NFC-2)	1000	0.49	0.58	845	57
Normal FC (NFC-3)	1400	0.74	0.69	794	35

Table 2.2: thermal properties of foamed concrete samples with different densities (Shankar Ganesan, 2015).

This research also used some additives to the mix of a selected density to check the effects on thermal conductivity. The following table shows the results:

Samples	Reference	Thermal Conductivity W/mK	Thermal Diffusivity mm2/s	Specific Heat Capacity (J/m3k)	Porosity (%)
Control mix	NFC-2	0.49	0.58	845	57
POFA (25%)	POFA-25	0.46	0.53	868	50
POFA (40%)	POFA-40	0.43	0.49	878	61
Polypropylene Fiber (0.2%)	PF-0.2	0.47	0.54	870	48
Polypropylene Fiber (0.4%)	PF-0.4	0.44	0.49	898	50
Steel Fiber (0.25%)	SF-0.25	0.45	0.52	865	55
Steel Fiber (0.4%)	SF-0.4	0.42	0.47	894	59
Silica Fume (10%)	SLF-10	0.43	0.49	878	49
PFA (15%)	PFA-15	0.44	0.50	880	48
PFA (30%)	PFA-30	0.41	0.46	891	45
Wood Ash (5%), PFA (15%)	W5-P15	0.41	0.46	891	49
Wood Ash (10%), PFA (15%)	W10-P15	0.44	0.50	880	54
Coconut Fiber (0.2%)	CF-0.2	0.41	0.44	932	48
Coconut Fiber (0.4%)	CF-0.4	0.38	0.40	950	46

Table 2.3: Thermal properties of 1000 kg/m^3 density samples with different additives (Shankar Ganesan, 2015).

2.8. Quality control of foamed concrete

In a study by Ashish Kurweti et all in 2017, the quality control of foam concrete is studied in detailed using a lot of variables like the quality of foam that is produced by open air mechanical stirring similar to this research. In the mix the air entrainment is 30% by volume to make a light weight foam concrete sample. The foam is generated by using the ratio of 1:25 of foaming agent to water which much a much economical ratio as compared to ratio of 1:1 used in this research. The foaming agent used however is not the same as the one used in this research so that might be one reason for this deviation from the mixing scheme. The results of these experiments showed that the increase in the sand content increased the density and the overall compressive strength was also increased. Similarly the water absorption was decreased with the increase in the density of samples. The foam was generated with mechanical stirring in order to lower the cost of the project.

2.9. Summary

The literature review suggests that the foam concrete is being widely used around the world not only in the papers but in the practical world as well to cater for a number of problems including the weak soils or high heat transfer through structures. In our modern world with scarcity of resources and a constant need of environmentally friendly materials that are also economical, foam concrete can act as a material that does both. It is environmentally friendly and also economical. The only thing needed now is to streamline this process of making and applying the foam concrete in a proper way.

CHAPTER 3: EXPERIMENTAL PROGRAM

3.1. Materials

The materials used the research are all obtained from the local market. All the materials were stored in air tight containers to prevent the moisture from contaminating the materials. More details of the materials used are given below:

3.1.1. Cement

The cement used in this research was manufactured by “Bestway Cement”. It was Ordinary Portland Cement of Grade 53 Type-1 (Pakistan Standards PS-232-2008) manufactured under ASTM C150-04 and EN-196. To investigate the chemical composition of the cement used, X-Ray Fluorescence (XRF) analysis test was done from ‘Institute of Environmental Sciences & Engineering’ (I.E.S.E) in National University of Sciences and Technology Islamabad using Axios Advanced WD-XRF PA Nalyical using pressed pellet procedure, BET-Specific surface area along with Particle size distribution (PSD) by Laser granulometry is shown in Table 3.1 below:

SiO_2	19.17
TiO_2	0.28
Al_2O_3	4.96
Fe_2O_3	3.21
MnO	0.04

MgO	2.23
CaO	65.11
Na_2O	0.57
K_2O	0.51
P_2O_5	0.77
LOI	3.85
BET (m^2/g)	1.1
Particle Size, (D_{50}), microns	16.2

Table 3.1: Chemical composition of Cement used

3.1.2. Foaming Agent

The foaming agent used in this research is named "Advafoam Crete" and is manufactured by 'Al Mutathawir Insulation Materials Industries L.L.C. in Sharjah, United Arab Emirates. It is a high quality foaming agent liquid with light yellow colour and is used for all type of lightweight screeeds. The advantages advertised on the product are as follows:

- Weight reduction
- Good thermal insulation
- Good acoustic value

- Does not attack iron or steel
- Low water absorption
- Fire resistant
- Resistant to organic growth
- Roof falls can be formed with greater ease
- Chloride free
- Economical to use

The main advantage of this foaming agent is that it is relatively cheap and easy to use. The general properties of Advafoam Crete are as follows:

Appearance	Light yellow liquid
Specific Gravity	1.1 at 20 degree Celsius
Chloride Content	Nil
Nitrate Content	Nil
Solubility in water	Infinite
Freezing point	Less than 0 degree Celsius
Flash point	None
VOC	14.9 less water

Table 3.2: General Properties of the Advafoam Crete foaming agent

3.1.3. Sand

The sand used in this research was all obtained from the sand reserved of an area called Lawrencepur in Punjab Pakistan. The usage was done after cleaning the sand to get rid of any organic matter that might alter the properties of the mix. Fineness Modulus (FM) of the sand was found using ASTM C-136 and the result was 2.01.

3.2. Experimental Procedure

The research was done in disciplined manner in the structural laboratory of National University of Sciences of Technology Islamabad with controlled environment inside the laboratory. The experimental procedures were carefully selected to mimic the field setting and are explained below:

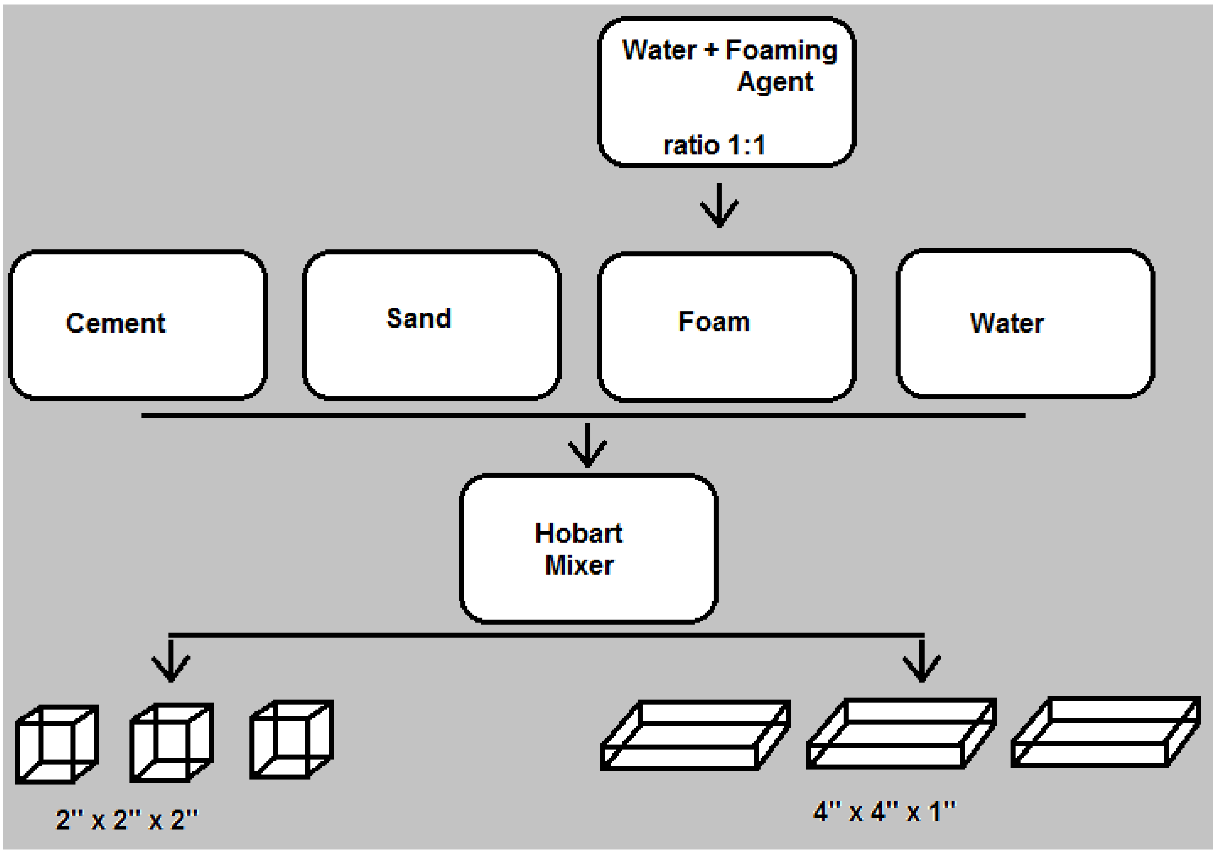


Fig 3.1: Flow chart summarizing the formation of foam concrete in this research

3.3. Mixing Methods used

In the field a special machine called the foam generator is used to generate foam that is then used in the foamed concrete. The foam generated by the foam generator is of consistent viscosity and is made in abundance by using a small amount of foam generator with a large amount of water. The picture below shows a foam generator in the field:

Fig 3.2: Worker making foam using foam generator machine in the field.

However, for this research the foam generator machine was not available so another method was needed in order to obtain the foam needed for the foaming concrete.

Therefore in order to make the foam, a custom made drill bit was made using ordinary steel rebar and strips of metals. This drill bit was made small enough to be used in a bucket and wide enough for it to be able to stir the liquid forcefully in order to get a large volume of foam. The end of the drill bit was made to fit into the drill as shown by the figure below:

Fig 3.3: Customized drill bit.

The drill bit had the following characteristics:

Length:	12 inches
Number of fins:	3
Area of each fin:	3 inch x 0.75 inch

This drill bit was then connected to a drill machine so that it can be used to mechanically stir the liquid of water and foaming agent. This mechanical stirring was expected to produce foam of the same density and consistency as is produced by the foam generator. Different ratios of foaming agent liquids were used with water to produce different foams and then it was compared with a foam sample produced by a foam generator seen in the field. The ratio of foaming agent to water of 1:1 was found to produce an exactly same foam. The figure below shows the custom made drill bit attached to the drill:

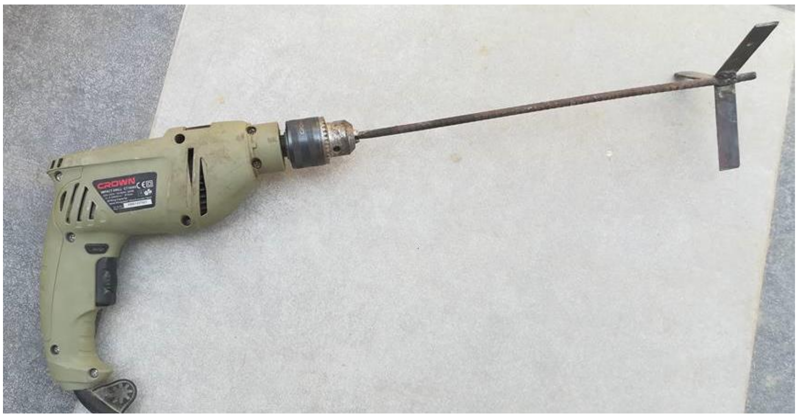


Fig 3.4: Customized drill bit attached to an ordinary drill

This drill was then used to mechanically stir the liquid of foaming agent and water in order to produce foam. The time it took for the foam to be generated was also noted. The foam initially took some time to generate but then increased in volume dramatically. The optimum time taken for the foam to be made by this drill was 40 seconds after which it was seen that no more foam was being produced. The pictures below shows the foam being made by mechanically stirring the liquid of foaming agent and water in a bucket for 45 seconds:

Fig 3.5: Mechanical stirring to produce foam

In order to test the consistency of both the foams from the field and the laboratory another small test was devised in which two buckets with equal amount of foam from both sources was taken and kept beside each other. After some time the settlement of the foam was taken after every hour interval in order to see the difference. The results of the settlement are shown in the graph below:

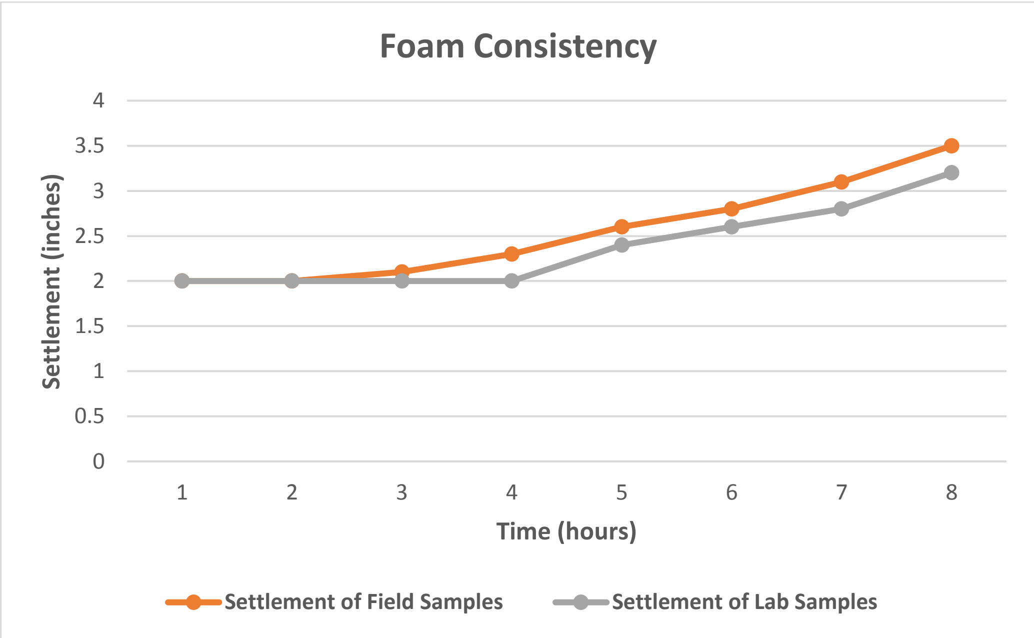


Fig 3.6: Consistency of the foam (field vs laboratory)

The graph above shows that there is almost a negligible difference between the consistency of the foam in the field and the laboratory. This test was really important to demonstrate that the foam used in both field and laboratory are the same so that their results can be compared with each other within including an extra variable i.e. consistency of the foam.

The sample casted for the compression tests were 2”x2”x2” in size and the formulations for the samples are explained in the coming chapters. Similarly a thermal conductivity test was to done on the samples and for that test a special apparatus was made in the laboratory that is explained below.

The apparatus as shown in the figure below and is made up of two compartments, one on top of the other. The compartments are made of wood with a glossy surface so that it acts as an insulator. Furthermore, the inside of the compartments are also lined with an insulating sheet for more insulation so that the heat does not leave the system. Both the compartments have a thermocouple probe in them so that the temperature can be measured in both the compartments simultaneously. In the middle of the compartment there is a slot of size 4”x4”x1” for our sample and it is placed in such a way that the heat has to pass through it to the other compartment. The upper compartment has a heat source in the shape of an electric bulb so that the temperature of that compartment can be raised. Once the sample is placed in the compartment and the bulb is switched on the temperature in the upper compartment starts to rise and the only way it can go now is through the specimen placed in the middle. When heat flows through the sample it starts to heat up the chamber below. However there is an obvious difference in the two compartments which is used to check for the thermal conductivity of the sample.

3.4. Thermal conductivity calculations

There are many different methods used to calculate the thermal conductivity of materials. Each method is suited for a range of materials and situations. These methods can be broadly categorised into two categories:

i) Steady state techniques: these techniques rely on the signals in the steady state. It usually takes a longer time to get to a steady state situation but this way of calculation is considered easier and is used a lot for solid concrete samples.

ii) Non-steady state techniques: these techniques rely on values from during the system is being heated up and are quite quick as compared to the steady state techniques. However, they are not usually used in the laboratories because the equipment is expensive.

One of the most common method used for the determination of thermal conductivity in concrete is called the “Guarded hot plate method” in which the sample of the solid concrete is place in between two plates and one of the plate is heated until the heat from the plate passes through the sample onto the other plate. Temperature on both the plates are monitored until it becomes constant, hence, this is a steady state technique. Then the thickness of the sample is used in a formula to calculate the thermal conductivity of the sample.

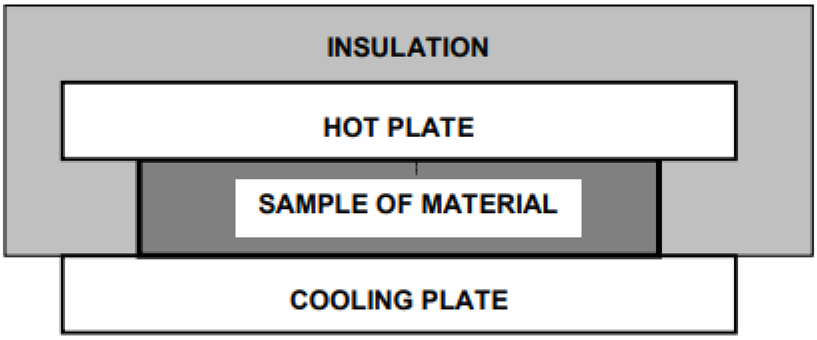


Fig 3.7: Scheme of guarded hot plate setup (Alena Vimmrova, 2002).

Thermal conductivity λ is given by the following equation:

$$\lambda = \frac{q \times d}{T_1 - T_2} \quad [W/mK]$$

where q is quantity of heat passing through a unit area of the sample in unit time $[W/m^2]$

d distance between two sides of the sample [m]

T_1 temperature on warmer side of the sample [K]

T_2 temperature on the colder side of the sample [K]

The quantity of transferred heat **q** is given by:

$$q = \frac{Q}{A} \quad [W/m^2]$$

where Q is quantity of heat passing through a base area of the sample [W]

A base area of the sample $[m^2]$

Fig 3.8: Equation of Thermal conductivity λ

Temperature in the laboratory should not vary more than ± 2 degree Celsius and the relative humidity should not exceed more than 65%.

The apparatus used in this research mimics the properties of this steady state methods and is shown in the following picture:

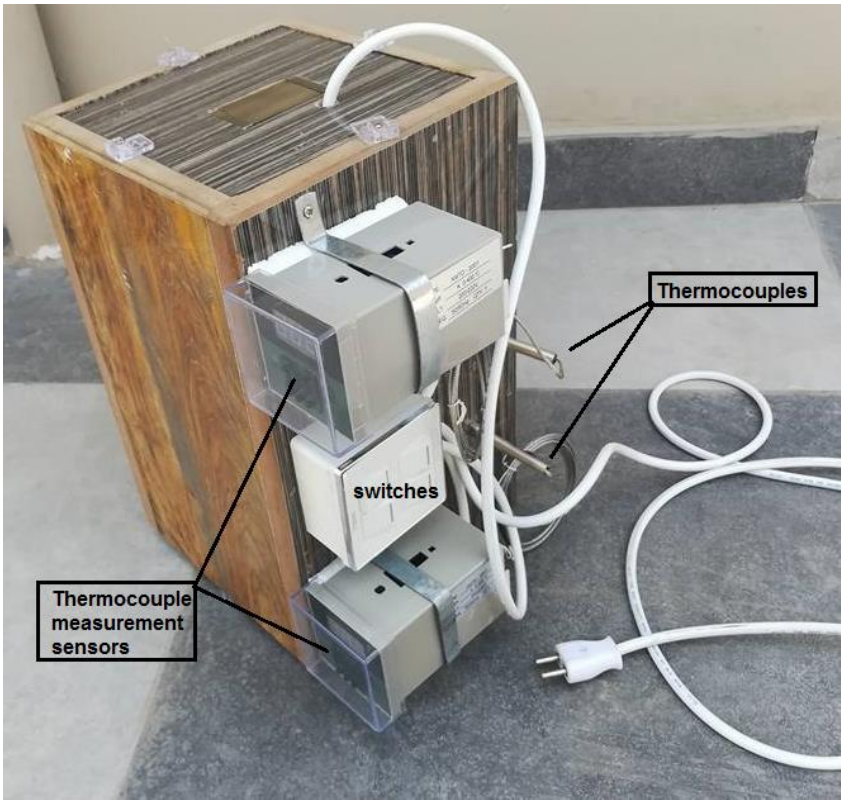


Fig 3.9: Apparatus for Thermal conductivity

There is not hot plate but there is a heat source in the shape of the bulb in the upper compartment that gives heat to the upper chamber of the apparatus and the only way the heat can go is through sample into the chamber below. There is a temperature sensor (in this case a thermocouple) in each of the compartments. This mimics the setup shown above and the formula shown above is used to calculate the thermal conductivity of our samples.

The pictures below shows the inside of the apparatus:

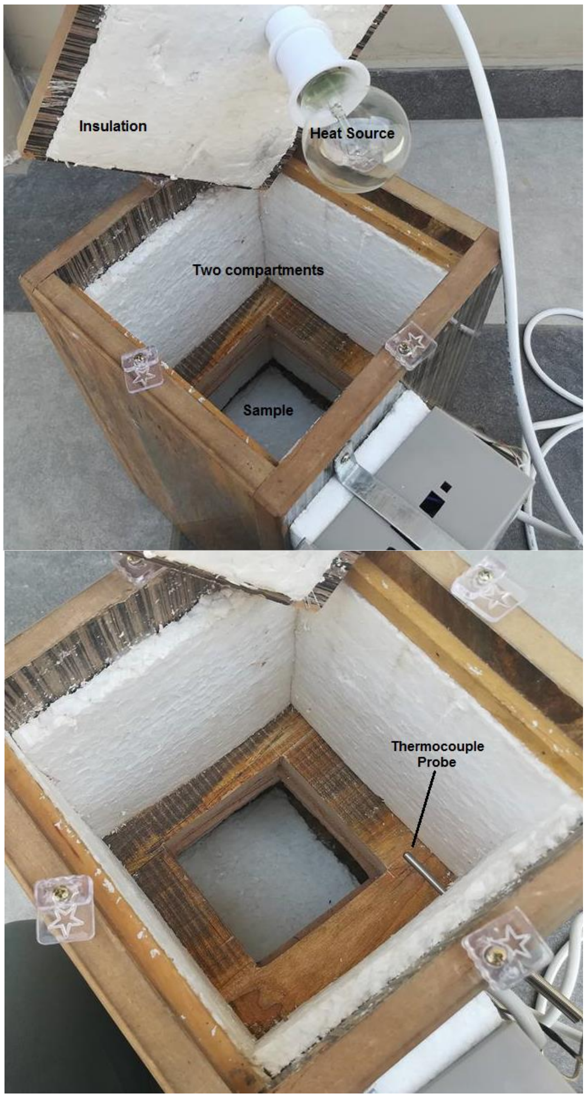


Fig 3.10: Inside of apparatus for Thermal conductivity

As shown in the pictures above there two compartments are insulated from the inside so that there is no heat loss from the system. The walls itself are made of glossy surface with wood inside as an extra insulator. This way the system mimics the apparatus of the steady state heat transfer apparatus. Two specimen were made, one of a normal mortar and the other of foam concrete formulation selected in this research to be compared to each other.

The thermal conductivity of normal concrete ranges from about 1.2 to 1.75

The thermal conductivity of light weight concrete ranges from 0.11 to 0.25

(Md Azree Othuman Mydin, 2011)

Our experiment shows that the thermal conductivity of mortar sample is 2.2 W/m.K

And the thermal conductivity of the foamed concrete sample is 0.78 W/m.K

3.5. Mixing Regime of formulations

A total of six formulations were studied as shown in table 3.3 below. Water cement ratio was changed three times to get different strengths and then the amount of foam was changed with each water cement ratio in order to see the changes due to the amount of foaming agent used in the system.

S.No.	Cement	Cement (ratio)	Sand (ratio)	Foam (amount in ml/kg)	W/C ratio	Formulation ID
1.	C1	2	3	60	0.5	2-3-0.5
2.	C1	2	3	60	0.6	2-3-0.6
3.	C1	2	3	60	0.7	2-3-0.7
4.	C1	1	1	60	0.5	1-1-0.5
5.	C1	1	1	60	0.6	1-1-0.6
6.	C1	1	1	60	0.7	1-1-0.7

Table 3.3: List of foam concrete formulations:

3.6. Test Specimens

The Specimens were prepared in Hobart mixer according to ASTM C305 and were tamped to get good compaction. Specimens were removed from the moulds in 24 hours and were air cured to replicate the site conditions. For all the specimens, cubes of 50mm (2in) were prepared for testing. Compressive strength of three specimens from each category was checked on 3 and 7 days. This was done because in the field usually the cold formed steel wall is loaded after 7 days so it needs to get proper strength within that time. Similarly 2 specimen of 3 samples each were casted in the size of 4”x4”x1” for the thermal conductivity testing in the apparatus made. The apparatus is explain further in the previous chapters.

Fig 3.11: Casting of samples

Results from the above tests were all recorded, compiled and analysed to check the usage of foam concrete in the cold form steel construction. Results and discussions are included in chapter 4 of this report.

3.7. ETABS Analysis

ETABS analysis was also done of the system to analyse the results in two different cases: one with the use of foam concrete and one without the use of foam concrete. A typical C section was taken of the exact same size and thickness as used our laboratory work and was incorporated in ETABS as shown in the following figure:

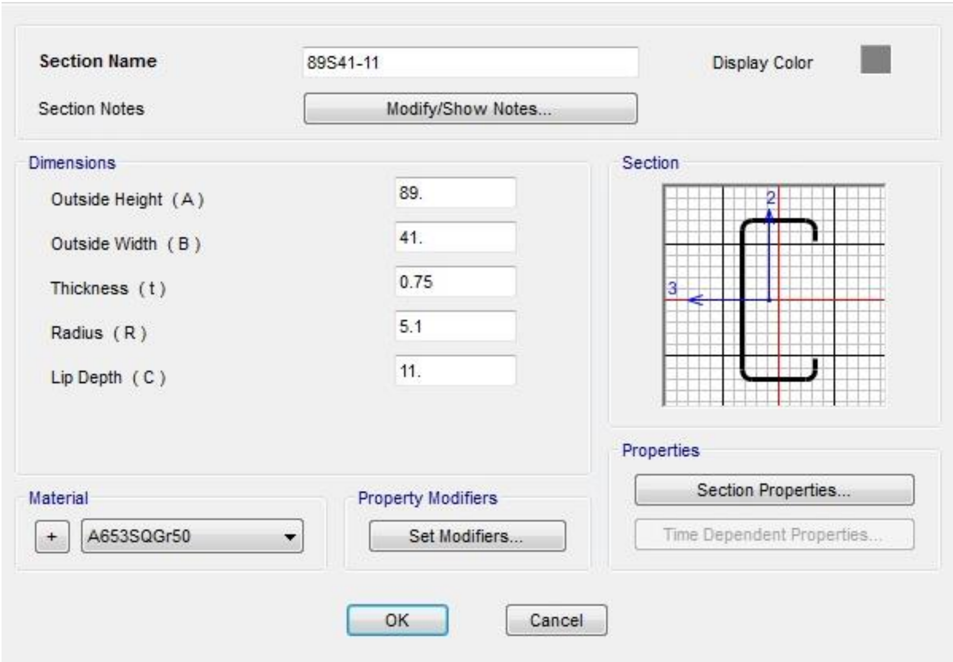


Fig 3.12: C section properties

Using the same C section in the analysis, a guard post room was made with the size of 6’x6’ and a height of 12’. There was a window of size 3’x4’ on one side and a door of size 3’x7’ on the other side to make it a typical room for guards that is used in Pakistan. The C section spacing on the walls was kept at 2’ c/c and the horizontal spacing of the members was kept at 4’ c/c. This is the maximum spacing that is allowed in C section cold formed construction and was used because the guard post has a small span and is just one storey high.

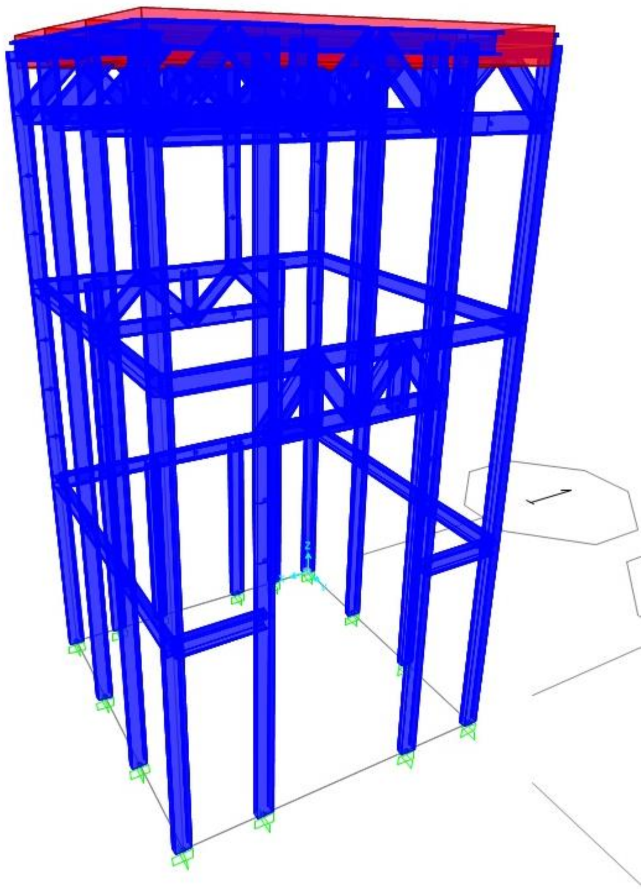


Fig 3.13: ETABS 3D Model Extruded

The load cases given to the guard post are as follows:

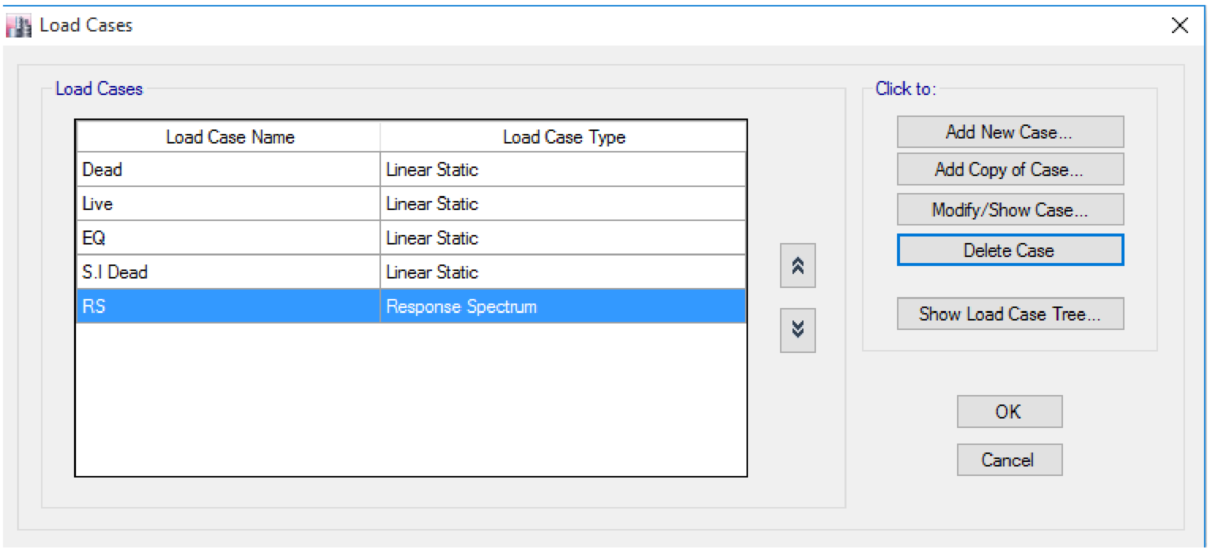


Fig 3.14: Load Cases used in ETABS Analysis

A non-linear analysis was then done to compare two guard posts of exactly same size with similar loading patterns given to both. In one guard post the sections were given the properties from the stress-strain curves of the compression tests from the sample with foam concrete and the other one took the results from the sample without any infill. This was then the comparison of a guard post with and without the use of foam concrete.

In order to model the foam concrete within the walls as infill a simple technique was used: diagonal struts were used of the same C section. This is a way to model the infill of a wall in ETABS used commonly by designers and researchers alike. The following figure shows the comparison of both the systems:

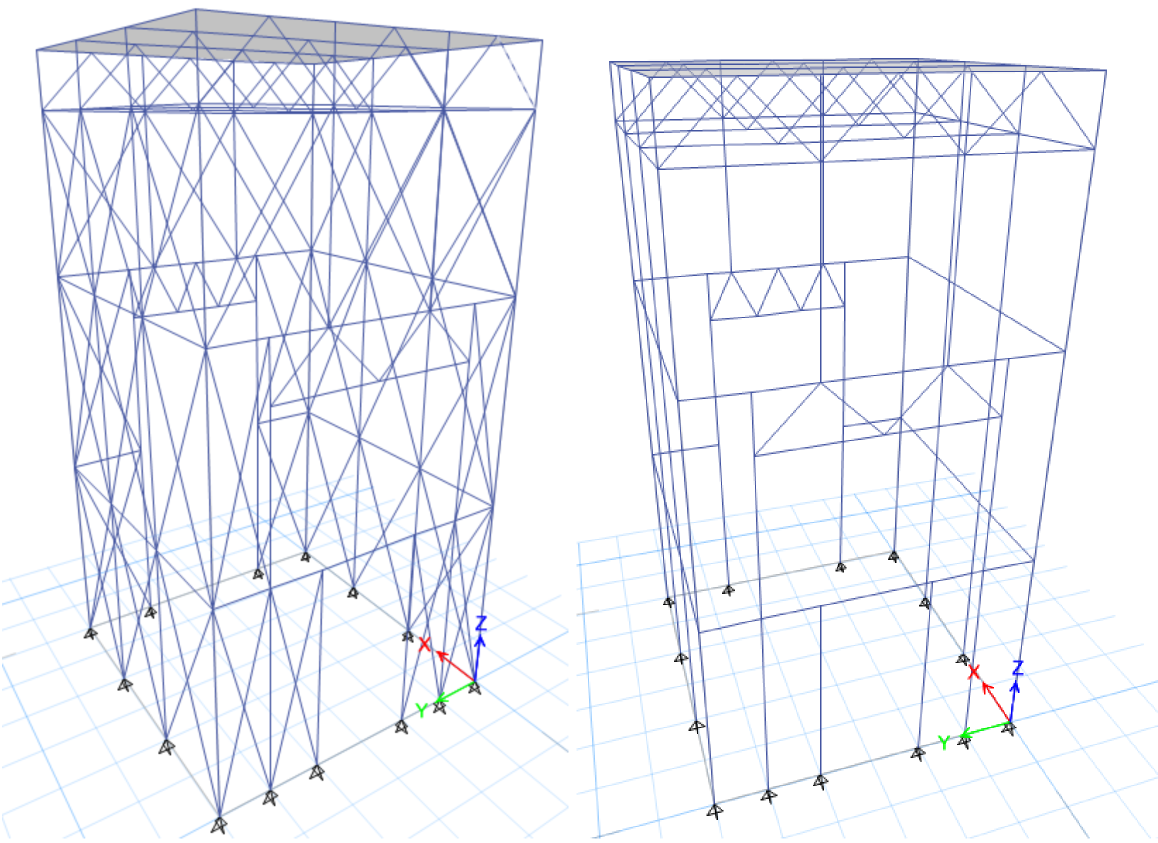
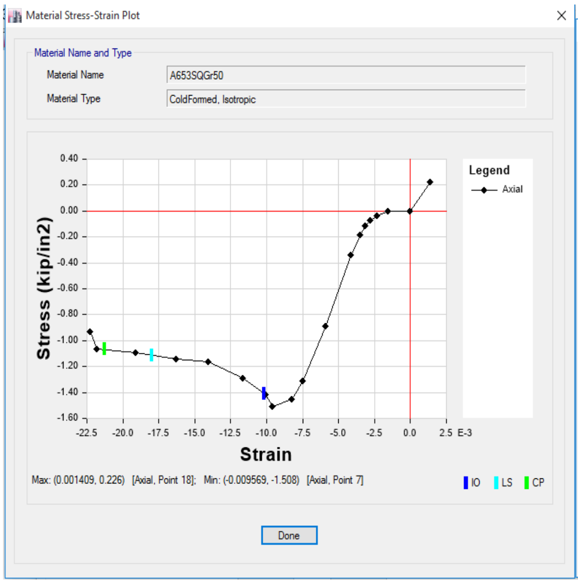


Fig 3.15: Comparison of guard posts with (left) and without infill (right)

The material properties were given to both materials in the non-linear analysis by manually giving values to a custom made stress strain curve. The values were taken directly from the stress-strain curves of the compression tests results. The following figures show the custom made stress strain curve of the C section that was made in the ETABS software. A portion (one seventh) of the compression was also taken to the tension side to assume a small tensile behaviour.



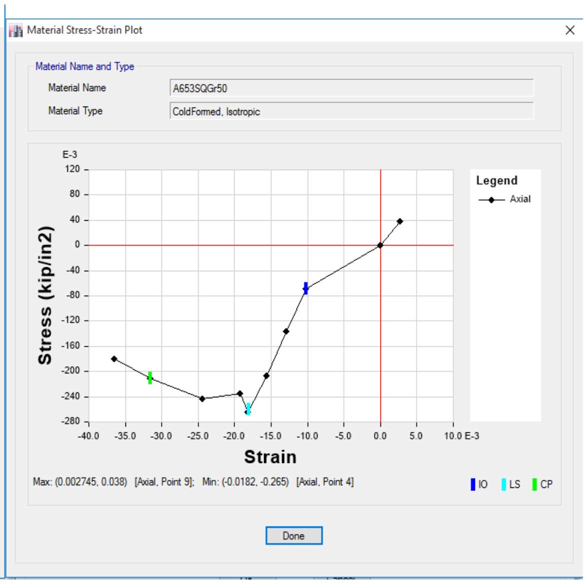


Fig 3.16: Comparison of stress strain plots of the material with (left) and without infill (right)

CHAPTER 4: RESULTS AND DISCUSSION

The main test done in this research was the compressive test because the tensile capacity of foam concrete is low and our main concern is to utilize the compressive strength of foam concrete within the cold formed steel structure.

S No.	Formulation ID	Density (kg/m^3)	Comp. Strength (psi)
1	2-3-0.5	1415	763
2	2-3-0.6	1380	721
3	2-3-0.7	1311	693
4	1-1-0.5	1530	1280
5	1-1-0.6	1505	1205
6	1-1-0.7	1460	1186

Table 4.1: Results of Compressive Strength tests

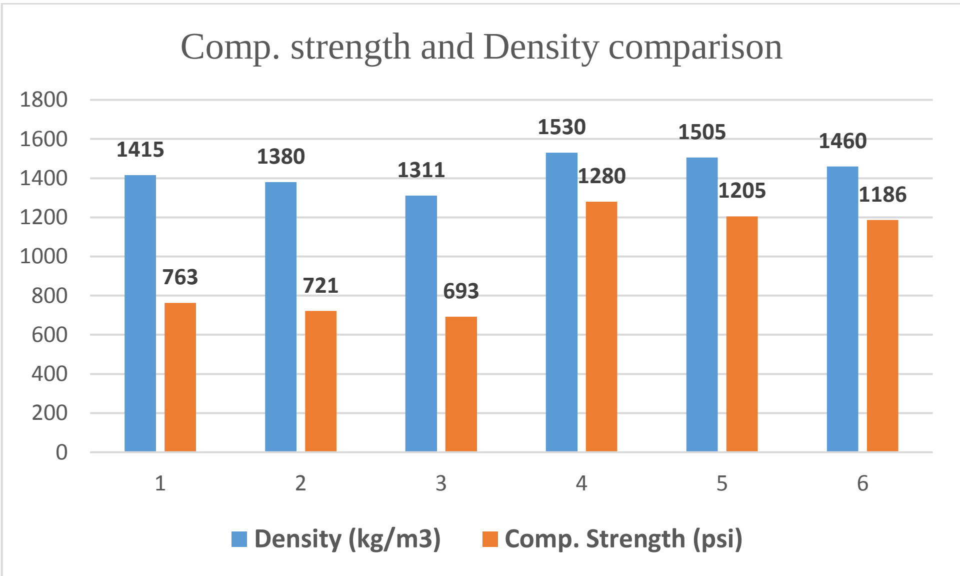


Fig 4.1: Comparison of strength and density of foam concrete samples

The compressive strength results along with the densities of the samples are shown in the figure above. The results were consistent with the assumption that with increase in the density of the samples, the compressive strength will also increase. After assessing the results, mix # 4 was selected as the mix to work with because it had the highest strength and a suitable density. This mix was then taken further for more testing of the heat transfer properties and the usage of foam concrete in cold formed steel construction.

The results of ETABS analysis were taken in terms of maximum story displacement to compare both the samples. The geometry and the loading were kept the same to see the results and compare them. The following figure shows the maximum story displacement in different loading conditions:

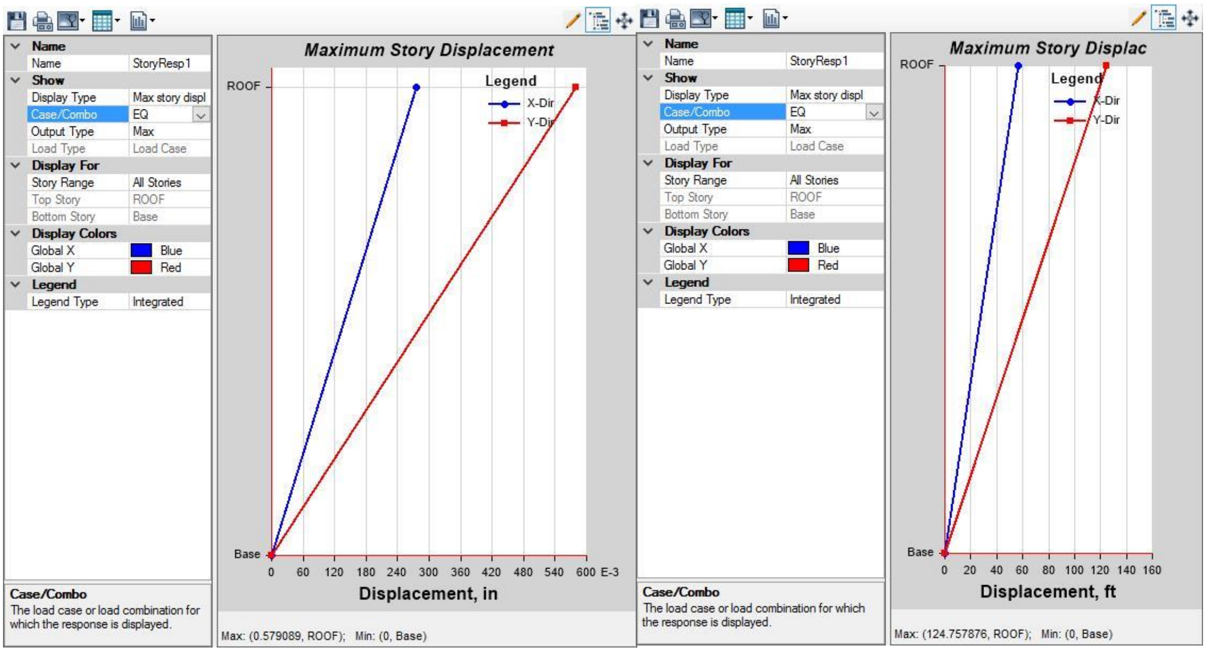


Fig 4.2: Comparison of story displacement under EQ loading

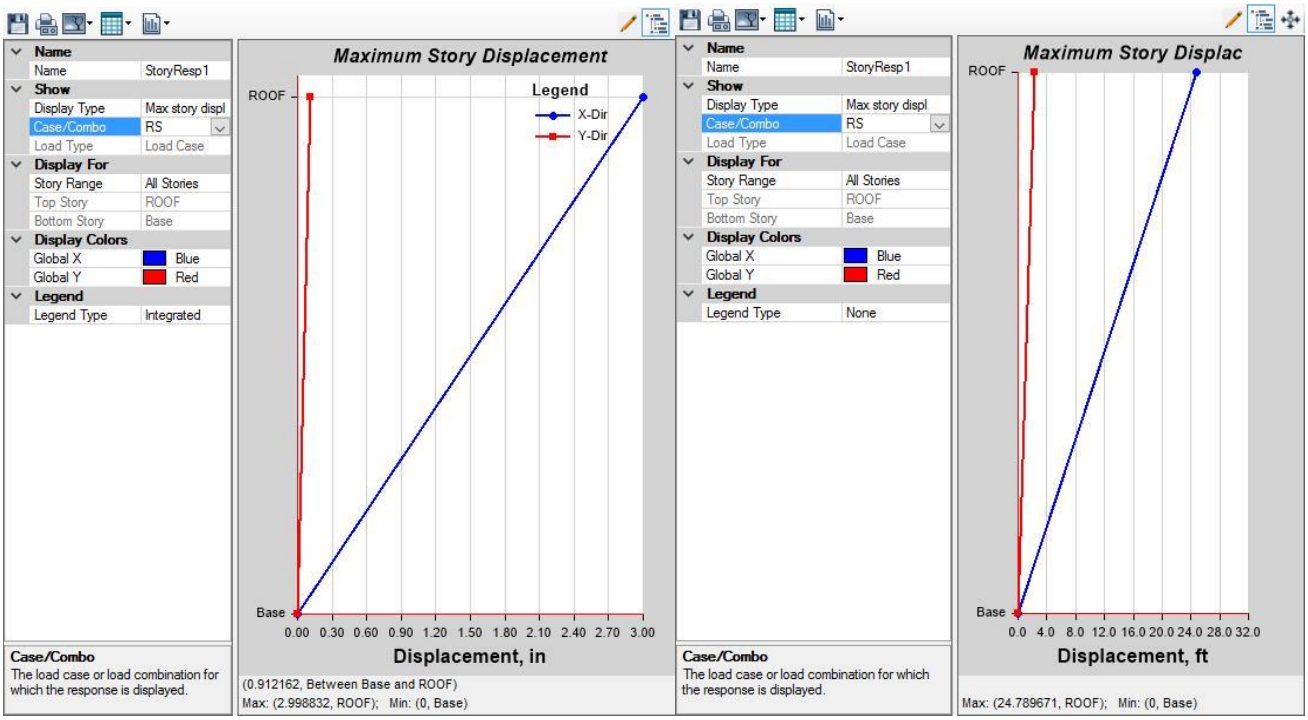


Fig 4.3: Comparison of story displacement under RS loading

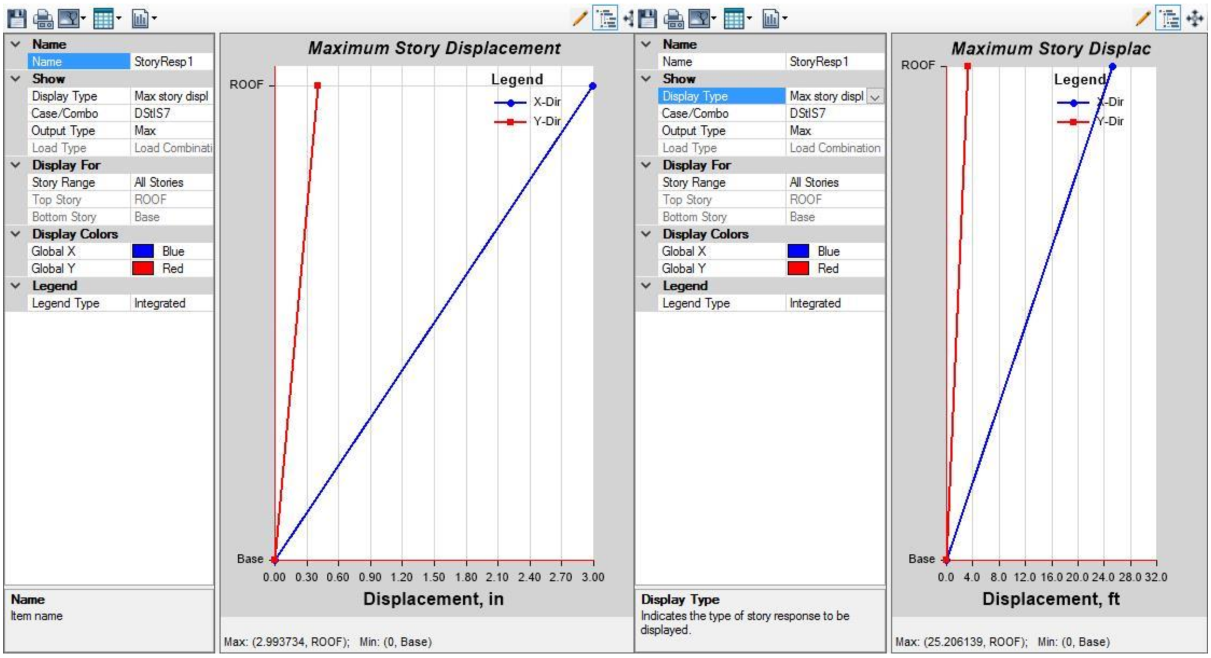


Fig 4.4: Comparison of story displacement under DStS7 loading

Overall the results from different load cases suggest that the guard post with the infill is much better structurally as compared to the guard post without the infill. The following table gives the values of displacement in the x direction in different load cases with and without the infill:

Loading Case	Max Story Displacement (in) with infill	Max Story Displacement (in) without infill
Earthquake	290	720
Response Spectrum	0.15	288
DStS7	0.51	288

Table 4.2: Displacements on different load cases

The results of the ETABS analysis clearly show a huge difference in the maximum story displacement. In the cases with infill, the maximum story displacement is far less when compared to the case without any infill. The cases without infill have completely failed under the loading conditions selected and are not fit for usage anymore. This analysis show a comparative result which shows the difference of using the infill and clearly suggest that the usage of infill brings about a great increase in the stiffness of the system. These results reiterate the results of the laboratory reports which a marked difference in the strength of the samples in both cases: with and without infill. To conclude it can be said that the usage of infill with light weight foam concrete does create a composite behaviour which can be used to strengthen the buildings of cold formed steel construction.

CHAPER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The main conclusions from this study are explained in a summarized point form below:

i) Making foam concrete is easy: There is a misconception in Pakistan that foam concrete requires a lot of skilled labour, expert engineers and specialized equipment. However, this is not the case. It is very easy to make and quite affordable in terms of the raw materials needed and the machinery is not that expensive either. In extreme circumstances, it can also be made without the machine as in this research with manual stirring.

ii) Foam concrete has a wide range of applications: There is a huge range of applications in which foam concrete can be used. Some of the examples are filling the sunken portions of washrooms in buildings because foam concrete engulfs and encapsulates all the plumbing and due to low water absorption it also seals the system, that too, without any compaction equipment. Similarly it can be used to strength weak soil, to fill the side of retaining walls, and even as a subgrade layer under road networks. There are so many applications in which foam concrete can be used and since it is so easy to manufacture it should be used in all such applications.

iii) In the special case of cold formed steel construction it is feasible to use foam concrete as it does not interfere with the main purpose of the cold formed steel construction which is to be light. In fact it eliminates the main problem associated with cold formed steel construction which is head transfer through the walls. As it is a good insulator it can seal the walls from heat and even given them a solid feel which is good for serviceability as well.

5.2. Recommendations

The recommendations are summarized below:

i) In a study done by Aswathy (2017) it is concluded that the density of foam concrete can vary with the size of the sample. This aspect is not examined in this study due the same size specimens. This aspect can have a profound effect on the results of the experiments and should be studied to confirm the results. (Aswathy, 2017).

ii) A foam generator machine should be installed in the NUST laboratory for future students to conduct experiments on foam concrete because it being used worldwide these days and it also has an environmentally friendly effect in construction.

iii) Research on the use of foam concrete in road construction should be done as well because in the literature review a lot of practical examples are given on this subject.

iv) Detailed study on the foam concrete should be done with scanning electron microscope (SEM) images, shrinkage studies, and freeze thaw cycle analysis in order to fully understand its behaviour and use it in a proper way.

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