Feasibility Study of Bendable Concrete in Building Infrastructures in Pakistan

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ABSTRACT

This report presents a feasibility assessment on the use of bendable concrete, commonly known as Engineered Cementitious Composite (ECC), in Pakistan's construction industry. The study addresses traditional concrete's significant challenges, such as durability and environmental impact. A complete life cycle analysis (LCA) is used to examine and compare the economic and environmental variables related with bendable concrete and standard concrete.

The study quantifies the environmental impact of both bendable and conventional concrete, including energy consumption, greenhouse gas emissions, water usage, and trash generation. The emphasis is on how bendable concrete contributes to a more environmentally friendly construction industry by reducing material use, waste generation, and associated emissions.

The results of this feasibility study offer important new insights into the performance of bendable concrete economically and environmentally in the context of Pakistan. The adoption of sustainable construction methods is made easier by these insights, which are used to guide the decision-making of engineers and construction experts. The study also advances the body of knowledge and encourages further study and development of environmentally friendly building materials in Pakistan. The study provides a basis for expanding sustainable building methods nationwide and promoting the usage of bendable concrete.

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1. INTRODUCTION

1.1. Study Background

The need to address issues facing the construction industry, particularly those relating to the durability and environmental impact of conventional concrete, is the reason behind this feasibility study on bendable concrete in Pakistan. Traditional concrete frequently cracks, which compromises the strength and durability of structures. Conventional concrete manufacture and use also considerably increase the use of resources and greenhouse gas emissions.

In recent years, bendable concrete, or Engineered Cementitious Composite (ECC), has emerged as a potential solution to these challenges. ECC exhibits enhanced flexibility and ductility compared to conventional concrete, allowing it to withstand deformations without developing cracks. This property opens possibilities for improved structural performance and increased durability.

The study's objective is to evaluate the feasibility of implementing bendable concrete in Pakistan, comparing it with conventional concrete through a comprehensive life cycle analysis (LCA) that considers both economic and environmental factors. The LCA will provide a holistic assessment of the entire life cycle of both materials, starting from raw material extraction to construction, service life, and eventual disposal or recycling.

By conducting this study, researchers aim to understand the economic implications of using bendable concrete, including material costs, labor requirements, transportation expenses, and maintenance costs. This analysis will also consider potential cost savings resulting from reduced repairs and maintenance over the life cycle of structures built with bendable concrete. Moreover, the study will examine the availability and affordability of bendable concrete materials in the local market.

Furthermore, the study will address the environmental impact of both bendable concrete and conventional concrete. It will quantify factors such as energy consumption, greenhouse gas emissions, water usage, and waste generation associated with each material. Special attention will be given to the reduction in material consumption, waste generation, and associated emissions offered by bendable concrete, as it has the potential to contribute to a more sustainable construction industry.

The results of this feasibility study will provide valuable insights into the economic and environmental performance of bendable concrete compared to conventional concrete in the specific context of Pakistan. These findings will help inform decision-making processes for policymakers, engineers, and construction professionals regarding the adoption of more sustainable construction practices in the country.

1.2. Research Significance

The research on the feasibility of implementing engineered cementitious composites (ECC) in Pakistan's construction industry holds significant significance in several areas.

Firstly, the study's findings will contribute to the body of knowledge regarding the use of ECC in a seismic-prone country like Pakistan. By evaluating the technical feasibility of ECC for seismic retrofitting, bridge decks, and durable pavements, the research will provide valuable insights into the performance and structural behavior of ECC under specific loading conditions. This information can help engineers and architects make informed decisions about using ECC to enhance the resilience and safety of structures in high seismic activity regions.

Secondly, the economic analysis conducted as part of the feasibility study will provide important insights into the cost implications of adopting ECC in the construction industry. Understanding the material costs, labor requirements, and potential long-term cost savings associated with ECC can assist policymakers and investors in assessing the economic viability of using this innovative material. By identifying any potential barriers or challenges related to cost, the research can help develop strategies to promote the widespread adoption of ECC by addressing affordability concerns and exploring ways to reduce overall construction costs.

The environmental assessment aspect of the study is equally significant. Evaluating the environmental benefits of ECC, such as reduced carbon emissions and the potential for using locally sourced materials, aligns with the global push for sustainable construction practices. The research can provide evidence of ECC's positive environmental impact, thereby supporting efforts to reduce the carbon footprint of the construction industry and promote the use of locally available resources. This aspect of the study has broader implications for sustainable development in Pakistan and can contribute to the country's goals of achieving carbon neutrality and environmental stewardship.

Furthermore, the research's significance extends to the managerial aspect of ECC implementation. By highlighting the social and organizational considerations associated with introducing ECC, such as community acceptance, local labor utilization, and skill development opportunities, the study can inform decision-making processes and promote effective project management practices. It can provide valuable insights into the potential challenges and opportunities involved in adopting ECC, enabling stakeholders to address social and organizational aspects effectively.

Overall, the research's significance lies in its potential to drive positive change in the construction industry in Pakistan. By providing a comprehensive analysis of ECC's technical, economic, and environmental feasibility, the study can support evidence-based decision making, facilitate the adoption of sustainable and resilient infrastructure solutions, and contribute to the overall development and well-being of Pakistan's built environment.

1.3. Problem Statement

Pakistan's geographical location exposes it to significant seismic activity, ranking it as the 6th most vulnerable country to earthquakes. This vulnerability highlights the urgent need to transfer the country's society to more resilient infrastructure that can withstand seismic events. However, the challenge lies in the limited resources and funds available in a developing country like Pakistan. According to a report by Oxford Economics, Pakistan faces a substantial infrastructure investment gap of approximately $124 billion.

Given these circumstances, it becomes crucial to develop infrastructure that is both economically viable and sustainable. After conducting extensive research, bendable concrete has emerged as a potential solution. Bendable concrete belongs to a special class of Fiber Reinforced Concrete (FRC) that exhibits mechanical properties similar to metal. It is known for its ductility, lightweight nature, cost-effectiveness, and overall durability.

While significant work has been done on the structural aspects of bendable concrete, there is a lack of comprehensive studies focusing on the managerial aspect of this technology. This gap necessitates a thorough feasibility study on the implementation of bendable concrete in Pakistan, encompassing its social, economic, and environmental dimensions.

Such a feasibility study would explore the social implications of introducing bendable concrete, considering aspects such as community acceptance, local labor utilization, and skill development opportunities. It would also examine the economic viability of implementing bendable concrete, analyzing factors like material costs, labor requirements, construction timelines, and long-term maintenance expenses. The study would address the affordability and accessibility of bendable concrete materials within the local market, considering Pakistan's limited resources and financial constraints.

Additionally, the feasibility study would delve into the environmental impact of bendable concrete, assessing its potential to reduce carbon emissions, minimize resource consumption, and promote sustainable construction practices. It would analyze the life cycle of bendable concrete, evaluating energy consumption, greenhouse gas emissions, water usage, and waste generation throughout the entire construction process and service life of structures

1.4. Research Objectives

The research objectives of the feasibility study on bendable concrete in Pakistan are as follows:

- Assess the feasibility of implementing bendable concrete (Engineered Cementitious Composite or ECC) as an alternative to conventional concrete in the construction industry in Pakistan.
- Conduct a comprehensive life cycle analysis (LCA) to evaluate and compare the economic and environmental factors associated with the use of bendable concrete and conventional concrete.
- Understand the economic implications of using bendable concrete, including material costs, labor requirements, transportation expenses, and maintenance costs.
- Evaluate potential cost savings resulting from reduced repairs and maintenance over the life cycle of structures built with bendable concrete.
- Examine the availability and affordability of bendable concrete materials in the local market in Pakistan.
- Quantify and compare the environmental impact of both bendable concrete and conventional concrete, including energy consumption, greenhouse gas emissions, water usage, and waste generation.
- Analyze the reduction in material consumption, waste generation, and associated emissions offered by bendable concrete, contributing to a more sustainable construction industry.
- Provide valuable insights into the economic and environmental performance of bendable concrete in the specific context of Pakistan.
- Inform decision-making processes for policymakers, engineers, and construction professionals regarding the adoption of more sustainable construction practices in Pakistan.

- Generate knowledge and data that can support future research and development efforts in the field of sustainable construction materials in Pakistan.

1.5. Summary

The feasibility study on bendable concrete in Pakistan aims to address the challenges faced by the construction industry, particularly regarding the durability and environmental impact of conventional concrete. Traditional concrete often cracks, compromising the strength and longevity of structures, while also contributing significantly to resource consumption and greenhouse gas emissions.

Bendable concrete, also known as Engineered Cementitious Composite (ECC), has emerged as a potential solution to these issues. It exhibits enhanced flexibility and ductility compared to conventional concrete, allowing it to withstand deformations without developing cracks. This property offers improved structural performance and increased durability.

The study's objective is to evaluate the feasibility of implementing bendable concrete in Pakistan by conducting a comprehensive life cycle analysis (LCA). This analysis considers both economic and environmental factors and assesses the entire life cycle of both bendable concrete and conventional concrete, from raw material extraction to construction, service life, and disposal or recycling.

Researchers aim to understand the economic implications of using bendable concrete, including material costs, labor requirements, transportation expenses, and maintenance costs. They will also examine potential cost savings resulting from reduced repairs and maintenance over the life cycle of structures built with bendable concrete. The availability and affordability of bendable concrete materials in the local market will be evaluated.

Furthermore, the study will address the environmental impact of both bendable concrete and conventional concrete. Factors such as energy consumption, greenhouse gas emissions, water usage, and waste generation will be quantified. Special attention will be given to the reduction in material consumption, waste generation, and associated emissions offered by bendable concrete, as it has the potential to contribute to a more sustainable construction industry.

The findings of this feasibility study will provide valuable insights into the economic and environmental performance of bendable concrete compared to conventional concrete in the specific context of Pakistan. These insights will inform decision-making processes for policymakers, engineers, and construction professionals regarding the adoption of more sustainable construction practices in the country. Additionally, the study will contribute to the knowledge base and support future research and development efforts in the field of sustainable construction materials in Pakistan.

CHAPTER-2

2. LITERATURE REVIEW

2.1. What is Bendable Concrete (ECC)?

Engineered Cementitious Composite (ECC), often known as bendable concrete, is a revolutionary building material created by Professor Victor Li in the 1990s. It has extraordinary tensile strength that surpasses that of regular concrete. Bendable concrete is becoming more well known for its adaptability and toughness after being successfully used in infrastructure projects across China, Japan, and the USA.

Engineered Cementitious Composite (ECC), a kind of Fiber Reinforced Concrete (FRC), has mechanical qualities like those of metal. It differs from conventional concrete, which is prone to breaking under strain, in that it has an outstanding capacity to absorb and distribute tensile stresses.

Numerous construction projects, such as bridges, roads, and buildings, use bendable concrete. Its durability in challenging settings, capacity for self-healing, and enhanced corrosion resistance all contribute to its lifespan and lower need for maintenance.

The growing use of flexible concrete reflects a trend towards robust and sustainable building techniques. The qualities of it are always being improved, and production methods are being optimized with the goal of enabling safer, more resilient, and ecologically friendly infrastructure around the world.

2.2. Difference between ECC and Conventional Concrete?

ECC and conventional concrete can be differentiated based on the following factors.

2.2.1. Raw materials

2.2.2. Processing

2.2.3. Properties

2.2.1. Raw materials

The major difference between ECC and conventional concrete is the raw materials that are used in the production of ECC and conventional concrete. The use of different raw materials is the key factor that gives ECC its unique properties.

When we look at the raw materials used in Conventional concrete, it is a mixture of Cement, water, sand, and coarse aggregate while ECC is a mixture of Cement, Water, Sand, High Range Water Reducers, Fly ash and PVA Fibers. It must be noted that no coarse aggregate is used in the production of ECC.

These raw materials are processed in a very specific pre-defined direction to produce optimum results.

The difference is shown in the table below.

Conventional System	**ECC System**
Cement	Cement
Sand	Sand
Gravel	Fly Ash
Water	HRWR
-	PVA Fiber
-	Water

2.2.2. Processing

Unlike conventional concrete ECC can only be produced in shear mixers only. For large scale production large transit mixing truck is the most suitable option.

For large scale batching and mixing of ECC using transit mixer trucks, first dry sand, water and high range water reducers are added and mixed followed by the addition of fly ash and cement.

After achieving homogeneity, fibres are added and mixed for further dispersion. It must be ensured that the fibres are dispersed thoroughly to obtain desired results.

This sequence was devised after multiple trials and tests and ECC is supposed to be produce according to these directions. This optimised sequence not only reduced the mixing time to match the requirements of commercial concrete batching plants but also ensured homogeneity of the ECC matrix resulting in optimised strength and durability.

Mixing time for each step:

- Dry sand, water, and water-reducing admixture: 1 to 2 minutes.
- Addition of other dry components (cement and fly ash) and complete mortar matrix mixing: Approximately 3 to 4 minutes or until homogenous and sufficiently fluid.
- Additional mixing time before fibre addition: 5 to 10 minutes to provide further agitation.
- Addition of fibers and complete ECC composite mixing: Additional 5 to 6 minutes or until fibers are well dispersed.
- Mixing of mortar matrix and fibres on-site: 5 minutes at high RPM for proper dispersion.

2.2.3. Properties

The used of unique raw materials and unique mixing sequence gives ECC very distinctive yet very amazing properties. Some of which are discussed below:

- **High Ductility:**

Unlike conventional concrete ECC is very ductile and can be molded into different shapes and forms as per the desired of the user. Moreover, it gives off a very neat and finished surface adding to the beauty of the structure.

- **Cost Effective:**

ECC is a cost-effective option since its life span is almost double then that of conventional concrete. The direct cost associated with ECC is although a bit higher when compared to conventional concrete but when the whole life cycle is considered, ECC is far more cost effective. ECC cuts the cost associated with coarse aggregate since there's no coarse aggregate used in it, its self-compacting properties allow it to settle without the need of any vibrator or labour work and most importantly since ECC has high tensile strength the amount of steel used in ECC structures is reduced by about 23% overall reducing the cost by 35% when compared to conventional system.

- **Light Weight:**

ECC is light weight since there's no coarse aggregate in it. The cross section of a structural member made up of ECC is way less then the cross section of the same structural member if developed using conventional concrete.

- **Greater Tensile Strength:**

The tensile strength of ECC is several hundred times greater than that of conventional concrete and hence can absorb more tensile stresses while producing less cracks. The fibres used in the production of ECC are responsible for this unique property. These fibres not only provide tensile strength but also act as a self-healing agent healing cracks and voids formed under stresses.

- **Earthquake Resistant**

ECC is earthquake resistant and produced very less damages under the influence of design base earthquake and service level earthquake. That is why its life span is greater than that of conventional concrete.

2.3. How is ECC is better than conventional concrete?

ECC is better than conventional concrete due to the following reasons:

- ECC offers a cost-effective alternative because of its many benefits.
- When compared to regular concrete, it has a much higher tensile strength.
- ECC may be easily molded into a variety of shapes and forms due to its ductility.
- ECC's final surface is much smoother and more attractive.
- ECC delivers a lifespan that is approximately twice as long as regular concrete.
- ECC has a smaller mass per unit volume and is lighter in weight because to the absence of coarse material.
- ECC performs better overall because of its excellent longevity and micro-level self-healing capabilities.
- Over time, less maintenance and repair may be needed due to its resilience to cracking and damage.
- ECC can therefore help infrastructure projects have reduced life cycle costs.

2.4. ECC Impact: Pakistan's Improvement

Pakistan, which is the sixth-most earthquake-vulnerable nation, confronts serious infrastructure problems because of the two design basis earthquakes and four service level earthquakes that occur per century. Pakistan faces constraints in terms of funding and resources for infrastructure development, nonetheless, as a developing country.

Engineered Cementitious Composite (ECC) stands out as the best solution in this situation for addressing Pakistan's requirement for durable and affordable infrastructure. ECC is highly adapted to the economic and social conditions of Pakistan since it provides a distinctive blend of affordability, resilience, and environmental friendliness.

ECC's outstanding qualities make it ideally suited to Pakistan's infrastructure objectives. It can endure seismic forces thanks to its greater tensile strength, which lowers the chance of infrastructure breakdowns during earthquakes. ECC's ductility makes it simple to shape and mold, which makes it easier to build intricate structures. ECC's self-healing powers and greater endurance also result in infrastructure that lasts longer and requires less maintenance.

Pakistan may gain a lot by incorporating ECC into infrastructure projects. Due to its robustness, ECC can lessen the disastrous effects of earthquakes, saving lives and limiting financial damages. ECC's cost-effectiveness gives an excellent way to deal with budgetary restrictions and maximize resource use. Furthermore, ECC's environmental friendliness supports sustainability goals and encourages greener building techniques.

2.5. Benefits of Feasibility Study of ECC

Engineered Cementitious Composite (ECC)'s economic and environmental effects in comparison to traditional concrete are thoroughly examined in the feasibility study for ECC. Although a lot of study has been done on the structural components of ECC, there is still a big knowledge vacuum when it comes to the management aspects and real-world implementation difficulties connected to ECC.

This study intends to provide light on the practical practicality of using ECC as an alternative to traditional concrete in Pakistan's construction sector. We can evaluate the viability of ECC adoption and identify its possible advantages in terms of cost-effectiveness and sustainability by performing a complete economic and environmental study.

This study will also offer insight on potential difficulties in the actual application of ECC in building practices. We can create strategies to promote the seamless integration of ECC technology in Pakistan's building sector by recognizing and addressing these problems.

This study will help to clarify the applicability of ECC and offer helpful suggestions for its effective implementation by conducting a thorough investigation of its managerial, economic, and environmental aspects. In the end, this study will assess the viability of ECC and raise awareness of the potential and obstacles related with its adoption in Pakistan's construction industry.

2.6. ECC Feasibility Assessment

A life cycle assessment (LCA) will be performed on a case study building to determine the viability of Engineered Cementitious Composite (ECC) in Pakistan. The LCA will follow the ISO 14040 standard, a well-known procedure for thorough environmental study.

The goal of this study is to evaluate the environmental effect of ECC over the course of its full life cycle, including considerations for the extraction of raw materials, production, construction, use, and end-of-life issues. This study does this by using the ISO 14040 technique. The LCA data will give important insights into how well ECC performs in terms of sustainability when compared to traditional building materials.

2.7. ISO 14040

The worldwide Organisation for Standardisation (ISO) is a well-known worldwide standard-setting organisation that creates predetermined criteria to evaluate the trustworthiness of companies and goods in domestic and international marketplaces. To conduct the life cycle assessment (LCA) of Engineered Cementitious Composite (ECC) in this study, a particular approach called ISO 14040 is being used.

Four essential phases are included in the ISO 14040 LCA approach to guarantee an exhaustive examination.

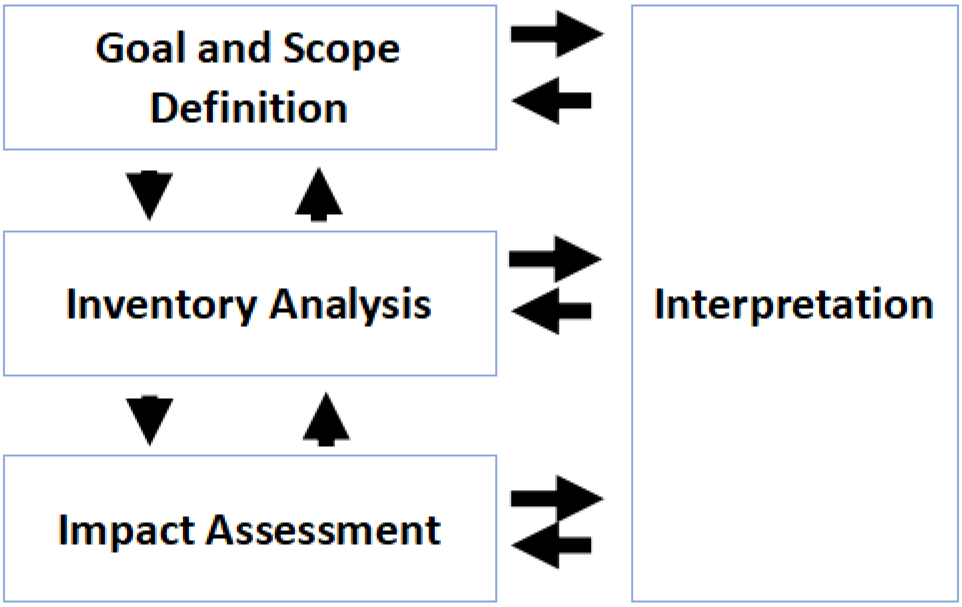
Setting the objective and parameters of the evaluation is the first stage. This entails stating the study's objectives, the scope of the research, and the precise environmental factors that will be assessed. The LCA can concentrate on pertinent elements and provide significant outcomes by setting a defined aim and scope.

The examination of the life cycle inventory is the second phase. This calls for compiling information on the materials utilised, emissions produced, and energy consumed during the life cycle of ECC. It includes gathering data on the gathering of raw materials, manufacturing procedures, transportation, building, consumption, and disposal or recycling.

The third step which is life cycle impact assessment comes after the examination of the life cycle inventory. Here, the gathered information is assessed to determine the environmental effects connected to ECC across several impact categories. These categories can include acidification, loss of resources, and climate change, among others. To understand the overall environmental performance of ECC, the impacts are measured and assessed.

The fourth and last phase, interpretation, is carried out concurrently with the first three. The interpretation entails examining and effectively communicating the LCA's findings. It could involve highlighting important findings, contrasting the environmental performance of ECC with that of conventional materials, and formulating recommendations considering the assessment's findings.

The relationship between these steps is shown in the diagram below:



2.8. Previous studies on the LCA of ECC

The use of life cycle assessment (LCA) in infrastructure construction is essential for assessing and reducing the environmental effects of various systems and components. It's conceivable that little study has been done on the LCA of building infrastructure components made of ECC designed expansion joints and composite link slabs, even though these materials have been extensively studied in other settings, such as transportation infrastructure.

The dearth of study on the LCA of ECC produced building infrastructure points to a potential area for future investigation. Professionals in the sector may learn crucial information on the environmental effects of these cutting-edge materials when used in infrastructure-building by filling this research gap.

A thorough knowledge of the environmental advantages and trade-offs will also be provided by performing comparative LCA studies between ECC and conventional materials or alternative solutions. Such comparisons can support sustainable practices in the building sector and help spot areas for development.

2.9. Phases involved in the Life Cycle Assessment

Raw Material Stage: The raw material stage in the optimization system involves the production of major concrete components. This includes the extraction, processing, and manufacturing of materials such as cement, aggregate (both coarse and fine), and water. The CO2 emissions associated with the production of these materials are considered. Additionally, other supplementary materials like blast furnace slag, fly ash, and chemical admixtures may also be considered, utilizing data from relevant databases. The goal is to assess the environmental impact and cost implications of the raw materials used in concrete production.

Construction Stage: The operations involved in utilising concrete to erect buildings or other infrastructure are referred to as the construction stage. It entails procedures including setting up formwork, pouring concrete, curing it, and finishing it. Although it isn't stated directly in the material given, the building phase is an important aspect of the whole life cycle of concrete. The optimisation system may consider elements like building methods, equipment uses, and on-site energy use at this point. The system may offer building techniques that reduce CO2 emissions and expenses while also assuring sustainable and effective construction processes by assessing these parameters.

Building Use Stage: Building Use Stage: During this phase, the optimisation system computes and assesses the energy and CO2 emissions incurred by the concrete building throughout the course of its operational life. It focuses on evaluating the building's energy efficiency and environmental effect when it is in operation.

End-of-Life Stage: The optimisation system also considers the concrete building's end-of-life stage, which entails assessing the environmental effect and sustainability factors associated to the structure's disposal or recycling. By properly demolishing, recycling, or reusing the building materials, the method might potentially reduce CO2 emissions and minimise trash output.

2.10. Carbon Footprint Evaluation

Life cycle assessment (LCA), which considers several stages of a product's life cycle, such as raw material extraction, production, transportation, usage, and end-of-life disposal or recycling, is frequently conducted as part of the evaluation of the carbon footprint. Environmental consequences, including greenhouse gas emissions like CO2, are quantified through LCAs.

The paper refers to research on cement and concrete done in 2006 by the Athena Institute, which used an LCA method to compare the global warming and embodied primary energy estimates for concrete and asphalt pavement constructions. This analysis would have considered energy consumption and related emissions during the pavements' lifetime.

It is essential to take emissions from combustion and calcination operations during cement manufacture into consideration when calculating the carbon footprint. The primary focus on lowering CO2 emissions in cement manufacturing is on increasing energy effectiveness.

CHAPTER-3

3. Methodology

Project completion has taken place in 3 stages.

1. **Availability of Raw Materials**

   It was done to know if the raw materials required to produce ECC are available in Pakistan or not.

2. **Life Cycle Assessment**

   It was done to identify the scope of our study and find if ECC is more environmentally friendly than Conventional Concrete.

3. **Life Cycle Cost Analysis**

   It was done to know if ECC would be more economical to be used in building infrastructures than Conventional Concrete.

3.1. Availability of Raw Materials

The raw materials to produce Conventional Concrete are generally available in Pakistan but our main concern was to find if the raw materials required to produce ECC are available in Pakistan. The main constitutes of ECC are Cement, Sand, Water, Fly Ash, PVA fiber and High Range Water Reducer.

Cement, Sand and water are like the conventional concrete, hence available in Pakistan. To check availability of other materials, we contacted different companies in Pakistan and It was found that Fly Ash and High Range Water Reducers are normally available in Pakistan, but PVA fibers are to be exported from other countries. PP and PE Fibers can be used as an alternative to PVA fiber but for our studies, we exported the PVA fiber and based our cost on the prices included the custom charges.

3.2. Life Cycle Assessment

There was a need of environmental assessment of the ECC during its whole life cycle which was done by doing Life Cycle Assessment using the method ISO 14040.

3.2.1. System Definition

In this study, the LCA of ECC building is based on the Ground + Seven Storied mid-rise case study building located in Islamabad, Pakistan. The building has dimensions of 15.24m by 45.72m with a total of 6 bays in longer direction and 2 bays in shorter direction. Figure 1 shows grey structure of the case study building while Table 1 shows the details of case study structure. For a comparative Study, the building is designed with both conventional Reinforced Cement Concrete (RCC) and Reinforced M45 Engineered Cementitious Composites (R/ECC) Mix. Quantities of M45 mix are shown in table 2.

Table 1. Details of the case study structure

Details	**Dimensions**
Number of Stories	G+7
Floor dimensions	15.24m x 45.72m
Functionality	Commercial
typical story height	12ft
Location	Islamabad, Pakistan
Distance from concrete batching plant	10 Km

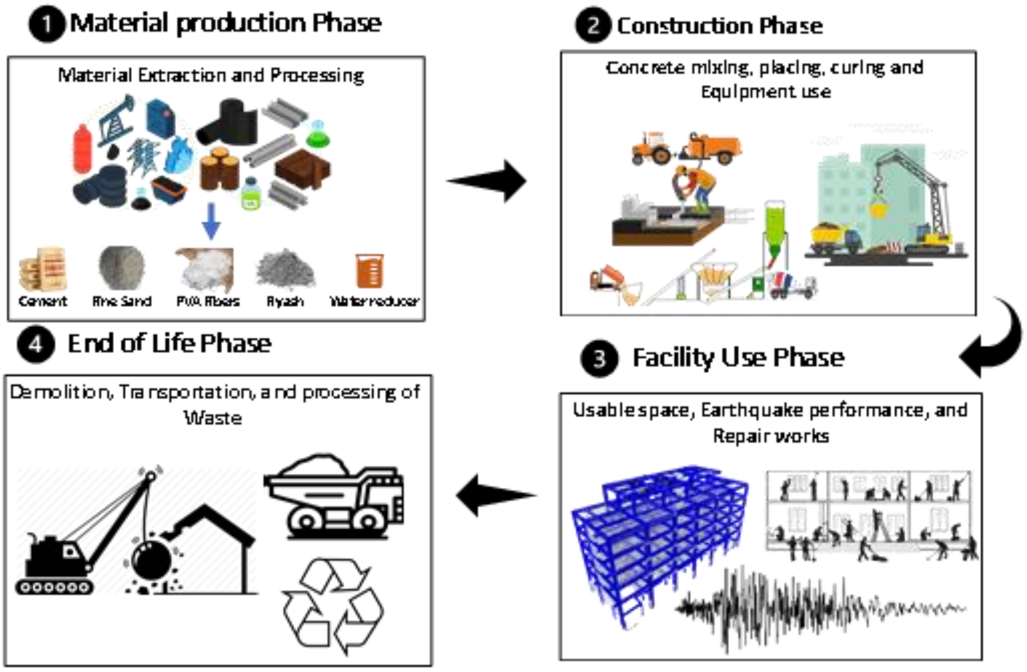
Table 2. Mix quantities of M45 ECC.

Mix	**Cement (kg/m^3)**	**Fly ash (kg/m^3)**	**Water (kg/m^3)**	**Sand (kg/m^3)**	**HRWR (kg/m^3)**	**PVA fibers (kg/m^3)**
M45	571	685	332	456	6.8	26

The design of conventional concrete is performed using ACI 318-19 as per Building Code of Pakistan. Where else, the R/ECC design was performed following JSCE Guidelines, since ACI 318-19 does not provide design assistance for ECC. Design results show that there is a 23% reduction in the steel reinforcement and around 27% reduction in the member’s cross-sections. These reductions are attributed to the overall reduction in weight of the structure, improved tensile capacity, and the almost negligible need for shear reinforcement. In this LCA model, building service life of 50 years is assumed for conventional concrete as per designed code and 100 years for the M45 mix R/ECC building. The double service life of R/ECC structure is analyzed by Lepech [] and suggested by professional who worked on its other applications [Li et al. 2003].

So, the total observation period for this study is taken as 100 years which is divided into four different phases of life cycle. Firstly, the material production phase involves the process of extraction and converting raw materials into usable. Second is the construction phase, that includes all the construction processes i.e., mixing, placing, curing. The use phase covers the usable space of building, earthquake performance during 100 years of service life, and repair and maintenance. The final phase of a building's life cycle involves the demolition of structure, transportation of the waste to recycling or landfill facilities, and processing those materials. Figure 2 illustrates the various life cycle phases of a building. Material production involves the process of extraction and converting raw materials into usable.

Figure 2. Life cycle phases of a building



Earthquake Impact

Exceptional ductility and high energy absorption makes ECC an excellent earthquake resistant material which must be incorporated in life cycle study. It is important to incorporate the additional cost of repair works during probable earthquakes of different intensities on the assumed site as per its seismic hazard probability of the site. The building is expected to experience three Service Level Earthquakes (SLE) and one Designed Based Earthquake (DBE). The damages to two buildings during an earthquake event were assessed using Non-Linear Time History Analysis, considering both conventional concrete and ECC material properties. The results indicate that the R/ECC structure exhibited very negligible plastic hinges, indicating less severe damage, owing to its superior ductility. Figures 3 and 4 show the damages in the form of Plastic hinges formed during SLE and DBE earthquake in RCC and R/ECC Structure.

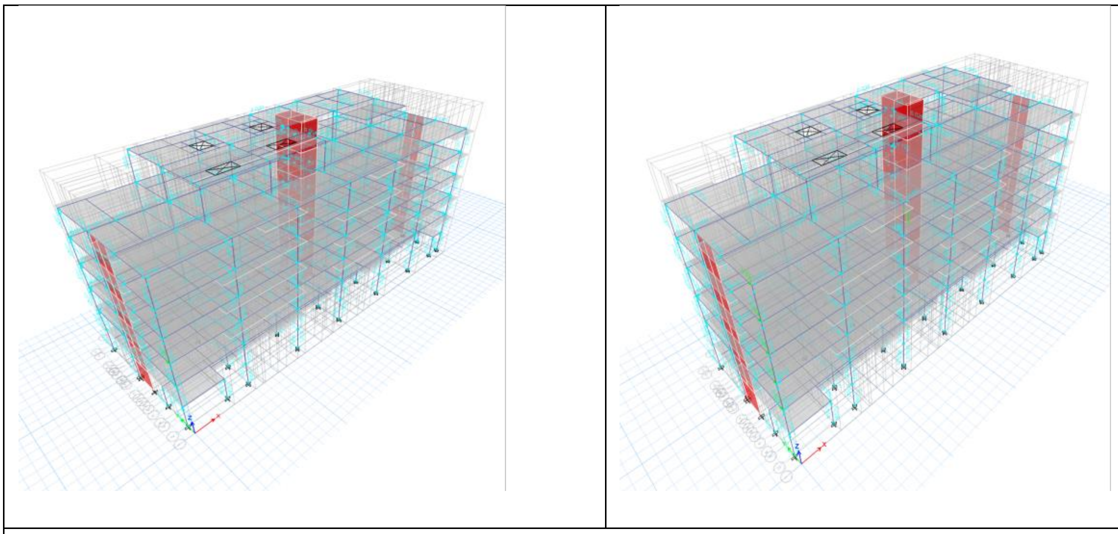


Figure 3. The hinge states (severe damages) of NLTHA at SLE on (a) RCC (b) ECC structures.

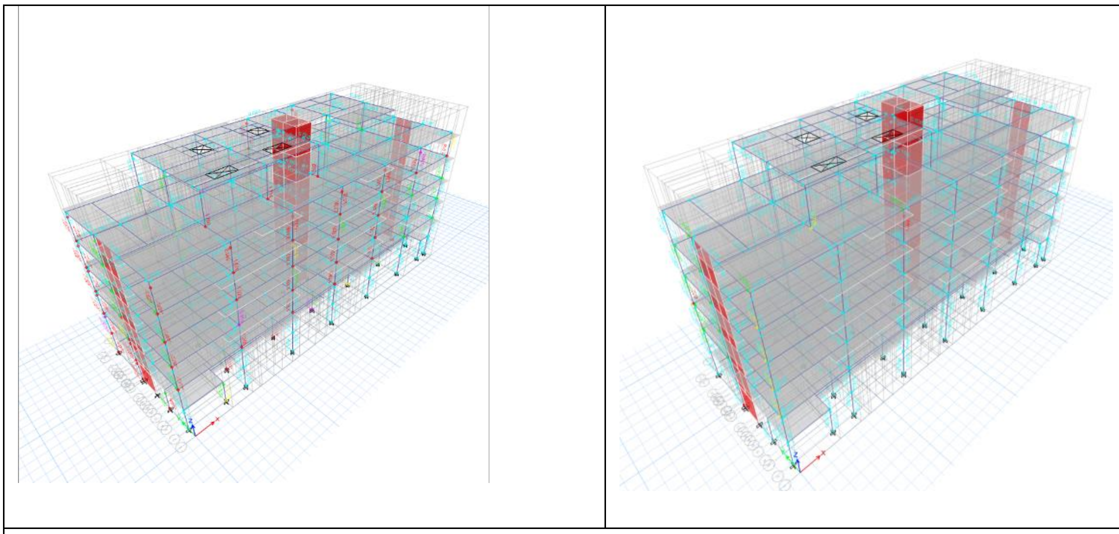


Figure 4. The hinge states (severe damages) of NLTHA at DBE on (a) RCC (b) ECC structures.

3.2.2. Inventory Analysis

For the raw material production phase of life cycle, the data for Cement was obtained from Portland Cement Association (PCA 2002) and Ecobilan (Ecobilan 2001) cement data, 1996, for gravel from Portland Cement Association (PCA 2002) and for its electricity and fuel production it was adjusted from Ecobilan (Ecobilan 2001), for sand from Original Ecobilan sources: Various, 1985–94. Equipment emissions from USEPA's (USEPA 2000), for PVA Fiber and superplasticizer from Keolein, and for steel from International Iron and Steel Institute (IISI

2000).

Based on this data, for production of 1m^3 concrete consumes 3.8 times more energy than production of ECC. The energy consumption of ECC is 6858 MJ and that of conventional concrete is 1809 MJ. Since conventional concrete consists of majorly Gravel and Sand, that are naturally available in environment, the energy associated with them is negligible contributing to less energy consumption in production of concrete. The strength used for concrete is 4000 psi with a ratio of cement, sand and aggregate as 1:2:3 and ECC of type M45. 1m^3 of conventional concrete has 288kg of cement which is almost double of cement present in ECC (i.e., 570 kg) which contributes to the greater energy intensity of ECC. The other major factor that contributes to the high energy intensity of ECC is PVA fiber with a high energy intensity of 110 kg. The other major raw material used is fly ash, since it is a waste product there is no energy intensity associated with it.

For construction phase of the life cycle includes the transportation of material from its production site to the building infrastructure and placing of concrete. The number of hours of batching plant operations were calculated. The distance is assumed to be 5 km. The transit mixer and batching plant environmental impacts were calculated from fuel combustion. The power of each construction equipment was known and number of hours of the use of that equipment was estimated.

In use phase of the life cycle, damages due to earthquake during the service life of infrastructure are incorporated. Since the return period of Service Level Earthquake is 30 years and that of Design Based Earthquake is 50 years, the building would be vulnerable to 4 SLEs and 2DBEs. The damages retrofitting is done by estimating the amount of steel and concrete required to repair them. Since ECC performs exceptionally better from conventional in case of earthquake the damages in case of ECC would be negligible. The other major contributing factor in the use phase is more space availability in case of ECC. Since the volume of Concrete in ECC is 25% lesser than that of conventional, the volume occupied by ECC column would be lesser.

In End phase of the life cycle, the building infrastructure is demolished, and the waste was transported to the dump site. The distance to the dump site was assumed to be 10 km. The power of each equipment was taken from different sites. The usage of equipment was estimated. All the waste material was dumped and none of it was recycled.

3.2.3. Impact Assessment

Concrete production is a significant contributor to global Carbon dioxide (CO2) emissions due to release of CO2 during cement manufacturing and energy intensive processes. It was important to be noted that how much carbon dioxide is released in production of ECC to compare it with conventional concrete.

GHG emissions during the material production phase was the highest. The GHG emissions data was obtained to produce each raw material from the source (Ma, F., Sha, A., Yang, P., & Huang, Y. (2016, June 24). The Greenhouse Gas Emission from Portland Cement Concrete Pavement Construction in China. International Journal of Environmental Research and Public Health, 13(7), 632.)

For construction and demolition phase, the GHG emissions were obtained by multiplying energy consumption with carbon intensity factor of diesel, since all the equipment used in construction and demolition operates on diesel.

The total Globing Warming Potential was found as Carbon Dioxide (CO_2) equivalent in metric tons. The CO2 equivalent was calculated by multiplying each emission with its Global Warming Potential. The GWP in this analysis are taken as CO2 (GWP=1), methane (GWP = 23) and Nitrous Oxide (GWP = 296) according to Houghton 2001. CO2 is the major contributor to the Global Warming despite the presence of other two gases. The ECC System showed a reduction in GWP by 33% than that of conventional system.

3.3. Life Cycle Cost Analysis

Life cycle cost analysis on the system defined in the section 1 uses the results from all four phases of life cycle like material specification, building requirement, construction machinery usage, repairs needed after earthquakes damages, better built environment implications, and cost associated to end of the life phase. The LCCA starts with the calculation of the raw material's cost used for production of ECC and RCC material. It is estimated that the unit price of ECC is almost 4 times that of conventional concrete.

When the two materials are implemented on complete structural scale using ACI-318 for RCC and JSCE guidelines for ECC, the reduction in overall material use is observed. The reduction in material use is due to the lighter weight of ECC, better tensile strength and excellent shear properties. Design results show that there is a 23% reduction in the steel reinforcement and around 27% reduction in the member's cross-sections.

Due to variations in the material's ingredients, there will also be variations in the processing, equipment usage and the labor needed. Equipment usage from inventory analysis is used to calculate costs associated with machinery used during construction. Machinery usage for the RCC structure will be double because the observation period is 100 in which RCC building will be reconstructed after 50 years. Also, there will be no need for a concrete vibrator in the case of R/ECC building due to the self-consolidating nature of ECC material.

During the use phase of two buildings, cost will be associated with the damage occurring due to the earthquake events at subjected case study building at assumed site. Damages analyzed using NLTH analysis and estimated the cost of repair using the model given by Hwang et al.1994. NLTH analysis shows a total of 17 hinges in the RCC structure, two hinges in each column, that makes total 8 column to failed in Service level earthquake (SLE). In DBE, which is a relatively higher intensity earthquake, the total number of hinges are 74 with total 37 column being damaged. During the Observation period of 100 years, case study building will be subjected to 4 SLE and 2 DBE due to their recurrence period of 30 and 50 years respectively. In ECC, due to its excellent seismic performance, there is almost negligible damage in R/ECC structure.

CHAPTER-4

4. RESULTS AND DISCUSSION

4.1. Availability of Raw Materials

The model is of a house that has dimensions of 36’x36’. Our house comprises of 2 bedrooms with attached bathrooms and open kitchen along with drawing room and dining. This is a single storey house. The rooms have dimensions of 12’x12’. Our ceiling height is 10’. This house is designed keeping in mind the family of 2-3 persons. This gives a vibe of studio apartment due to its open kitchen and dining. Since, we ha the limitations of the width of house, we did not want to make separate rooms for drawing room and kitchen. The open design is made to give less crowded look. Our house takes 8 days to get built in factory and the installation time on site is 1 day.

4.2. Life Cycle Analysis

Quantity survey of ECC and Conventional Concrete grey structure was done. Amount of concrete and steel used in both cases are shown in table 3.

Table 3. Quantity of Concrete and Steel in Conventional Concrete and ECC

Structural Detail	Volume	Conventional Concrete	ECC
Beams	Concrete (m^3)	423	317.25
	Steel (tons)	45.4	32.69
Columns	Concrete (m^3)	180	147.6
	Steel (tons)	30	24
Walls	Concrete (m^3)	147	132.2
	Steel (tons)	25	22.5
Slabs	Concrete (m^3)	605	395.2
	Steel (tons)	46	32.2

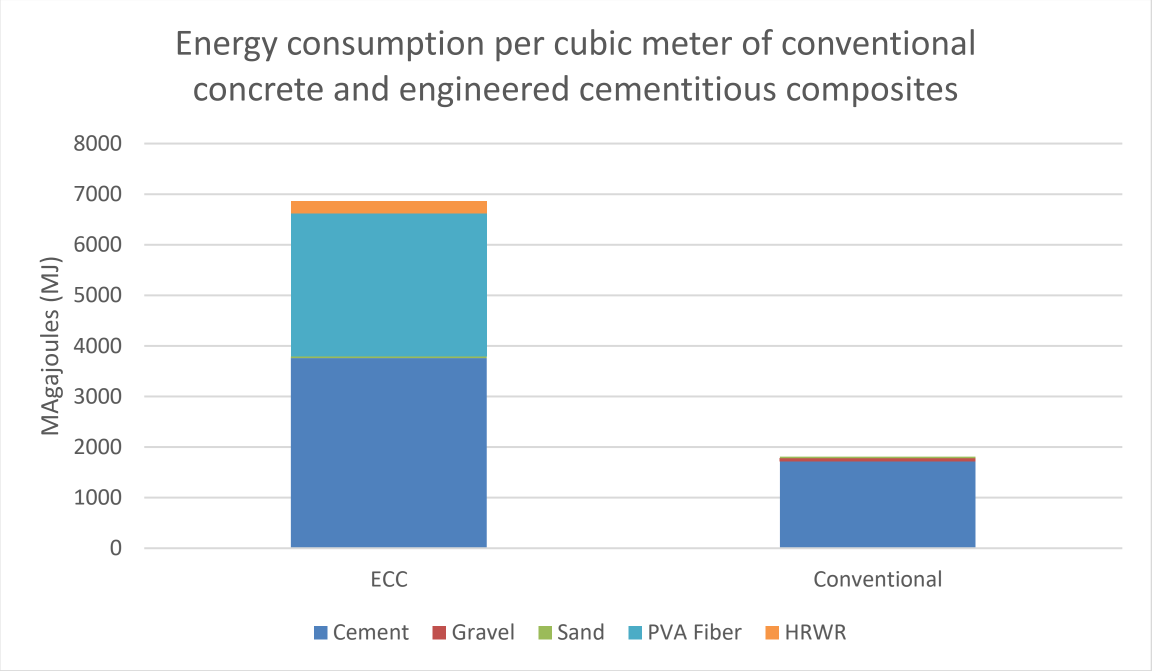
When the whole life cycle of the case study building was considered, the total mass of Conventional Concrete and ECC used was calculated. The total mass of each raw material along with their energy intensity is shown in Table 4.

Table 4. Life Cycle Mass of Conventional Concrete and ECC

Material	Conventional System Mass		ECC System Mass		Unit	Energy Intensity (MJ/kg)
	Initial	Life Cycle	Initial	Life Cycle		
Portland Cement	469.53	1093.86	565.6	565.6	T	4.5-6.5
Gravel	2026.37	4590.94	0	0	T	0.067
Sand	1065	2412.89	452.5	452.5	T	0.067
Fly Ash	0	0	679.8	679.8	T	0
PVA Fiber	0	0	27.8	27.8	T	101
Super Plasticizer	0	0	6.7	6.7	T	35
Steel	146.4	322.17	112.75	112.75	T	8.95

Using the data above, the energy consumption of 1m^3 of conventional concrete and ECC was found.

Figure 4. Energy Consumption of 1m^3 of Conventional Concrete and ECC



The number of hours an equipment used during construction were calculated. It is shown in table 5.

Table 5. Number of hours of equipment usage during Construction of Conventional Concrete and ECC during Life Cycle

Equipment	**Power (KW)**	**Conventional Initial Construction**	**Conventional Reconstruction**	**Conventional Repair and Maintenance**	**ECC Initial Construction**	**ECC Repair and Maintenance**
Concrete Mixer	215.5	45.27	45.27	12.47	46.3	0
Concrete Pump	55-65	45.2	45.2	12.47	24.81	0
Vibration	1.5	22.6	22.6	6.2	0	0
Transit Mixer	6	90.6	90.6	24.94	66.16	0

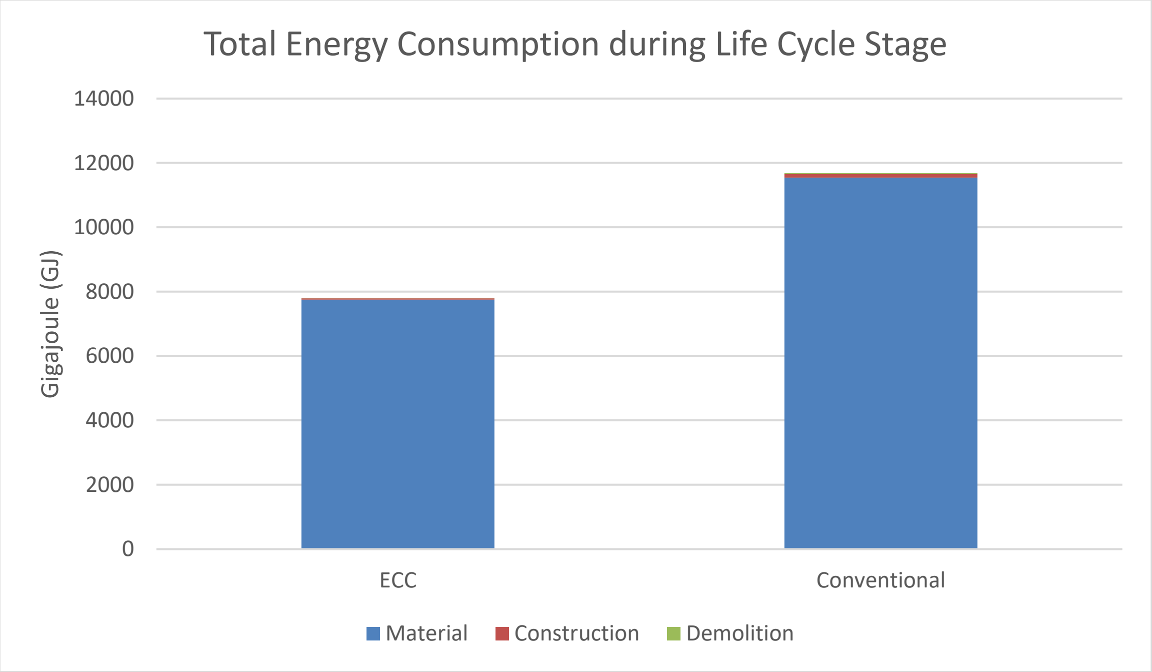
The number of hours an equipment used during demolition were calculated. It is shown in table 6.

Table 6. Number of hours of equipment usage during demolition of Conventional Concrete and ECC during Life Cycle

Equipment	Power (KW)	Conventional Initial	Conventional Final	ECC
Front End Loader	90	26.25	26.25	18.75
Dumper	17	120	120	85.71

The power of each equipment was multiplied by their usage hours to calculate energy consumption. The energy consumption for total life cycle of Conventional Concrete and ECC was obtained which is shown in figure 5.

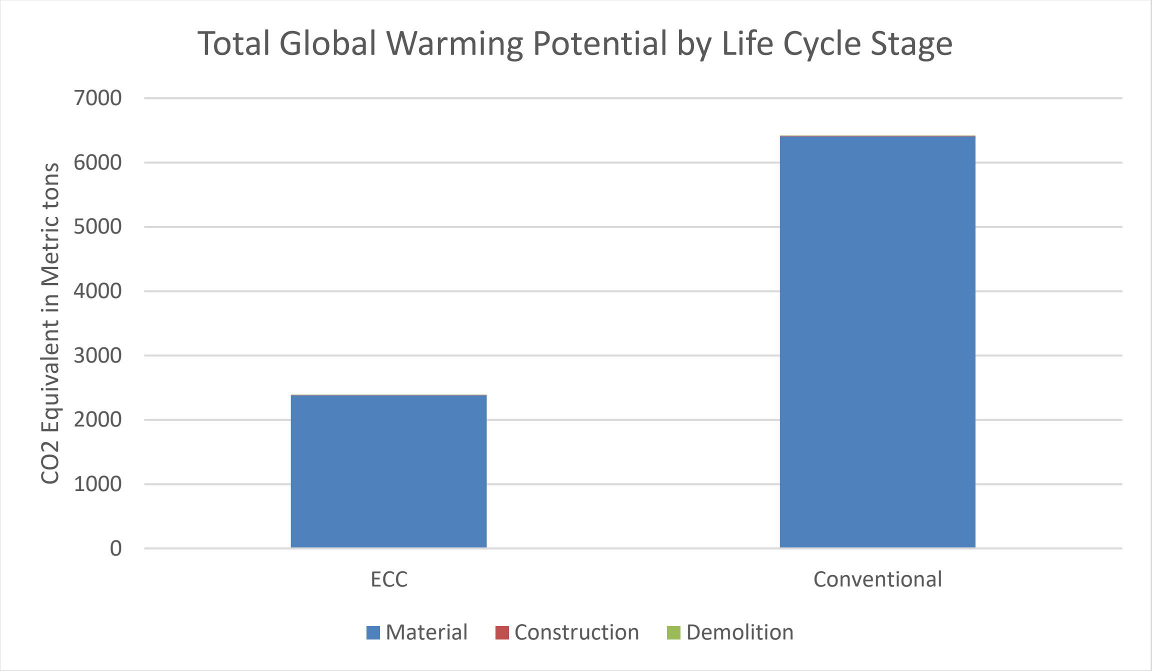
Figure 5. Total Energy Consumption of Conventional Concrete and ECC during Life Cycle



The GHG emissions during life cycle of Conventional Concrete and ECC was found. The Figure 6 shows total Global Warming Potential of Conventional Concrete and ECC during Life

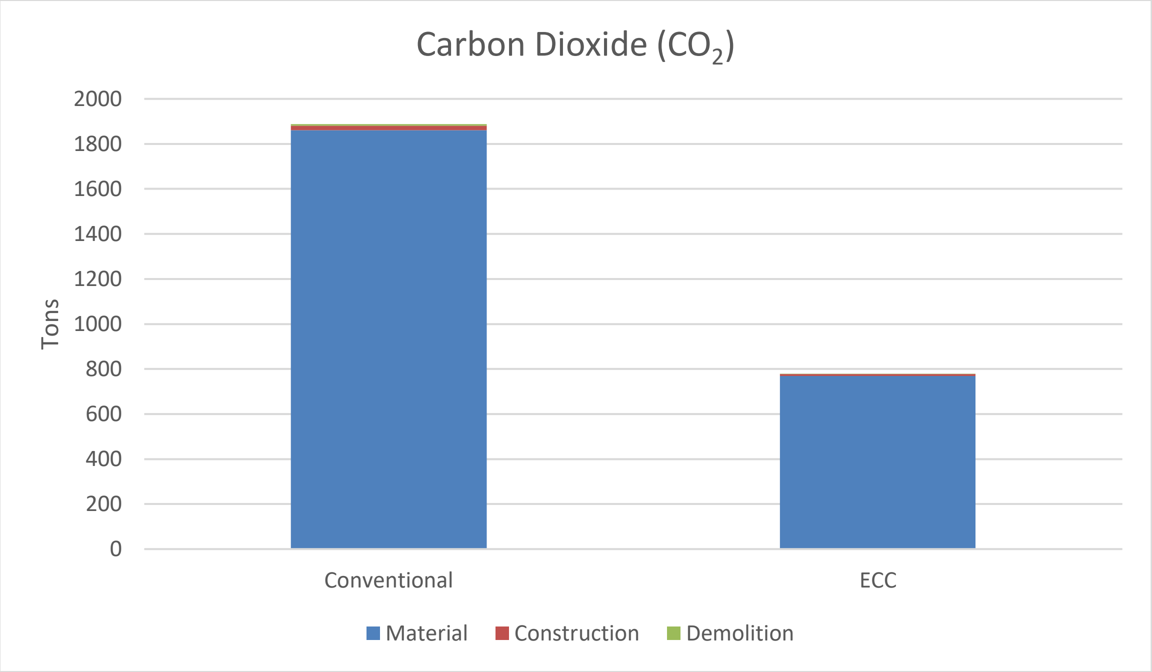
Cycle.

Figure 6. Total Global Warming Protentional of Conventional Concrete and ECC during Life Cycle



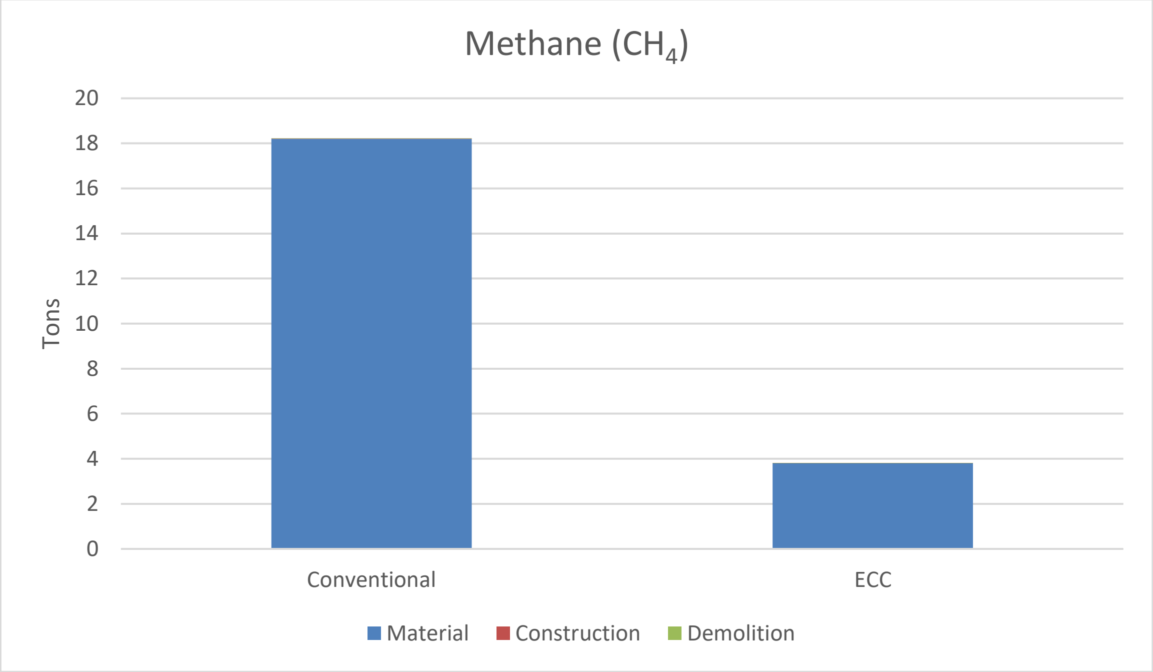
The CO_2 emissions by life cycle stage are shown in figure 7.

Figure 7. Total Carbon Dioxide Emissions of Conventional Concrete and ECC during Life Cycle



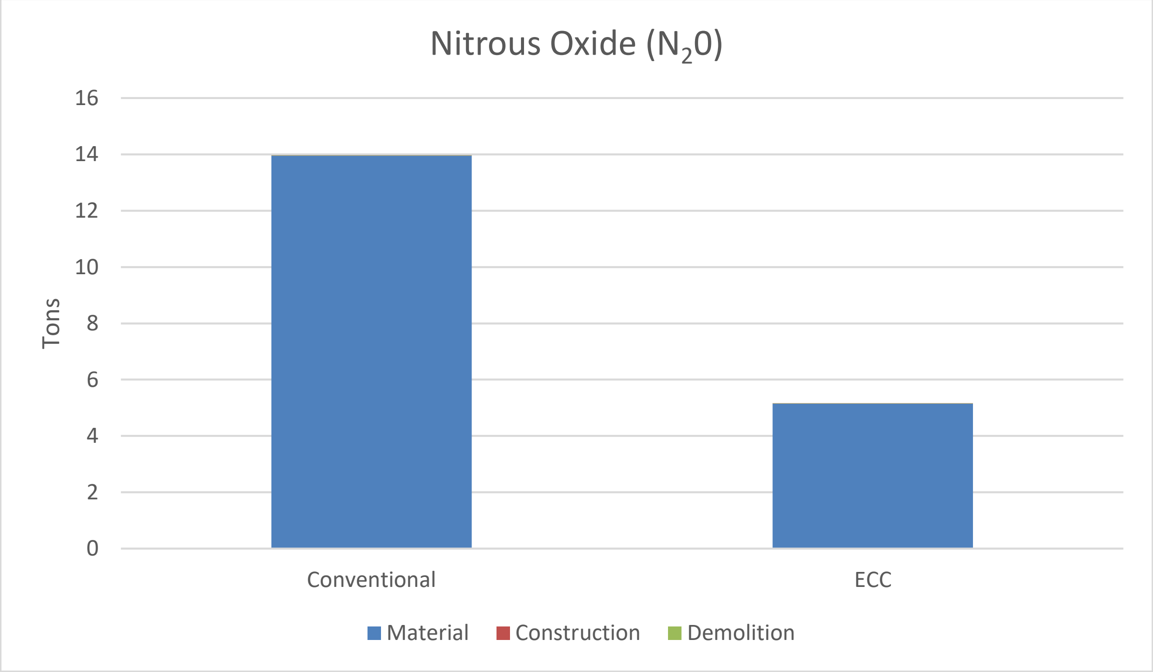
The Methane emissions during life cycle is shown in figure 8.

Figure 8. Total Methane Emissions of Conventional Concrete and ECC during Life Cycle



The Nitrous Oxide emissions during life cycle is shown in figure 9.

Figure 9. Total Nitrous Oxide Emissions of Conventional Concrete and ECC during Life Cycle



4.3. Life Cycle Cost Analysis

The Economic Assessment of both Conventional Concrete and ECC was done. The material cost of $1m^3$ Conventional Concrete and ECC was calculated shown in Table 7.

Table 7. Material Cost of $1m^3$ of Conventional Concrete and ECC

Material	ECC			Conventional		
	Quantities (Kg)	Unit price (PKR/kg)	Cost (PKR)	Quantities (Kg)	Unit price (PKR/kg)	Cost (PKR)
Cement	571	26	14846	411.05	26	10687.3
Sand	456	2.23	1016.88	756.17	2.23	1686.26
Coarse Aggregate	-	-	-	1438.7	2.9	4172.23
Water	332	-	-	165.6	-	-
Superplasticizer	6.8	600	4080	-	-	-
Fly Ash	685	6	4110	-	-	-
Fibers	26	1200	31200	-	-	-
Total	55584.88 PKR			16545 PKR		

The raw material cost for life cycle was also calculated shown in Table 8.

Table 8. Material Cost Conventional Concrete and ECC during life cycle.

Quantities	**Total Life Cycle Concrete Mass (m3)**	**Total Life Cycle Steel (tons)**	**Concrete Cost (PKR/m3)**	**Steel Cost (PKR/t)**	**Total Cost (PKR)**
Conventional Concrete	3090.12	322.17	12140	316881.80	**153 million**
ECC	992.35	112.75	58452	316881.80	**90 million**

The equipment cost for construction was also calculated for both Conventional concrete and ECC shown in table 9 and 10 respectively.

Table 9. Equipment Cost for Construction of Conventional Concrete during life cycle.

Equipment	**Power (kW)**	**Usage hours (hours)**	**Rent (PKR/hour)**	**Fuel Usage (kWh)**	**Total rent (PKR)**	**Fuel cost (PKR)**	**Total cost (PKR)**
Concrete Mixer	215.5	103.01	6511	22198.655	670698.11	560738.0253	**1231436.135**
Concrete Pump	60	102.87	3525	411.48	362616.75	119329.2	**481945.95**
Vibration	1.5	51.4	386	69.904	19840.4	20272.16	**40112.56**
Transit Mixer	6	206.14	4213	371.052	868467.82	107605.08	**976072.9**

Table 10. Equipment Cost for Construction of ECC during life cycle.

Equipment	**Power (kW)**	**Usage hours (hour)**	**Rent (PKR/hour)**	**Fuel Usage (kWh)**	**Total rent (PKR)**	**Fuel cost (PKR)**	**Total cost (PKR)**
Concrete Mixer	215.5	46.3	6511	252035.439	301459.3	11669240.83	**11970700.13**
Concrete Pump	60	24.81	3525	198.48	87455.25	57559.2	**145014.45**
Vibration	1.5	0	386	0	0	0	**0**
Transit Mixer	6	46.86	4213	84.348	197421.18	24460.92	**221882.1**

The equipment cost for demolition was also calculated for both Conventional concrete and ECC shown in table 11 and 12 respectively.

Table 11. Equipment Cost for Demolition of Conventional Concrete during life cycle.

Equipment	**Power (kW)**	**Usage (hour)**	**Rent (PKR/hour)**	**Fuel Usage (kWh)**	**Total Rent (PKR)**	**Fuel Cost (PKR)**	**Total Cost (PKR)**
Front end Loader	89.5	52.5	6167	630	323767.5	182700	506467.5
Dumper	17	240	3558	3120	853920	904800	1758720

Table 12. Equipment Cost for Demolition of ECC during life cycle.

Equipment	Power (kW)	Usage (hour)	Rent (PKR/hour)	Fuel Usage (kWh)	Total Rent (PKR)	Fuel Cost (PKR)	Total Cost (PKR)
Front end Loader	89.5	18.75	4450	225	83437.5	65250	148687.5
Dumper	17	85.71	3558	1114.23	304956.18	323126.7	628082.88

So, the total equipment cost for construction and demolition was estimated as shown in table 13.

Table 13. Total Equipment Cost of Conventional Concrete and ECC during life cycle.

	Construction Total cost (PKR)	Demolition Total cost (PKR)
Conventional Concrete	2.7 million	2.2 million
ECC	1.2 million	0.7 million

The total labor cost was also calculated shown in table 14.

Table 14. Total Labor Cost of Conventional Concrete and ECC during life cycle.

	Cost (PKR)
Convectional Concrete	8.3 million
ECC	3.9 million

The Total Cost for Conventional Concrete and ECC calculated is shown in Table 15.

Table 15. Total Cost of Conventional Concrete and ECC during life cycle.

	Material Cost (PKR)	**Construction Equipment Cost (PKR)**	**Demolition Cost (PKR)**	**Labour Cost (PKR)**	**Total Cost (PKR)**
Conventional	153218286.1	2729567.545	2265187.5	8383200	**166 million**
ECC	90888078.62	12337596.68	776770.38	3903450	**107 million**

CHAPTER-5

5. CONCLUSION

It was observed that there was application of ECC in other countries but not in Pakistan. After a lot of research, it was found that it was due to the lack of studies on its management aspect in Pakistan so, we did a comprehensive study on its Life Cycle to know if its more economical and environmentally friendly in Pakistan.

- The project was carried out in stages i.e., Availability of Raw Materials, Life Cycle Analysis, and Life Cycle Cost Analysis to compare grey structure of ECC with conventional concrete. Thorough research was done knowing about the materials required to make ECC and conventional Concrete, behavior of building under earthquake, energy consumption and Greenhouse Gas Emissions (GHG) of ECC and Conventional Concrete and their cost comparison.

- All raw materials required for ECC are available in Pakistan except PVA which was to be exported from other countries.

- Energy Consumption of ECC grey structure was found out to be lesser than that of the conventional when whole life cycle is considered making it more sustainable.

- Greenhouse Gasses Emissions (GHG) of ECC grey structure was also found to be lesser than that of the Conventional Concrete during whole life cycle making it more environmentally friendly.

- Cost of ECC grey structure was also found to be lesser than that of the Conventional Concrete during its whole life cycle making it more economical.

- Cost of ECC grey structure was also found to be lesser than that of the Conventional Concrete during its whole life cycle making it more economical.

- In Developing countries, ECC is FEASIBLE to be used encountering less damages due to earthquake and providing greater service life.

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