LIFE CYCLE COSTING FOR SELECTED STRUCTURAL MATERIALS FOR OFFSHORE PLATFORMS

BY

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This Thesis Is Dedicated

To:

My beloved parents and my wife for

their tender care and efforts.

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ABSTRACT

NAME: EZELDINE AL-KALDI

TITLE OF STUDY: LIFE CYCLE COSTING FOR SELECTED STRUCTURAL MATERIALS FOR OFFSHORE PLATFORM

MAJOR FIELD: CONSTRUCTION ENGINEERING & MANAGEMENT

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This research discusses life cycle costing (LCC) for selected structural materials at offshore topside platforms. Two materials have been included in this study. Steel materials have been selected as the base materials for offshore structural materials, while new glass reinforced plastic (GRP) materials have been selected as alternative materials. The purpose of this study is to determine whether or not the new materials (GRP) are life cycle cost effective relative to the predictable materials. The AB-platform at Al-Shaheen field in Qatar was selected as a case study. Both the grating and handrail systems at AB-platform were evaluated by using life cycle costing techniques.

Factors that affect material selection were studied in the literature review, and the evaluation and selection model for offshore materials was developed based on both qualitative and quantitative measures. In the qualitative evaluation, the factors that affect materials selection were weighted using a scoring matrix. In the quantitative evaluation, weighted criteria were used in the evaluation matrix to rank the selected materials. This method provides the users with effective tools to select among competing alternative materials with the desired function and it has to be performed prior the life cycle costing analysis.

Finally, the results of the study revealed GRP materials are more economical over the platform lifetime at all selected interest rates with significant difference in the final cost by using (LCC) techniques. The results show that the GRP handrails are less than steel handrails in LCC at all times; however steel gratings are lower in LCC for a short period less than 6 years, otherwise GRP gratings are more economical.

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خلاصة الرسالة

الأسم : **عزالدين فضل حسين صالح الكلدي**
موضوع الدراسة : **حساب التكلفة الكلية خلال فترة دورة الحياة لبعض المواد الأنشائية المختارة في المنصات البحرية**
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هذا البحث يناقش تكاليف دورة الحياة لبعض المواد الأنشائية المختارة في مجال تشييد المنصات البحرية في قطاع النفط والغاز حيث تم أختيار نوعين من أنواع المواد الأنشائية لعمل هذة الدراسة وهما الحديد كمادة أساسية والمادة الأخرى هي مادة اللدائن المدعمة بالألياف الزجاجية كمادة أختيارية.حيث أن الهدف من هذه الدراسة معرفة اذا كانت المواد الأختيارة المستحدثة أقل تكلفة من المواد التقليدية المستخدمة حاليا كالحديد. تم أختيار المنصة الرئيسية ألفا بيتا بحقل الشاهين بقطر لتطبيق الدراسة على نظام المشبك الحديدي المخصص للمشاة ونظام الدرابزين الحديدي ومن ثم تطبيق حسابات دورة تكاليف الحياة لكلا النظامين في حال أختيار الحديد او اللدائن المدعمة بالألياف الزجاجية كمادة أنشائية ومن ثم حساب المادة الأقل تكلفة خلال العمر الأفتراضي للمنصة البحرية.

هذه الدراسة تناولت أيضا دراسة العوامل المؤثرة في أختيار المواد الأنشائية في مجال المنصات البحرية ومن ثم تقييمها تقييما كيفيا على حسب الأهمية لكل عامل ومن ثم يتم تقييم المواد المراد أستخدامها تقييما كميا بالنسبة لأهمية العوامل المؤثرة من خلال أستخدام المصفوفة التقييمية.الهدف من هذا الجزء هو توفير أداة فعالة تساعد بأختيار المادة الأنسب على حسب العملية المطلوب أداؤها وذلك قبل القيام بتطبيق حسابات دورة تكاليف الحياة.

أظهرت نتائج الدراسة أن مواد اللدائن المدعمة بالألياف الزجاجية هي المادة الأقل تكلفة على طول عمر المنصة البحرية بالنسبة لنظام الدرابزين اما بالنسبة لنظام المشبك المخصص للمشاة فأن مادة الحديد هي الأقل بالنسبة للفترات القصيرة (أقل من ستة سنوات) أما بالنسبة للفترات الأكثر من ستة سنوات فأن مادة اللدائن هي الأقل تكلفة. كما أستخدم تحليل الحساسية لتأكيد ذلك. كما أظهر التقيم الكمي والكيفي من خلال أستخدام المصفوفة التقييمية أن مادة اللدائن هي ألافضل وألانسب للظروف البيئية القاسية كمقاومتها للصدأ وعوامل التعرية هذا بالأضافة الى خفة وزنها مقارنة بالمعادن.

درجة الماجستير في العلوم

جامعة الملك فهد للبترول و المعادن

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يونيو 2010

CHAPTER ONE

INTRODUCTION

1.1 GENERAL

An offshore platform, referred to as an oil platform, is a large structure used to house workers and equipment needed to drill wells in the ocean bed, extract oil or natural gas, and finally send them to shore. Offshore structures are not similar to onshore structures; offshore structure components are fabricated and assembled onshore and then transported to an offshore location for installation. Therefore, material specifications differ significantly from those applicable to onshore structures. The offshore industry needs to act in a very competitive market and subsequently reducing costs, deliver within short periods and deal with scientific and technological innovation. A generic technology that increasingly provides new opportunities for innovative offshore structures is material technology (Chkrabarti, 2005).

1. **Figure 1.1: Offshore Platform (Al-Shaheen Field,Qatar)**

Figure 1.2: Offshore Platform (Al-Shaheen Field,Qatar)

New materials are developed from composite and metals and because they have characteristic such as light weight, high strength, long service life, corrosion resistance and low maintenance cost, offshore industries start using an introducing these materials in the construction applications. In offshore industries corrosion is consider one of the major cost factors. NACE estimates that tubular corrosion only in oil and gas industry costs Billion of dollar per year.

1.2 PROBLEM STATEMENT

In the oil and gas business, the best economic position was to achieve production as quickly as possible, without working at a cost reduction. From an economic point of view, it is more economical to start production as early as possible; however, cost saving now is something that needs extra consideration, especially after the fall in oil prices in eighties. Cost saving in materials could lead to significant figures of the total project cost if true materials are selected in early stages and because there are new materials are developed recently like the Glass Reinforced Plastic, so these materials must be evaluated from the life cycle costing point view.

1.3 OBJECTIVE OF THE STUDY

This study represents an evaluation of selected offshore structure materials by using life cycle cost techniques. In addition, factors will be presented that affect the selection of materials and advantages versus disadvantages. This study will focus on two type of offshore structure materials: steel and glass reinforced plastic (GRP). Moreover, areas for further research will be recommended.

1.4 SIGNIFICANCE OF THE STUDY

Offshore platform structures are subject to environmental conditions, soil characteristics, fatigue stress, and corrosion. These conditions make the selection of the material very difficult. Selecting the proper materials in the early stages of the design will offers the best opportunity to reduce future costs. The quality of the design for an offshore structure and material selection can result in less life cycle cost.

The main materials for offshore structures are steel and concrete. Composite material like glass reinforced plastic (GRP) have been used in piping systems in offshore, however, composites are implemented recently in offshore structures, but on a small scale.

To date, no study has been done to show the running cost among offshore structure materials to determine the most economic materials; this is due to the rapid growth of offshore oil and gas exploration and ignoring the future cost.

1.5 SCOPE AND LIMITATION

This study is limited to the following:

- Top side module structure of the fixed platform.
- It will be done on steel and glass reinforced plastic (Vinylester/Polyester and Phenolic resins) structure material.

The case study will apply to the (grating and handrail) system for AB-platform at Al-Shaheen Field in Qatar considering both type of materials. Subsea structures and pipeline systems are beyond the scope of this research study.

1.6 THESIS ORGANIZATION

This thesis will be divided to six chapters and an appendix. The six chapters they are as follows:

Chapter 1: Introduction

Gives an overview about the topic of the thesis. It presents the research objectives, significance of the study and the scope and limitations of the research.

Chapter 2: literature Review

This chapter presents a literature review to the life cycle cost concept and techniques, offshore platforms background, offshore structural materials and some concern associated with the offshore structural materials like corrosion and cost of corrosion control.

Chapter 3: Research Methodology

This chapter presents the methodology applied in the study.

Chapter 4: Data Collection & Data Analysis

This chapter presents the LCC techniques used for the analysis.

Chapter 5: Results and Discussions

This chapter shows the results and the findings from the results.

Chapter 6: Summary, Conclusion and Recommendations

This chapter presents the conclusion and the recommendations for further study.

CHAPTER TWO

LITERATURE REVIEW

2.1 LIFE CYCLE COSTING BACKGROUND

2.1.1 LCC Definitions

SAE 1999 defines LCC as "Life cycle cost is the total cost of ownership of machinery and equipment, including the cost of acquisition, operation, maintenance, conversion, and/or decommissioning" This definition excludes the purpose of estimating the cost in relation to business unlike the definition introduced by ISO 156868, that highlights the business dimension in LCC and its purpose by stating that LCC is “a technique which enables comparative cost assessment to be made over a specified period of time taking into account all relevant economic factors both on terms of initial cost and future operational costs.” This is a broader definition since it includes all the relevant economic factors that contribute to LCC.

The American Society for Testing and Materials (ASTM) (Al-busaad, 1997) gives a similar definition with a minor difference related to highlighting the purpose of the LCC estimation as being the investment feasibility. It states that LCC is “a technique of economical evaluation that sums, over a given study period, the costs of initial investment (less resale value), replacements operations (including energy use), and maintenance and repair for an investment decision (expressed in present or annual value terms)".

The American Institute of Architects (AIA) (Al-busaad, 1997) presents a definition that echoes the definition of ISO 156868 stating that LCC is "a technique that shows the assessment of a given solution or choice among alternate solutions on the basis of considering all relevant economical consequences over a given time or Life Cycle". Design professionals, cited by Al-busaad 1997, also give a definition that echoes the gist of the previous definition with the difference that the estimated cost is expressed in dollars. The definition goes that LCC is "an economical assessment of competing design alternatives considering all significant cost ownership over the economic life of each alternate expressed in equivalent dollars". The National Institute of Standard and Technology (NIST) Handbook 135, 1995 edition states that LCC is "the total discounted dollar cost of owning, operating, maintenance, and disposing of a building or a building system" over a period of time. Another definition given by the construction best practice programme (CBPP 1998) and cited by Kishk et al 2003, states that LCC is" the systematic consideration of all relevant costs and revenues associated with acquisition and ownership of an asset".

More or less, these definitions pivot around the cost of purchasing equipment, operating, maintaining, and decommissioning as part of estimating the economic feasibility of the investment enterprise. Cost has to be estimated in terms of money units so as to articulate the cost accurately.

2.1.2 Life Cycle Costing History

LCC is relatively a recent concept that was incorporated in the study of system design after reports that it can be crucial to system engineering. According to Sparks et al 2005 Gupta and Chow 1985 state that in 1960, officials within the US Department of Defense (DoD) noted that operations and support costs for a weapons system could account for 75%or more of total costs incurred over its useful life span. Hence, subsequent military procurements were adjusted in the light of this observation which gave rise to life cycle engineering and costing concepts and more consideration was given to total costs of manufacture (construction), operation, use, maintenance, support, and phase-out of product and infrastructure systems explicitly enter and inform the engineering design process. By the early 1970s, the concept of operating assets was formalized and frequently used as "cost-in-use" to refer to the cost of operating assets.

In 1971 operation cost was translated by the establishment of Building Maintenance Cost Information Service by the Royal Institution of Chartered Surveyors as a method of collecting operational and running cost data. AL-busaad (1997) reports that in 1972, the term was also used in the construction industry as reported by Alphonse J.Dell'Isola and used by the American Institute of Architects in 1977 when it published a set of guidelines intended to present the basis of LCC technique as well as an indication of where LCC fits best into the process of planning and design

The term was further used in the field of energy conservation in 1978 when a guide for selecting energy conservation projects based on life cycle costs for public buildings was presented by the Department of Commerce, USA, followed by a life cycle costing manual for Federal Energy Management Program in 1980 (Ruegg, 1980). The term was formalized further when the American Standard for Testing Material (ASTM) developed a method for life cycle costing in 1983, and by 1992, LCC was a familiar concept to building economists throughout the world, and a standard was developed in the UK under British Standard BS38433. In 2000, LCC was incorporated into ISO 156868-1.

In short, from 1970s to the beginning of 1980s, the LCC analysis was mainly applied in the military field, but it spread afterwards to other industries such as aircraft, electrical power plants, oil and chemical industries (Kawauchi , 1999).

2.2 TIMING FOR LIFE CYCLE COSTING

Life Cycle Cost analysis has become an integral part of feasibility study of any project and in case of public utilities, it is important to ensure the durability of the service offered to the public. It is preferably carried out in any and all phases of a product's life cycle to provide input to decision makers. The earlier the analysis is carried out, the better decisions come out regarding the execution of the project or its continuity and balancing performance, reliability, maintenance support and other goals against life cycle costs. It also helps to minimize operating cost before it aggravates in later stages of the project. It is generally believed that 80 % of the

LCC is allocated by decisions that are made within the first 20 % of the life of the project (Kawauchi , 1999).

It is worth mentioning that there is an element of uncertainty that exists in LCC estimation and it is usually greater in the conceptual framework and in the early stages of any enterprise. However, after operation and development, this uncertainty diminishes because the machinery is tested and its LCC becomes more predicTable as shown in Figure.2.1, Hence, timing of LCC analysis has a crucial value in balancing commitment and uncertainty (Kawauchi , 1999).

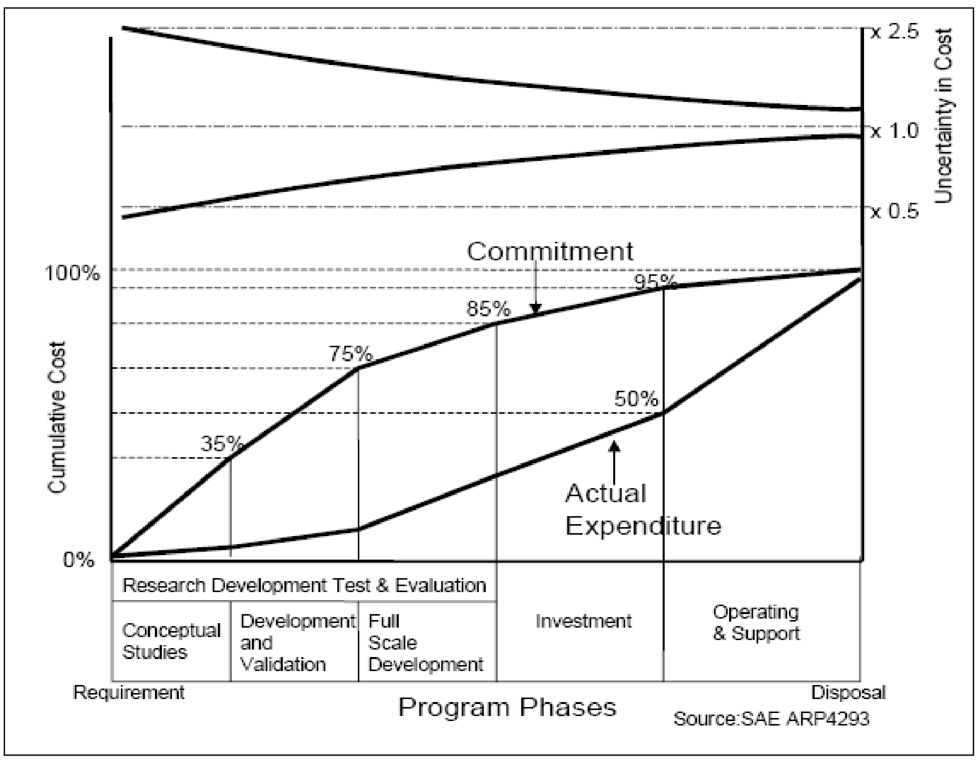


Figure 2.1: Influence of Program Decision Stage (Kawauchi, 1999)

If there are a number of competing alternatives, WLC is necessary to help select one. It can be done in any stage of the project as shown in figure 2.2, but it is more effective if it is done in early stages when option is open and there is still a chance to make the right decision and there to influence cost (Kishk et al , 2003).

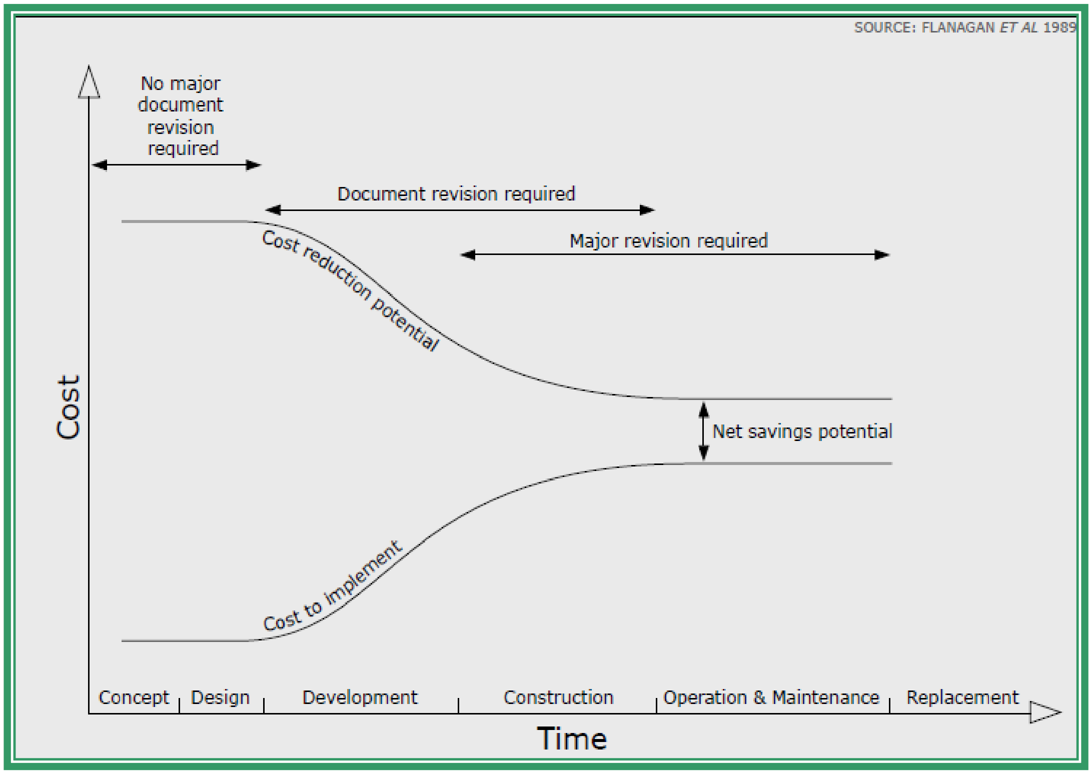


Figure 2.2: **Relation between WLC Savings and Time of Implementation (Kishk et al, 2003)**

2.3 THE NEED FOR LIFE CYCLE COSTING AND APPLICATIONS

Life Cycle Cost Analysis is crucial to any enterprise as it enables decision makers to choose the correct alternatives from a number of alternatives. It is also a vital part of managing tools like economic appraisal, financial appraisal, value management, and risk management. However, there some factors that enhanced the need for LCC analysis. These include: increasing maintenance cost, budget limitation, competition, new expensive products in the market, rise in inflation.

LCC can be implemented in many fields like evaluation and comparison of alternative design, economic feasibility, identifying cost drivers and cost effective improvements, selecting the best strategy for product use, operation, test, inspection, maintenance, selecting best way for replacement, rehabilitation, life extension, disposal of aging facilities, the best allocations of the available funding, assessment of product, long-term financial planning, selecting the best procurement strategy, forecasting future budgets and assessing new technology application (Kawauchi , 1999).

2.4 COST COMPONENTS IN THE LIFE CYCLE COSTING ANALYSIS

Assaf 2008, Al-Khalil 2008 and Philip 2001 mention the following components of LCC:

2.4.1 Initial or Capital Cost Investment

This refers to the expense required to get a project in place and ready for service and it includes land acquisition, research and development, engineering, like design, planning construction, and construction inspection; and quality control and testing.

2.4.2 Operating Costs

Operating costs are incurred in operating the facility throughout its operational life and can be divided to the following costs:

A. <u>Operating Cost – Administration</u>

This includes labor services cost, facility cleaning, security, financing, and logistics.

B. <u>Operating Cost – Energy</u>

This is the cost related to energy consuming equipment needed to operate the facility, including fuel and labor costs associated with energy.

C. <u>Operating cost – Maintenance</u>

This includes costs associated with repairing the system to maintain it in its original state, such as lubricants, spare parts, preventive maintenance, and unscheduled maintenance.

D. <u>Operating cost – Replacement</u>

This is the cost of replacing the equipment or other facility elements that have an estimated life shorter than that of the major components.

2.4.3 Residual Cost

Residual value cost is the sales value of the assets at the end of the project life.

2.5 LIFE CYCLE COSTING TECHNIQUE AND METHODS

2.5.1 Simple Interest and Compound Interest

According to Assaf 2008, Alkhalil 2008 and Philip 2001, interest is defined as the rental amount charged for the use of money or the increase over the original cost. The interest rate is the rate of gain received from an investment over a specified period.

Under simple interest, the amount is proportional to the length of time and the principal amount, as shown in Equation (2.1).

$I = P.n.i$ ………………………………………………………………….Eq 2.1

Where

I = interest earned

P= principal amount

n = number of periods

i= interest rate

Under compound interest, the interest depends on the principal amount, the period, and the accumulated interest from previous periods, as shown in Equation (2.2).

$I = P(1+i)^n$ …………………………………………… …. ………..Eq 2.2

2.5.2 Nominal and Effective Interest Rate

Interest may be compounded more frequently than once a year, for example, half yearly, quarterly, monthly, and so on. This introduces two terms (1) nominal interest rate per year (r) is the annual interest rate per year without compounding, and (2) effective interest rate per year (i) is the annual rate with compounding, refer to Equation (2.3).

$i = (1 + r/m)^c - 1$ …………………………… Eq 2.3

Where

i = effective interest rate

r = nominal interest rate per year

m = the reciprocal of the length of the compounding period in years.

C = number of compounding periods in the time interval of interest.

2.5.3 Concept of Time Value of Money

Time value of money is a basic concept to economic engineering analysis. The time value of money means that "an amount of money has a greater value if received now than if received on a future date." Therefore, to account for the time value of money, all expenditures and revenues need to be converted to a common denominator. The common point in time may be present, future, or even annual, and this is achieved by discounting the cash flow streams. The rate used for discounting is referred to as the discount rate (Assaf, 2008; Alkhalil, 2008; Philip, 2001).

A. Cash Flow Diagram

A cash flow diagram is a graphical description of cash transactions for an alternative, a person, or a company.

A cash transaction is either:

- A cash receipt (earning).
- A cash disbursement (cost).

If receipts and disbursements occur in the same period, we can find a net cash flow that is equal (receipts = disbursements).

The following conventions are used in the construction of the cash flow diagram:

- The horizontal axis represents period or the time.
- The vertical axis represents costs and benefits
- Costs are shown by downward arrows
- Benefits are shown by upward arrows

B. Present Worth Value

Present worth value is the value on a given date of a future payment or series, and discounted to the present, refer to Equation 2.4.

$P = F\,[1/(1+i)^{N}] = F\,(P/F, i, N)$ ……………………………………… .Eq 2.4

Where is:

P = Principal amount.

F = Future amount.

N = Number of interest period (years).

i= interest rate.

C. Future Worth Value

Future worth value measures what a given sum of money is worth at a specified time in the future assuming a certain or selected interest rate. Here, interest is added to the cash flow compounding versus discounting, refer to Equation 2.5.

$F = P\,(1+i)^{N}$ …………………………………………………………Eq 2.5

D. Uniform Annual Series Value

This is a collection of end of period cash payments or receipts arranged in a uniform series and continuing for (n) periods. Such series is equivalent to (P) or (F) at interest rate (i), as shown in Equations 2.6 and 2.7.

$A = F\,[\,i / (1+i)^{N} - 1]$ …………………………………………………Eq 2.6

Or

$A = P\,[i\,(1+i)^{N} / (1+i)^{N} - 1]$ …………………………………….…Eq 2.7

Where

A = the periodic payment

2.5.4 Discount Rate

The discount rate is selected to reflect the investor's time value of money. The discount rate is used to convert future costs and revenues occurring at different times to equivalent costs at a common point in time.

2.5.5 Inflation and Deflation

Inflation and deflation are defined as the increase or decrease in the price paid for materials, labor, and other goods, and they affect the purchasing power of the monetary unit. When inflation occurs, the purchasing power of the dollar decreases; in the case of deflation, it increases.

Mian 2002 states that the basic factors of inflation-deflation that influence the cash flow are actual dollar, real dollar, and inflation-deflation rate. Therefore, the investors adjust their minimum accepTable rate of return (MARR) to reflect the expected inflation rate during their investment.

The relation between actual dollars and real dollars are given in Equation 2.8 as:

$So = Sn\ (1+f)^{-n}$………………………………………………….…….Eq 2.8

Where,

Sn = Actual dollar value after n years.

So = Constant or real dollar value.

f= rate of inflation.

n= period of time, and usually years.

2.5.6 Evaluating Alternative

According to Mian 2002, the following evaluating techniques are mentioned:

2.5.6.1 Present Worth Method

The present worth method compares alternatives on the basis of the equivalent value of each proposal at the present time.

2.5.6.2 Future Worth Method

The future worth method compares alternatives on the basis of the equivalent value of each proposal in the future.

2.5.6.3 Uniform Annual Method

The uniform annual method compares alternatives on the basis of their equivalent uniform annual series.

2.5.6.4 Internal Rate of Return Method

Mian 2002 maintains that the internal rate of return is the interest rate that sets the equivalent receipts of an investment equal to the equivalent disbursements, or the interest rate that makes the net present value equal to zero. The investment or the project will be acceptable if the IRR higher than MAAR minimum attractive rate of return.

2.5.6.5 Pay Back Period

Simple Method:

This measure the time required to return the initial investment from the revenue without considering the time value of money.

Discounted Method:

This is the same as the simple method except the time value of money on the cash flow is considered.

2.5.6.6 Benefit to Cost Ratio

This is the ratio of the benefits of the proposed project relative to its costs, discounted to the present.

2.5.7 Evaluation of the Life Cycle Costing Techniques

From the previous we can notice that several methods are available to calculate the life cycle costing and each one has its advantages and disadvantages. It has been found that the most suitable method is NPV in the construction industries. Table 2.1 shows the advantages and disadvantages of each method.

Table No2.1: Advantages and Disadvantages of LCC Evaluation Methods (Schade,2007)

Method	What does it calculate	Advantage	Disadvantage	Usable for
Simple payback	Calculate the time required to return the initial investment. The investment with the shortest pay-back time is the most profiTable one. (Flanagan et al., 1989).	Quick and easy calculation. Result easy to interpret. (Flanagan et al., 1989).	Does not take inflation, interest or cash flow into account. (Öberg, 2005, Flanagan et al., 1989).	Rough estimation if the investment is profiTable (Flanagan et al., 1989).
Discount payback method (DPP)	Basically the same as the simple payback method, it just takes the time value into account (Flanagan et al., 1989).	Takes the time value of money into account (Flanagan et al., 1989).	Ignores all cash flow outside the payback period (Flanagan et al., 1989)	Should be only used as a screening devise not as a decision advice. (Flanagan et al., 1989).
Net present value (NPV)	NPV is the result of the application of discount factors, based on a required rate of return to each years projected cash flow, both in and out, so that the cash flows are discounted to present value. In general if the NPV is positive it is worth while investing (Smullen and Hand, 2005). But as in LCC the focuses is one cost rather than on income the usual practice is to treat cost as positive and income as negative. Consequently the best choice between tow competing alternatives is the one with minimum NPV (Kishk et al., 2003).	Takes the time value of money into account. Generates the return equal to the market rate of interest. It use all available data (Flanagan et al., 1989).	Not usable when the comparing alternatives have different life length. Not easy to interpret (Kishk et al., 2003).	Most LCC models utilize the NPV method (Kishk et al., 2003). Not usable if the alternatives have different life length (Flanagan et al., 1989).
Equivalent annual cost (ECA)	This method express the one time NPV of an alternative as a uniform equivalent annual cost, for that it take the factor present worth of annuity into account (Kishk et al., 2003).	Different alternatives with different lifes length can be compared (ISO, 2004).	Just gives an average number. It does not indicate the actual coast during each year of the LCC (ISO, 2004).	Comparing different alternatives with different life's length (ISO, 2004).
Internal rate of return (IRR)	The IRR is a discounted cash flow criterion which determines an average rate of return by reference to the condition that the values be reduced to zero at the initial point of time (Moles and Terry, 1997). It is possible to calculate the test discount rate that will generate an NPV of zero. The alternative with the highest IRR is the best alternative (ISO, 2004)	Result get presented in percent which gives an obvious interpretation (Flanagan et al., 1989).	Calculations need a trail and error procedure. IRR can be just calculated if the investments will generate an income (Flanagan et al., 1989).	Can be only use if the investments will generate an income which is not always the case in the construction industry (Kishk et al., 2003).
Net saving (NS)	The NS is calculated as the difference between the present worth of the income generated by an investment and the amounted invested. The alternative with the highest net saving is the best (Kishk et al., 2003).	Easily understood investment appraisal technique (Kishk et al., 2003).	NS can be only use if the investment generates an income (Kishk et al., 2003).	Can be used to compare investment options (ISO, 2004). But just if the investment generates an income (Kishk et al., 2003).

2.5.8 Project Risk and Uncertainty

It is clear from the previous discussion that LCC is a core part of any project so that managers can avert any possible additional costs and decrease the level of risk and impact of uncertainty. Therefore, LCC should be carefully assessed to help in the process of decision making. There are various risk assessment techniques which are either deterministic or stochastic (probabilistic).

A. Deterministic Technique

1. Sensitivity Analysis

Mian 2002 defines sensitivity test as a test of the outcome of an appraisal based on alternative values of one or more parameters about which there is uncertainty. It enables the investors to determine variations in the rate of return on an investment in accordance with changes in a critical factor.

2. Break-Even Analysis

The breakeven point is the level at which an investment recovers all of its costs and starts making profit.

B. Probability – Based Technique

According to this technique, uncertainties are random by nature and it is difficult to assess them except through studying historical data and predicting the what is probably going to happen and assess its quantity. The most famous approaches are Mont Carlo Simulation, Markov Chain, Multiple linear regression and Fuzzy approaches.

Summary for Mont Carlo Simulation and the Fuzzy approach will be mentioned.

1. ***Mont Carlo Simulation (MCS)***

Monte Carlo Simulation (MCS) is a stochastic technique that randomly sample values from the probability distribution functions (pdf's) of variables in a model to compute the likely outcomes (Davis, 2006). In other words, it is a method for finding a solution where no unique solutions can be obtained whereby a substantial amount of iterations is run to cover different possibilities and the results are used to get a pdf of probable outcomes from which statistics can be calculated such as mean, median, level of confidence and standard deviation.

2. ***Fuzzy Approach***

In this approach, subjective description is used to assess risk linguistically and this description can be presented in mathematical terms using fuzzy sets. So description is usually vague and qualitative and turned into haphazard mathematical terms. It has been used widely in risk analysis and cost uncertainty assessment (Kishk, et al, 2003; Davis, 2006).

2.6 OFFSHORE PLATFORM HISTORY

2.6.1 General

Offshore platform, which was constructed for the first time on the gulf coast of Louisiana, consists of two types: fixed and floating platform. The fixed platform is used to produce oil, while the mobile one is used for drilling and sometimes for a temporary accommodation. The first fixed platform was installed by the Kerr-McGee Company in 1947 (Chkrabarti, 2005). These two types are different in structure, transport and function, but they have a common characteristic that they both have deck space, payload capacity to support equipment and production operations. In the fixed platform, deck loads are moved to the foundation material under the seabed through steel piles while in the floating platform, they are moved by buoyancy force of the hull supporting the deck.

A fixed offshore platform consists of an upper part and lower part. The upper part is above the sea level and contains a number of decks while the other is under the sea level and it consists of jacket legs, tubular members driven through its main piles that carry the topside module. Since the first offshore well was constructed in the Gulf of Mexico, more than 10,000 offshore platforms of various types and sizes have been constructed (Chkrabarti, 2005).

2.6.2 Major Structural Component for Fixed Platform

Chkrabarti, 2005 lists the following parts as the main component parts of a fixed platform:

A. Deck

This supports the drilling and production equipment, as well as and life support systems, of the platform

B. Jacket

It provides supports for the deck, conductors, and other substructure, such as boat landing and barge bumpers.

C. Foundation

Piles driven through the jacket legs fix the jacket atop the seabed.

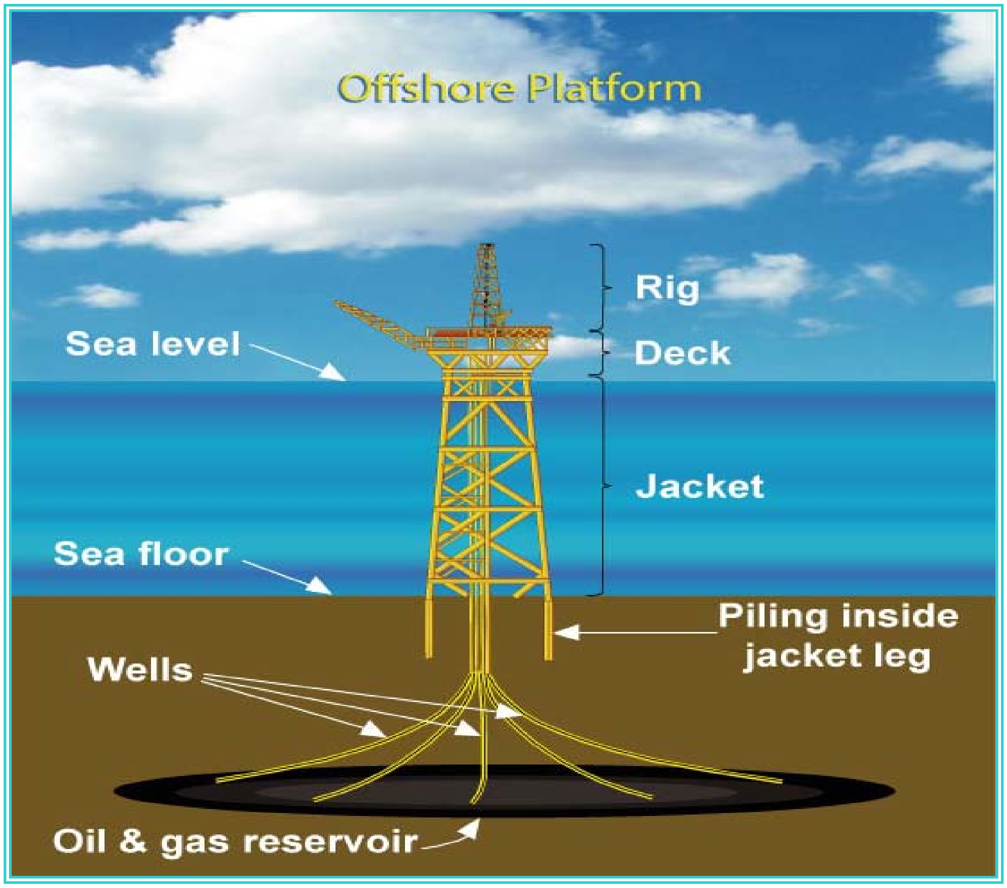


Figure 2.3: Offshore Platform Components (State of California, 2007)

2.6.3 Offshore Loads

Chkrabarti, 2005 mentions two major types of loads considered in offshore platforms, static which refers loads which come from gravity and dynamic loads which refer to mobile loads that come from the variable wind and waves**.**

Chkrabarti, 2005 also classifieds the major loads based on its function, location and construction methods as shown down:

A. **Functional Loads**

- Deck & Equipment Loads

These include dry and operational weight of the deck equipment and facilities, as well as the self weight of the structural members.

B. **Environmental Loads**

- Metocean loads

These loads, which include wind, wave, and current, generally affect the jacket design.

- Ice loads

If the platform is located in cold regions, calculations must be made for loads from ice, ice floes and snow on the platform. Cold temperatures affect the type and quality of the materials.

- Seismic loads

Loads caused by the earthquakes must be taken into account if the platform is located in a seismic zone.

- Seabed movement

Settlements due to motion of the waves can cause depletion of the reservoir or soil consolidation.

C. Construction Loads

- Assembly and erection loads

These loads result from lifting of the deck and jacket during construction phase.

- Transportation loads

The deck and jackets are brought to the installation site by transportation barges. Temporary braces are installed to the barge deck to ensure that the structures stay on the barge and resist all transportation loads.

- Installation loads

Jackets may be lifted or launched from barges using lifting beams uprighted and placed over the intended seabed location using derrick barges. Decks may be lifted or floated over jackets, so calculations must be made for loads and stress on the structures from these operations.

D. Accidental Loads

Refer to loads may occur due to human error, or operational or equipment failure such as :

- Vessel impact loads from construction equipment.
- Dropped objects.
- Fires and explosions caused by process equipment vessel or pipe.

Calculations must be made for loads and stress on the platform from these actions.

2.6.4 Codes and Standards

The following codes and standards are used for design fixed offshore platforms:

- API RP 2A, Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms - Working Stress Design, latest edition;
- AISC Manual of Steel Construction, Allowable Stress Design, latest edition;
- NACE RP 0176, "Corrosion Control of Steel Fixed Platforms Associated with Petroleum Production";
- American Welding Society (AWS) AWS D1.1, Structural Welding Code, Steel;
- (NACE) RP 0176, Corrosion Control of Steel Fixed Offshore Platforms Associated with Petroleum Production

2.7 MATERIALS FOR OFFSHORE STRUCTURE

2.7.1 Introduction

Chkrabarti, 2005 states that cost, safety, and reliability of offshore developments depend largely on the cost-effective and proper selection of materials for the different components. Good materials are characterized based on several parameters including type, strength, fracture control, corrosion resistance, chemistry, and weldability. The selection of materials for applications which may affect the operational safety and reliability level shall be made among the listed qualified materials. Norsok Standard states that qualified materials have to meet the following requirements:

- The material should be listed by the relevant design code for use within the stated design requirements.
- The material should be standardized by recognized national and international standardization bodies.
- The material should be readily available in the market and stocked by relevant dealers.
- The material should be readily weldable, if welding is relevant, and known by potential fabricators.
- The material should have a past experience record for the applicable use, e.g. same type of component and dimensional range.

2.7.2 Factors Affecting Material Selection

Structural members are fabricated using different materials, including carbon steel, corrosion-resistant alloys, and composites.

The following key factors shall be applied to the material selection:

- Materials market availability.
- Spare parts availability.
- Design life.
- Inspection and corrosion monitoring possibilities.
- Experience with materials and corrosion protection methods from conditions with similar corrosivity.

- Philosophy applied for maintenance and degree of system redundancy.
- Weight reduction.
- Fracture toughness.
- Fatigue resistance.
- Weldability.
- Machine-ability.
- Operating conditions such as :
    1. Operating loads and environments.
    2. Possible extreme and upset conditions.
    3. Operating temperature.
    4. Environmental issues related to corrosion inhibition and other chemical treatments.
- Mechanical Properties:
    1. Tensile strength.
    2. Yield stress.
    3. Ultimate strength and percent elongation.
    4. Charpy V- notch impact tests results.
    5. Strain age test .
    6. Through Thickness (Z direction) tensile testing.

If materials and fabrications represent significant investment LCC becomes very necessary for the material selection.

2.7.3 Classification of Materials

Chkrabarti, 2005 present the following classification of material:

2.7.3.1 Structural Seel

These are carbon and low alloy steels used for structures members and pipelines.

2.7.3.2 Production Equipment Steel

Theses are carbon, low alloy, and alloy steels used for pipes, fittings, production equipment, and process equipments.

2.7.3.3 Corrosion-Resistant Alloys

These materials are used for equipment that is subjected to corrosive environments containing CO2 and H2S. Some of these materials are stainless steel, nickel base alloys, and titanium alloys.

2.7.3.4 Non-Metal

These include plastic and composite materials.

This study will focus on the structural steel and composite materials.

2.7.4 Steel in Offshore Structures

Structural steels generally are specified, based on the appropriate national or industry standards such as ASTM (American Society for Testing and Materials), API (American Petroleum Institute) and AISC (American Institute for Steel Construction). Structural steels are characterized by the following parameters:

- Minimum yield strength
- Minimum ultimate strength
- Minimum elongation at rupture
- Notch toughness at low temperature
- Weldability
- Fatigue stress
- Resistance to corrosion

2.7.5 Composite Materials in Offshore Structures

Shafeeq 2006 states that composite materials consist of an assemblage of two materials of different natures that allows us to obtain a material of which the set of performance characteristics is greater than that of the components taken separately. A composite material consists of one or more discontinuous phases distributed in one continuous phase; the discontinuous phase usually is harder and with material properties superior to those of the continuous phases. The discontinuous phase is called reinforcement, like fibers, while the continuous phases is called matrix.

The combination results in a material that maximizes specific performance properties.

The fibers (reinforcing agent) provide the strength and stiffness, while the polymer resin (matrix) serves as a binder. When a load is applied to the composite, it is resisted by fibers through the polymer binder (Nizamaudden, 2008).

In fiber-reinforced composites, fibers are the principal load carrying members, while the surrounding matrix keeps them in the desired location and orientation. Matrix also acts as a load transfer medium between the fibers, and protects them from environmental damages due to elevated temperatures, humidity and corrosion (Shafeeq, 2006)

Fiber reinforced polymer (FRP) is the general term for composites. It is defined as fiber reinforced polymer (plastic) or matrix. FRP composites are anisotropic in which is mean that the properties appear in the direction of the applied load In other words it means the mechanical properties are in the direction of the fiber placement unlike the steel and aluminum which are isotropic which means uniform properties in all direction.

Many terms have been used to define FRP composites. Modifiers have been used to recognize a particular fiber such as Glass Fiber Reinforced Polymer or Plastic (GFRP), Carbon Fiber Reinforced Plastic (CFRP. Other markets use Fiber Reinforced Composites (FRC), Glass Reinforced Plastic (GRP) and some markets refer to the fiber's name and the type of resin such as (GRE) Glass Fiber Reinforced Epoxy. However all the terms mean the same thing, i.e., FRP composites.

2.7.5.1 Classification By Matrix

Organic matrix

Polymer resins with mineral fibers, organic fibers and or metallic fibers.

Metallic matrix

Alloys of aluminum, magnesium, and/or titanium as matrices with mineral fibers and/or metallic fibers.

Mineral matrix

Composite ceramic as matrices with metallic fibers like boron, metallic particles like cermets, and/or mineral particles like carbides.

This study will present the Organic Matrix that is used in composites materials.

2.7.5.2 Organic Matrix

The matrices used in composite materials have the role of transferring the mechanical loading to the fibers and to protect them from outside environment, so the resins must be quite flexible and offer good compatibility with the fibers. Two large families of polymer resins exist:

a. Thermoplastic resins

b. Thermosetting resins

Because thermosetting resins have mechanical properties, and especially higher thermo-mechanical ones than of those thermoplastic resins as a result of these higher characteristics, thermosetting resins generally are used in the manufacture of composite materials (Berthelot, 1999).

2.7.5.3 Thermosetting Resins

The principal thermosetting resins used in manufacturing composite materials are:

- Unsaturated polyester resins like condensed polyesters and vinyl esters
- Condensation resins like phenolics
- Epoxide resins

The study will focus on the Polyester/Vinyl ester and Phenolic resins.

Polyester Resins

These most widely used of all resins have the following advantages:

- Good stiffness resulting from a quite high modulus of elasticity
- Good dimensional stability
- Good wet-ability of fibers and cloths
- Ability to be manufactured
- Good chemical behavior
- Low production cost
- Good chemical resistance to hydrocarbons (petrol, fuel, etc.)

Among the disadvantages are:

- Mediocre behavior with temperature less than 120°C in continuous use
- Considerable shrinkage on the order of 8–10 percent
- Flammability

Vinylester Resins

It has the same advantages and disadvantages of the polyester , however, vinylester resins are stronger than polyester resins and offer better resistance to moisture absorption than polyester resins (Berthelot, 1999).

Phenolic Resins

The best known of these is Bakelite; these resins have these advantages:

- Excellent dimensional stability
- Good thermal stability
- Good chemical resistance
- Low shrinkage
- High temperature resistance
- Excellent fire, smoke and smoke toxicity properties than Polyester and Vinyl ester.
- Good mechanical characteristics
- Low cost

Among the disadvantages are:

- Low production rate because the molding process is done by pressure
- Dark colors of the resins

2.7.5.4 Classification By Fiber

Shafeeq 2006 and Nizamaudden 2008 define fiber as an important element in a composite because of its high tensile and impact strength, lightweight and excellent fatigue resistance. Fiber reinforced composites have largely replaced metals and now are used in the application where fatigue resistance is required.

The fibers generally occupy 30 to 70% of the volume in the composites. There are various types of fibers used as reinforcements in composites; these include carbon, boron, aramid, graphite, glass materials. Each one possesses different chemical and mechanical properties, and their durability gets affected by exposure to different environments.

The most common types of fibers used in advanced composites for structural applications are the glass and carbon. The glass fiber is the least expensive and carbon being the most expensive.

In this research the glass fiber will be studied as reinforcement in composite materials.

2.7.5.5 Glass Fibers

Glass in bulk form is characterized by great brittleness attributed to a high sensitivity to cracking. However, when made in the form of fibers of small diameter, glass loses this character and then has good mechanical characteristic. And because glass fibers have low cost compared to their high tensile and impact strength, lightweight and corrosion resistance, they have become the most widely used as reinforcement (Berthelot, 1999).

There are three types of glass fibers: are E-glass, S-glass and C-glass. E-glass is designated for electrical use, S-glass for high strength and the C-glass is for high corrosion resistance. E-glass has good strength and high electrical insulating properties at low cost. It is considered to be the predominant reinforcement for the polymer composites, and the most common glass fiber material used in civil structures (Shafeeq, 2006; Nizamaudden, 2008).

GRP, Glass Reinforced Plastic

As mentioned previously, FRP composites are defined as fiber reinforced polymer (plastic) or matrix. FRP composites are anisotropic which is mean that the properties can take place in the direction of the applied load. In other words it means the mechanical properties are in the direction of the fiber placement, unlike the steel and aluminum which are isotropic which means uniform properties in all directions. In structural application glass reinforced plastic is used widely, and the most common thermosetting resins used in the GRP are Polyester, Vinylester and Phenolics.

2.7.6 GRP Mechanical Properties Compare to Steel

The mechanical properties are affected by the type and the quantity of materials selected as well as to the manufacturing process to fabricate the product. The major factors that affect the mechanical properties are:

- Type of fiber reinforcement for example (E,S or C glass fiber).
- Type of resin (Polyester, Vinyl ester or Phenolics).
- Percentage of the fiber in the product.
- Orientation of the fiber.
- Manufacturing process.

As mentioned previously the composites are made of two major parts the fibers and the resin or the matrix. The fiber is the strongest material which has high modulus of elasticity and high ultimate strength more than steel, however the resin has very low modulus of elasticity and strength but when it is combined with the fibers yield a high strength and high modulus composites. The main function of the resin is to transfer the stress to the fibers and bind the fiber together as well as protect the fibers from mechanical and environmental damages. The Table (2.2) below summarize a comparison between glass fiber as organic and unreinforced plastic (polyester, vinylester and phenolics) as well as the steel.

Table 2.2: Material Properties

Material properties	Specific Gravity	Ultimate Tensile Strength (MN/M^2)	Modulus of elasticity (GN/M^2)
Glass Fiber			
E -Glass	2.55	3500	73.0
S-Glass	2.5	4900	87.0
Thermosetting Resin			
Polyester	1.28	45-90	2.5-4.0
Vinyl ester	1.30	70-80	3-4.0
Phenolics	1.40	45-59	5.5-8.0
Steel			
Mild Steel	7.80	370-700	210.0

From Table (2.2) , we notice that glass fiber has ultimate strength more than the traditional construction materials while resins have low strength; however when these two materials are combined in one (composites), they will yield better materials in terms of strength compared to the weight ratio. Table (2.3) shows a comparison between the composite glass fiber reinforced plastic and the steel.

Table 2.3: Material Properties for the GRP VS Steel

Material properties	Specific Gravity	Ultimate Tensile Strength (MN/M^2)	Modulus of elasticity (GN/M^2)
Glass Reinforced Plastic GRP			
GRP	1.6-2.0	60-1250	6-50
Steel			
Mild Steel	7.80	370-700	210.0

From the above Table we notice that GRP has high ultimate strength to weight ratio; however, steel is superior in terms of Modulus and this gives high resistance to bending and elongations. In order to give comparable performance the thickness of the GRP has to be increased.

The variety shown in Table (2.3) in the ultimate strength and Modulus of elasticity is due to the factors which have been mentioned earlier.

In terms of fatigue, Carbon and Aramid FRP have high fatigue characteristic three times more than steel; however, Glass FRP are generally less than Steel (Boyd, 1997).

2.8 MAIN CONCERNS ASSOCIATED WITH OFFSHORE STRUCTURE

2.8.1 Corrosion

Corrosion is defined as the deterioration of material by reaction to its environment. It results from a natural tendency in metals to return to their natural state. For instance, iron in the presence of moist air will revert to its natural state, iron oxide. Metals can be corroded by the direct reaction of the metal to a chemical; e.g., zinc will react with dilute sulfuric acid, and magnesium will react with alcohols (John et al, 1994).

Substances differ in their impact on metal. For example, sea water can be said to be more corrosive than fresh water as it contains approximately 3.5 percent of salt and lightly alkali of PH8 and is fairly electrical conducting electrolyte. Conductivity of electricity of a substance plays a main role in the degree of its corrosivity, that is why sea water is higher than fresh water. Besides, it has abundant existence of chloride ions which easily penetrate the surface protective films formed on the metal. Manufacturers take into account the factor of corrosivity in sea water and protect materials against corrosion (Lee et al, 1996).

2.8.2 Offshore Steel Corrosion

Most offshore structures are made of metals which are susceptible to electrolytic corrosion, and this entails much attention to protect such material from corrosion. Most of the offshore structures are made of carbon steel or low alloy steel as they are relatively cheap and they are susceptible to corrosion and have to be protected against it.

2.8.2.1 Areas Subject to Corrosion

Edge Corrosion

Edges are usually exposed to strikes and knocks during shipment and installment and they are more prone to corrosion than other parts. Besides, sometimes the edges are coated with protective material and this coat shrinks as a result of use or environmental conditions and makes the edges exposed to external destructive factors (John et al 1994; Thumborg, 2007).

Crevice Corrosion

These are the pits in the structure where parts and inserted together. These are usually open to air and moisture which makes them corrode inside. As a result of the many connections and edges between the bolted elements. Crevice corrosion occurs in the pockets that form when pieces of metal are held together in a lap joint, under washers or between a bolt and a nut. When there is lack of oxygen in a pocket it becomes like an anode to the surface outside. There is a second type of crevice corrosion which results from salt and moisture inside the pocket which makes it a cathode and the exterior becomes a cathode and as a result severe corrosion occurs (John et al 1994; Thumborg, 2007).

Exfoliation Corrosion

In this type of corrosion, steel swells and disintegrates and flakes off into layers. This process is called which refers to a case where layer corrosion h starts at the edge, proceeds within the body of the material in paths parallel to the rolling direction of he steel. The corrosion formed is greater in volume than the metal it replaced, and the layers of steel are forced apart (John et al 1994; Thumborg, 2007).

Flat Surface Corrosion

Flat surface corrosion occurs when the material is approaching end of life due to corrosion of coating and paint system which protects steel (John et al 1994; Thumborg, 2007).

2.8.3 Harmful Effects of Corrosion

According to (eds Ashworth et al, n.d) corrosion has a very serious impact on performance even if it occurs to a small portion of the metal and can cause structure failure or break down. Moreover, it can cause hazards that to the people who work on the site as a result of structure failure or break down like what happens in bridges, cars or aircraft. Corrosion also causes loss of time in availability of profile-making industrial equipment. Needless to say, it decreases the value of goods due to deterioration of appearance. In case of preparation of liquids through corrosive pipes, the liquids are contaminated (e.g. beer goes cloudy when small quantities of heavy metals are released by corrosion). In addition, perforation of vessels and pipes can cause a lot of harm to the surroundings. For example a leaky domestic radiator can cause expensive damage to carpets and decorations, while corrosive sea water may enter the boilers of a power station if the condenser tubes perforate, and if there is loss in metallic coating that protects a pipe surface, it becomes frictional and there is a possibility of bearing properties, ease of fluid flow over a pipe surface, electrical conductivity of contacts, surface reflectivity or heat transfer across a surface. Corrosion also causes mechanical damage to valves, pumps, etc, or blockage of pipes by solid corrosion products. Finally, corrosion adds complexity and expense. This illustrates that equipment needs to be designed to withstand a certain amount of corrosion, and to allow corroded components to be conveniently replaced.

2.8.4 Corrosion Control and Cost of Corrosion Control

2.8.4.1 Corrosion Control Methods

As per Koch and Ruschau in their report, the corrosion control methods that were considered include protective coatings, corrosion-resistant metals and alloys, corrosion inhibitors, Composites, anodic and cathodic protection.

Protective Coatings

Both organic and metallic coatings are used to provide protection against corrosion of metallic substrates

Organic Coatings

The major organic coatings are often classified by a curing mechanism, with the two basic types of cured coatings being nonconvertible and convertible.

The common types of nonconvertible coatings include chlorinated rubber, vinyls, Acrylic, bitumen, flame spray polymer and coalescence coatings.

Most convertible coatings cure by polymerization. Polymerization occurs when two or more resin molecules combine to form a single, more complex molecule. There are four main types of polymerization used in coating technology.

- Oxygen-induced polymerized coatings like alkyds and drying oils.
- Chemically-induced polymerized coatings like epoxies, polyurethanes.
- Heat-induced polymerized coatings polyester, vinyl ester, phenolics and silicons.
- Hydrolysis-induced polymerized coatings like inorganic zinc and Moisture-cured polyurethanes.

Metallic Coatings

The most widely used metallic coating process for corrosion protection are metallizing and galvanizing which involves the application of metallic zinc to carbon steel for corrosion control purposes.

Galvanizing

Hot-dip galvanizing differs from other zinc coatings and the metallizing process in that the zinc is alloyed to the metal during galvanizing. The degree of protection offered by galvanizing depends entirely on the thickness of the galvanized layer. Hot-dip galvanizing is the most common process, and as the name implies, it consists of dipping the steel member into a bath of molten zinc.

Metallizing

Metallizing is defined as the application of very thin metallic coatings for either active corrosion protection (zinc or aluminum anodes) or as a protective layer (stainless steels and alloys).

Metal and Alloys

Corrosion-resistant alloys are used where corrosive conditions prohibit the use of carbon steels and where protective coatings provide insufficient protection or are economically not feasible. These alloys include stainless steels, nickel-based alloys, and titanium alloys.

Corrosion Inhibitors

A corrosion inhibitor is a substance which, when added in a small concentration to an environment, effectively reduces the corrosion rate of a metal exposed to that environment. It acts by interaction and reaction between the corrosion inhibitor and the metal surface resulting in the formation of an inhibitive surface film. Manufacturers use this method as an economic way and an alternative to stainless steels and alloys, coatings, or non-metallic composites. The major industries that use corrosion inhibitors are petroleum production and refining. Inhibition is used internally with carbon steel pipes and vessels as an economic corrosion control.

Composities

Composites made of fiber (glass or carbon fibers) reinforced thermoset resin are frequently used in construction for their corrosion resistance properties.

Composites found applications as a replacement for steel as handrails, I-beams, pipes, tanks and many other applications that are made of steel.

Because composites in these applications are replacement for steel, the difference in cost between steel and composite is the money spent to combat corrosion and not the total cost of the composite.

2.8.4.2 Cost of Corrosion Control

Koch and Ruschau have reported that the total annual cost of corrosion estimated with these methods for the average year of 1998 was $121.41 billion, more than 100 billion have spent in protective coatings, refer to Table 2.4.

Table 2.4: Cost of Corrosion Control (Koch & Ruschau)

MATERIAL AND SERVICES	RANGE	AVERAGE COST	
	($ x billion)	($ x billion)	(%)
Protective Coatings			
Organic Coatings	40.2 – 174.2	107.2	88.3
Metallic Coatings	1.4	1.4	1.2
Metals and Alloys	7.7	7.7	6.3
Corrosion Inhibitors	1.1	1.1	0.9
Polymers	1.8	1.8	1.5
Anodic and Cathodic Protection	0.73 – 1.22	0.98	0.8
Services	1.2	1.2	1.0
Research and Development	0.020	0.02	<0.1
Education and Training	0.01	0.01	<0.1
TOTAL	**$54.16 – $188.65**	**$121.41**	**100%**

2.8.5 Fatigue Stress

Fatigue is the failure of a component subjected to repeated loads at levels below the short-term ultimate strength of the materials.

2.8.6 Weld Inspection

All welds have discontinuity, so the role of weld inspection is to determine the size of this discontinuity. If discontinuity is small, the performance of the of the welded parts is not affected; however, large discontinuities affect the performance of the weldment and then as a result the weld will fail.

The method used here is the NDE Non-Destructive Examination. This method is used to check the quality of the weld without damaging the weld itself. The responsibility of the inspector is to determine the point at which a discontinuity becomes large and critical. The methods used for NDE for topside structure include:

- Visual Inspection.
- Magnetic Particle Inspection.
- Liquid Penetrant Inspection.
- Ultrasonic Testing.
- X-ray Inspection.
- Visual Inspection:

Visual inspection considers the most common types among the offshore inspection methods. This type is made to tell where the defect like cracks and inclusion is. Visual inspection is limited to the external surface of weld and looks for spatter and to see if all slag has been removed from the weld. Visual Inspection can involve use of templates, gauges, magnifying glass, scales and cameras.

Magnetic Particle Inspection:

This type is best applied to inspect welds in the material that can be magnetized. First, the place is cleaned well before applying the magnetic material which can be liquid or in its dry form. After that, the metal is subjected to the effect of strong magnetic field, as a result, metal particles are attracted to the cracks and pits because of their magnetism. When magnetic field is removed, the inspector will find a concentration of the magnetic particles in the area of every crack. If defects or cracks are found, the cracks and metals around it are removed. The part is rewelded and tested again.

Liquid Penetrant Inspection:

This method uses colored liquid dyes and fluorescent liquid penetrants to check for surface defects.

Ultrasonic Testing:

This method is used to determine the size of discontinuities (flaws) by means of sound waves. The sound waves are passed through the material and reflected from flaws.

X-Ray Inspection:

For checking the internal discontinuities x-ray will be applied. A wave of energy will pass through the materials and produce their image on film.

2.9 OFFSHORE APPLICATION OF FRP

Most applications of FRP in offshore industries have been made in the areas of pipe work. Glass fiber reinforced plastic is used in both offshore and onshore application.

Initial cost of FRP products exceeds that of metallic products, but because of their resistance for corrosion and their lower cost in its installation compared to metals such as cooper, nickel alloys, stainless steel and titanium, this will leads to lower life cost.

Two main areas in offshore industries apply the FRP products, Piping and structural systems.

2.9.1 Pipe Work and Tanks

GRE, glass reinforced epoxy has been used offshore for both low and high pressure application. Standards for the use of composite piping such as ISO/DIS 14692(2000), and qualification procedures such as ASTM 2992 and ISO 109281(1997), are facilitating the wider use of these products.

Fire water pipe work is an example of successful application of GRE. Fire water system requires to be repeatedly tested with sea water, which causes corrosion problems in case of metallic pipes, in addition, blockage of deluge nozzles occurs when wax additives are used to prevent corrosion in the metallic pipes (University of Newcastle Upon Tyne & HSE 2003).

FRP have been used for making tanks for water and diesel storage and pressure vessels. There are codes that enable both tanks and vessel to be designed for moderate pressure such as BS 4994, 1997; ASME, 1992.

This will lead in the near future to its use in the high pressure processing equipment as well as where non corrosion materials are required.

In the oil and gas industries, for example, SHELL had more than 600 km of epoxy-based FRP piping installed by 1990 with 37% of the piping used for onshore hydrocarbon flow lines. SHELL had 10 years of successful experience with pipe diameters smaller than 150 mm where the highest pressure used was 95 bar and the maximum temperature was up to 650C. Significant cost savings were obtained in comparison with carbon steel when considering corrosion protection cost. A more recent study in 1999 indicated that SHELL has over 2250 km of FRP piping in service (Shafeeq, 2006).

Due to the widespread of the corroded metallic pipes in oil and gas industries, a number of FRP material solutions have been developed. This involves adding reinforcement to the exterior of the pipe to compensate for the loss of section thickness due to corrosion. A clock spring system which was developed in USA by the Gas Research Institute is the most successful system. The procedure is to clean the surface and then to fill the external pits to allow stress to be transferred from the pipe to the repair. After that, clock spring laminate is wound around the pipe, which is coated with adhesive which was allowed to cure. Recently, GRE tube started to be used in rehabilitation of water injection wells with corroded steel casings (University of Newcastle Upon Tyne & HSE 2003).

2.9.2 Structural Application

Composite materials are used in offshore at a small scale compared to piping systems. In structural application the FRP is used in gratings, walkways and handrails.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 INTRODUCTION

The research being of the exploratory type will consist of two parts. The first part of this research will use a model for selecting and evaluating the materials at topside offshore platform to prove that the selected materials are qualified form the value engineering point view. After having been proven that the selected materials are qualified from the value engineering point of view, the second part will deal with the life cycle costing techniques and for that the AB-Platform at Al-Shaheen field in Qatar is selected as case study. The life cycle costing techniques will apply on grating and handrail systems for the AB-platform. As mentioned before two types of materials the study will focus on, the steel and the glass reinforced plastic.

3.2 DATA SOURCE & COLLECTION

3.2.1 Case study AB-platform at Al-Shaheen Field (general)

According to A.P.Moller-Maersk Group websites that “in 1992, Maersk Oil entered into an Exploration and Production Sharing Agreement with Qatar Petroleum on behalf of the Government of Qatar. Under the agreement, Maersk Oil would evaluate the possibilities of establishing commercial oil production from **Block 5** - an area of originally 3,500 square kilometers offshore Qatar. The exploration and exploitation rights include all Block 5 geological formations above the Khuff Formation, which contains the "North Field", the world's largest non-associated natural gas field.

The drilling of appraisal wells in the Al Shaheen Field was completed in 1994. An early test production scheme was agreed with Qatar Petroleum and implemented accordingly providing for start of regular oil production in 1994, 2 years after commencing the activities in Qatar. The Al Shaheen Field production facilities were extended during 1995 to 1996 with new subsea export pipelines, an additional single point mooring loading buoy, new process facilities and a STAR type wellhead platform.

Simultaneously, a number of horizontal wells were drilled in the field. Besides adding to the total production, the new wells targeted previously unexploited reservoirs, tested alternative well completion techniques and enabled water injection trials. During the period 1996-1999, further wells were drilled.

The Al Shaheen Field crude oil blend is lifted by customers from a floating storage tanker moored at the Al Shaheen Field location

For the purpose of further development of the Al Shaheen Field, a new development plan was prepared by Maersk Oil in cooperation with Qatar Petroleum in early 1996. Implementation of the development plan was initiated in March 1996, more than two years ahead of the time schedule visualized in 1992. The development plan including both primary and secondary recovery schemes contained provisions for three platforms A, B &C and up to 70 horizontal wells. The facilities were inaugurated in December 1998.

The next plan for development of the Al Shaheen Field was prepared in cooperation with Qatar Petroleum and agreed in February 2001. The Al Shaheen Field Development Plan 2001 comprises 40 new production wells, 20 new water injection wells and conversion of 14 existing wells to water injection, as well as new production platforms D, E&F, facilities for gas compression and a gas export pipeline to Qatar Petroleum's North Field Alpha Platform, offshore Qatar. The new Al Shaheen facilities were inaugurated by his Excellency the Second Deputy Prime Minister and Minister of Energy and Industries in February 2005.

In December 2005 Maersk Oil and Qatar Petroleum agreed on a plan for further development of the Al Shaheen Field. The development plan includes drilling of more than 160 additional horizontal production and water injection wells as well as construction of 15 new platforms and 300 km pipelines/cables. As part of the plan, Maersk Oil will build and operate additional facilities for gathering and delivery of associated gas to Qatar Petroleum for utilisation at their onshore plants. Implementation of the development plan is ongoing. In 2008 the oil production was in average some 300,000 barrels per day".

Figure 3.1: Alshaheen Field -Block 5 (A.P.Moller-Maersk Group Website)

3.2.2 AB Platform

AB Platform was constructed and installed in the first phase of developing the Al-Shaheen Field in 1998. It consists of two modules the first module which is the ABA has 5 levels as mentioned downed:

- Sub cellar deck at elevation +10.800 m above sea level.
- Cellar deck at elevation +14.100 m above sea level.
- Mezzanine deck at elevation +20.100 m above sea level.

- Main deck at elevation +27.300 m above sea level.
- and finally, Top deck at elevation +35.500 m above sea level.

The second module is the ABB, gas compression module which has been installed above the first module ABA. Gas compression module ABB consist of 3 levels as mentioned below:

- Lower deck at elevation +38.00 m above sea level.
- Middle deck at elevation + 46.600 m above sea level.
- Upper deck at elevation +52.600 m above sea level.

In addition to that the AB platform has connected to the accommodation platform with a bridge length of 97 meter almost.

Main structural materials are the steel, gratings and handrails that had been used are from the steel.

3.2.3 Vendor Data.

For the alternative materials (glass reinforced plastic), two main supplier in the gulf region are contacted to get the required information for the LCC costing model for the GRP materials.

3.3 SELECTING AND EVALUATING STRUCTURAL MATERIALS FOR OFFSHORE TOPSIDE PLATFORMS

3.3.1 Design Approach

- Materials selected have to be certified for offshore environment.
- Define factors affecting offshore materials selection.
- Weighted evaluation of the selected factors will be carried out by using scoring matrix.
- Evaluate materials against the weighted factors by using evaluation matrix.
- Ranked the materials, and based on that final decision should be taken.

3.3.2 Model Development

According to the model that had been developed by Flanagan et al 1989 for building materials selection, same concept will be applied here.

I. Qualitative Selection and Evaluation

Structural members are fabricated using different materials, including carbon steel, corrosion-resistant alloys, and composites.

The following key factors shall be applied to the material selection:

1. Mechanical Properties:

- Tensile and ultimate strength.
- Modulus of elasticity.
- Impact and strain age test.
- Fatigue property.

2. Durability and Environmental Stability :

   - Long term mechanical durability after exposure to offshore environmental like temperature variation, exposure to humidity and sea water.
   - Chemical and corrosion resistance.

3. Economic consideration:

   - Capital cost
   - Maintenance cost

4. Maintainability :

   - Ease of repair and cleaning
   - Corrosion monitoring system and protection methods.

5. Ease of offshore installation:

   - Offshore installation cost is very high, because it is required specific procedure and special equipments. In some projects the installation cost is double than initial cost.

6. Weight Reduction:

   Reduce the weight for the offshore platform is very important factors, and in some areas where structural members are highly utilized a materials with low weight must be selected. Also selection of materials with low weight will save a percentage of the installation cost.

7. Design Life.

8. Fire, Smoke and Toxicity Performance

The above key factors shall be weighted by using the scoring matrix as shown in chapter 4.

II. Quantitative Selection by Evaluation Matrix

In this stage the selected materials will be scored from 1 to 5 according to the degree to which it satisfied each of the criteria set out in the previous matrix. After that, the score will be multiplied by the weight for each criteria and finally, all scores will be added together to rank the materials, refer to chapter 4.

3.4 LIFE CYCLE COSTING FOR THE GRATING & HANDRAIL FOR OFFSHORE PLATORM AT TOPSIDE

3.4.1 Design Approach

The following steps were followed to obtain final results of life cycle costing model for the gratings and handrail systems:

- AB-Platform at Al-Shaheen Field in Qatar was selected as case study.
- Total quantities of the gratings and handrail systems for the AB-Platform were determined from the Existing drawings.
- Total Weights of the existing steel gratings and handrails were calculated to compare it with the GRP products.

- Collecting all information required related to the initial and maintenance costs for the GRP alternatives from vendors and materials suppliers.
- Initial, replacement and maintenance costs of the steel gratings and handrail were collected from steel suppliers and the Data base of Maersk oil Qatar.
- Installation and pre-fabrication costs for both steel and GRP products were calculated from the data base of Maersk Oil Qatar.
- Life time of the steel gratings and handrails were calculated from the Data base of Maersk Oil Qatar.
- Life time of the GRP products was provided from the vendors.
- Developing a model that is suitable for gratings and handrails systems at the topside of the offshore platforms.
- Using uniform annual methods to compare between the alternatives.
- Offshore platform is designed for 25 years as lifetime, so the analysis will be done based on it.
- 5% as interest rate was selected for making the LCC analysis.
- Sensitivity analysis was applied and has considered the followings factors:
    a. Discount rates are fluctuating at 10% and 15%.
    b. Deflation in the steel materials by 5% and offshore installation cost by 10% yearly.

c. Deflation in both steel materials and offshore installation cost by 10% yearly.

d. Age of platforms 20 and 30 years

3.4.2 Life Cycle Costing Model for Gratings and Handrail

Developing a model for LCC for Gratings and handrails systems need to consider the followings three main steps:

<u>MODEL</u>

A. Life time of the selected materials have to be determined.

B. Cost breakdown items for gratings and handrails systems were included:

✓ Capital costs of the product including:

a. Initial cost.

b. Prefabrications cost.

c. Offshore Installation cost.

✓ Maintenance cost.

✓ Replacement costs.

C. Sensitivity analysis.

Total life cycle costing was determined by applying annual uniform method to the above model and after that sensitivity analysis was applied.

CHAPTER FOUR

DATA COLLECTION AND DATA ANALYSIS

4.1 SELECTING AND EVALUATING MATERIALS FOR OFFSHORE PLATFORM AT TOPSIDE

4.1.1 Qualitative Selection and Evaluation

As mentioned early in chapter three the following key factors shall be applied to the material selection:

- Mechanical Properties.
- Durability and Environmental Stability.
- Economic Consideration.
- Maintainability.
- Ease of Offshore Installation.
- Weight Reduction.
- Design Life.
- Fire, Smoke and Toxis.

The above key factors will be weighted according to the importance to the desired criteria selected.

Two examples will be illustrated in this study according to two desired criteria, they are: economic consideration and the weight reduction.

EXAMPLE I- Economic Consideration

The Figure 4.1 shows how are the selected factors are weighted by the scoring matrix when the Economic Considerations are desired.

Weighted Performance Criteria		Scoring Matrix
Type of Material	**Offshore Grating for Topside**	
Main Criteria Required	**Economic Consideration**	

	Criteria	Raw Score	Assigned Wt.
A	Mechanical Properties	6	6
B	Durability & Environment Stability	4	4
C	Economic Consideration	10	10
D	Maintainability	5	5
E	Ease of Offshore Installation	8	8
F	Weight Reduction	6	6
G	Design Life	2	2
H	Fire, Smoke and Toxic	10	10

	B	C	D	E	F	G	H
A	A2	C2	A/D	E2	A1	A1	A/H
	B	C2	B/D	E2	F/B	B/G	B/H
		C	C2	C/E	C1	C1	C/H
			D	D/E	D/F	D/G	H2
				E	F/E	E1	H2
					F	F2	F/H
						G	H2

Please fill boxes of the above scoring matrix in one of the following ways:

A/B	means A is as important of B
A1	means A is minor importance over B
A2	means A is of medium importance B
A3	means A is of major importance over B

HOW IMPORTANT

3. Major Preference
2. Medium Preference
1. Minor Preference

Figure 4.1: Scoring Matrix (Example of Economic Consideration)

EXAMPLE II Weight Reduction

The Figure 4.2 shows how are the selected factors are weighted by the scoring matrix when the Weight Reduction is desired.

Weighted Performance Criteria		**Scoring Matrix**
Type of Material	**Offshore Grating for Topside**	
Main Criteria Required	**Weight Reduction**	

Criteria		**Raw Score**	**Assigned Wt.**
A	Mechanical Properties	6	4
B	Durability & Environment Stability	3	2
C	Economic Consideration	8	5
D	Maintainability	3	2
E	Ease of Offshore Installation	5	3
F	Weight Reduction	17	10
G	Design Life	3	2
H	Fire, Smoke and Toxic	9	5

	B	C	D	E	F	G	H
A	A2	C2	A1	A/E	F2	A/G	A/H
	B	C2	B/D	E1	F2	B/G	B/H
		C	C2	C/E	F3	C1	H1
			D	D/E	F3	D/G	H2
				E	F3	E1	H2
					F	F3	F1
						G	H2

Please fill boxes of the above scoring matrix in one of the following ways:

A/B	means A is as important of B
A1	means A is minor importance over B
A2	means A is of medium importance B
A3	means A is of major importance over B

HOW IMPORTANT	
3.	Major Preference
2.	Medium Preference
1.	Minor Preference

Figure 4.2: Scoring Matrix (Example of Weight Reduction)

4.1.2 Quantitative Selection by Evaluation Matrix

In this part, the weighted factors from the previous examples will be used to evaluate the selected materials by using evaluation matrix as show down Figure 4.3.

<u>EXAMPLE I- Economic Consideration</u>

From the previous stage, the assigned value for each criterion has been determined and shown in the assigned value raw. Refers to Figure 4.3

OFFSHORE GRATING — ECONOMIC CONSIDERATION											
Type of Materials	**CRITERIA**	**Mechanical Properties**	**Durability & Environ.**	**Economic Consideration**	**Maintainability**	**Ease of offshore Installation**	**Weight Reduction**	**Design Life**	**Fire, Smoke & toxic**	**Total**	**Rank**
	WT	**Assigned Value**									
		6	**4**	**10**	**5**	**8**	**6**	**2**	**10**		
STEEL GRATING	5	5							5		
	4										
	3		3	3	3			3			
	2					2	2				
	1										
	Sub. Tot										
		30	12	30	15	16	12	6	50	171	**4**
GRP GRATING PHENOLIC	5			5	5	5	5	5			
	4		4								
	3	3							3		
	2										
	1										
	Sub. Tot										
		18	16	50	25	40	30	10	30	219	**1**
GRP GRATING VINYLESTER	5			5	5	5	5	5			
	4		4								
	3	3									
	2								2		
	1										
	Sub. Tot										
		18	16	50	25	40	30	10	20	209	**2**
GRP GRATING POLYESTER	5			5	5	5	5	5			
	4		4								
	3	3									
	2										
	1								1		
	Sub. Tot										
		18	16	50	25	40	30	10	10	199	**3**

Figure 4.3: (Evaluation Matrix , Economic Consideration)

EXAMPLE II- Weight Reduction

EVALUATION MATRIX												
Type of Material :		**OFFSHORE GRATING**										
Desired Performance :		**WEIGHT REDUCTION**										
EVALUATING MATERIALS TO THE WEIGHTED PERFORMANCE												
No	**Type of Materials**	**CRITERIA**	**Mechanical Properties**	**Durability & Environ.**	**Economic Consideration**	**Maintainability**	**Ease of offshore Installation**	**Weight Reduction**	**Design Life**	**Fire, Smoke & toxic**	**Total**	**Rank**
		WT	**Assigned Value**									
			4	**2**	**5**	**2**	**3**	**10**	**2**	**5**		
1	STEEL GRATING	5	5							5		
		4										
		3		3	3	3			3			
		2					2	2				
		1										
		Sub. Tot	20	6	15	6	6	20	6	25	104	**4**
2	GRP GRATING PHENOLIC	5			5	5	5	5	5			
		4		4								
		3	3							3		
		2										
		1										
		Sub. Tot	12	8	25	10	15	50	10	15	145	**1**
3	GRP GRATING VINYLESTER	5			5	5	5	5	5			
		4		4								
		3	3									
		2								2		
		1										
		Sub. Tot	12	8	25	10	15	50	10	10	140	**2**
4	GRP GRATING POLYESTER	5			5	5	5	5	5			
		4		4								
		3	3									
		2										
		1								1		
		Sub. Tot	12	8	25	10	15	50	10	5	135	**3**

Figure 4.4: (Evaluation Matrix , Weight Reduction)

4.1.3 Conclusion:

From the above two examples, the GRP products have been ranked first , the next part is to use and apply the life cycle costing techniques to the above selected materials.

4.2 DATA COLLECTION

4.2.1 General

The data related to the AB platform has been collected from Maersk oil Qatar Data base, and from the existing drawings. The gratings and the handrails on AB platforms had been made from the steel. The steel as the base materials will be compared with the new GRP alternatives. The required GRP data have been collected by contacting the GRP suppliers at the Gulf region.

4.2.2 Data of the AB platform

AB platform has been installed in 1998 and consists of two modules; the first module which is the ABA module consists of 5 levels and the second module ABB consists of three levels. All structural materials have been designed in accordance to the following codes and specifications:

- ✓ API RP 2A-WSD Recommended Practice for Planning Designing and Construction Fixed Offshore Platforms 21ST Edition.
- ✓ AISC-ASD Manual of Steel Construction Allowable Stress Design, 9th Edition, 2nd Revision, 1995.

Age of Platform

Mainly offshore platform are designed for 25 years (lifetime).

Steel Gratings

Hot dip galvanized steel gratings 25mm thickness to ISO 1461 or ASTM A123 had been used in AB platform for corrosion protection, however, it has been found from MOQ data base that the lifetime of the steel gratings is 6 years and after this period the gratings have fully corroded due to the galvanizing damage. No maintenance is required over those periods; however, Replacement of new gratings is required after 6 years. Figures 4.5 and 4.6 show grating panels.

One of the main reasons of damaging galvanizing steel gratings is rigging and pulling heavy equipments on the gratings that damage the galvanizing layers. Consequently the corrosions start due the harsh environments on offshore.

Figure 4.5: Example of Grating Panel

Figure 4.6: Example of Grating Panel

Steel Handrails

Steel Handrails with steel grade A36 or similar have been used on AB platform with protective coating. Annual inspection for the handrails is required and usually maintenance is required every 5 years with new protective coatings and need to be replaced after 25 years. The other approach that is using in Maersk oil Qatar which includes no maintenance and just replace it after 12 years. In Maersk Oil Qatar welded connection is the common for the steel handrails no bolted connection are used.

The Table (4.1) summarizes the quantity take off of the steel gratings and handrails on AB platform.

Table 4.1: Grating Quantity take off at AB-Platform

AB-PLATFORM				
ABA-Module				
level	**Gratings Quantity (M^2)**	**Weight of Gratings (Kg)**	**Handrails Quantity (Lm)**	**Weight of Handrails (Kg)**
Subcellar Deck El+10.80	260	7280	153.5	5372.5
Cellar Deck El+14.100	1731	48468	190	6650
Mezzanine Deck El+20.10	1510	42280	199	6965
Main Deck El+27.300	0	0	192	6720
Top Deck El+35.50	0	0	116	4060
Main Stairs	230	6440	254	8890
AD-AB Bridge	110	3080	190	6650
Mis.Access Platforms	120	3360	80	2800
Sub total	**3961**	**110908**	**1374.5**	**48107.5**
ABB-Module				
level	**Gratings Quantity (M^2)**	**Weight of Gratings (Kg)**	**Handrails Quantity (Lm)**	**Weight of Handrails (Kg)**
Lower Deck El+38.00	0	0	87.8	3073
Middle Deck El+46.60	407.8	11418.4	80.1	2803.5
Upper Deck El+52.60	0	0	90.3	3160.5
Main Stairs	83.5	2338	110	3850
Mis.Access Platforms	60	1680	40	1400
Sub total	**551.3**	**15436.4**	**408.2**	**14287**

`

Summary	**Gratings Quantity (M^2)**	**Weight of Gratings (Kg)**	**Handrails Quantity (Lm)**	**Weight of Handrails (Kg)**
Total	**4512.3**	**126344.4**	**1782.7**	**62394.5**

Pre-fabrication Cost

For minimizing offshore assembly and also because steel gratings can only be cut with trouches and that work need to be controlled through the hot work permit system in offshore, the onshore prefabrication cost is high and estimated to be 50 percent of the initial cost of the gratings. Opposite the GRP gratings which can be cut to fit offshore with simple tools like Saw which mean no prefabrication process is required.

Offshore Installation Cost

It has been found from MOQ data base that $1m^2$ of grating needs 6 hours offshore to be installed this is include the hours need to remove the existing grating and replace it with the new one. For the handrail system, it was found that 1m long of handrail needs 8 hours for painting, 20 hours for scaffolding, 8 hrs for welding per joint and 4 hours for final fixing. See Table (4.2) that summarize the offshore installation hours for both steel gratings and handrails. Table (4.3) summarize offshore hours rate in USD.

Table 4.2 Man-hours for Offshore Installation

Offshore Man- Hours				
Material Type	Painting (hr)	Scaffoldings (hr)	Welding (hr)	Final Installation (hr)
Gratings	0	0	0	6/m^2
Handrails	8 Lm	20 Lm (First time)/ 10 Lm (Maintenance)	8 per Joint	4

Table 4.3 Man-hours Rate for Offshore Installation

Offshore Hours Rate			
Painting USD	Scaffoldings USD	Welding USD	Final fixing USD
40	45	50	40

4.2.3 Vendors Data for The Alternatives

Two main suppliers in the Gulf are contacted to get the capital cost of the GRP gratings and handrails. Different types of gratings are found based on the type of the manufacturing process that have been used.

GRP composite can be manufactured by using different types of techniques that include pultrusion process, hand lay-up, spry-up, filament windings, compression moulding, resin transfer moulding, compression molding and etc.The most common method of creating a desired structural shape that can be ultimately used for construction is pultrusion.

Because pultruded GRP gratings are the common types that are used in offshore industries and this study will be focus in GRP product made by this technique, so the pultrusion process will be described.

"Pultrusion is a manufacturing process for producing continuous lengths of reinforced polymer structural shapes with constant cross-sections. Raw materials are a liquid resin mixture (containing resin, fillers and specialized additives) and flexible textile reinforcing fibers. The process involves pulling these raw materials (rather than pushing, as is the case in extrusion) through a heated steel forming die using a continuous pulling device.

The reinforcement materials are in continuous forms such as rolls of fiberglass mat and doffs of fiberglass roving. As the reinforcements are saturated with the resin mixture ("wet-out") in the resin bath and pulled through the die, the gelation, or hardening, of the resin is initiated by the heat from the die and a rigid, cured profile is formed that corresponds to the shape of the die." (Strongwell, 2010).

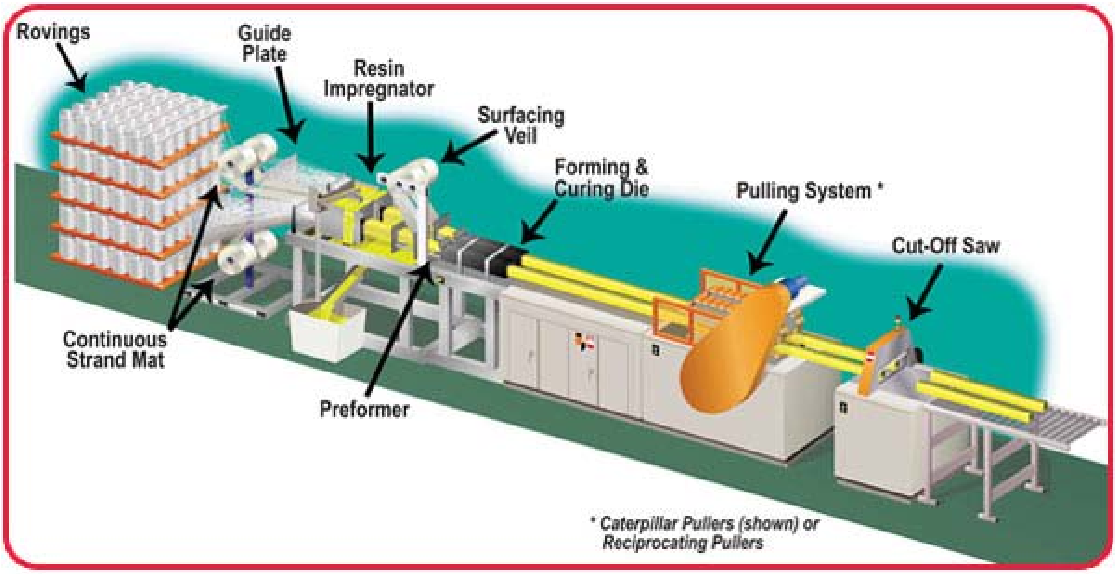


Figure 4.7: Pultrusion Process (Strongwell, 2010)

Offshore Installation Cost

Recently, GRP gratings are implemented in some of Maersk oil platforms and has been found that 1 m^2 needs 6 hours including cut to fit at offshore, however no prefabrication cost are recorded which mean that big saving can be made. For the GRP handrail systems bolted connection are used, however to make proper joint connection small steel brackets or angle will be welded to the main steel. After that, GRP handrails will be bolted to the brackets as shown down in Figure 4.8, scaffoldings will be required and as previous estimated 20 hours per meter length. Final fixing hours are estimated to be half of the steel handrails hours.

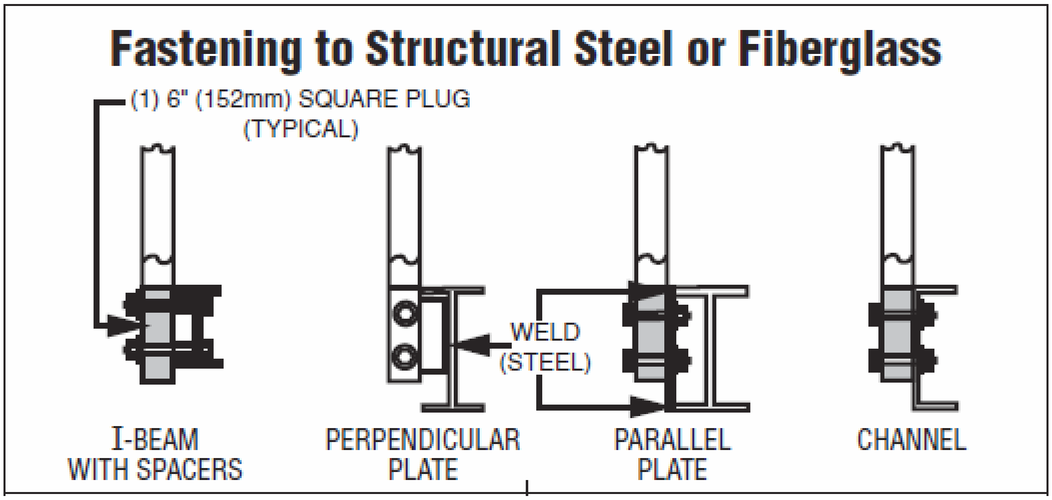


Figure 4.8: Example of GRP Handrail Connection to Steel Structure (Strongwell, 2010)

GRP Lifetime

Supplier's data mentioned that GRP products are fabricated and designed for 40 years.

4.3 DATA ANALYSIS FOR THE BASE MATERIALS

4.3.1 LCC for Steel Gratings

The following is a detailed analysis for steel gratings data that enter into the LCC model.

4.3.1.1 Cost Break Down

Capital Cost of Steel Gratings

Initial Cost: It was found from the steel grating vendor that one square meter is cost 86 USD.

Calculation

The total quantity of the steel grating as described in the previous section is 4512.3 m2.

Initial cost of the steel gratings will be 4512.3 x 86 USD = **388,057.8** USD

Pre-fabrication Cost: as described and mentioned in the previous section, the pre-fabrication cost was found to be equal to 50% of the initial cost.

Calculation

The pre-fabrication cost will be **0.50 x 388,057.8 USD = 194,028.9** USD

Offshore Installation Cost: Offshore installation cost is very costly for the offshore companies due to the labors wages and safety concern at offshore. It was from MOQ data base that one square meter of grating requires 6 hours to perform the job. The rate for one hour at offshore is 40 USD.

Calculation

The offshore Installation cost will be calculated as follows :

Total quantity of grating x 6 hr x hour rate.

= 4512.3 x 6 x 40 USD = 1,082,952 USD say, **1,083,000.0 USD**

As we can notice that offshore installation cost is more than initial cost.

Summary of the capital cost:

Total capital cost equal 388,057.8+194,028.9+1,083,000.0= **1,665,086.70 USD**

Maintenance Cost

There is no maintenance cost for the steel gratings opposite than the handrails which needs to be painted frequently.

Replacement Cost

Hot dip galvanized steel gratings had been used in AB platform for corrosion protection**,** however, the lifetime for the steel grating at Al-Shaheen field was found 6 years, this mean the replacement with new gratings have to be done every 6 years. The 6 hours required to install one square meter of gratings has considered the hours for the removing parts. This mean demolishing cost is negligible.

Calculation

Replacement cost will be calculated as follows :

Replacement Cost = Capital Cost = 388,057.8 + 194,028.9 + 1,083,000.0= **1,665,086.70 USD.**

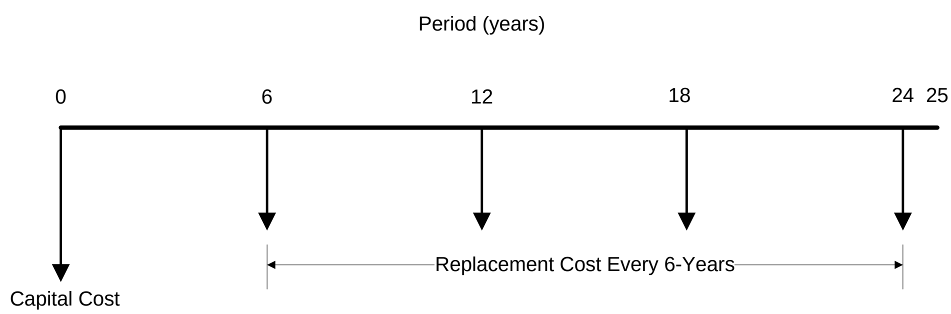
Table 4.4: Cost Break Down for The Steel Gratings

COST BREAK DOWN FOR THE STEEL GRATING	
Capital Cost	**1,665,086.70 USD**
Replacement Cost	**1,665,086.70 USD**
Lifetime	**6-YEARS**

4.3.1.2 Cash Flow Diagram

Elements of the cash flow as described in the literature review are cash transaction, periods and interest rate. To establish a cash flow diagram for the LCC model for the steel gratings the periods and interest rate will be defined. In the LCC of the steel gratings the periods will be the age of the platform which is defined earlier as 25 years, and 5% will be consider as interest rate over this periods.

The cash flow diagram will be as follows:



Cash Flow Diagram

4.3.1.3 Equivalent Uniform Annual Worth (EUAW)

Solving the previous cash flow using engineering economy equations as follows:

<u>Step 1:</u>

All future amount of money at years 6, 12, 18 and 24 will be discounted to present by using *Present worth Value* equation as follows:

$P= F [1/ (1+i)^{N}] = F (P/F, i, N)$ …………………………………………..Eq 4.1

<u>Step 2</u>

All present amount of money will be converted to an equivalent uniform annual cost by using AUP annual uniform payment method as follows:

$A = P\,[i\,(1+i)^{N} / (1+i)^{N} - 1]$ ……………………………………...…Eq 4.2

4.3.2 LCC for Steel Handrails

The following is a detailed analysis for steel handrail data that enter into the LCC model.

4.3.2.1 Cost Break down

<u>Capital Cost of Steel Handrail</u>

Initial Cost: It was found from the steel Handrail vendor that one meter long (LM) is cost 200 USD includes painting materials and prefabrication cost.

<u>Calculation</u>

The total quantity of the steel handrail as described in the previous section is 1782.7 LM.

Initial cost of the steel handrails will be 1782.7 LM x 200 USD = **356,540** USD

Offshore Installation Cost: It was found from MOQ data base that one meter long of handrail requires 20 hours to make scaffolding and pressure tent for welding, and 10 hours incase of maintenance, 8 hours for painting, 4 hours for final fixing and installation. About welding hours, each 1.5 m long of handrails has two welding joint and each joint take 8 hours. Refer to Tables (4.2) & (4.3) for Man-hours and Man-hour's rate at offshore.

Calculation

The offshore Installation cost will be calculated as follows :

Cost of scaffolding & pressure tent for welding =1782.7 X 20 X 45 USD = **1,604,430.0 USD**

Cost of welding will be calculated as follows every 1.5 LM has two welding joints that means the number of welding joints are 1782.7/1.5 m = 1189 Joint. This imply the cost of welding equal 1189 X 8 hours X 50 = **475,600.0 USD**

Cost for final fixing 1782.7 X 4 X 40 = **285,232.0 USD**

Total Installation cost = 1,604,430.0 + 475,600.0 + 285,232.0 = **2,365,262.0 USD**

Summary of the capital cost:

Total Capital cost = Initial cost +Installation cost = 356,540 +2,365,262.0

= 2,721,802.0

Maintenance Cost

First approach if the maintenance is applying every 5 years, otherwise if the maintenance not applied as I mentioned in the previous section the replacement of the handrail with new one will be considered every 12 years.

Calculation

Protective painting material cost per LM is 50 USD. The offshore working man hours as mentioned previously is 8 hours per LM.

Maintenance cost will be calculated as follows:

Material cost = 50 USD X 1782.7 LM = **89,135.0 USD**

Offshore working man hours = 8 HR X 1782.7 LM X 40 USD = **570,464.0 USD**

Scaffolding for Painting =1782.7 X 10 X 45 USD = **802,215.0USD**

Total maintenance cost = 89,135.0 + **570,464.0** +**802,215.0** = **1,461,814.0 USD**

Replacement Cost

Steel handrails at offshore have to be replaced every 25 years in general , however in some areas specially in the lower decks which is near from the sea level, the steel handrails will be fully corroded after 10 to 12 years and needs to be replaced.

Calculation

Demolishing cost for the existing handrails is estimated to be 4 man hours per joint. This imply the demolishing cost equals 1189 x 4 x 45 USD = **214,020.0 USD.**

Replacement cost will be calculated as follows :

Initial cost + Installation cost + Demolishing cost = 356,540.0 + 2,365,262.0 + 214,020.0 = **2,935,822.0 USD**

Table 4.5: Cost Break Down for The Steel Handrail

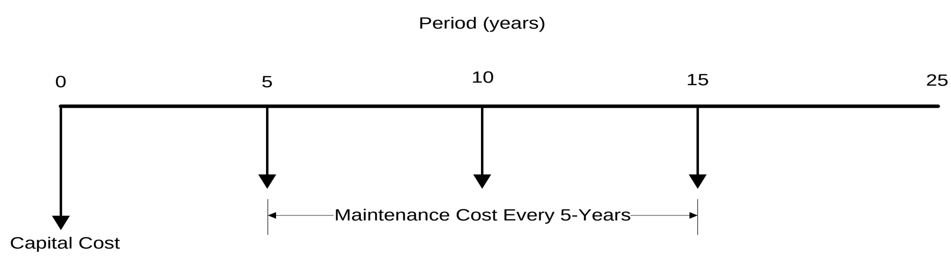
Cost Break Down for The Steel Handrail	
Capital Cost	**2,721,802 USD**
Maintenance Cost (If Applied)	**1,461,814.0 USD**
Replacement Cost	**2,935,822 USD**
Lifetime	**12-YEARS**

4.3.2.2 Cash Flow Diagram

Elements of the cash flow as described in the literature review are cash transaction, periods and interest rate. To establish a cash flow diagram for the LCC model for the steel handrail the periods and interest rate will be defined. In the LCC of the steel handrail the periods will be the age of the platform which is defined earlier as 25 years, and 5% will be consider as interest rate over this periods.

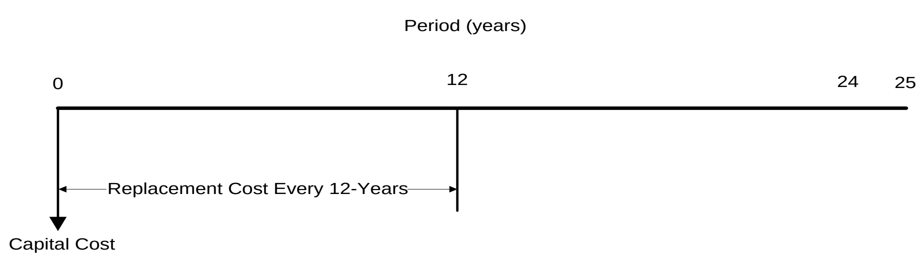
Two cash flow diagrams will be considered:

In case of maintenance are applied every 5-years, the cash flow will be as follows



Cash Flow Diagram

In case of the maintenance are not applied and the replacement after 12 years is the intended then the cash flow will be as follows:



Cash Flow Diagram

No replacement at years 24 is considered since the period is 25 years.

4.3.2.3 Annual Uniform Payment

Solving the previous cash flow using engineering economy equations as follows:

Step 1:

All future amount of money due to the maintenance or replacement will be discounted to present by using *Present worth Value* equation as shown in the previous example using Equation 4.1.

Step 2

All present amount of money will be converted to an equivalent uniform annual cost by using AUP annual uniform payment method as shown in the previous example by using equation 4.2.

4.4 DATA ANALYSIS FOR THE GRATING ALTERNATIVES

4.4.1 LCC for GRP Grating (Polyester Type)

The following is a detailed analysis for GRP gratings data that enter into the LCC model.

4.4.1.1 Cost Break down

Capital Cost of GRP/Polyester Gratings 25/38 mm Thickness

Initial Cost: It was found from the GRP grating vendor that one square meter for 25 mm thickness is cost 136 USD and for 38 mm Thickness is 162 USD

<u>Calculation</u>

The total quantity of the steel grating as described in the previous section is 4512.3 m2.

Initial cost of the 25 mm Thickness GRP gratings will be 4512.3 x 136 USD = **613,672.8 USD**

Initial cost of the 38 mm Thickness GRP gratings will be 4512.3 x 162 USD = **730,992.6 USD**

Pre-fabrication Cost : as described and mentioned in the previous no prefabrication are required to be perform since the GRP product is easy in installation and to adjust it at site with simple machine.

Offshore Installation Cost : Offshore installation cost for the GRP grating will not differ from the steel grating, we know that no prefabrication will be required for the GRP gratings this mean cut to fit at offshore site is required , at first sight it comes to mind that this will affect on the offshore man hours, however since the GRP gratings is lighter than the steel gratings and easy to be installed and carried from place to place as mentioned before will end up with same number for offshore man hours required to perform the job which is 6 hours per square meter same as steel grating.

<u>Calculation</u>

The offshore Installation cost will be calculated as follows :

Total quantity of gratings x 6 hours x hour’s rate.

= 4512.3 x 6 x 40 USD = 1,082,952 USD

Summary of the capital cost:

Total capital cost (25mm) = Initial cost + Installation Cost = 613,672.8 + 1,082,952 = 1,696,624.8 USD

Total capital cost (38mm) = Initial cost + Installation Cost = 730,992.6 + 1,082,952 = 1,813,944.6 USD

Maintenance and Replacement Cost

No maintenance is required over the life time of the product which is 40 years as specified by the vendor just a replacement will be done.

Table (4.6) below summarizes the cost break down for the GRP (Polyester) grating.

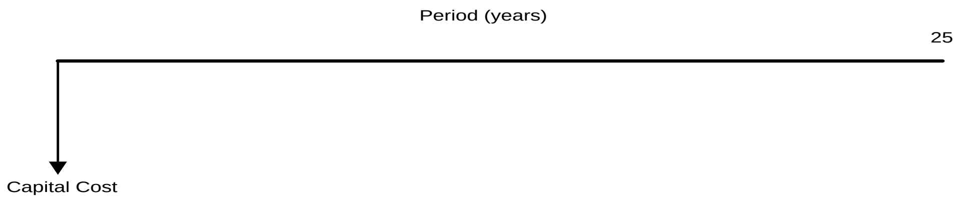
Table 4.6: Cost Break Down for The Polyester Gratings

COST BREAK DOWN FOR GRP(Polyester) GRATING	
Capital Cost 25mm	**1,696,624.8 USD**
Capital Cost 38 mm	**1,813,944.6 USD**
Maintenance Cost	**-**
Lifetime	**40-YEARS**

4.4.1.2 Cash Flow Diagram

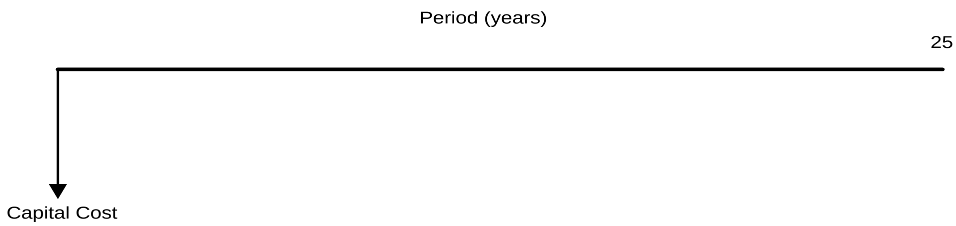
In the LCC of the GRP gratings the periods will be the age of the platform which is defined earlier as 25 years, and 5% will be consider as interest rate over this periods.

The cash flow diagram for the 25 mm thickness will be as follows:



Cash Flow Diagram

The cash flow diagram for the 38 mm thickness will be as follows:



Cash Flow Diagram

4.4.1.3 Annual Uniform Payment

Solving the previous cash flow using engineering economy equations as follows:

<u>Step 1</u>

All present amount of money will be converted to an equivalent uniform annual cost by using AUP annual uniform payment method by using equation 4.2.

4.4.2 LCC for GRP Grating (Vinylester Type)

The following is a detailed analysis for GRP gratings data that enter into the LCC model.

4.4.2.1 Cost Break down

<u>Capital Cost of GRP/Vinylester Gratings 25/38 mm Thickness</u>

Initial Cost: It was found from the GRP grating vendor that one square meter for 25 mm thickness is cost 162 USD and for 38 mm Thickness is 175 USD

<u>Calculation</u>

The total quantity of the steel grating as described in the previous section is 4512.3 m2.

Initial cost of the 25 mm Thickness GRP gratings will be 4512.3 x 162 USD = **730,992.6 USD**

Initial cost of the 38 mm Thickness GRP gratings will be 4512.3 x 175 USD = **789,652.5 USD**

Pre-fabrication Cost : as described and mentioned in the previous no prefabrication are required to be perform since the GRP product is easy in its installation and can be easily adjusted at offshore with simple machine.

Offshore Installation Cost : As it is calculated for the Polyester Type.

<u>Calculation</u>

The offshore Installation cost will be calculated as follows :

Total quantity of grating x 6 hours x hour’s rate.

= 4512.3 x 6 x 40 USD = 1,082,952 USD

<u>Summary of the capital cost:</u>

Total capital cost (25mm) = Initial cost + Installation Cost = **730,992.6 + 1,082,952 = 1,813,944.6 USD**

Total capital cost (38mm) = Initial cost + Installation Cost =

789,652.5 + 1,082,952 = 1,872,604.5 USD

<u>Maintenance and Replacement Cost</u>

No maintenance is required over the life time of the product which is 40 years as specified by the vendor just a replacement will be done.

Table (4.7) below summarizes the cost break down for the GRP (Vinylester) grating.

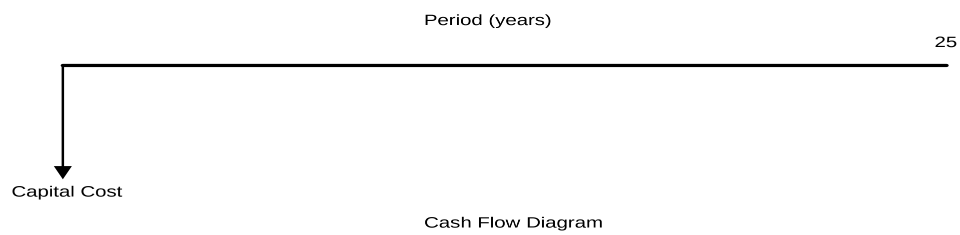
Table 4.7: Cost Break Down for the Vinylester Gratings

COST BREAK DOWN For GRP(Vinylester) GRATING	
Capital Cost 25mm	**1,813,944.6 USD**
Capital Cost 38 mm	**1,872,604.4 USD**
Maintenance Cost	**-**
Lifetime	**40-YEARS**

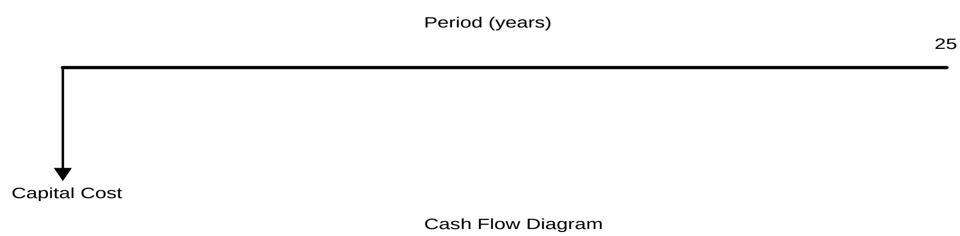
4.4.2.2 Cash Flow Diagram

In the LCC of the GRP gratings the periods will be the age of the platform which is defined earlier as 25 years, and 5% will be consider as interest rate over this periods.

The cash flow diagram for the 25 mm thickness will be as follows:



The cash flow diagram for the 38 mm thickness will be as follows:



4.4.2.3 Annual Uniform Payment

Solving the previous cash flow using engineering economy equations as follows:

Step 1

All present amount of money will be converted to an equivalent uniform annual cost by using AUP annual uniform payment method by using equation 4.2.

4.4.3 LCC for GRP Grating (Phenolic Type)

The following is a detailed analysis for GRP gratings data that enter into the LCC model.

4.4.3.1 Cost Break down

Capital Cost of GRP/Phenolic Gratings 25/38 mm Thickness

Initial Cost: It was found from the GRP grating vendor that one square meter for 25 mm thickness is cost 182 USD and for 38 mm Thickness is 215 USD

Calculation

The total quantity of the steel grating as described in the previous section is 4512.3 m2.

Initial cost of the 25 mm Thickness GRP gratings will be 4512.3 x 182 USD = **821,238.6 USD**

Initial cost of the 38 mm Thickness GRP gratings will be 4512.3 x 215 USD = **970,144.5 USD**

Pre-fabrication Cost : as described and mentioned in the previous no prefabrication are required to be perform since the GRP product is easy in its installation and can be easily adjusted at offshore with simple machine.

Offshore Installation Cost: As it is calculated for the Polyester Type

Calculation

The offshore Installation cost will be calculated as follows :

Total quantity of grating x 6 hour x hour's rate.

= 4512.3 x 6 x 40 USD = 1,082,952.0 USD

Summary of the capital cost:

Total capital cost (25mm) = Initial cost + Installation Cost = **821,238.6 + 1,082,952.0 = 1,904,190.6 USD**

Total capital cost (38mm) = Initial cost + Installation Cost =

970,144.5 + 1,082,952.0 = 2,053,096.5 USD

Maintenance and Replacement Cost

No maintenance is required over the life time of the product which is 40 years as specified by the vendor just a replacement will be done.

Table (4.8) below summarizes the cost break down for the GRP (Phenolic) grating.

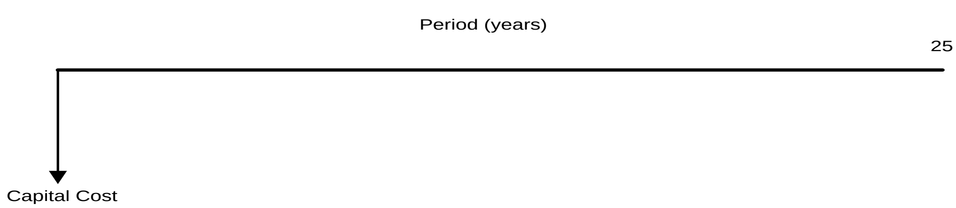
Table 4.8: Cost Break Down For The Phenolic Gratings

COST BREAK DOWN For GRP (Phenolic) GRATING	
Capital Cost 25mm	**1,904,190.6 USD**
Capital Cost 38 mm	**2,053,096.5 USD**
Maintenance Cost	**-**
Lifetime	**40-YEARS**

4.4.3.2 Cash Flow Diagram

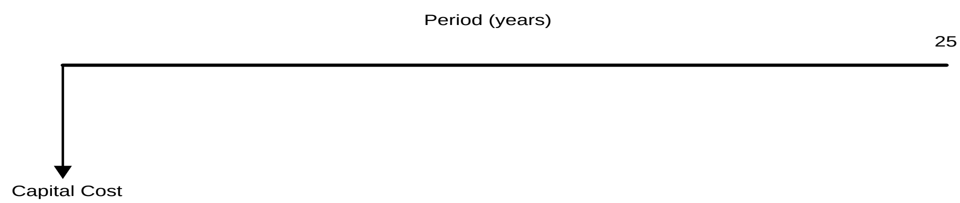
In the LCC of the GRP gratings the periods will be the age of the platform which is defined earlier as 25 years, and 5% will be consider as interest rate over this periods.

The cash flow diagram for the 25 mm thickness will be as follows:



Cash Flow Diagram

The cash flow diagram for the 38 mm thickness will be as follows:



Cash Flow Diagram

4.4.3.3 Annual Uniform Payment

Solving the previous cash flow using engineering economy equations as follows:

<u>Step 1</u>

All present amount of money will be converted to an equivalent uniform annual cost by using AUP annual uniform payment method by using equation 4.2.

4.5 DATA ANALYSIS FOR THE HANDRAIL ALTERNATIVES

4.5.1 LCC for GRP Handrail (Polyester Type)

The following is a detailed analysis for GRP Handrail data that enter into the LCC model.

4.5.1.1 Cost Break down

<u>Capital Cost of GRP (Polyester) Handrail</u>

Initial Cost: It was found from the GRP Handrails vendor that one length meter is 100 USD

<u>Calculation</u>

The total quantity of the steel Handrail as described in the previous section is 1782.7 Lm.

Initial cost will be 1782.7 x 100 USD = **178,270.0 USD**

Pre-fabrication Cost : as described and mentioned in the previous no prefabrication are required to be perform since the GRP product is easy in installation and to adjust it at site with simple machine.

Offshore Installation Cost: The offshore Installation cost will be calculated as follows:

<u>Calculation</u>

Cost of scaffolding & pressure tent for welding =1782.7 X 20 Hr X 45 USD = **1,604,430.0 USD**

Cost of welding will be calculated as follows every 1.5 LM has two welding joints that means the number of welding joints are 1782.7/1.5 m = 1189 Joint. This imply the cost of welding equal 1189 X 8 hours X 50 = **475,600.0 USD**

Cost for final fixing will be consider half of the steel handrail cost, because GRP handrails is lighter and easy to carry and install = 1782.7 X 4 X 40 X 0.5 = **142,616.0 USD**

Total Installation cost = 1,604,430.0+475,600.0 +142,616.0 = **2,222,646.0 USD**

<u>Summary of the capital cost:</u>

Total Capital cost = Initial cost +Installation cost = 178,270.0 +2,222,646.0 = 2,400,916.0 USD.

<u>Maintenance and Replacement Cost</u>

No maintenance is required over the life time of the product which is 40 years as specified by the vendor just a replacement will be done.

Table 4.9 below summarizes the cost break down for the GRP (Polyester) handrail.

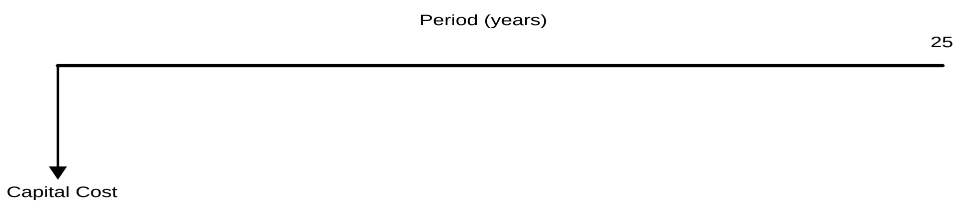
Table 4.9: Cost Break Down for The Polyester Handrail

COST BREAK DOWN FOR THE GRP (Polyester) HANDRAIL	
Capital Cost	**2,400,916.0 USD**
Maintenance Cost	**-**
Lifetime	**40-YEARS**

4.5.1.2 Cash Flow Diagram

In the LCC of the GRP Handrails, the periods will be the age of the platform which is defined earlier as 25 years, and 5% will be consider as interest rate over this periods.

The cash flow diagram for the GRP Handrail (Polyester Type) will be as follows:



Cash Flow Diagram

4.5.1.3 Annual Uniform Payment

Solving the previous cash flow using engineering economy equations as follows:

<u>Step 1</u>

All present amount of money will be converted to an equivalent uniform annual cost by using AUP annual uniform payment method by using equation 4.2.

4.5.2 LCC for GRP Handrail (Vinylester Type)

The following is a detailed analysis for GRP Handrail data that enter into the LCC model.

4.5.2.1 Cost Break down

<u>Capital Cost of GRP (Vinylester) Handrail</u>

Initial Cost: It was found from the GRP Handrails vendor that one length meter is 110 USD

<u>Calculation</u>

The total quantity of the steel Handrail as described in the previous section is 1782.7 Lm.

Initial cost will be 1782.7 x 110 USD = **196,097.0 USD**

Pre-fabrication Cost : as described and mentioned in the previous no prefabrication are required to be perform since the GRP product is easy in installation and to adjust it at site with simple machine.

Offshore Installation Cost: The offshore Installation cost will be calculated as follows:

Calculation

Cost of scaffolding & pressure tent for welding =1782.7 X 20 Hr X 45 USD = **1,604,430.0 USD**

Cost of welding will be calculated as follows every 1.5 LM has two welding joints that means the number of welding joints are 1782.7/1.5 m = 1189 Joint. This imply the cost of welding equal 1189 X 8 hours X 50 = **475,600.0 USD**

Cost for final fixing will be consider half of the steel handrail cost, because GRP handrails is lighter and easy to carry and install = 1782.7 X 4 X 40 X 0.5 = **142,616.0 USD**

Total Installation cost = 1,604,430.0+475,600.0 +142,616.0 = **2,222,646.0 USD**

Summary of the capital cost:

Total Capital cost = Initial cost +Installation cost = 196,097.0 +2,222,646.0 = 2,418,743.0 USD.

Maintenance and Replacement Cost

No maintenance is required over the life time of the product which is 40 years as specified by the vendor just a replacement will be done.

Table 4.10 below summarizes the cost break down for the GRP (Polyester) handrail.

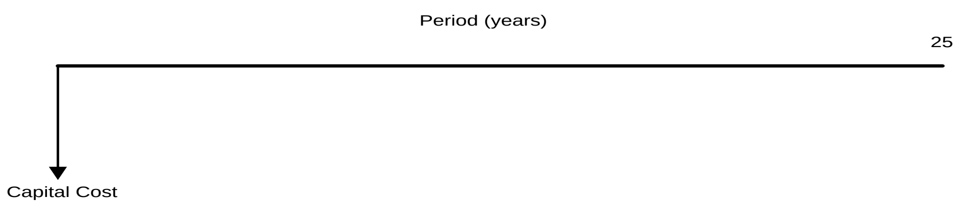
Table 4.10: Cost Break Down for The Vinylester Handrail

COST BREAK DOWN FOR THE GRP (Vinylester) HANDRAIL	
Capital Cost	**2,418,743.0 USD**
Maintenance Cost	**-**
Life Time	**40-YEARS**

4.5.2.2 Cash Flow Diagram

In the LCC of the GRP Handrails, the periods will be the age of the platform which is defined earlier as 25 years, and 5% will be consider as interest rate over this periods.

The cash flow diagram for the GRP Handrail (Vinylester Type) will be as follows:



Cash Flow Diagram

4.5.2.3 Annual Uniform Payment

Solving the previous cash flow using engineering economy equations as follows:

<u>Step 1</u>

All present amount of money will be converted to an equivalent uniform annual cost by using AUP annual uniform payment method by using equation 4.2.

4.5.3 LCC for GRP Handrail (Phenolic Type)

The following is a detailed analysis for GRP Handrail data that enter into the LCC model.

4.5.3.1 Cost Break down

<u>Capital Cost of GRP (Phenolic) Handrail</u>

Initial Cost: It was found from the GRP Handrails vendor that one length meter is 120 USD

<u>Calculation</u>

The total quantity of the steel Handrail as described in the previous section is 1782.7 Lm.

Initial cost will be 1782.7 x 120 USD = **213,924.0 USD**

Pre-fabrication Cost : as described and mentioned in the previous no prefabrication are required to be perform since the GRP product is easy in installation and to adjust it at site with simple machine.

Offshore Installation Cost: The offshore Installation cost will be calculated as follows:

<u>Calculation</u>

Cost of scaffolding & pressure tent for welding =1782.7 X 20 Hr X 45 USD = **1,604,430.0 USD**

Cost of welding will be calculated as follows every 1.5 LM has two welding joints that means the number of welding joints are 1782.7/1.5 m = 1189 Joint. This imply the cost of welding equal 1189 X 8 hours X 50 = **475,600.0 USD**

Cost for final fixing will be consider half of the steel handrail cost, because GRP handrails is lighter and easy to carry and install = 1782.7 X 4 X 40 X 0.5 = **142,616.0 USD**

Total Installation cost = 1,604,430.0+475,600.0 +142,616.0 = **2,222,646.0 USD**

<u>Summary of the capital cost:</u>

Total Capital cost = Initial cost +Installation cost = 213,924.0 +2,222,646.0 = **2,436,570.0USD.**

<u>Maintenance and Replacement Cost</u>

No maintenance is required over the life time of the product which is 40 years as specified by the vendor just a replacement will be done.

Table 4.11 below summarizes the cost break down for the GRP (Polyester) handrail.

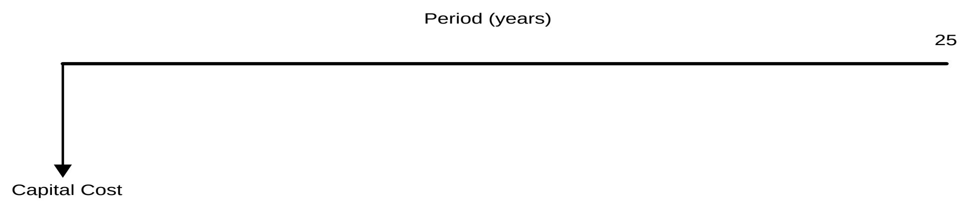
Table 4.11: Cost Break Down for The Phenolic Handrail

COST BREAK DOWN FOR THE GRP (Phenolic) Handrail	
Capital Cost	**2,436,570.0 USD**
Maintenance Cost	**-**
Lifetime	**40-YEARS**

4.5.3.2 Cash Flow Diagram

In the LCC of the GRP Handrails, the periods will be the age of the platform which is defined earlier as 25 years, and 5% will be consider as interest rate over this periods.

The cash flow diagram for the GRP Handrail (Phenolic Type) will be as follows:



Cash Flow Diagram

4.5.3.3 Annual Uniform Payment

Solving the previous cash flow using engineering economy equations as follows:

<u>Step 1</u>

All present amount of money will be converted to an equivalent uniform annual cost by using AUP annual uniform payment method by using equation 4.2.

4.6 SENSITIVITY ANALYSIS

In this study some selected input parameters in the LCC models that have been analyzed in the previous sections will be altered to determine the effect of such changes. The parameters that have been selected as follows:

- What will be the result if the discount rate changes from 5% to 10% and then to 15%?
- What will be the result if deflation in the steel materials has been happened by 5% and offshore installation cost by 10% yearly?
- What will be the result if deflation in both steel materials and offshore installation cost by 10% yearly?

- What will be the result if the lifetime of the platform has changed to 20 or 30 years instead of 25 years?

These changes will be applied to the previous models that have been shown in the previous sections and then the result will be shown in chapter 5 of this study.

CHAPTER FIVE

RESULTS & DISCUSSION

This chapter presents the results of the LCC and their analyses. The first and second section, present the LCC results of the steel grating versus GRP alternatives 25mm and 38mm thicknesses respectively. The third section, presents the LCC results of the Steel handrail versus GRP handrails alternatives. Deflation impact on the LCC results of the steel gratings versus GRP alternatives for both 25mm and 38mm have been presented in section four and five respectively of this chapter. The sixth section presents the deflation impact on the LCC results of the steel handrail versus GRP alternatives. All cash flows analysis have been shown in the appendix. Finally, some conclusions have been presented in section seven.

5.1 LIFE CYCLE COSTING RESULTS FOR THE STEEL GRATINGS VERSUS GRP ALTERNATIVES 25MM

5.1.1 Results for 20 years at 5%, 10% & 15%

The Figure 5.1 shows that EUAW for steel grating is higher than GRP alternatives at 5% interest rate for 20 years.

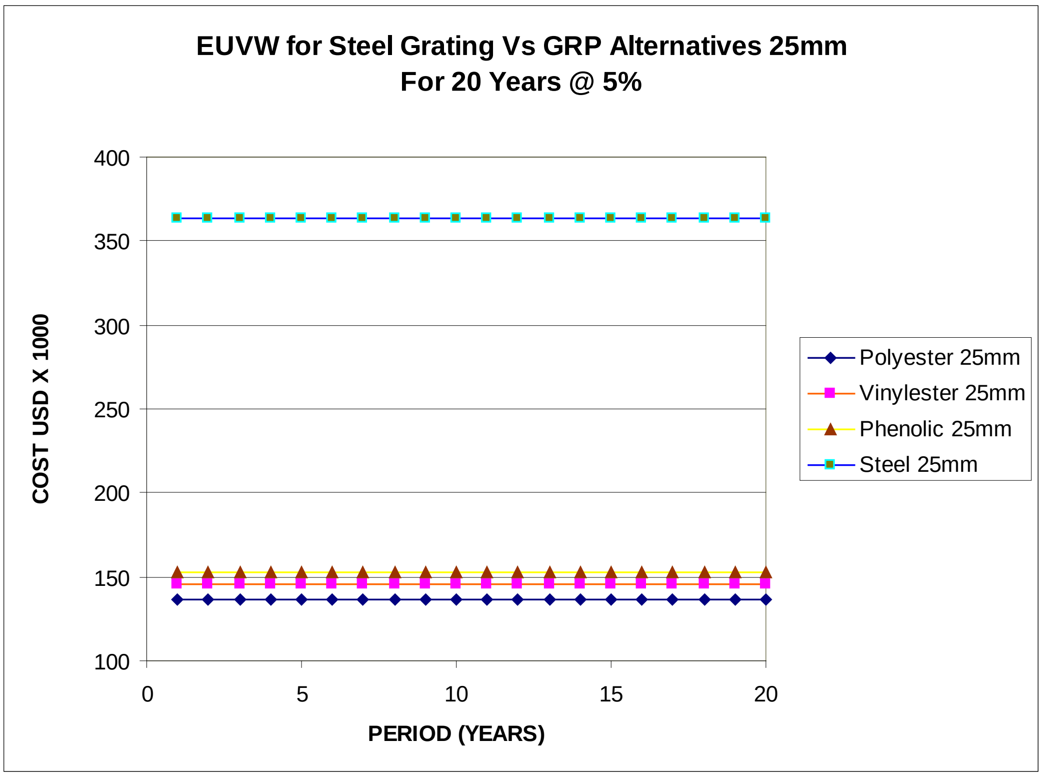


Figure 5.1: EUAW for Steel Gratings VS GRP Alternatives 25mm (5%,20)

The Figure 5.2 shows that EUAW for steel grating is higher than GRP alternatives at 10% interest rate for 20 years.

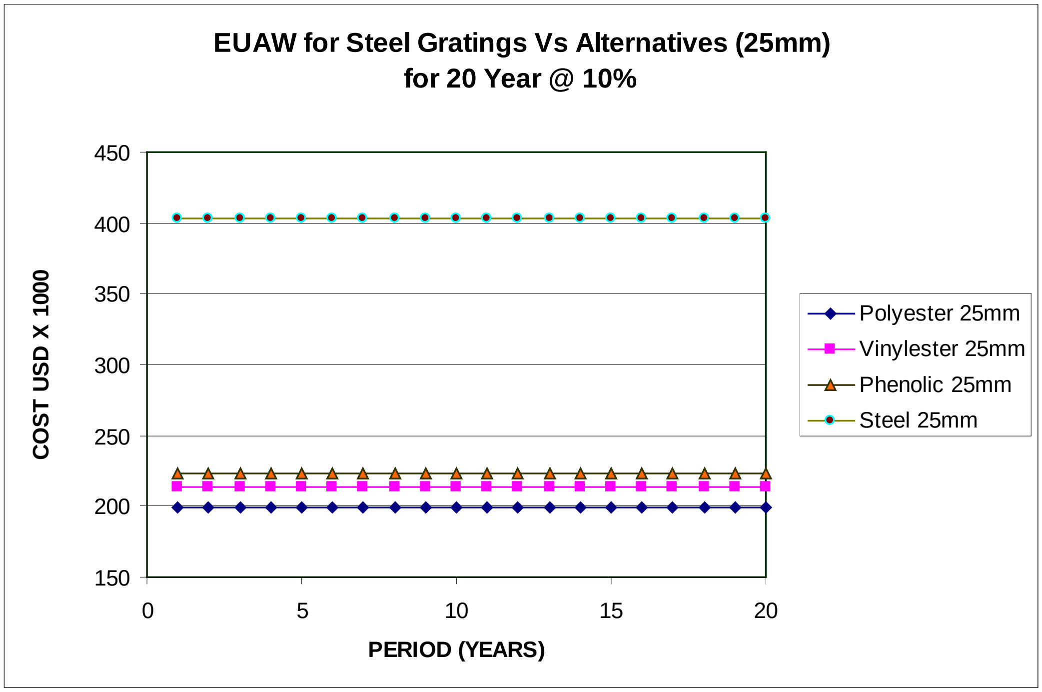


Figure 5.2: EUAW for Steel Gratings VS GRP Alternatives 25mm (10%,20)

The Figure 5.3 shows that EUAW for steel grating is higher than GRP alternatives at 15% interest rate for 20 years.

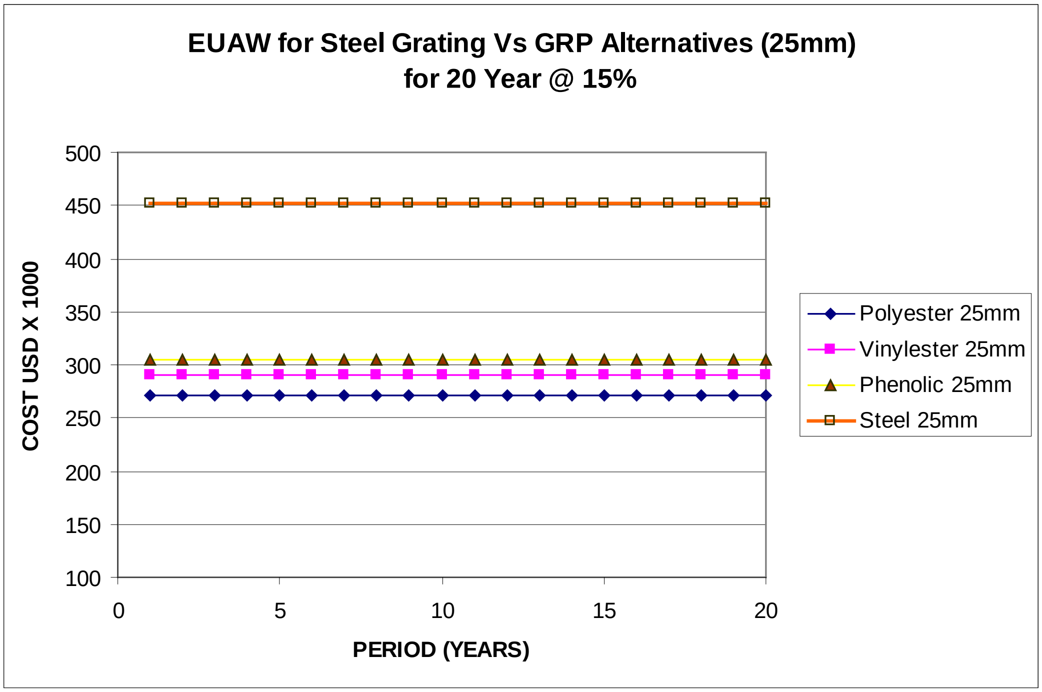


Figure 5.3: EUAW for Steel Gratings VS GRP Alternatives 25mm (15%,20)

5.1.2 Results for 25 years at 5%, 10% & 15%

The Figure 5.4 shows that EUAW for steel grating is higher than GRP alternatives at 5% interest rate for 25 years.

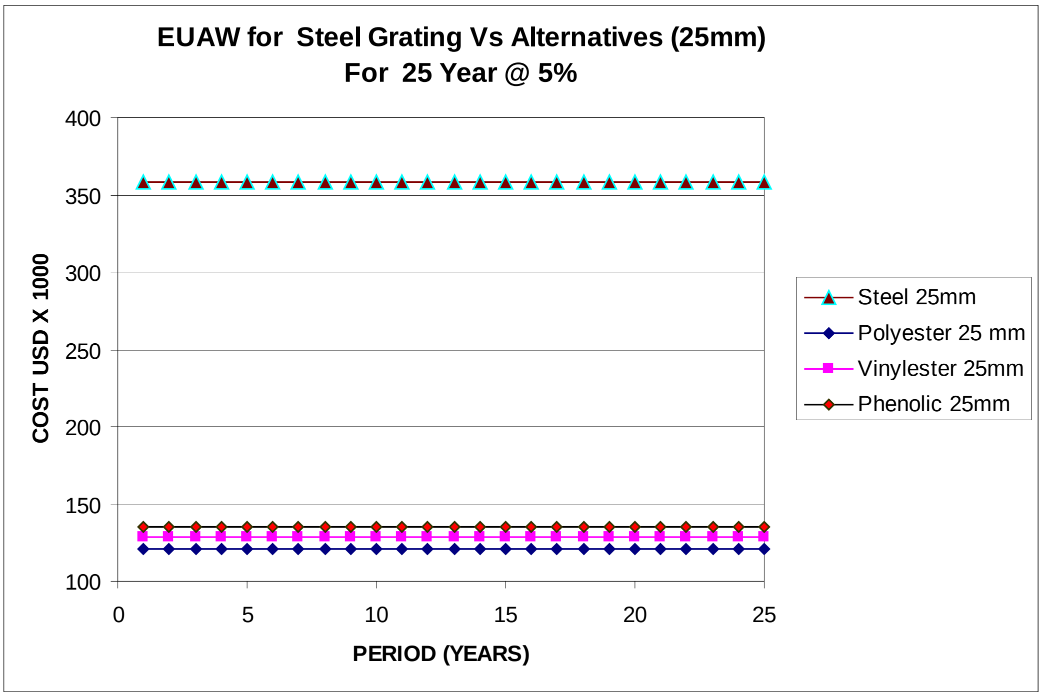


Figure 5.4: EUAW for Steel Gratings VS GRP Alternatives 25mm (5%, 25)

The Figure 5.5 shows that EUAW for steel grating is higher than GRP alternatives at 10% interest rate for 25 years.

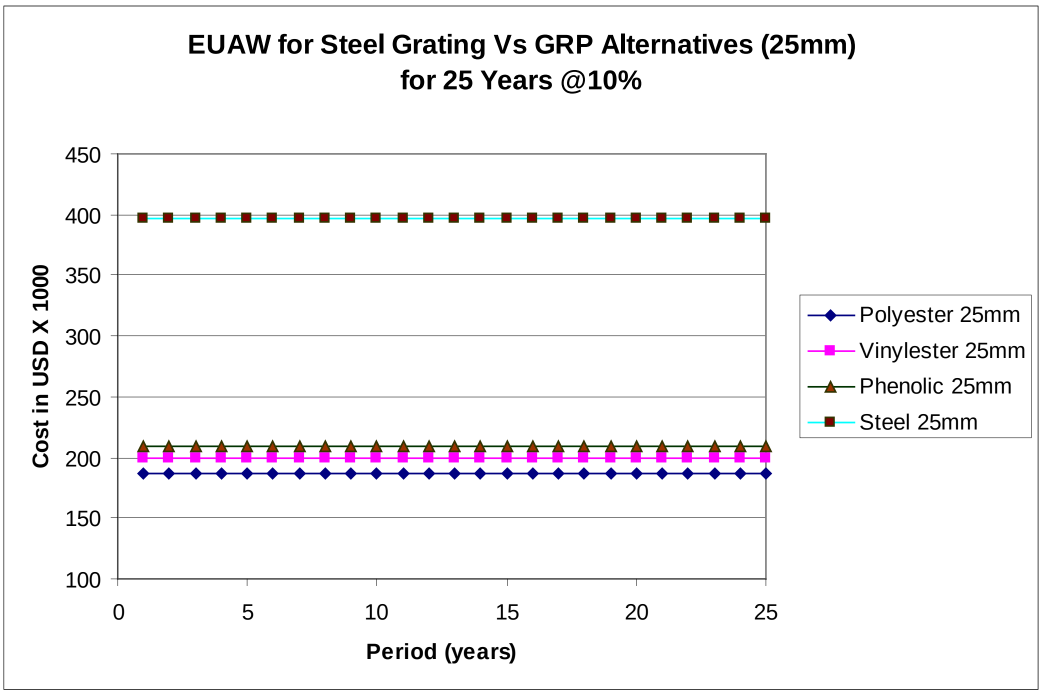


Figure 5.5: EUAW for Steel Gratings VS GRP Alternatives 25mm (10%, 25)

The Figure 5.6 shows that EUAW for steel grating is higher than GRP alternatives at 15% interest rate for 25 years.

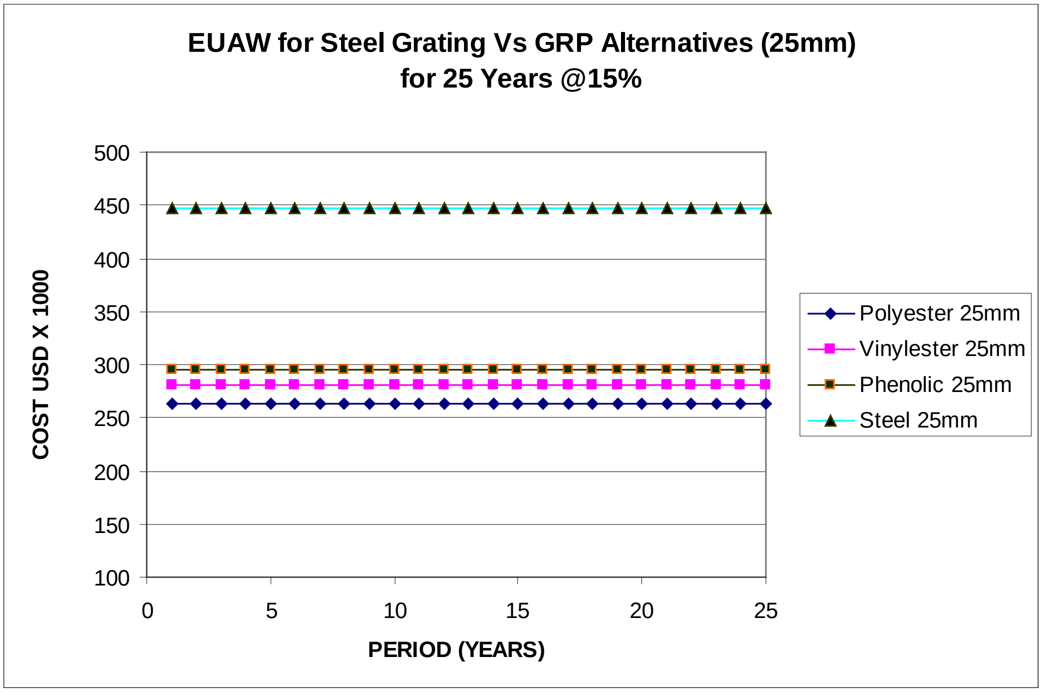


Figure 5.6: EUAW for Steel Gratings VS GRP Alternatives 25mm (15%, 25)

5.1.3 Results for 30 years at 5%, 10% & 15%

The Figure 5.7 shows that EUAW for steel grating is higher than GRP alternatives at 5% interest rate for 30 years.

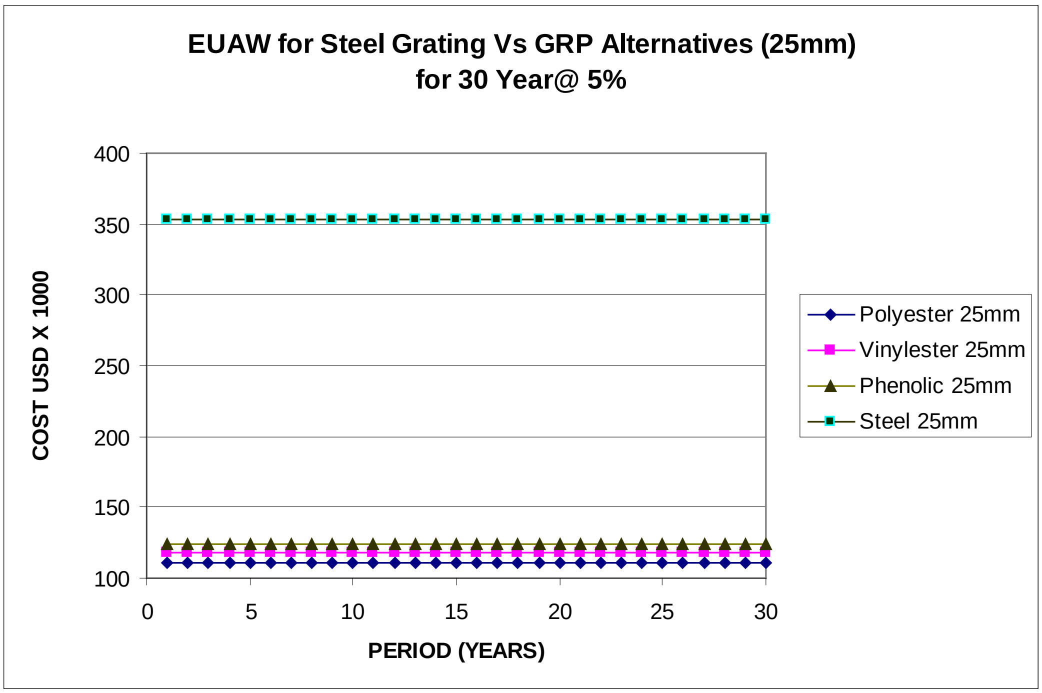


Figure 5.7: EUAW for Steel Gratings VS GRP Alternatives 25mm (5%, 30)

The Figure 5.8 shows that EUAW for steel grating is higher than GRP alternatives at 10% interest rate for 30 years.

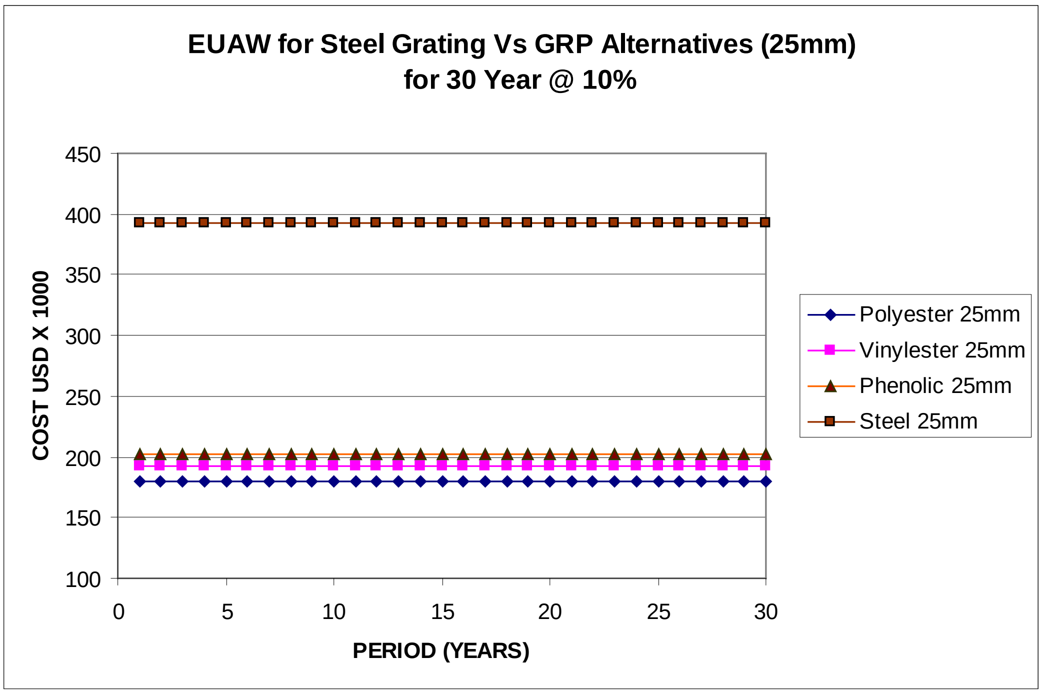


Figure 5.8: EUAW for Steel Gratings VS GRP Alternatives 25mm (10%, 30)

The Figure 5.9 shows that EUAW for steel grating is higher than GRP alternatives at 15% interest rate for 30 years.

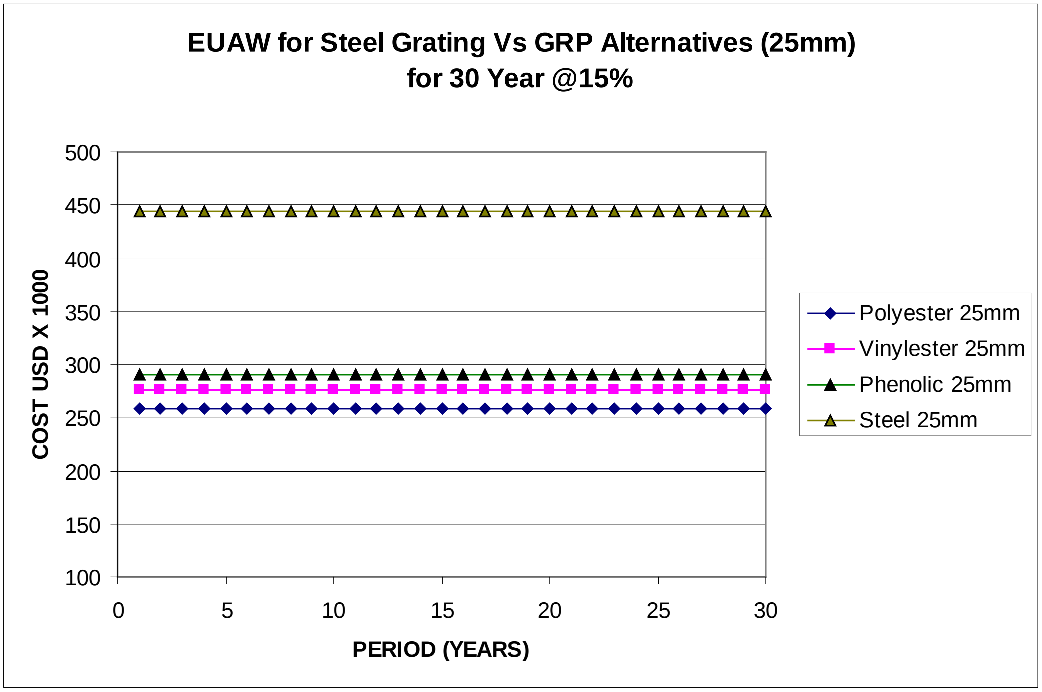


Figure 5.9: EUAW for Steel Gratings VS GRP Alternatives 25mm (15%, 30)

5.2 LIFE CYCLE COSTING RESULTS FOR THE STEEL GRATINGS VERSUS GRP ALTERNATIVES 38MM

5.2.1 Results for 20 years at 5%, 10% & 15%

The Figure 5.10 shows that EUAW for steel grating is higher than GRP alternatives at 5% interest rate for 20 years.

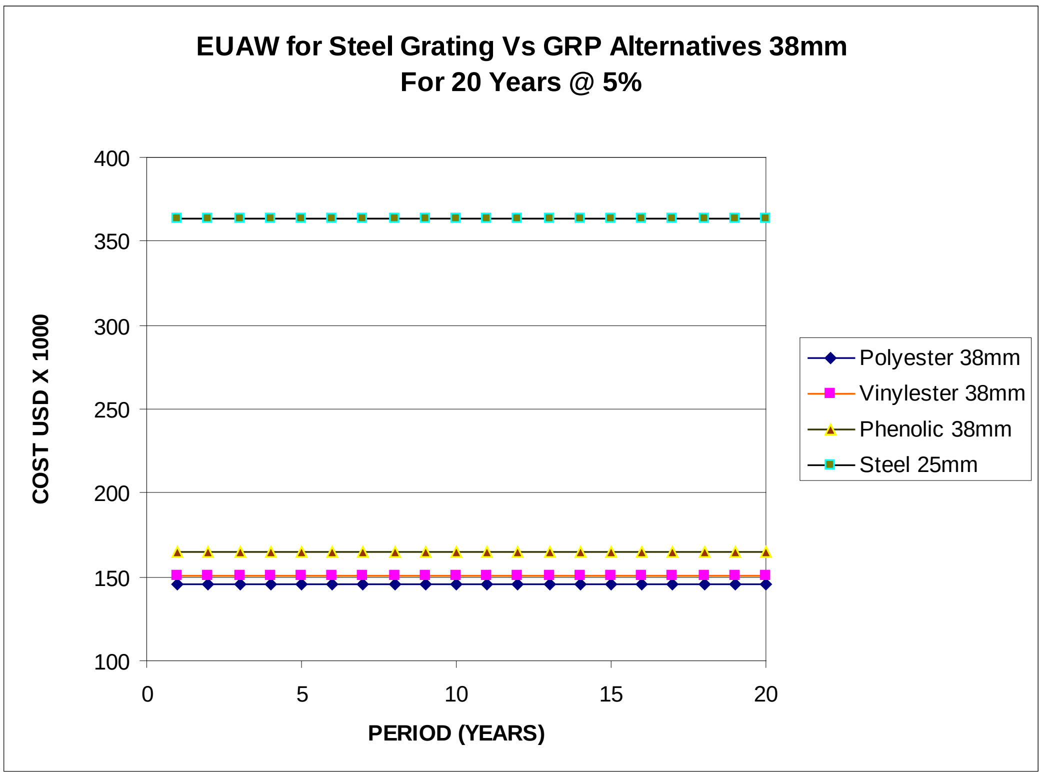


Figure 5.10: EUAW for Steel Gratings VS GRP Alternatives 38mm (5%, 20)

The Figure 5.11 shows that EUAW for steel grating is higher than GRP alternatives at 10% interest rate for 20 years.

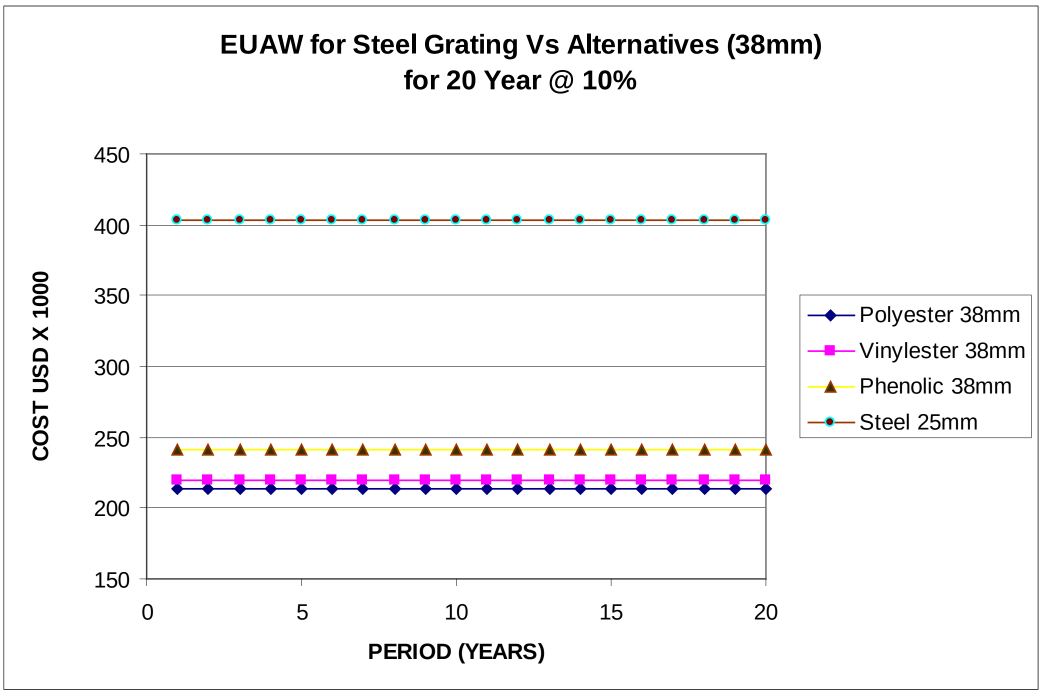


Figure 5.11: EUAW for Steel Gratings VS GRP Alternatives 38mm (10%, 20)

The Figure 5.12 shows that EUAW for steel grating is higher than GRP alternatives at 15% interest rate for 20 years.

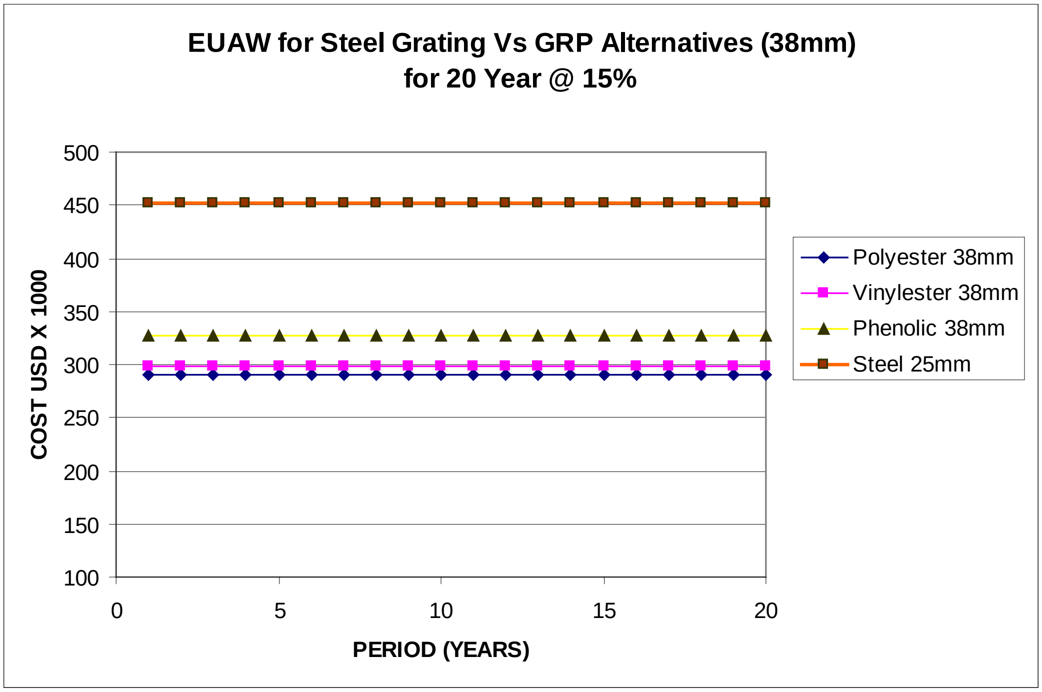


Figure 5.12: EUAW for Steel Gratings VS GRP Alternatives 38mm (15%, 20)

5.2.2 Results for 25 years at 5%, 10% & 15%

The Figure 5.13 shows that EUAW for steel grating is higher than GRP alternatives at 5% interest rate for 25 years.

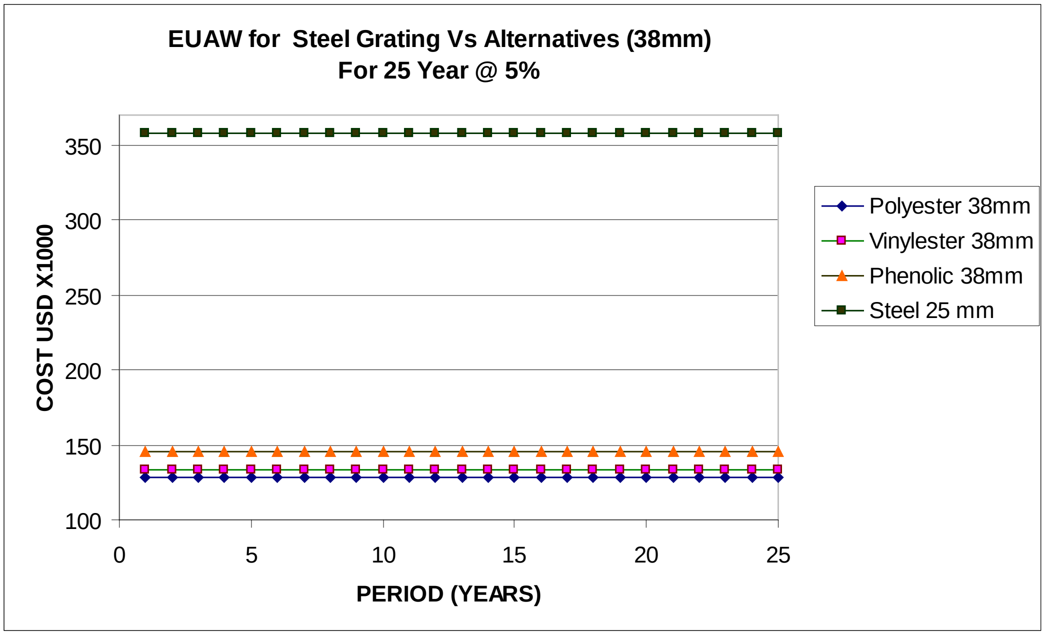


Figure 5.13: EUAW for Steel Gratings VS GRP Alternatives 38mm (5%, 25)

The Figure 5.14 shows that EUAW for steel grating is higher than GRP alternatives at 10% interest rate for 25 years.

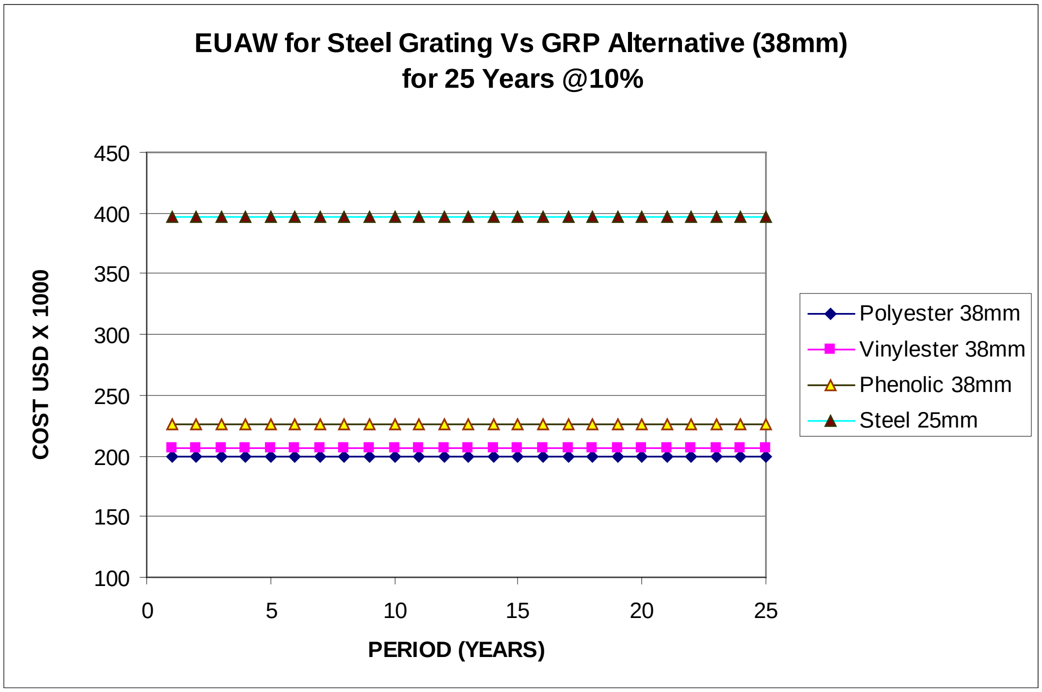


Figure 5.14: EUAW for Steel Gratings VS GRP Alternatives 38mm (10%, 25)

The Figure 5.15 shows that EUAW for steel grating is higher than GRP alternatives at 15% interest rate for 25 years.

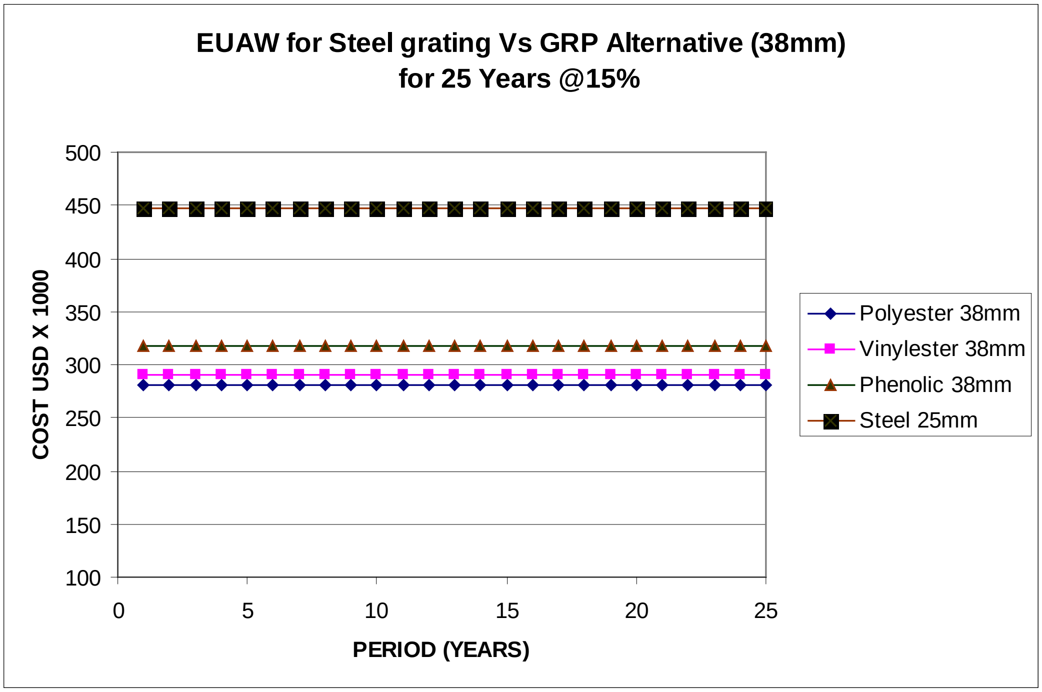


Figure 5.15: EUAW for Steel Gratings VS GRP Alternatives 38mm (15%, 25)

5.2.3 Results for 30 years at 5%, 10% & 15%

The Figure 5.16 shows that EUAW for steel grating is higher than GRP alternatives at 5% interest rate for 30 years.

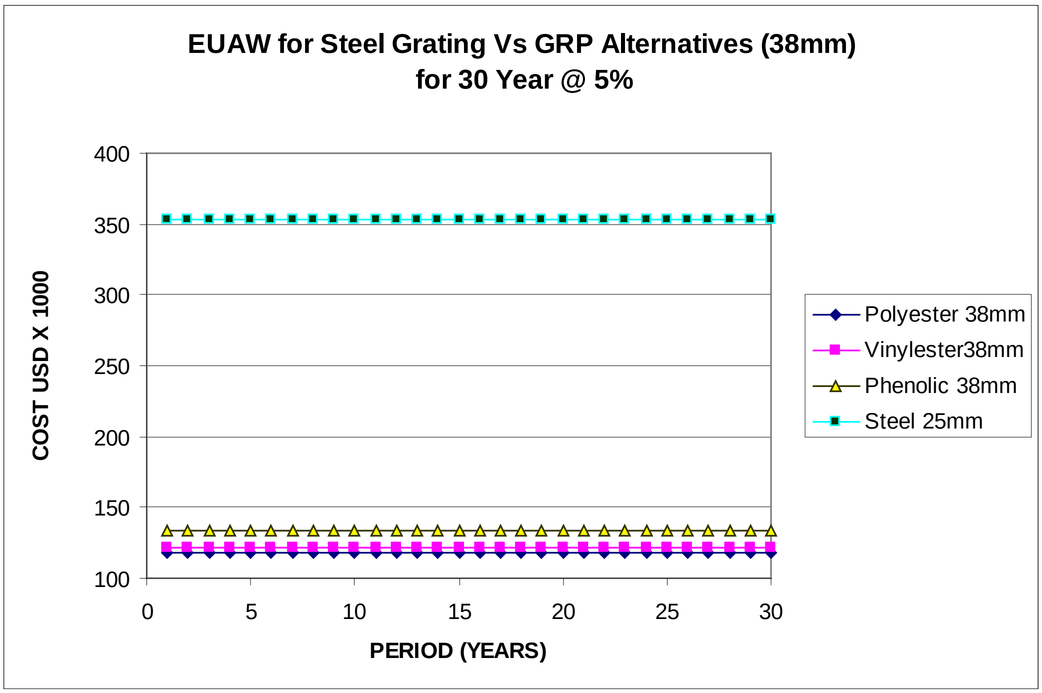


Figure 5.16: EUAW for Steel Gratings VS GRP Alternatives 38mm (5%, 30)

The Figure 5.17 shows that EUAW for steel grating is higher than GRP alternatives at 10% interest rate for 30 years.

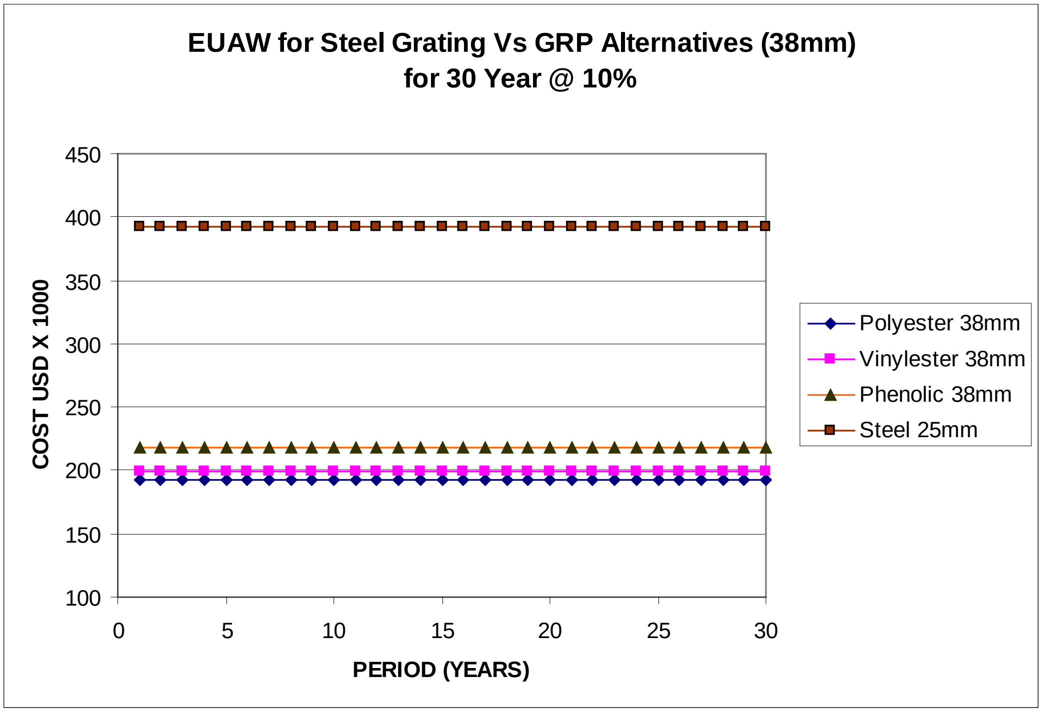


Figure 5.17: EUAW for Steel Gratings VS GRP Alternatives 38mm (10%, 30)

The Figure 5.18 shows that EUAW for steel grating is higher than GRP alternatives at 15% interest rate for 30 years.

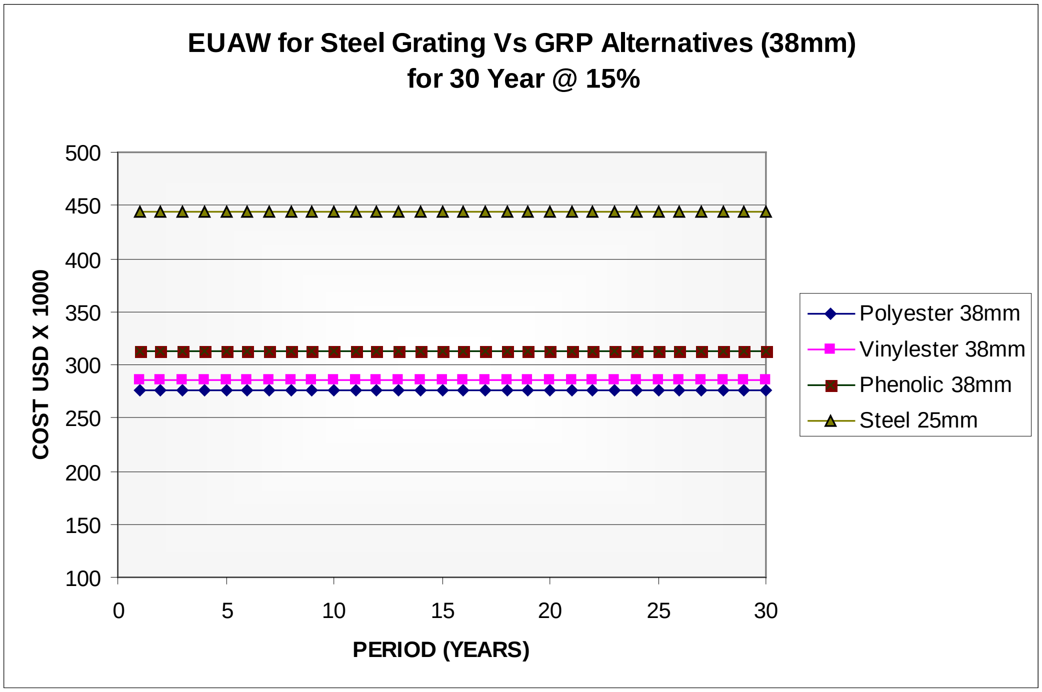


Figure 5.18: EUAW for Steel Gratings VS GRP Alternatives 38mm (15%, 30)

5.3 LIFE CYCLE COSTING RESULTS FOR THE STEEL HANDRAIL VERSUS GRP ALTERNATIVES

5.3.1 Results for 20 years at 5%, 10% & 15%

The Figure 5.19 shows that EUAW for steel handrail for both replacement and maintenance approaches is higher than GRP alternatives at 5% interest rate for 20 years.

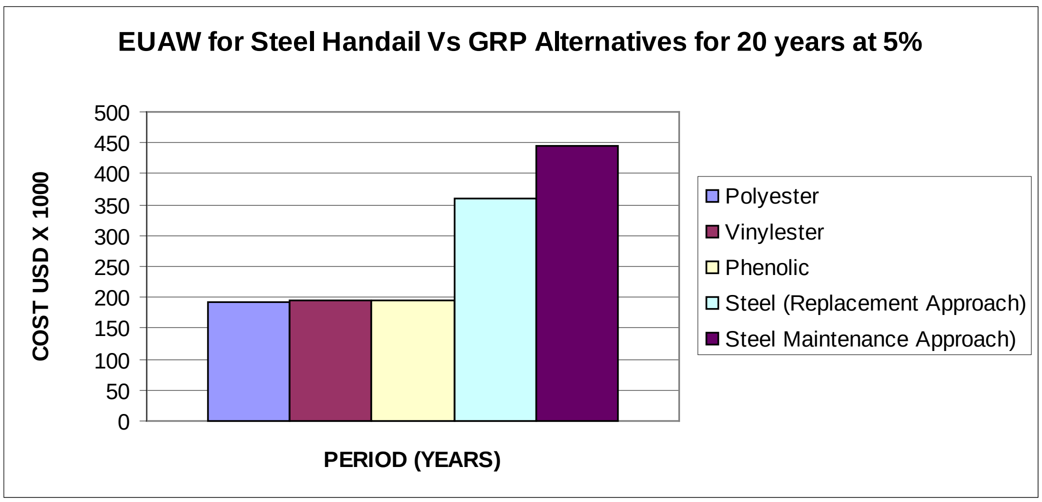


Figure 5.19: EUAW for Steel Handrail VS GRP Alternatives (5%, 20)

The Figure 5.20 shows that EUAW for steel handrail for both replacement and maintenance approaches is higher than GRP alternatives at 10% interest rate for 20 years.

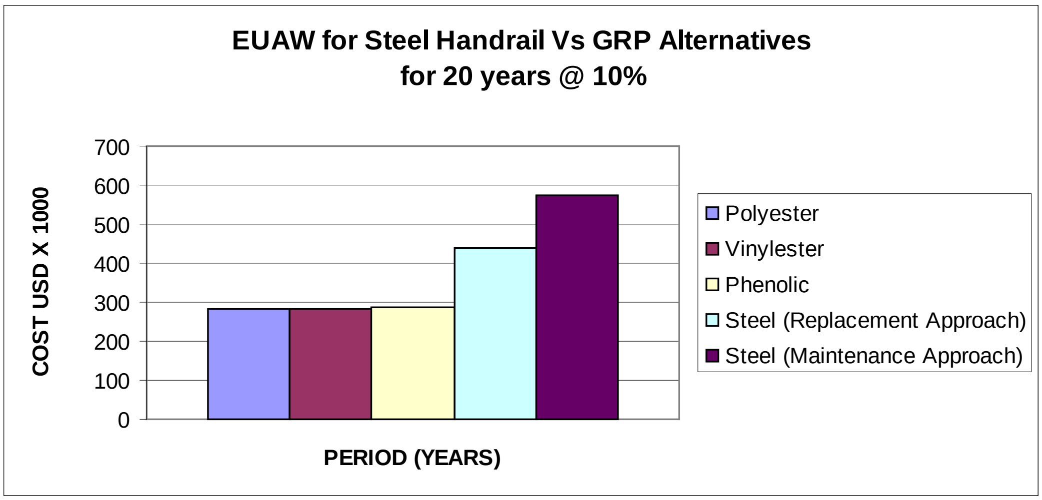


Figure 5.20: EUAW for Steel Handrail VS GRP Alternatives (10%, 20)

The Figure 5.21 shows that EUAW for steel handrail for both replacement and maintenance approaches is higher than GRP alternatives at 15% interest rate for 20 years.

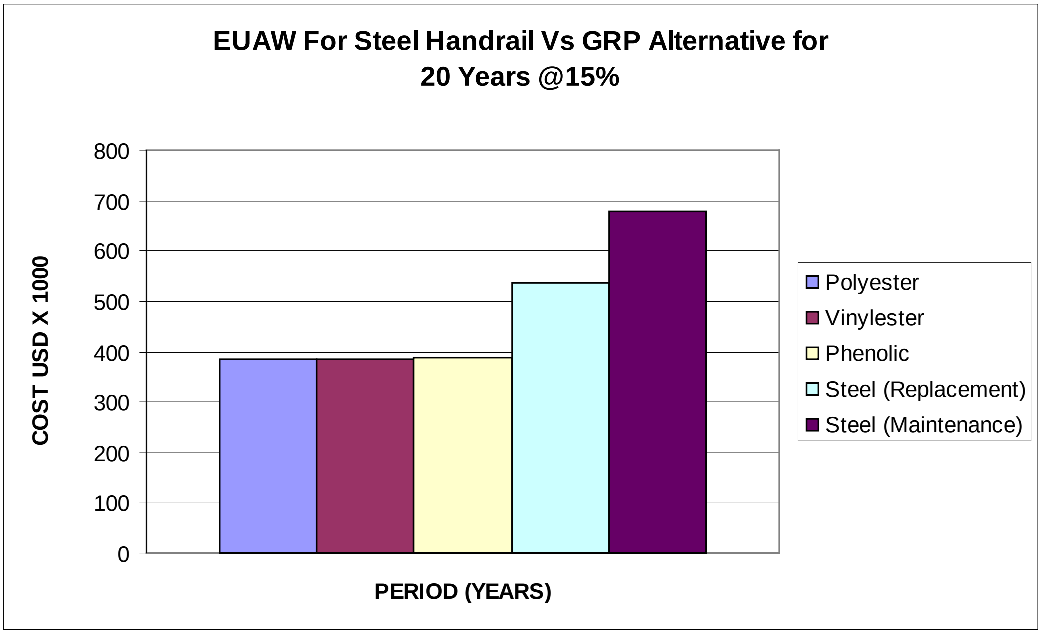


Figure 5.21: EUAW for Steel Handrail VS GRP Alternatives (15%, 20)

5.3.2 Results for 25 years at 5%, 10% & 15%

The Figure 5.22 shows that EUAW for steel handrail for both replacement and maintenance approaches is higher than GRP alternatives at 5% interest rate for 25 years.

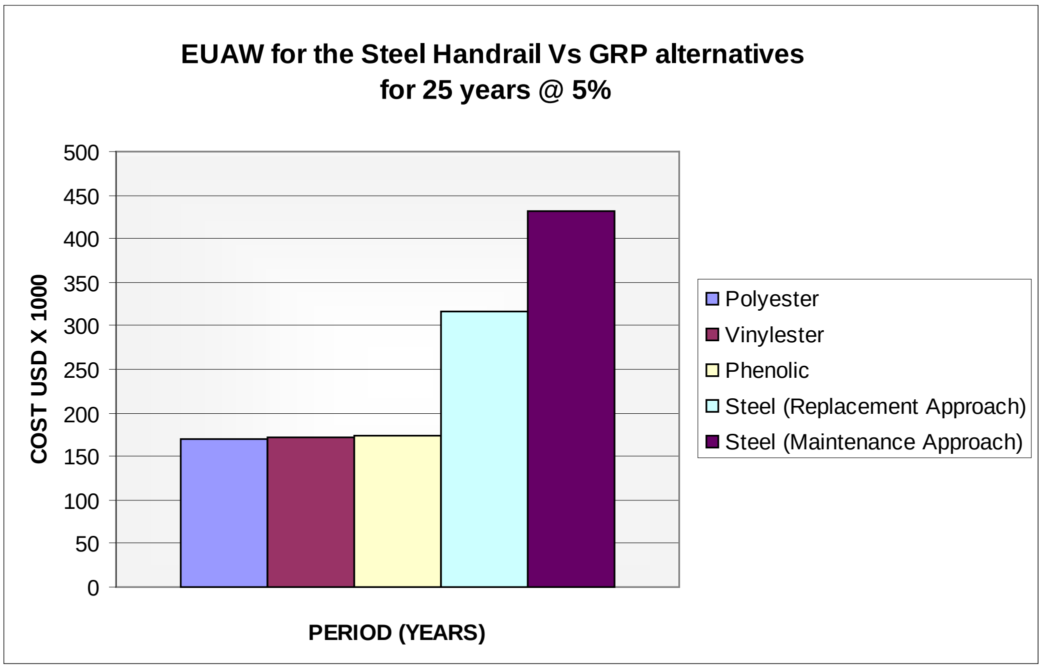


Figure 5.22: EUAW for Steel Handrail VS GRP Alternatives (5%, 25)

The Figure 5.23 shows that EUAW for steel handrail for both replacement and maintenance approaches is higher than GRP alternatives at 10% interest rate for 25 years.

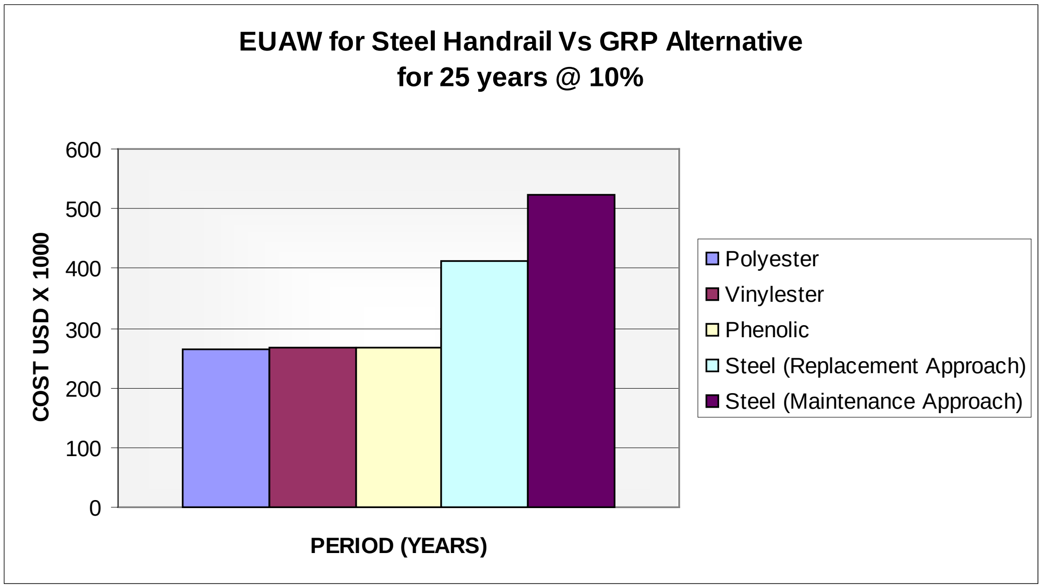


Figure 5.23: EUAW for Steel Handrail VS GRP Alternatives (10%, 25)

The Figure 5.24 shows that EUAW for steel handrail for both replacement and maintenance approaches is higher than GRP alternatives at 15% interest rate for 25 years.

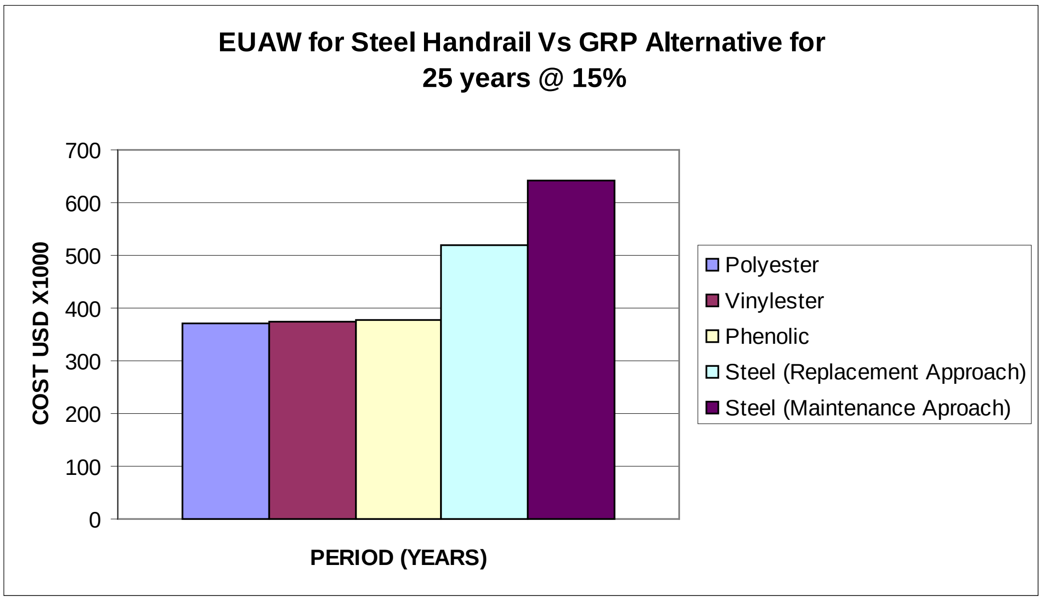


Figure 5.24: EUAW for Steel Handrail VS GRP Alternatives (15%, 25)

5.3.3 Results for 30 years at 5%, 10% & 15%

The figure 5.25 shows that EUAW for steel handrail for both replacement and maintenance approaches is higher than GRP alternatives at 5% interest rate for 30 years.

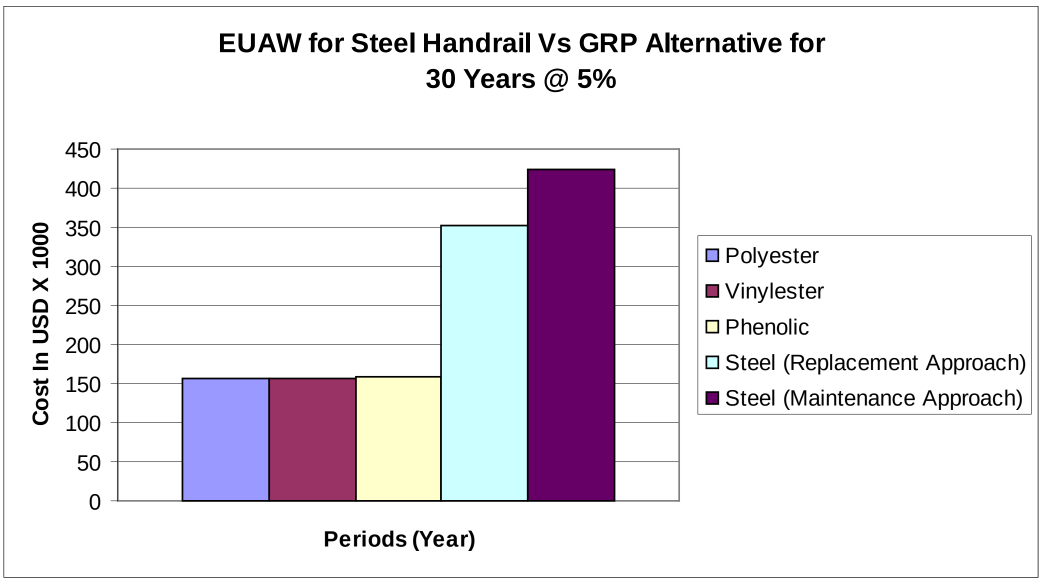


Figure 5.25: EUAW for Steel Handrail VS GRP Alternatives (5%, 30)

The Figure 5.26 shows that EUAW for steel handrail for both replacement and maintenance approaches is higher than GRP alternatives at 10% interest rate for 30 years.

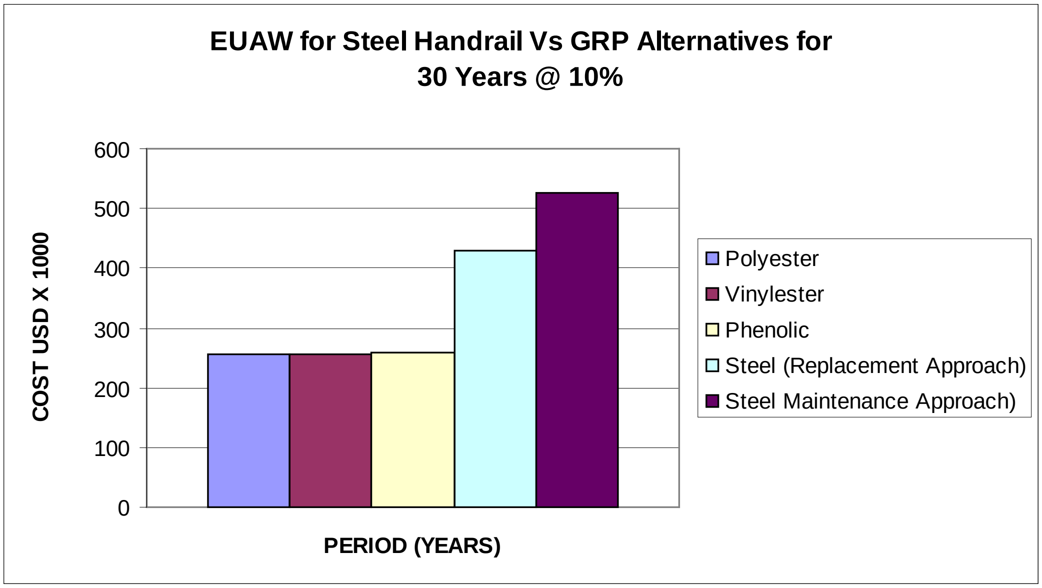


Figure 5.26: EUAW for Steel Handrail VS GRP Alternatives (10%, 30)

The Figure 5.27 shows that EUAW for steel handrail for both replacement and maintenance approaches is higher than GRP alternatives at 15% interest rate for 30 years.

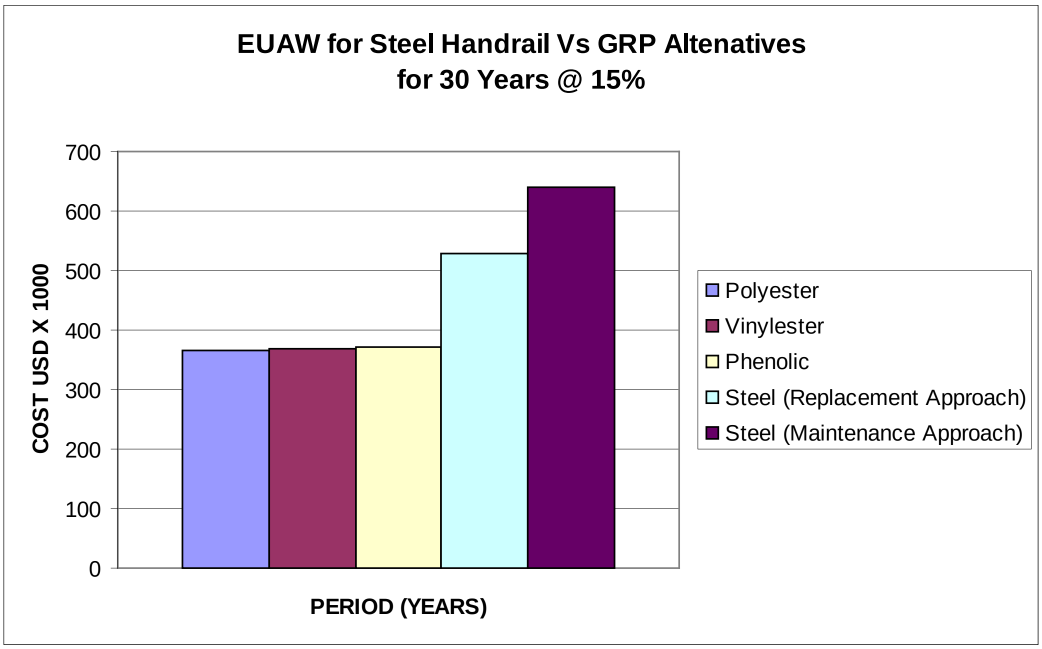


Figure 5.27: EUAW for Steel Handrail VS GRP Alternatives (15%, 30)

5.4 DEFLATION IMPACT ON THE LCC FOR THE STEEL GRATINGS VERSUS GRP ALTERNATIVES (25MM)

5.4.1 Deflation by 5% in Materials Cost and 10% In Installation Cost

5.4.1.1 Results for 20 years at 5%, 10% & 15%

When deflation took into account, Figure 5.28 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 5% interest rate for 20 years.

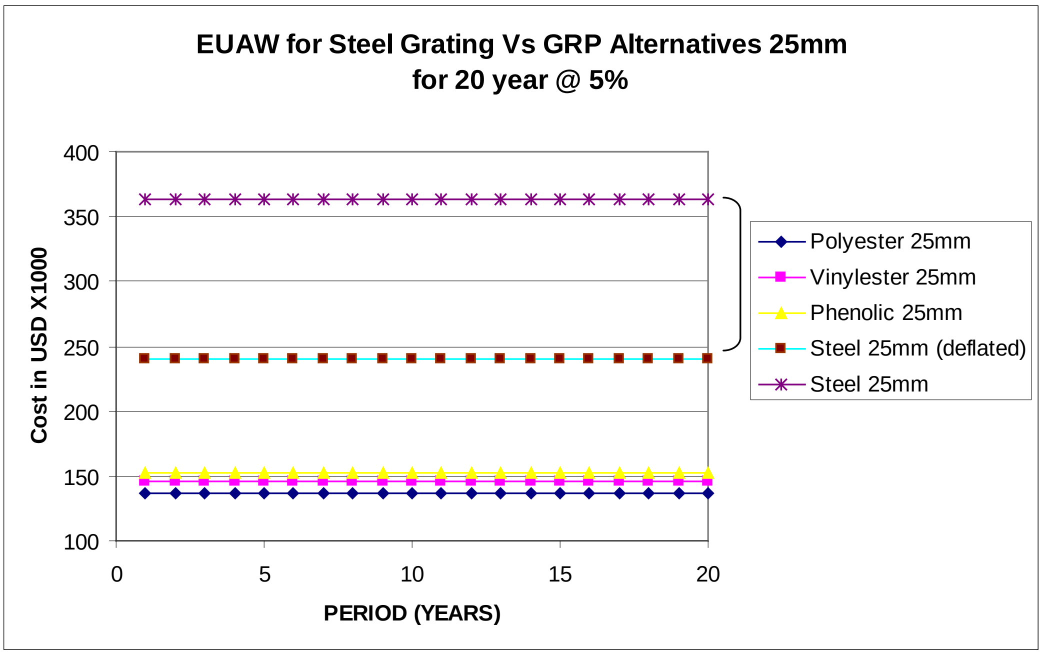


Figure 5.28: EUAW for Steel Grating (Deflated) VS GRP Alternatives 25mm (5%, 20)

When deflation took into account, Figure 5.29 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 10% interest rate for 20 years.

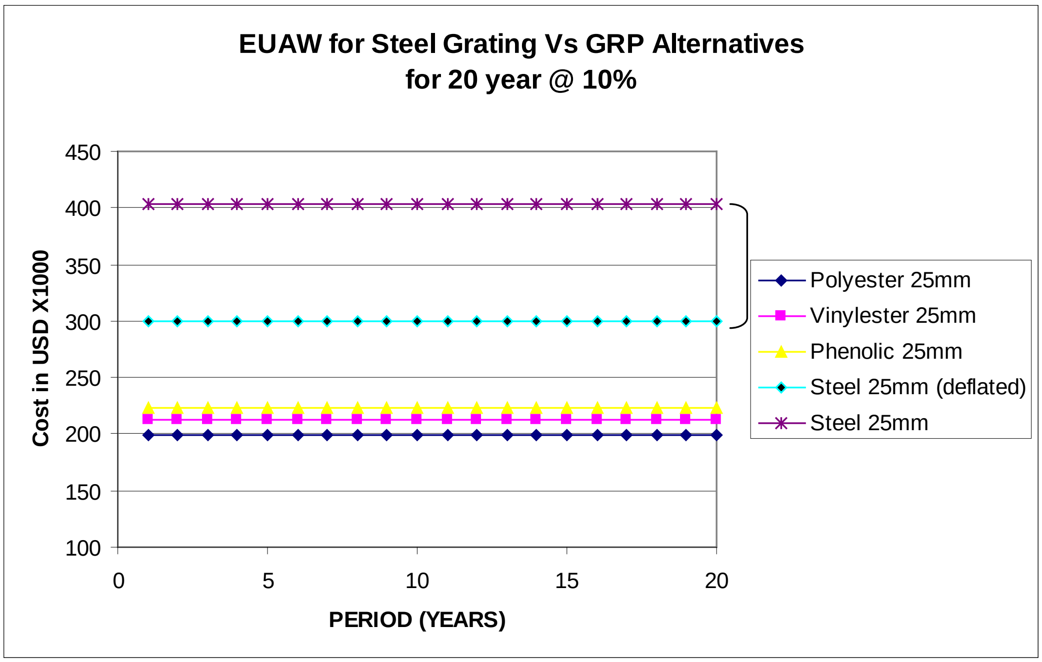


Figure 5.29: EUAW for Steel Grating (Deflated) VS GRP Alternatives 25mm (10%, 20)

When deflation took into account, Figure 5.30 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 15% interest rate for 20 years.

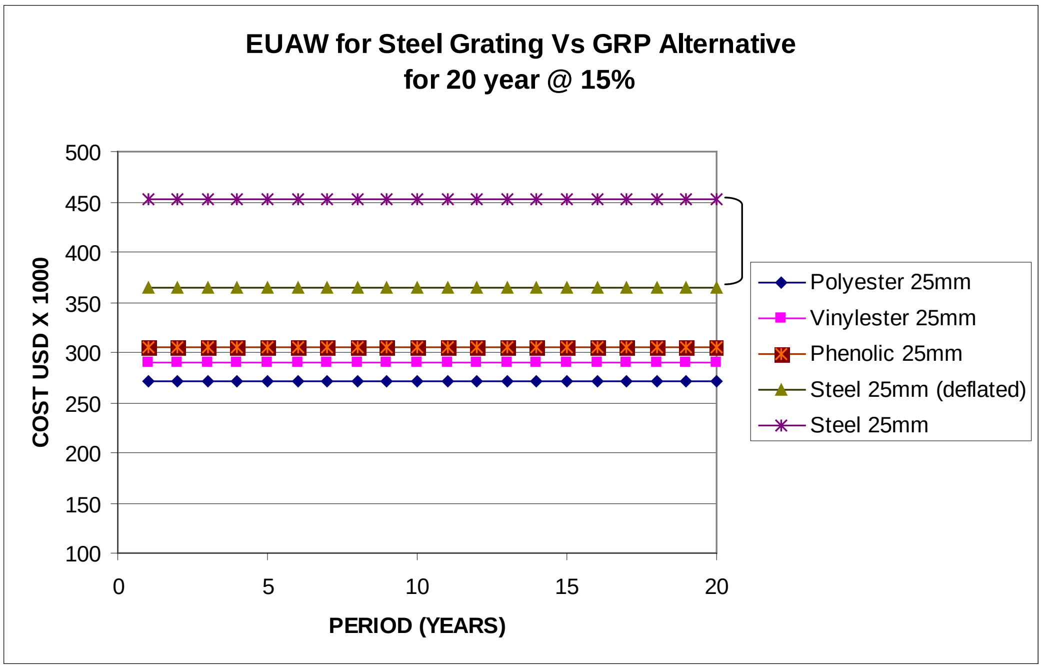


Figure 5.30: EUAW for Steel Grating (Deflated) VS GRP Alternatives 25mm (15%, 20)

5.4.1.2 Results for 25 years at 5%, 10% & 15%

When deflation took into account, Figure 5.31 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 5% interest rate for 25 years.

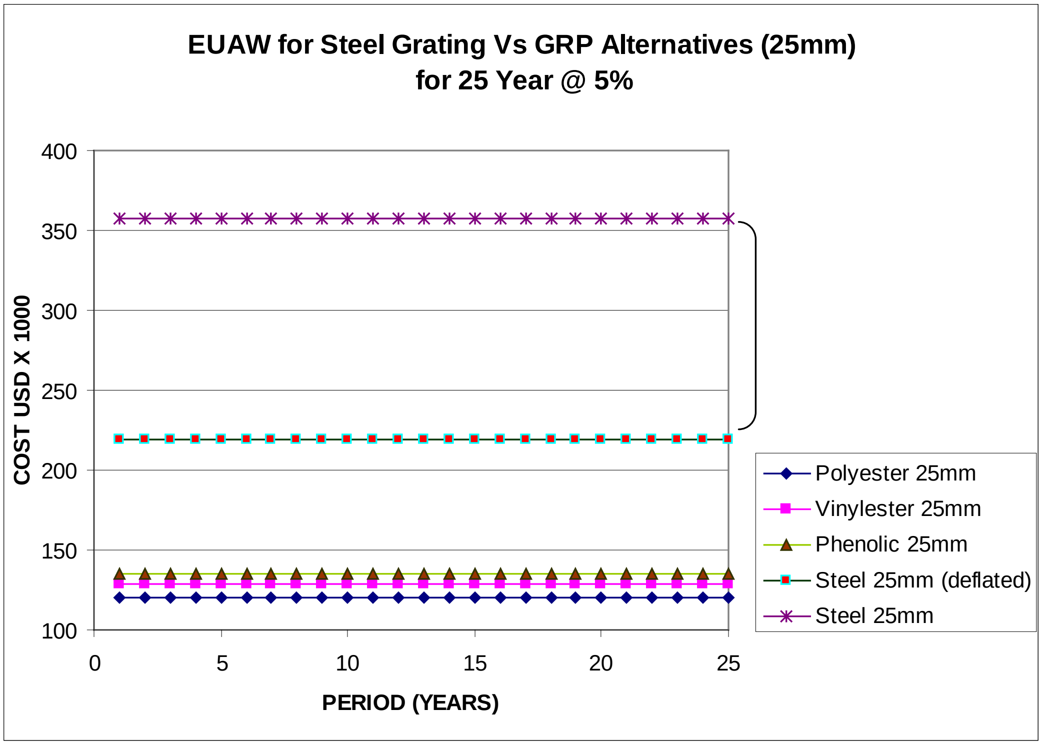


Figure 5.31: EUAW for Steel Grating (Deflated) VS GRP Alternatives 25mm (5%, 25)

When deflation took into account, Figure 5.32 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 10% interest rate for 25 years.

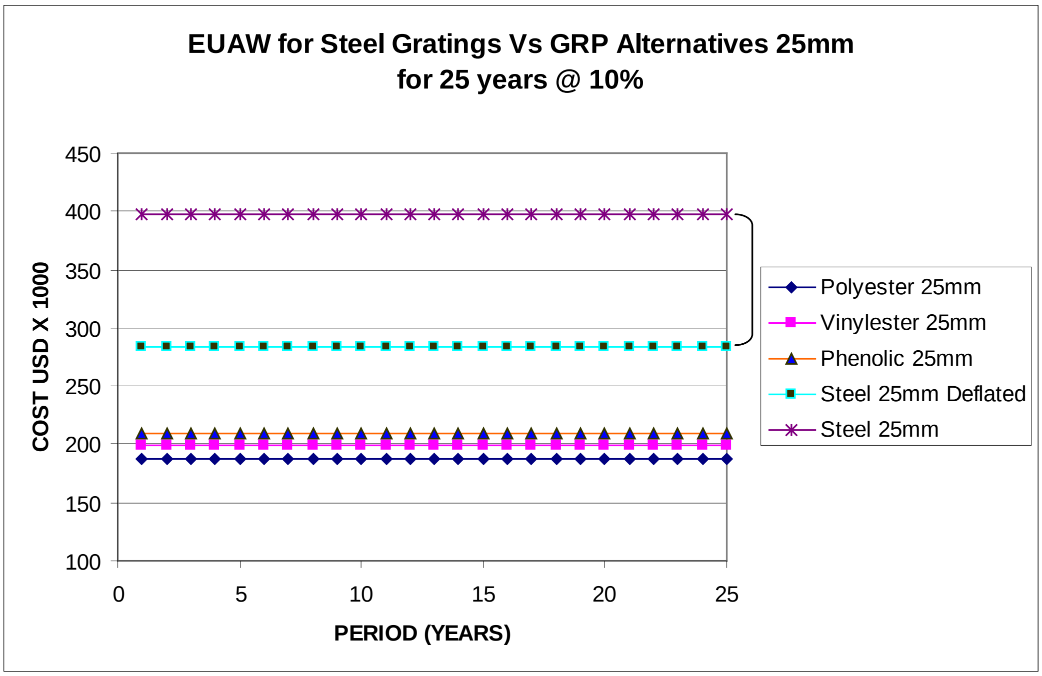


Figure 5.32: EUAW for Steel Grating (Deflated) VS GRP Alternatives 25mm (10%, 25)

When deflation took into account, Figure 5.33 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 15% interest rate for 25 years.

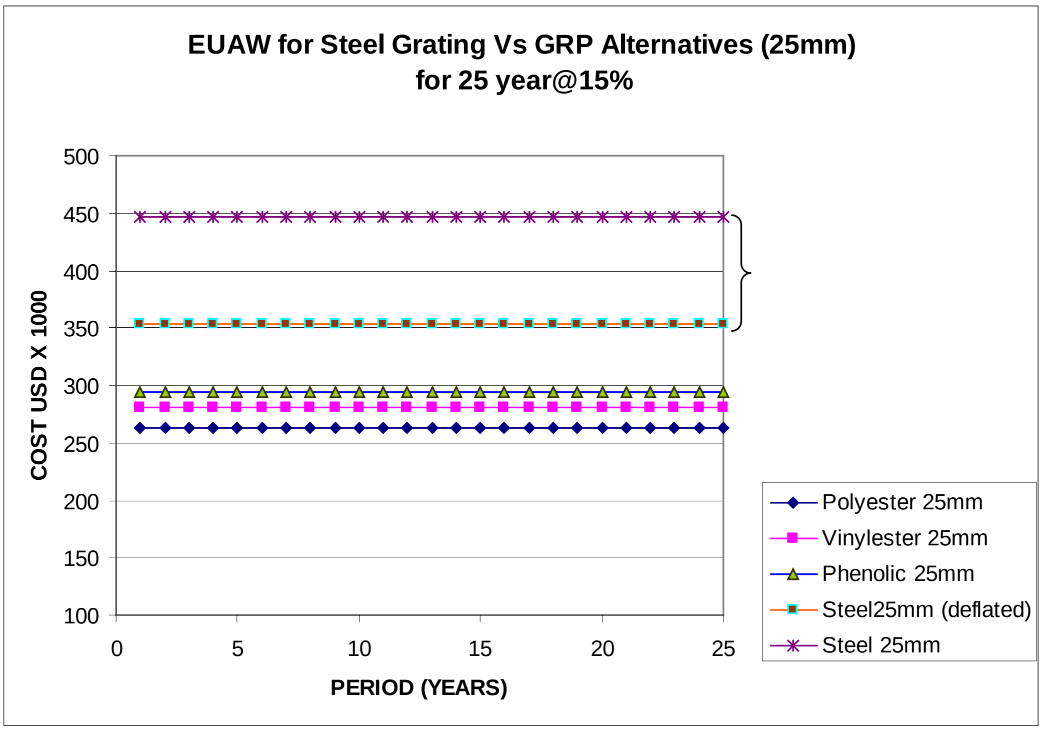


Figure 5.33: EUAW for Steel Grating (Deflated) VS GRP Alternatives 25mm (15%, 25)

5.4.2 Deflation by 10% in Both Materials & Installation Cost

5.4.2.1 Results for 20 years at 5%, 10% & 15%

When deflation took into account, Figure 5.34 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 5% interest rate for 20 years.

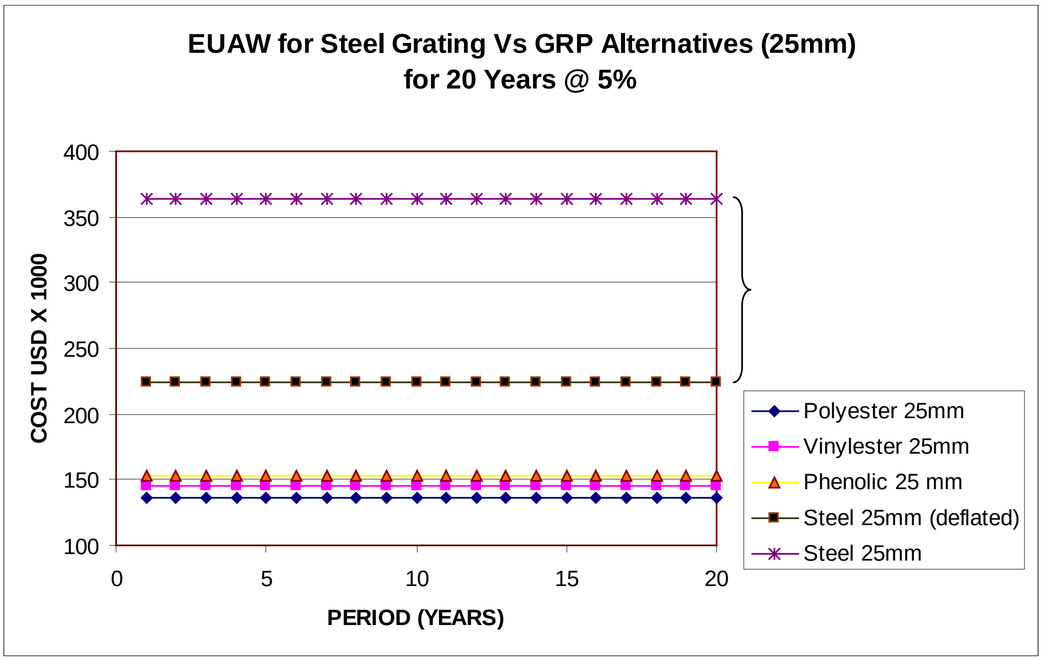


Figure 5.34: EUAW for Steel Grating (Deflated 10%) VS GRP Alternatives 25mm (5%, 20)

When deflation took into account, Figure 5.35 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 10% interest rate for 20 years.

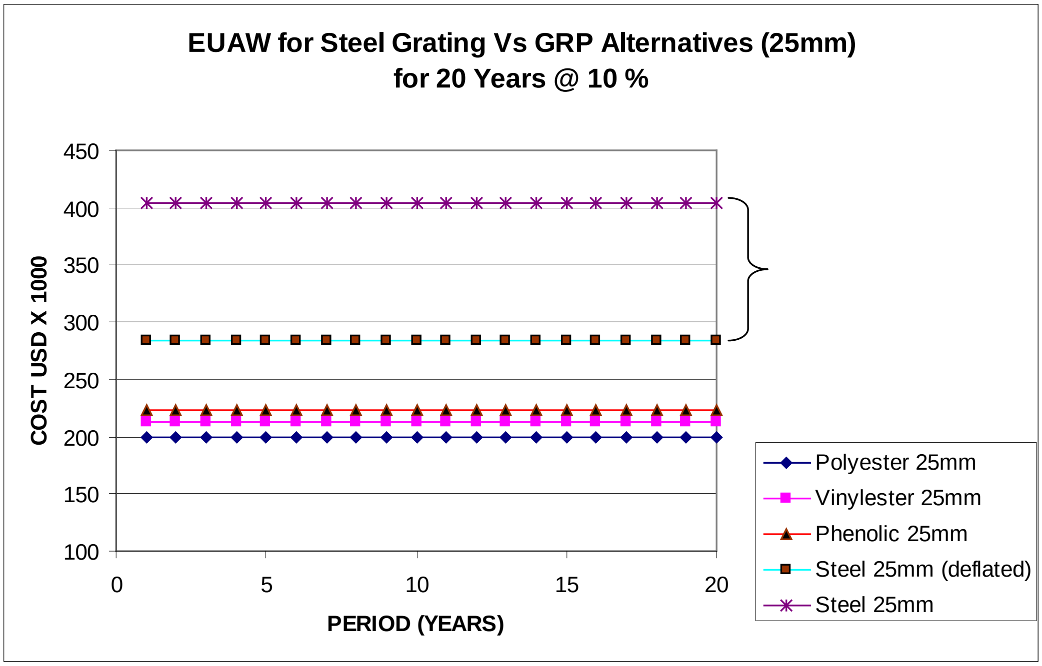


Figure 5.35: EUAW for Steel Grating (Deflated 10%) VS GRP Alternatives 25mm (10%, 20)

When deflation took into account, Figure 5.36 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 15% interest rate for 20 years.

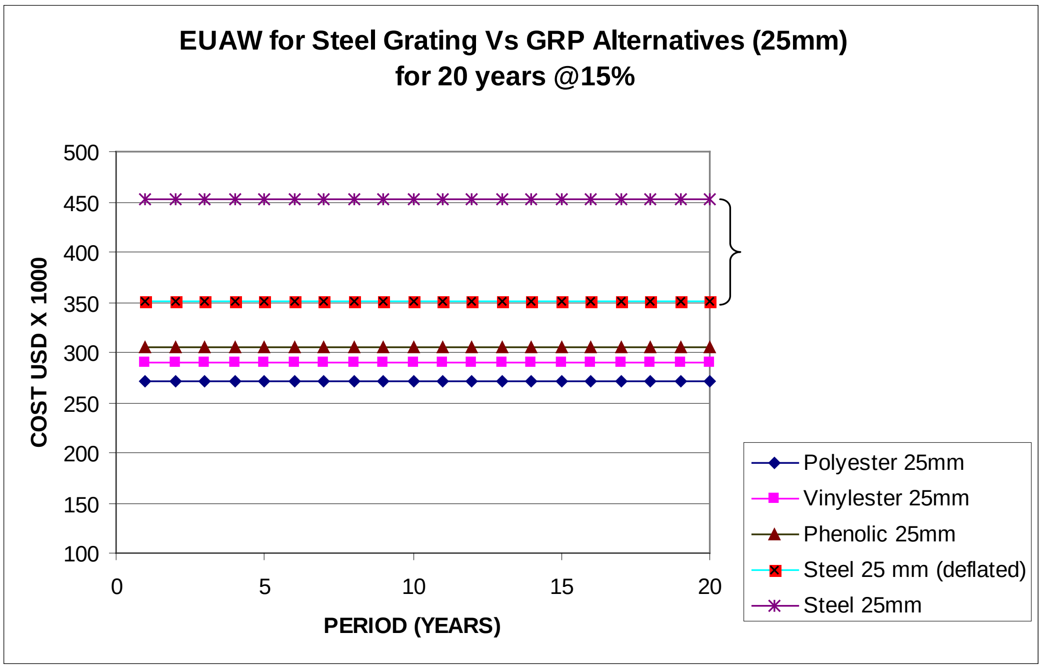


Figure 5.36: EUAW for Steel Grating (Deflated 10%) VS GRP Alternatives 25mm (15%, 20)

5.4.2.2 Results for 25 years at 5%, 10% & 15%

When deflation took into account, Figure 5.37 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 5% interest rate for 25 years.

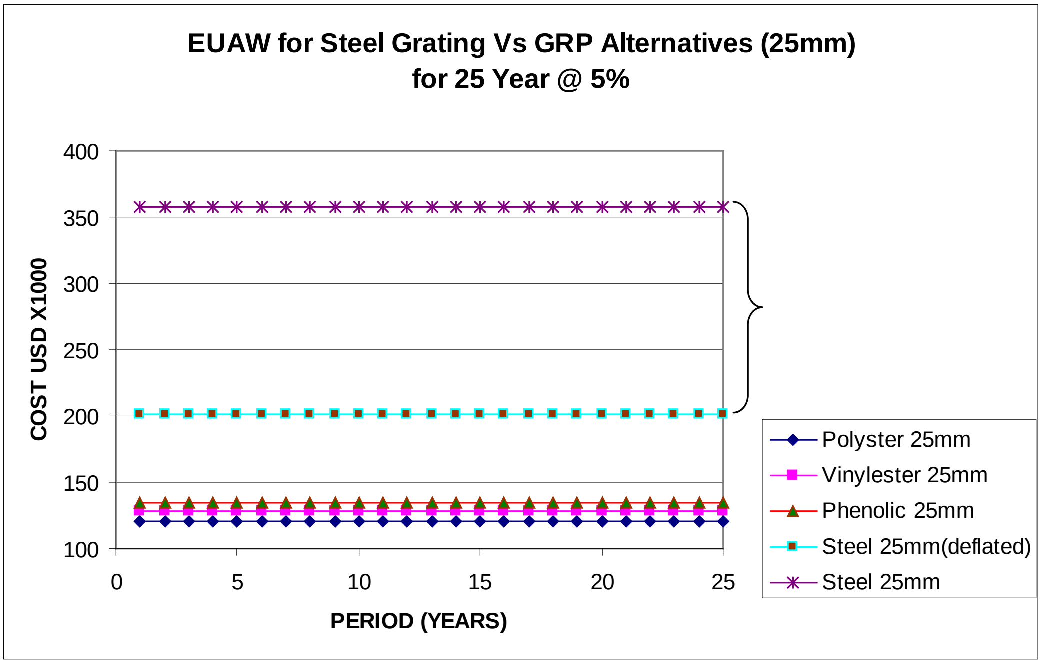


Figure 5.37: EUAW for Steel Grating (Deflated 10%) VS GRP Alternatives 25mm (5%, 25)

When deflation took into account, Figure 5.38 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 10% interest rate for 25 years.

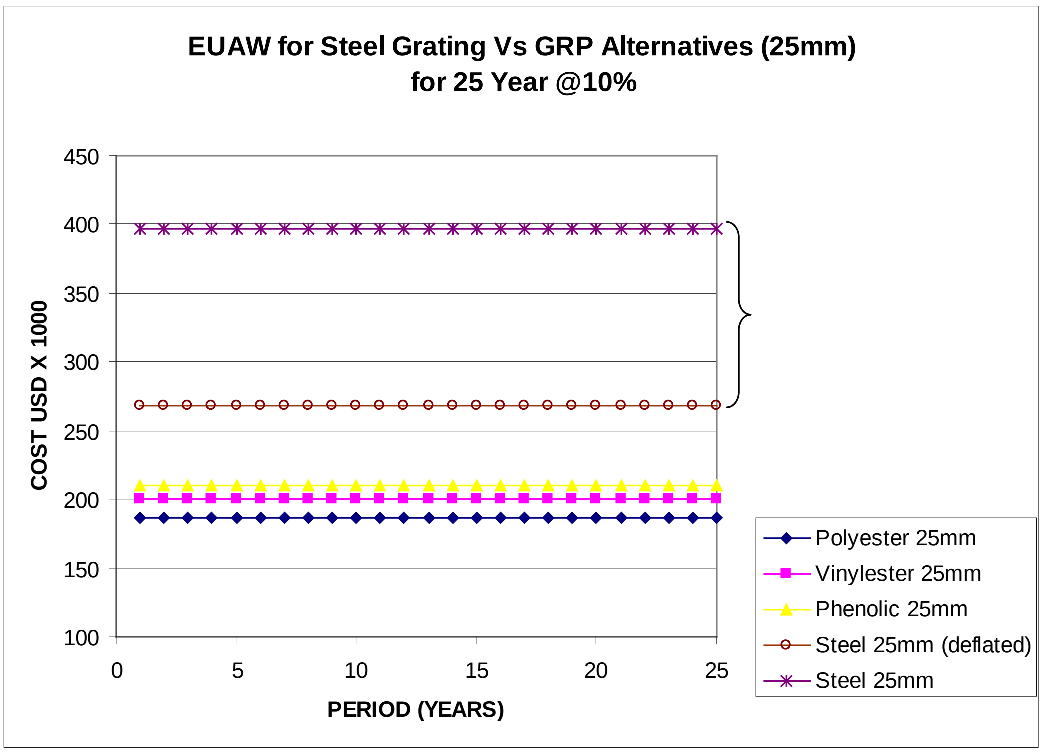


Figure 5.38: EUAW for Steel Grating (Deflated 10%) VS GRP Alternatives 25mm (10%, 25)

When deflation took into account, Figure 5.39 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 15% interest rate for 25 years.

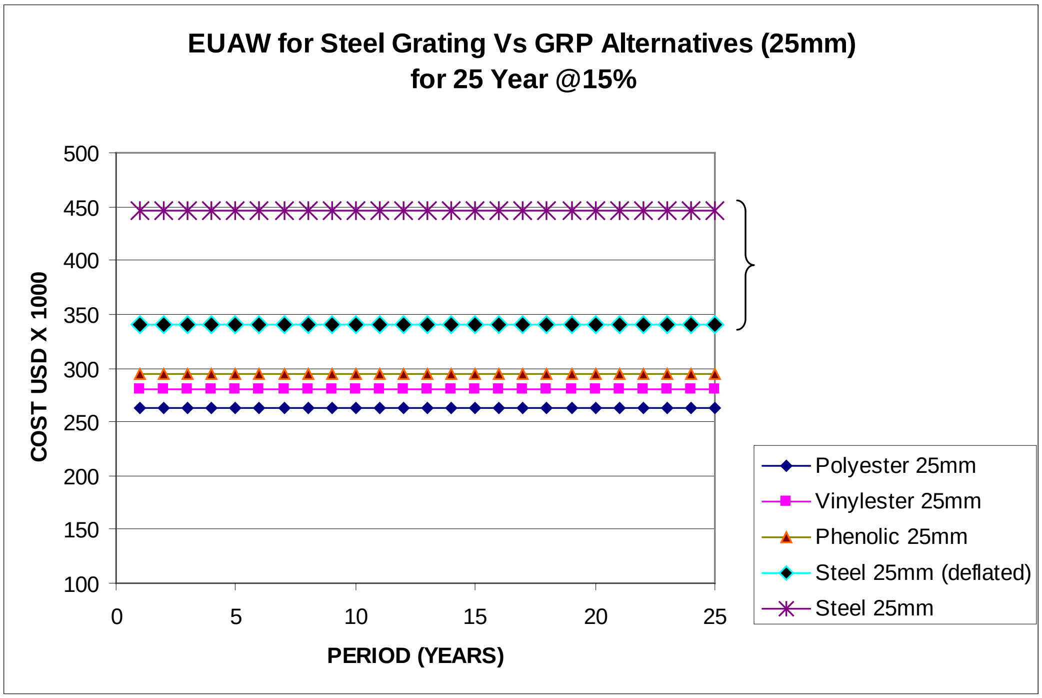


Figure 5.39: EUAW for Steel Grating (Deflated 10%) VS GRP Alternatives 25mm (15%, 25)

5.5 DEFLATION IMPACT ON THE LCC FOR THE STEEL GRATINGS VERSUS GRP ALTERNATIVES (38MM)

5.5.1 Deflation by 5% in Materials Cost and 10% In Installation Cost

5.5.1.1 Results for 20 Years at 5%, 10% & 15%

When deflation took into account, figure 5.40 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 5% interest rate for 20 years.

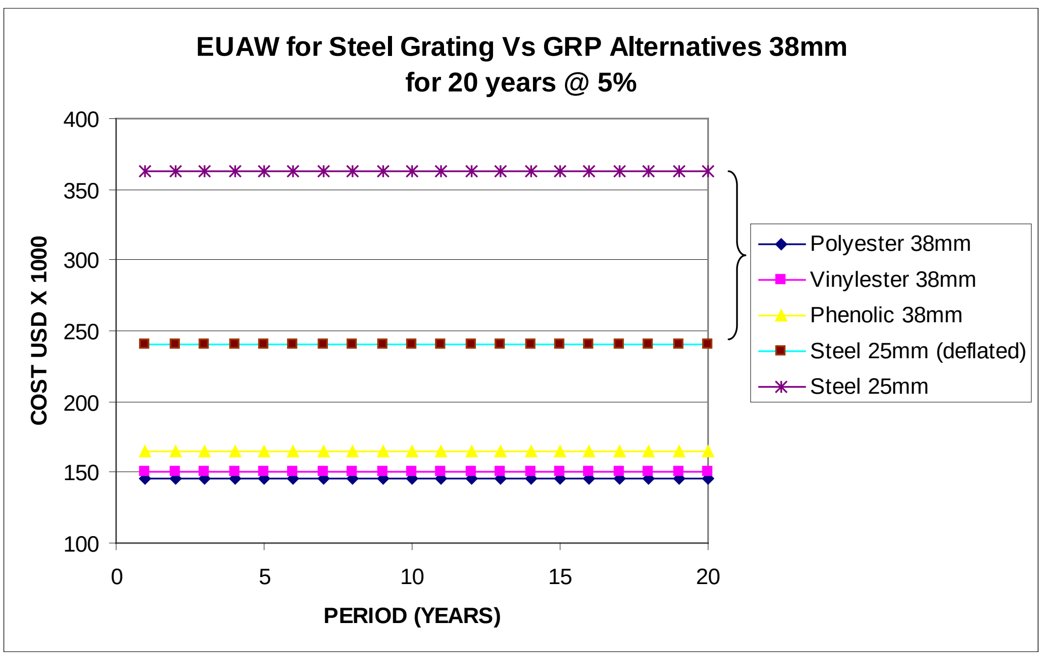


Figure 5.40: EUAW for Steel Grating (deflated) VS GRP Alternatives 38mm (5%, 20)

When deflation took into account, Figure 5.41 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 10% interest rate for 20 years.

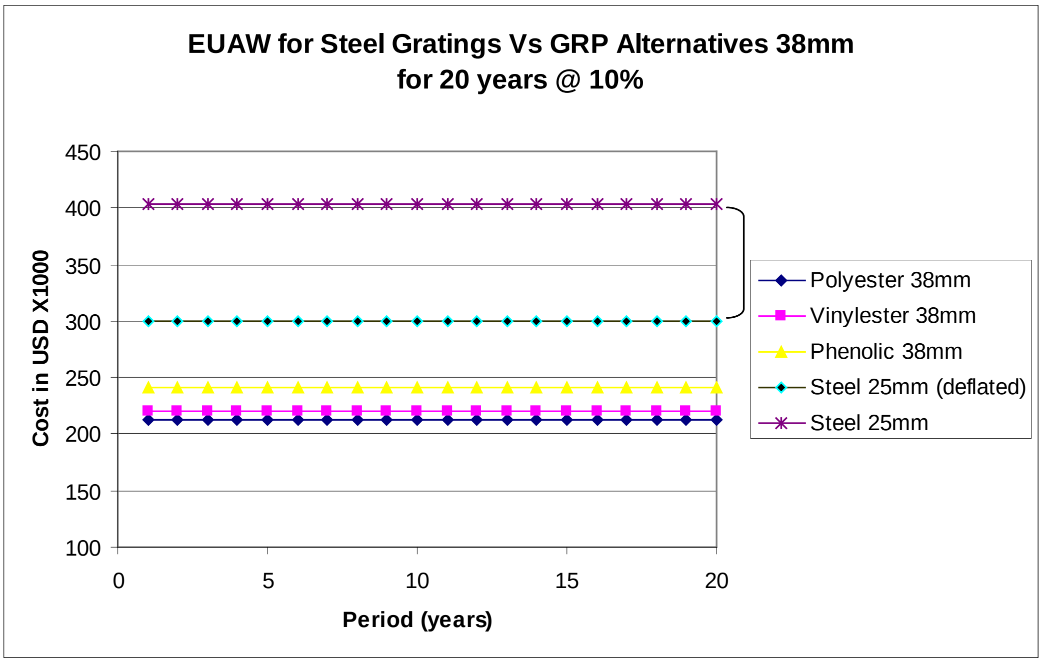


Figure 5.41: EUAW for Steel Grating (deflated) VS GRP Alternatives 38mm (10%, 20)

When deflation took into account, Figure 5.42 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 15% interest rate for 20 years.

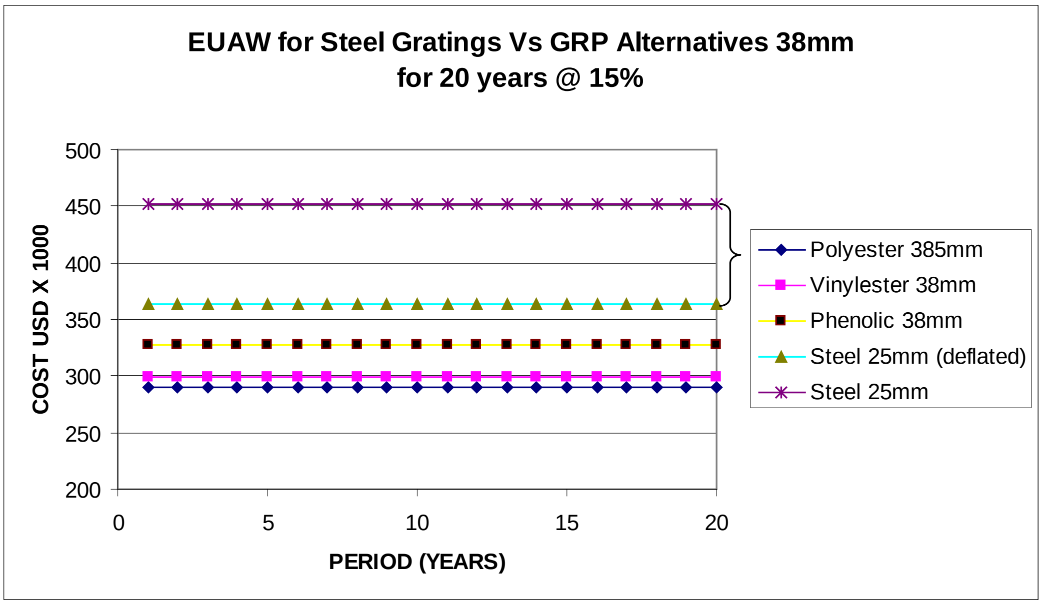


Figure 5.42: EUAW for Steel Grating (deflated) VS GRP Alternatives 38mm (15%, 20)

5.5.1.2 Results for 25 Years at 5%, 10% & 15%

When deflation took into account, Figure 5.43 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 5% interest rate for 25 years.

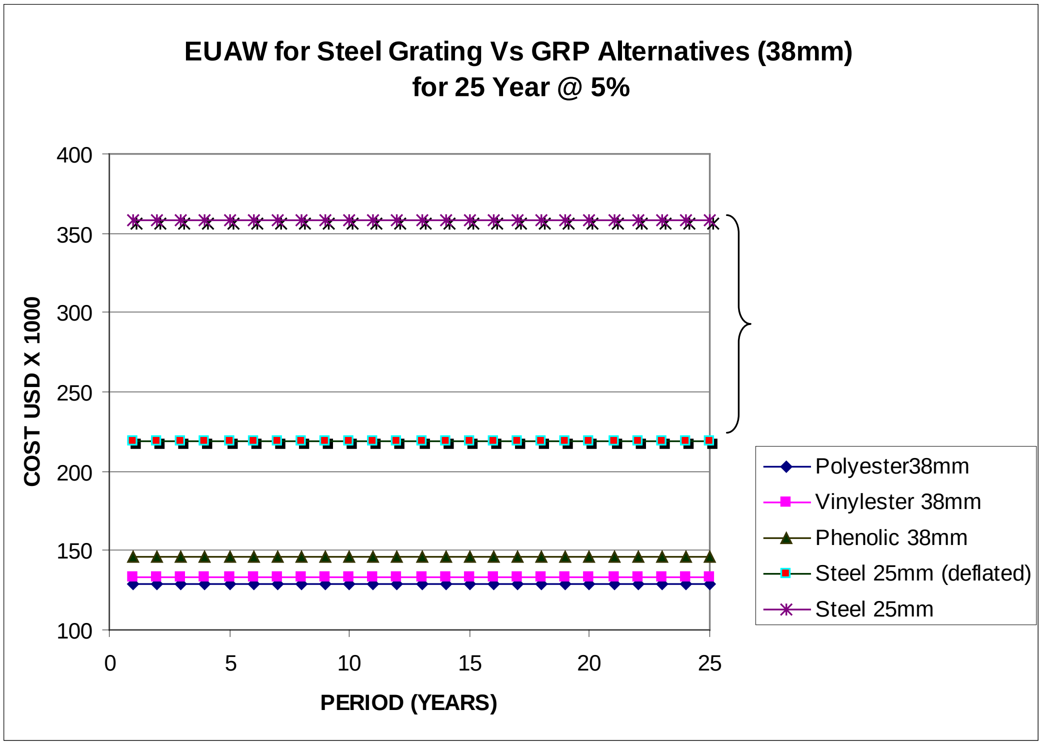


Figure 5.43: EUAW for Steel Grating (deflated) VS GRP Alternatives 38mm (5%, 25)

When deflation took into account, Figure 5.44 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 10% interest rate for 25 years.

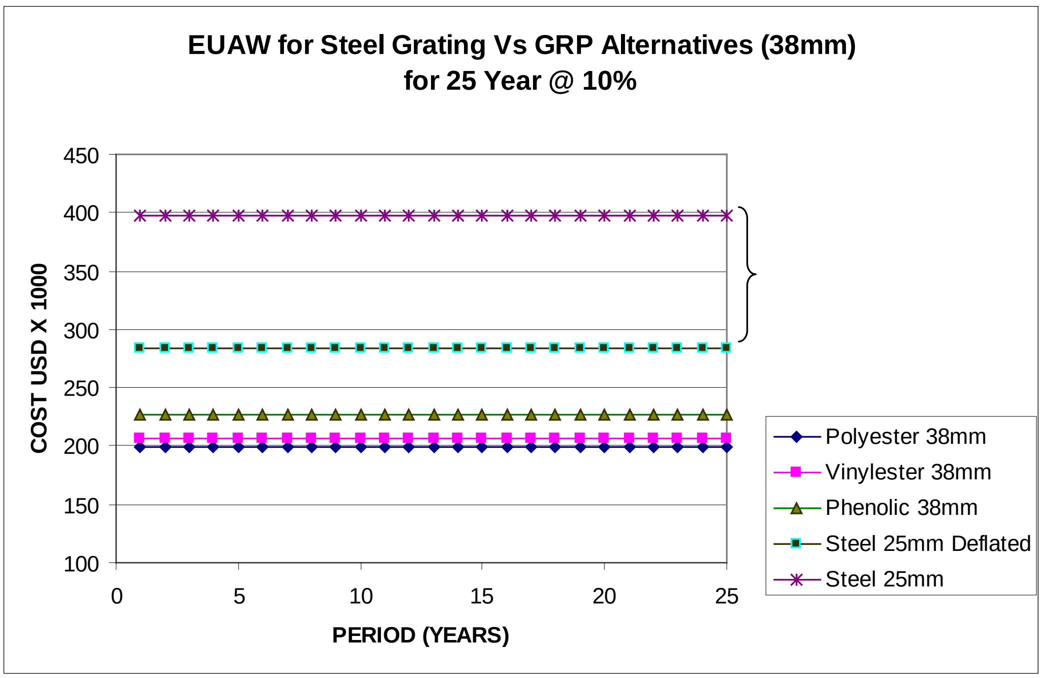


Figure 5.44: EUAW for Steel Grating (deflated) VS GRP Alternatives 38mm (10%, 25)

When deflation took into account, Figure 5.39 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 15% interest rate for 25 years.

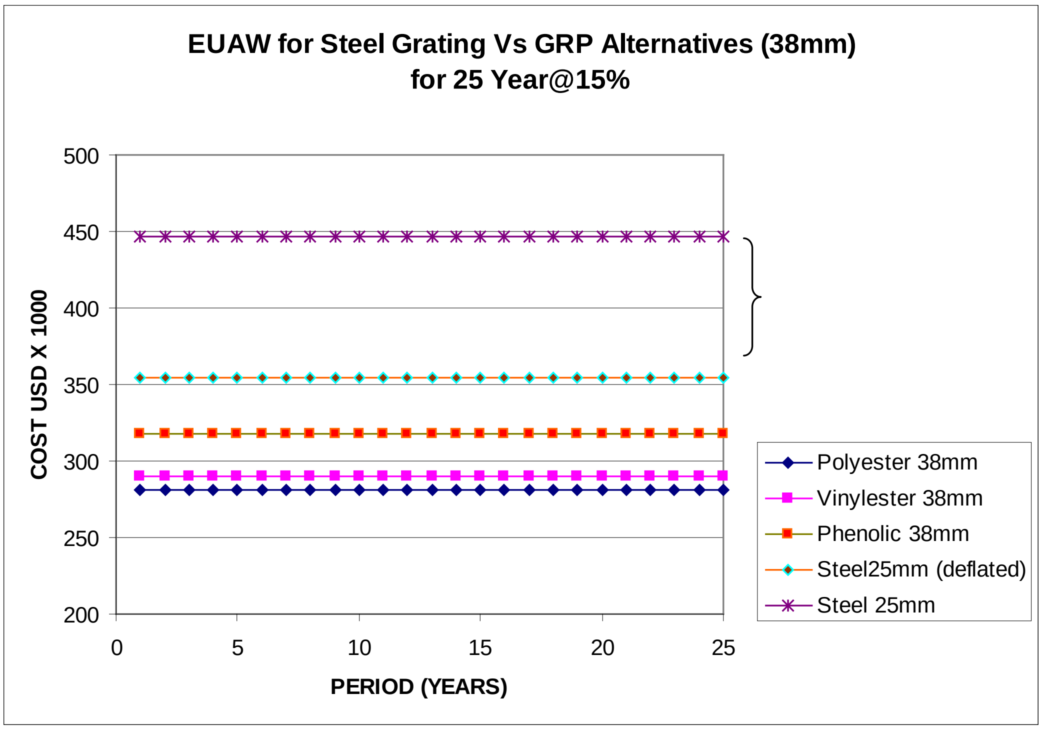


Figure 5.45: EUAW for Steel Grating (deflated) VS GRP Alternatives 38mm (15%, 25)

5.5.2 Deflation By 10% In Both Materials & Installation Cost

5.5.2.1 Results for 20 Years at 5%, 10% & 15%

When deflation took into account, Figure 5.46 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 5% interest rate for 20 years.

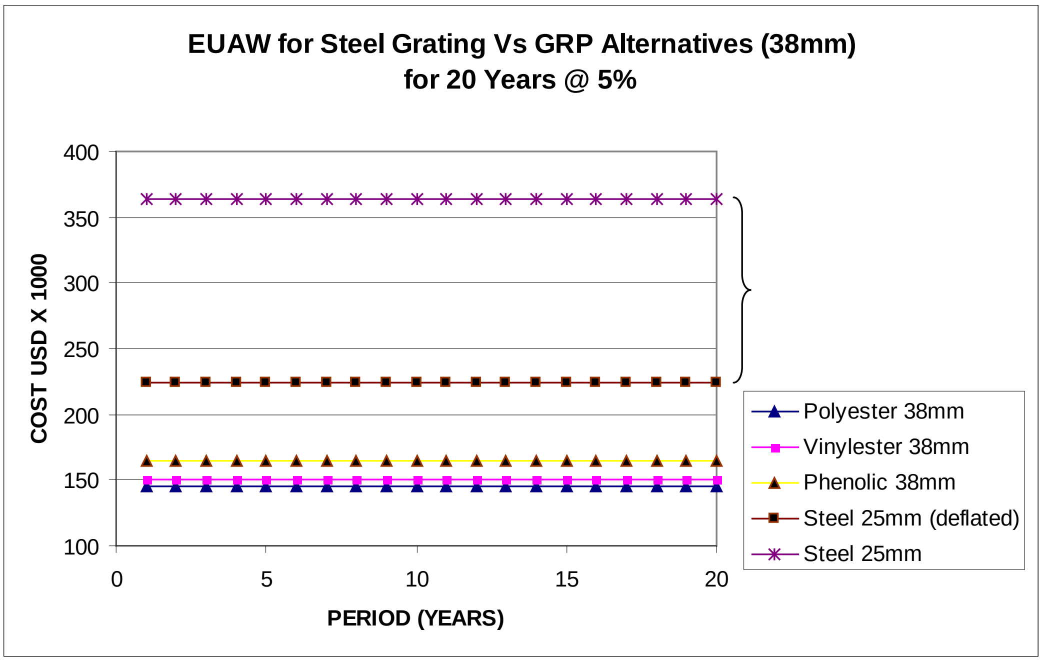


Figure 5.46: EUAW for Steel Grating (Deflated 10%) VS GRP Alternatives 38mm (5%, 20)

When deflation took into account, Figure 5.47 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 10% interest rate for 20 years.

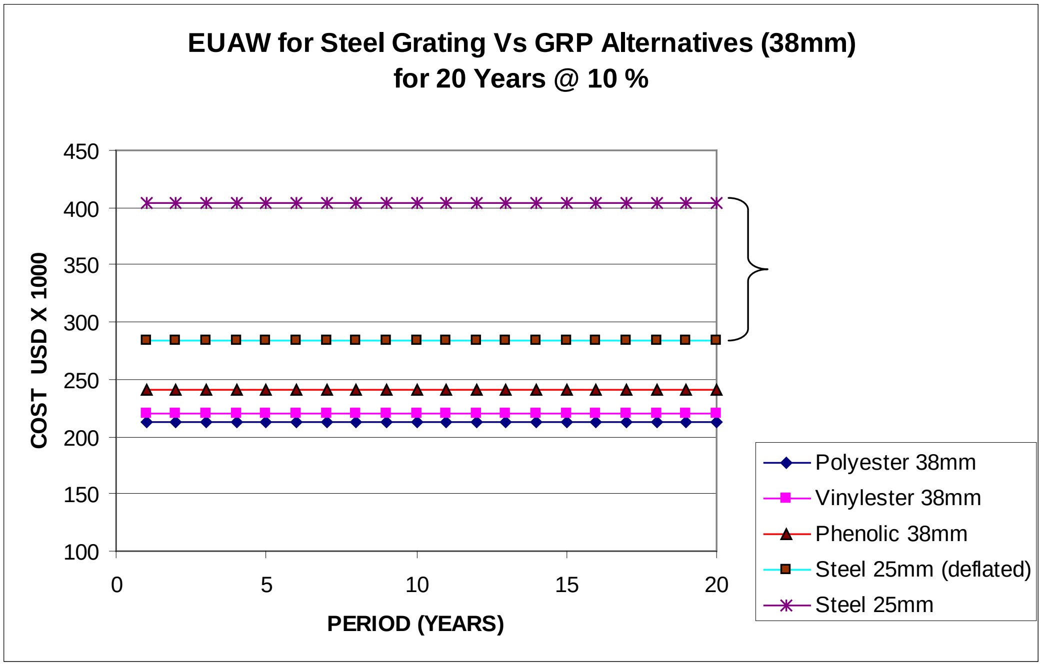


Figure 5.47: EUAW for Steel Grating (Deflated 10%) VS GRP Alternatives 38mm (10%, 20)

When deflation took into account, Figure 5.48 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 15% interest rate for 20 years.

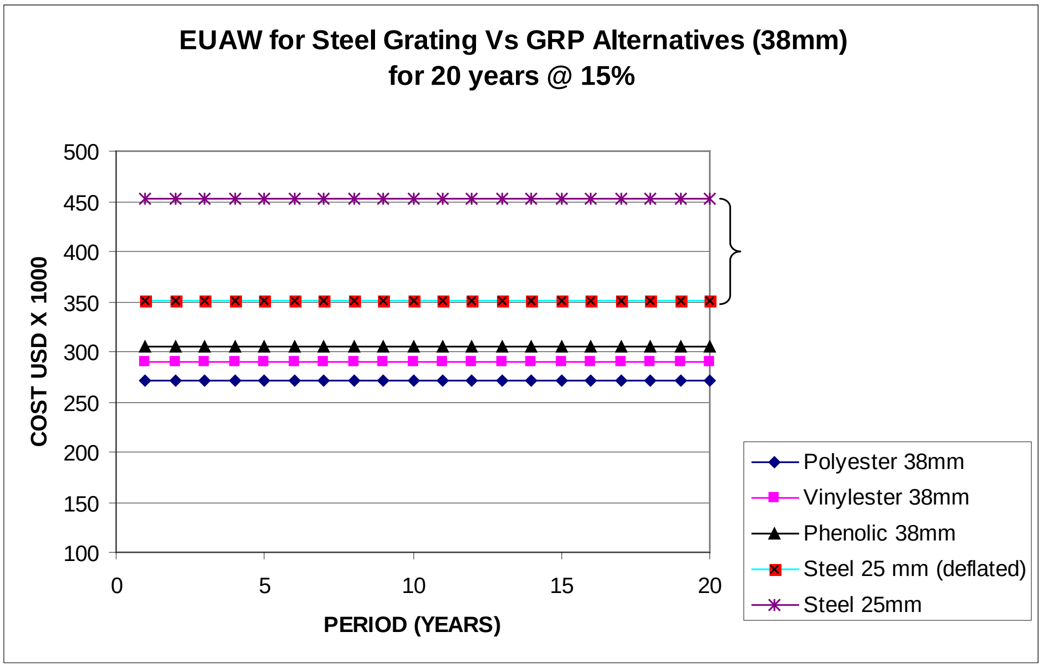


Figure 5.48: EUAW for Steel Grating (Deflated 10%) VS GRP Alternatives 38mm (15%, 20)

5.5.2.2 Results for 25 Years at 5%, 10% & 15%

When deflation took into account, Figure 5.49 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 5% interest rate for 25 years.

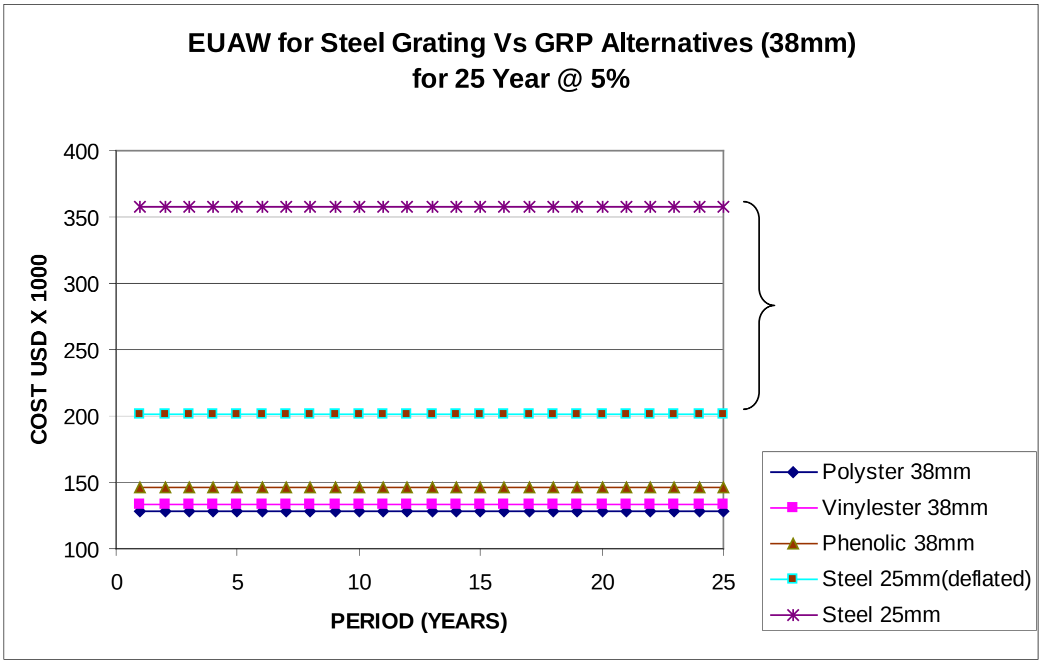


Figure 5.49: EUAW for Steel Grating (Deflated 10%) VS GRP Alternatives 38mm (5%, 25)

When deflation took into account, Figure 5.50 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 10% interest rate for 25 years.

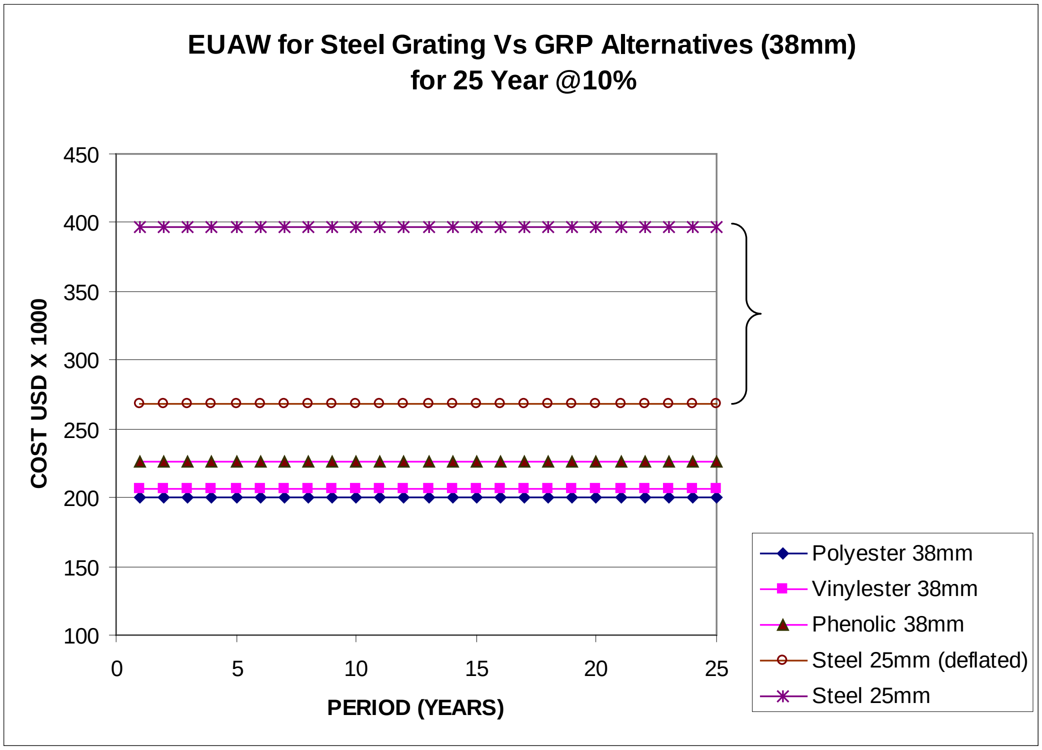


Figure 5.50: EUAW for Steel Grating (Deflated 10%) VS GRP Alternatives 38mm (10%, 25)

When deflation took into account, Figure 5.51 shows that EUAW for steel gratings (deflated) is higher than GRP alternatives at 15% interest rate for 25 years.

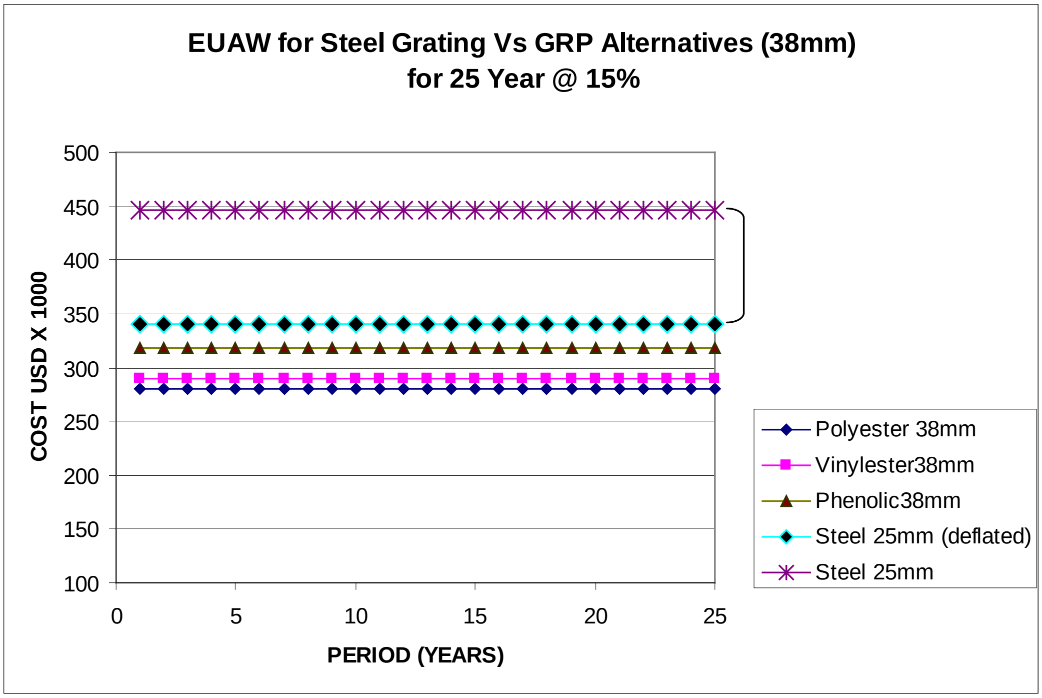


Figure 5.51: EUAW for Steel Grating (Deflated 10%) VS GRP Alternatives 38mm (15%, 25)

5.6 DEFLATION IMPACT ON THE LCC FOR THE STEEL HANDRAIL VERSUS GRP ALTERNATIVES

5.6.1 Deflation by 5% in Materials Cost and 10% In Installation Cost

5.6.1.1 Results for 20 years at 5%, 10% & 15%

When deflation took into account, Figure 5.52 shows that EUAW for steel handrail (deflated) is still higher than GRP alternatives at 5% interest rate for 20 years.

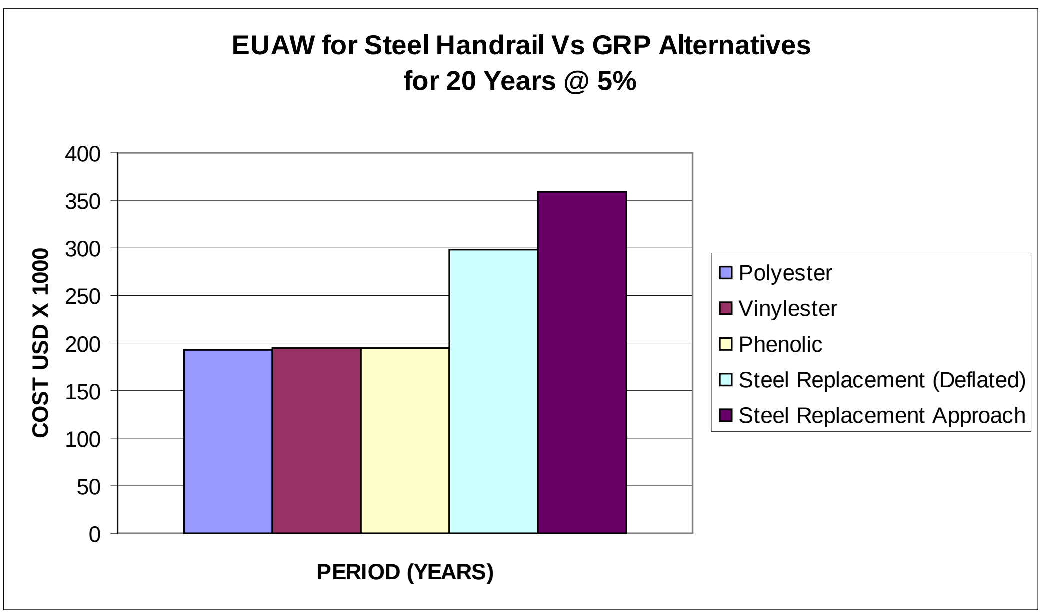


Figure 5.52: EUAW for Steel Handrail (Deflated) VS GRP Alternatives (5%, 20)

When deflation took into account, Figure 5.53 shows that EUAW for steel handrail (deflated) is still higher than GRP alternatives at 10% interest rate for 20 years.

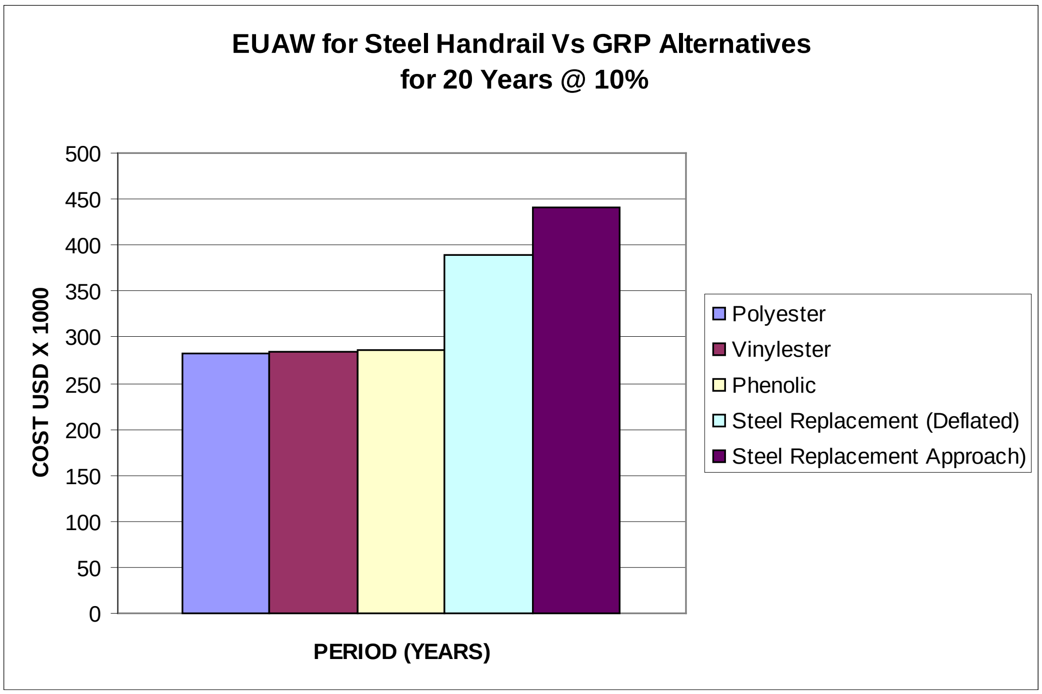


Figure 5.53: EUAW for Steel Handrail (Deflated) VS GRP Alternatives (10%, 20)

When deflation took into account, Figure 5.54 shows that EUAW for steel handrail (deflated) is still higher than GRP alternatives at 15% interest rate for 20 years.

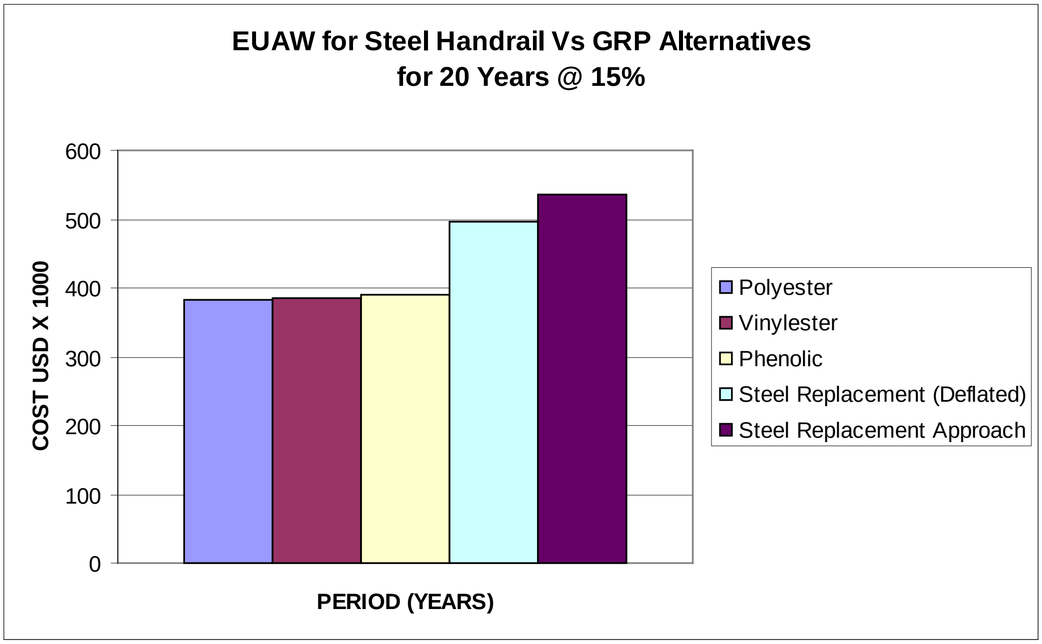


Figure 5.54: EUAW for Steel Handrail (Deflated) VS GRP Alternatives (15%, 20)

5.6.1.2 Results for 25 years at 5%, 10% & 15%

When deflation took into account, Figure 5.55 shows that EUAW for steel handrail (deflated) is still higher than GRP alternatives at 5% interest rate for 25 years.

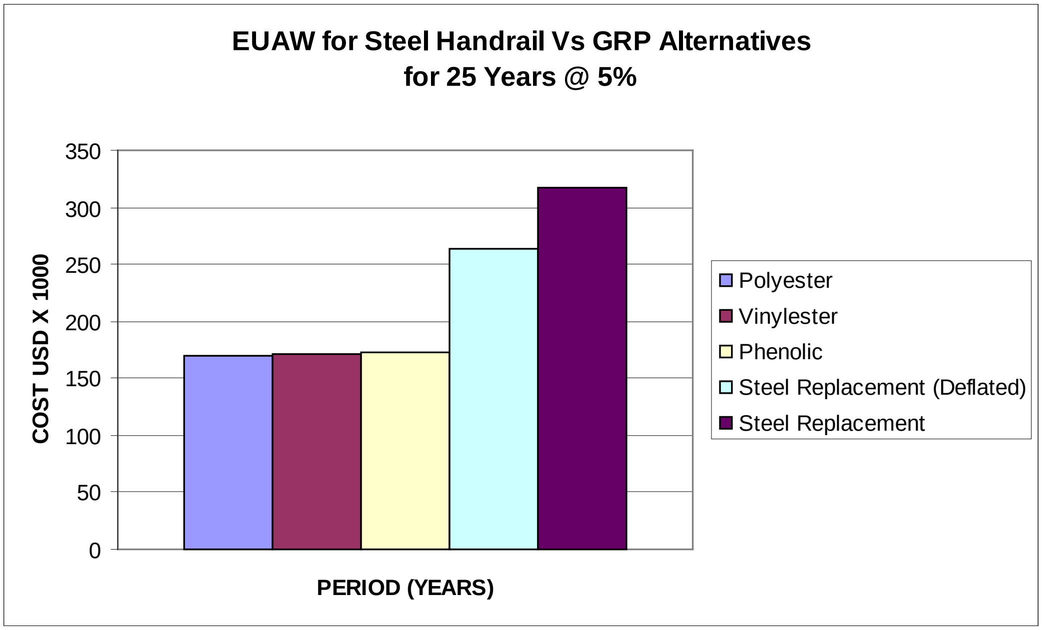


Figure 5.55: EUAW for Steel Handrail (Deflated) VS GRP Alternatives (5%, 25)

When deflation took into account, Figure 5.56 shows that EUAW for steel handrail (deflated) is still higher than GRP alternatives at 10% interest rate for 25 years.

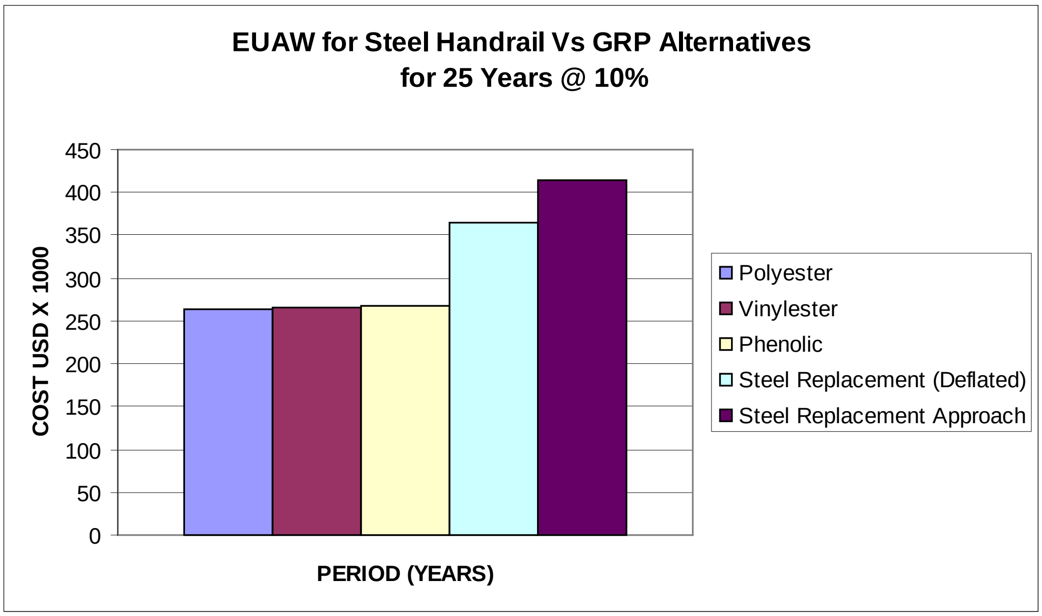


Figure 5.56: EUAW for Steel Handrail (Deflated) VS GRP Alternatives (10%, 25)

When deflation took into account, Figure 5.57 shows that EUAW for steel handrail (deflated) is still higher than GRP alternatives at 15% interest rate for 25 years.

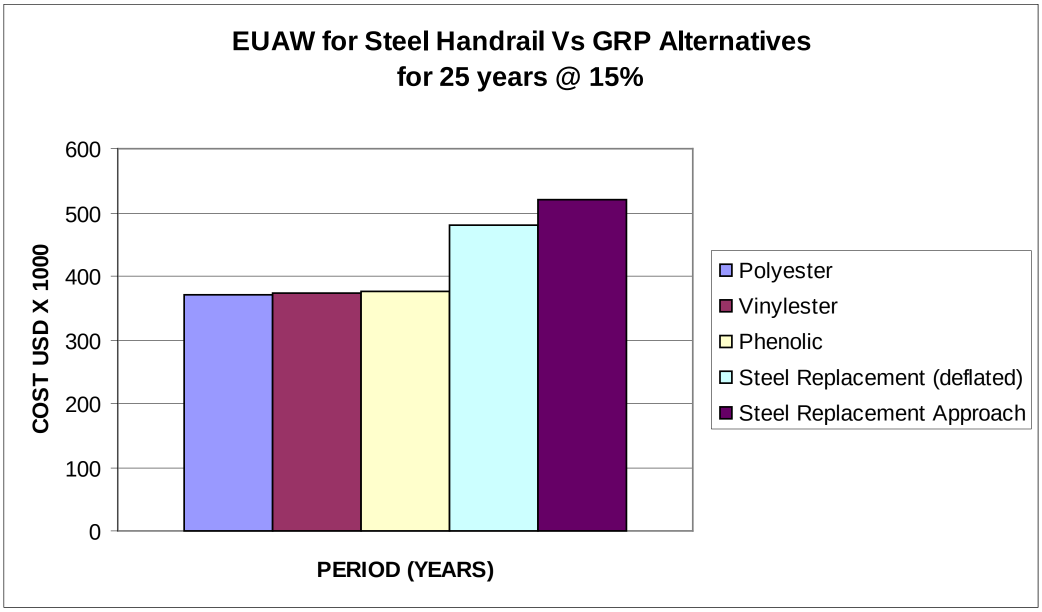


Figure 5.57: EUAW for Steel Handrail (Deflated) VS GRP Alternatives (15%, 25)

5.6.2 Deflation by 10% in Both Materials and Installation Cost

5.6.2.1 Results for 20 years at 5%, 10% & 15%

When deflation took into account, Figure 5.58 shows that EUAW for steel handrail (deflated) is still higher than GRP alternatives at 5% interest rate for 20 years.

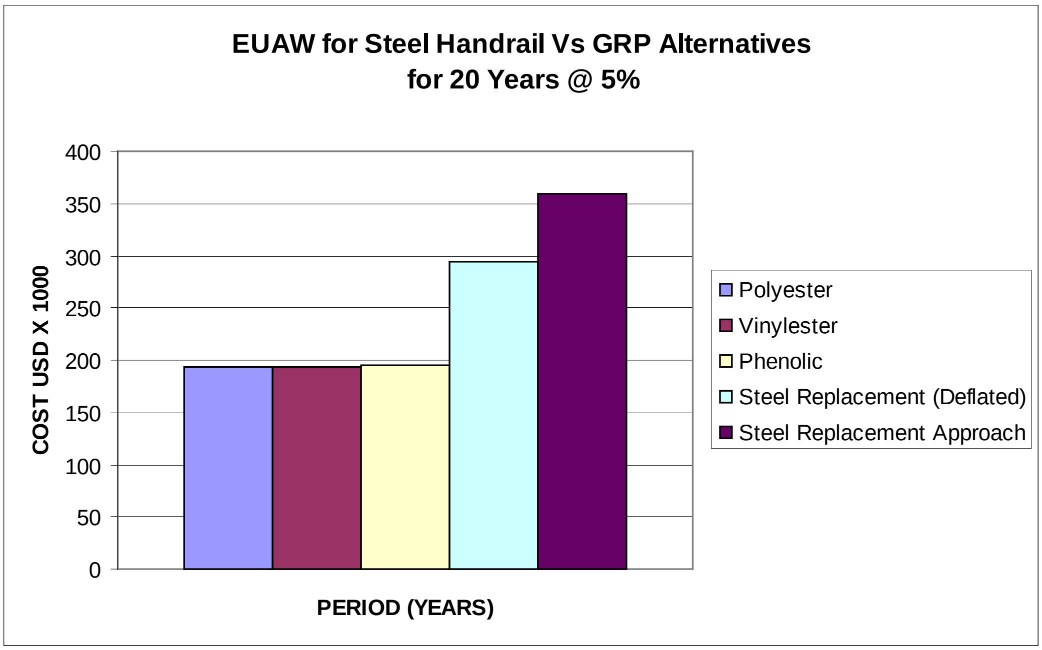


Figure 5.58: EUAW for Steel Handrail (Deflated 10%) VS GRP Alternatives (5%, 20)

When deflation took into account, Figure 5.59 shows that EUAW for steel handrail (deflated) is still higher than GRP alternatives at 10% interest rate for 20 years.

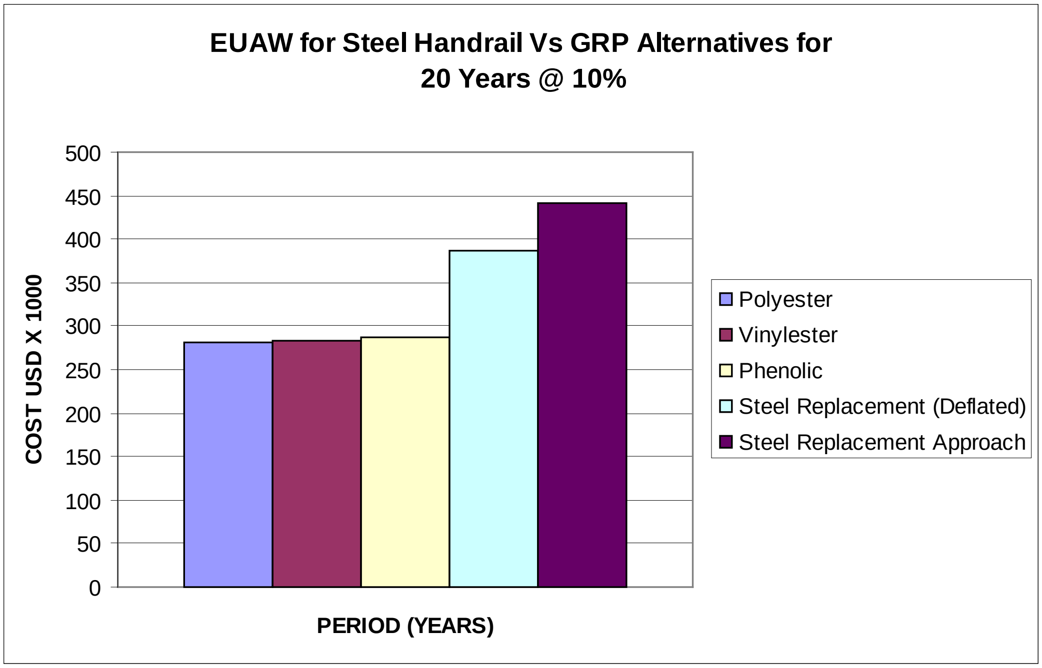


Figure 5.59: EUAW for Steel Handrail (Deflated 10%) VS GRP Alternatives (10%, 20)

When deflation took into account, Figure 5.60 shows that EUAW for steel handrail (deflated) is still higher than GRP alternatives at 15% interest rate for 20 years.

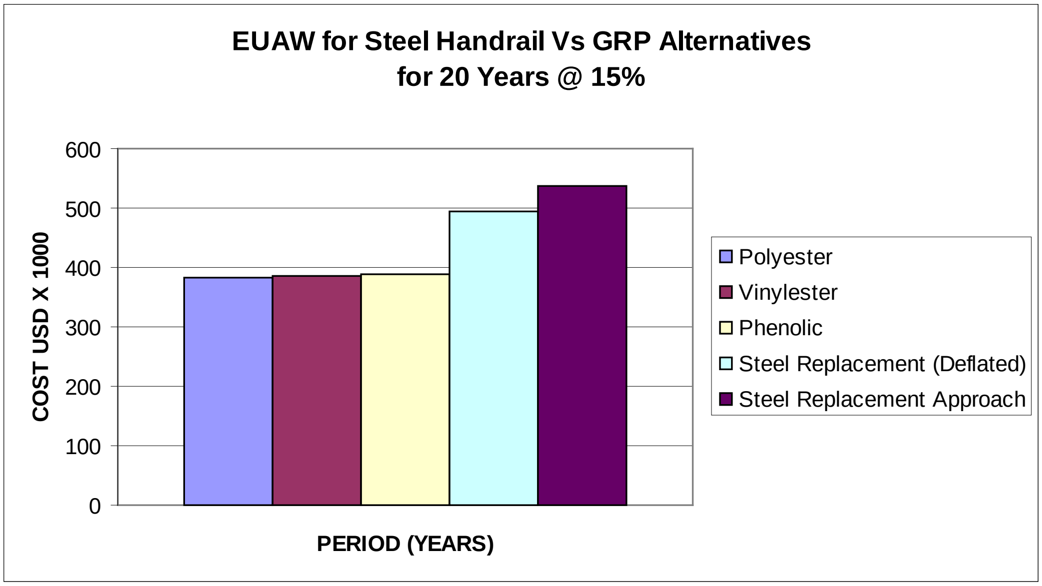


Figure 5.60: EUAW for Steel Handrail (Deflated 10%) VS GRP Alternatives (15%, 20)

5.6.2.2 Results for 25 years at 5%, 10% & 15%

When deflation took into account, Figure 5.61 shows that EUAW for steel handrail (deflated) is still higher than GRP alternatives at 5% interest rate for 25 years.

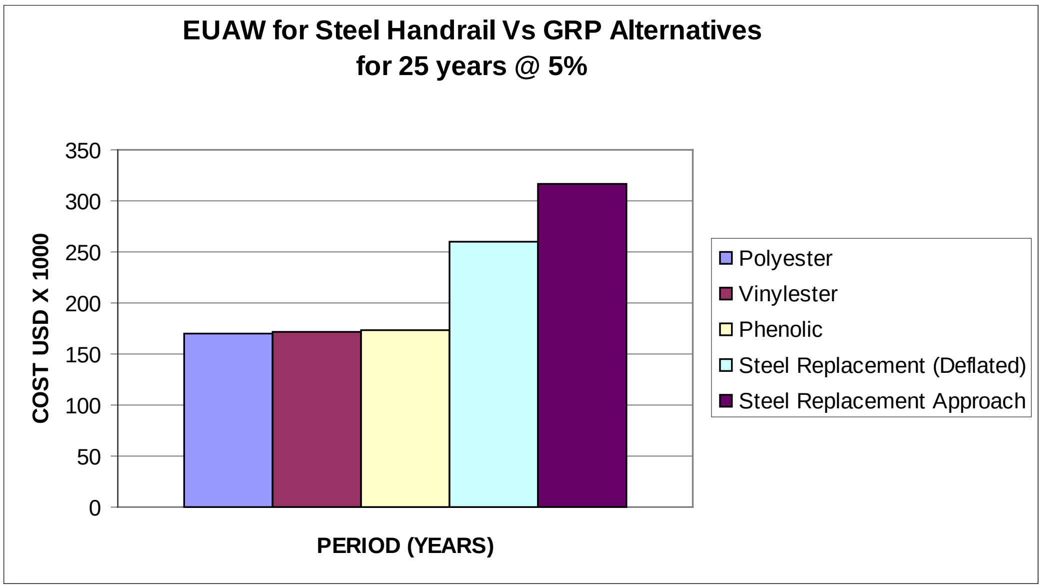


Figure 5.61: EUAW for Steel Handrail (Deflated 10%) VS GRP Alternatives (5%, 25)

When deflation took into account, Figure 5.62 shows that EUAW for steel handrail (deflated) is still higher than GRP alternatives at 10% interest rate for 25 years.

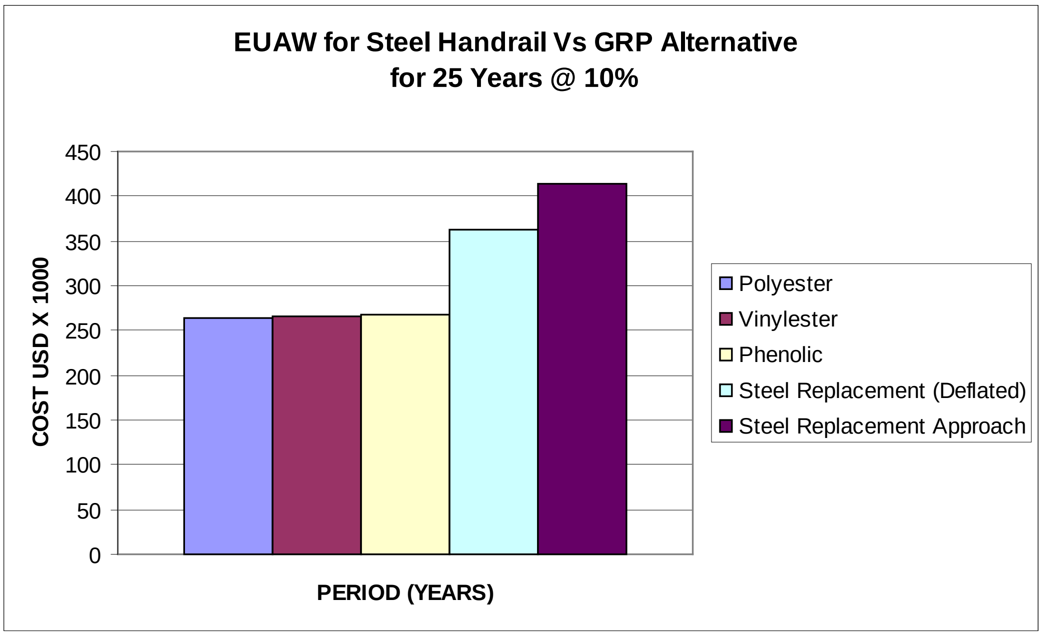


Figure 5.62: EUAW for Steel Handrail (Deflated 10%) VS GRP Alternatives (10%, 25)

When deflation took into account, Figure 5.63 shows that EUAW for steel handrail (deflated) is still higher than GRP alternatives at 15% interest rate for 25 years.

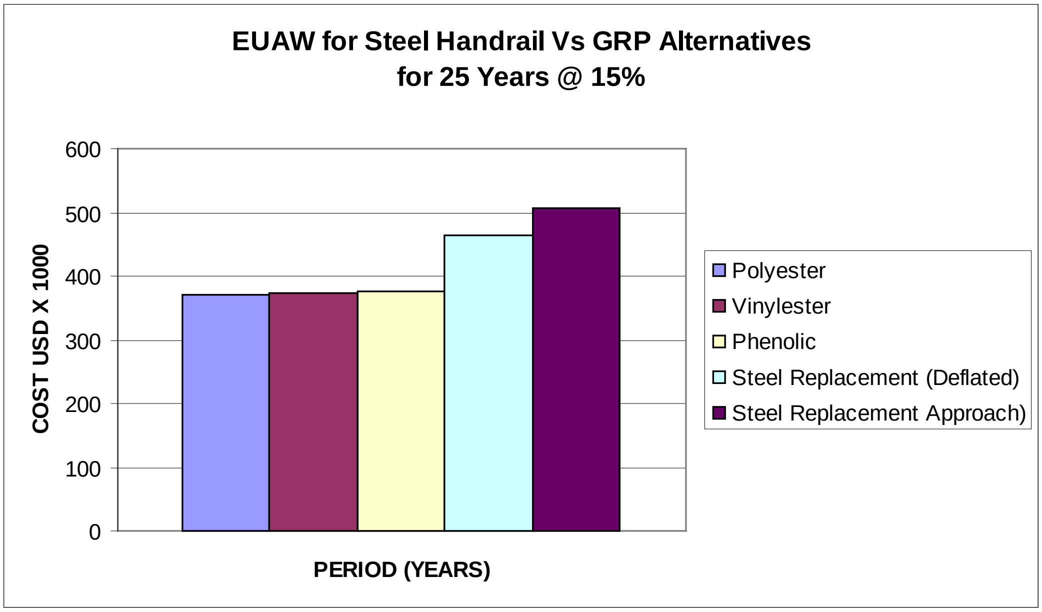


Figure 5.63: EUAW for Steel Handrail (Deflated 10%) VS GRP Alternatives (15%, 25)

5.7 ANALYSIS AND SENSETIVITY ANALYSIS CONCLUSION

5.7.1 Gratings

It has been found from the analysis that the GRP gratings are more economical than the steel gratings over the platform lifetime for both 25mm and 38mm thicknesses; however, as shown down in figures 5.64 & 5.65 steel gratings are lower in LCC for a short period less than 6 years.

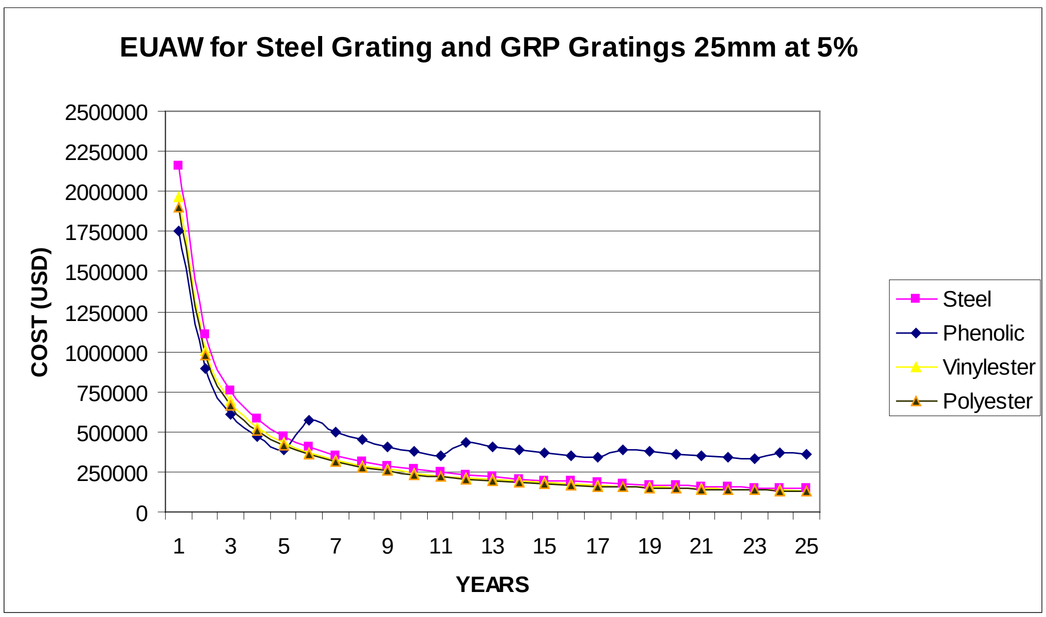


Figure 5.64: LCC For Steel Grating VS GRP Alternatives 25mm @ 5% at Different Years

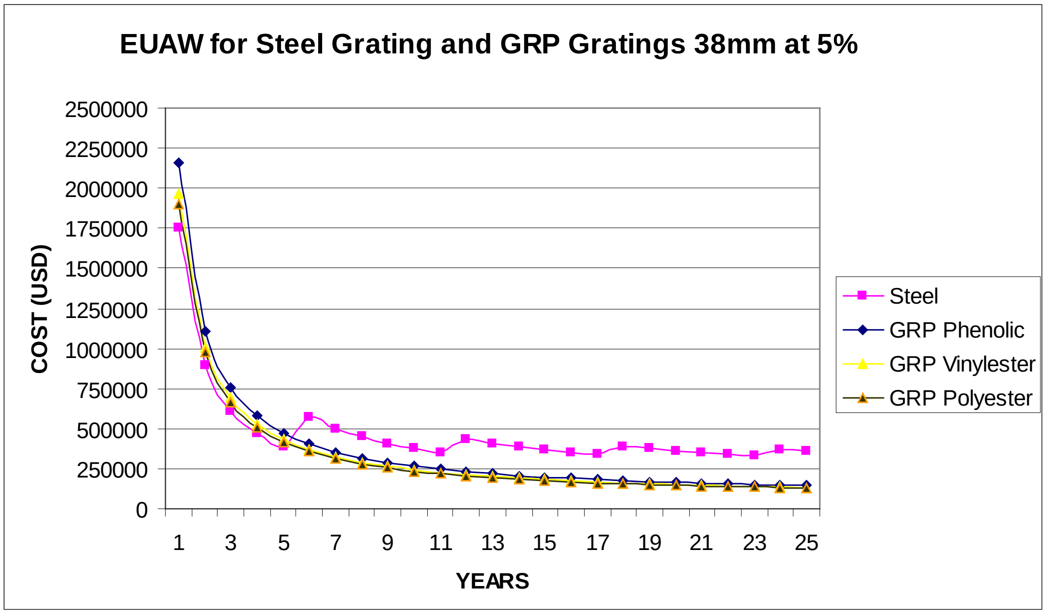


Figure 5.65: LCC For Steel Grating VS GRP Alternatives 38mm @ 5% at Different Years

Also, it has been found that with the increase of the interest rate the LCC for the steel gratings increases as shown in Figures 5.66 and 5.67.

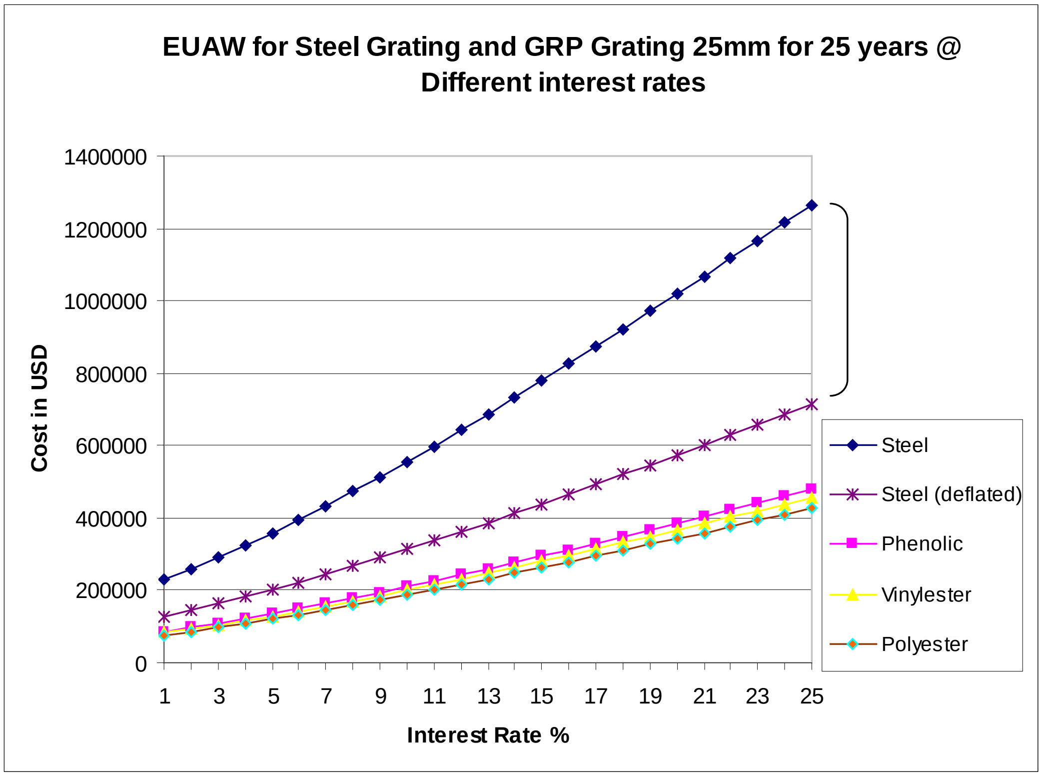


Figure 5.66: LCC For Steel Grating VS GRP Alternatives 25mm for 25 Years @ Different Interest Rate

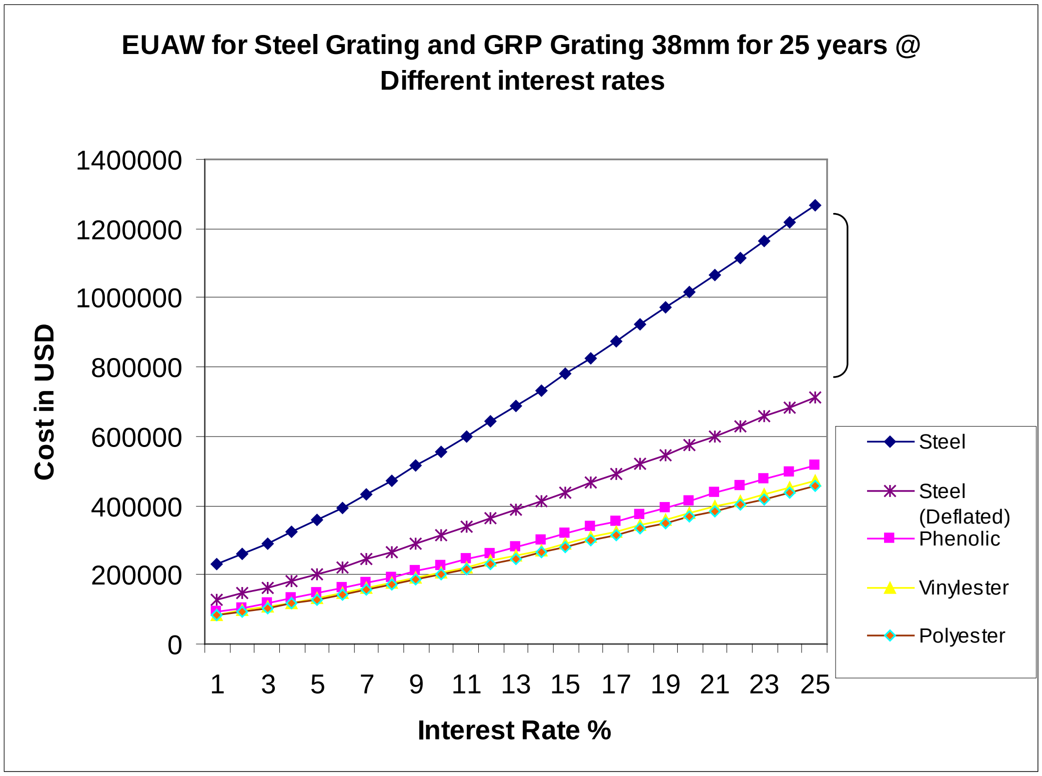


Figure 5.67: LCC For Steel Grating VS GRP Alternatives 38mm for 25 Years @ Different Interest Rate

5.7.2 Handrails

It has been found from the analysis that the GRP handrails are more economical than the steel handrails over the platform lifetime at all times and all selected interest as shown down in Figures 5.68 & 5.69.

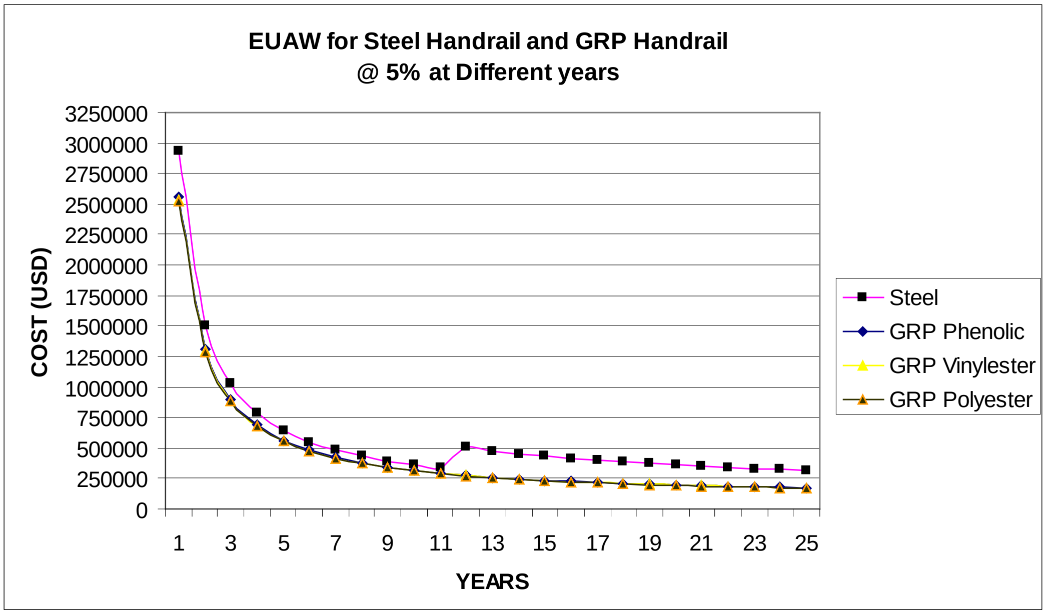


Figure 5.68: LCC For Steel Handrail VS GRP Alternatives @ 5% at Different Years.

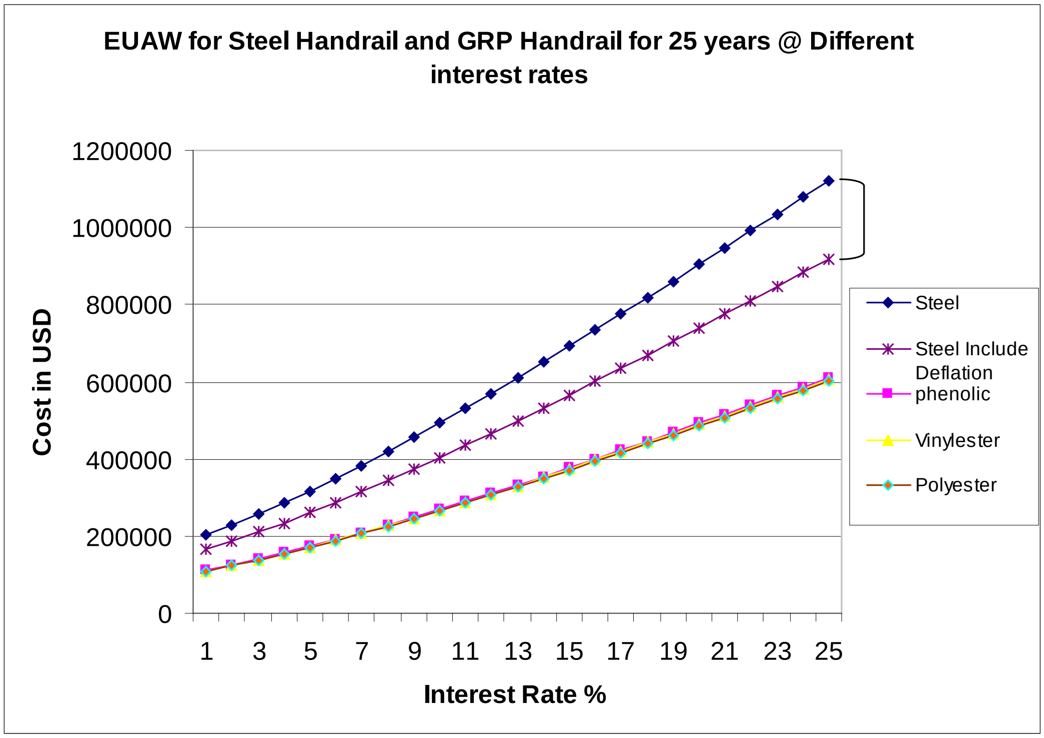


Figure 5.69: LCC For Steel Handrail VS GRP Alternatives for 25 years @ Different Interest Rate.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 SUMMARY

Cost savings in the oil and gas business are sometimes difficult to come by, but materials selection is one of the ways to do it. New materials have been developed from composites and have superior characteristic for offshore environments. These materials need to be evaluated from the life cycle costing point of view.

The AB-platform at Alshaheen field in Qatar was selected as a case study. Both the gratings and handrails systems at AB-platform were evaluated by using life cycle costing techniques using steel materials as the base material for offshore structural materials and new GRP materials as an alternative material. The analysis was based on 25 years of use, which is the design platform's lifetime, and used 5% as the interest rate. Sensitivity analysis was applied considering changes in the interest rate and in the platform lifetime. Sensitivity analysis also considered deflation in steel materials and offshore installation costs to determine its impact on the life cycle costing results.

Factors that affect material selection were studied in the literature review, and evaluation and selection model for offshore materials was developed based on both qualitative and quantitative measures. In the qualitative evaluation, the factors that affect materials selection were weighted using a scoring matrix. In the quantitative evaluation, weighted criteria were used in the evaluation matrix to rank the selected materials. This method provides the users with effective tools to select among competing alternative materials with the desired function prior using life cycle costing analysis.

An intensive literature review was carried out in the areas of life cycle costing techniques and methods, offshore platform background in terms of types of loads and types of materials, and corrosion control and cost of corrosion control, as these are the main concerns associated with offshore structures.

Finally, the results of the study revealed GRP materials are more economical over the platform lifetime at all selected interest rates with significant difference in the final cost by using (LCC) techniques. The results show that the GRP handrails are less than steel handrails in LCC at all times; however steel gratings are lower in LCC for a short period less than 6 years, otherwise GRP gratings are more economical.

6.2 CONCLUSION

Based on the present study, several conclusions can be drawn:

General:

From the literature review and from the data gathering, GRP materials have superior qualities that make them suitable for use in harsh environments like the offshore environment:

- GRP materials are corrosion resistant and do not require coating or galvanizing, as steel does.

- GRP gratings have high impact resistance, which means they will not deform under impact, as steel gratings do.
- Unlike steel, GRP materials have low electrical and thermal conductivities, which make them the best materials to use where electrical equipment is stationed and used. This mean GRP offers superior safety thanks to non conductive properties.
- GRP gratings and handrails do not require any prefabrication prior to its installation. It can be cutting on site with simple tools unlike steel gratings which need grindings and sometimes welding on site.
- GRP gratings and handrails offer free maintenance and replacement costs.
- The cost of offshore installations is one of the major expenses in the oil and gas industry. As shown in this study, the cost of constructing offshore installations is sometimes double the materials cost. GRP materials can be cut, installed and repaired using simple tools, and it can be shipped from place to place more easily than steel which is heavier than GRP and then need lifting equipment. This means GRP offers cheap offshore installation cost.
- The major advantage of the GRP materials is the weight reduction that can be achieved because of its low density compare to that of steel. GRP has a higher strength-to-weight ratio than steel.

- From this study at AB platform, weight reduction by 43% gained if 25mm thickness of GRP gratings is used and by 29% reduction in the weight if 38mm thickness of GRP gratings is used. Refer to Table 6.1.

Table 6.1: Weight Comparison (Gratings)

WEIGHT COMPARSION (GRATINGS)			
Item	**Base Materials**	**GRP Alternatives**	
	Steel Grating 25mm	**GRP 25 mm**	**GRP 38mm**
Grating Quantity at AB Platform (m2)	4512.3	4512.3	4512.3
Weight Kg	126344.4	72196.8	90246
Weight Reduction %		**43%**	**29%**

- Weight reduction by 73% was found when use GRP handrail, see Table 6.2 below.

Table 6.2: Weight Comparison (Handrails)

WEIGHT COMPARSION (HANDRAIL)		
Item	**Base Materials**	**GRP Alternatives**
	Steel Handrail	**GRP Handrail**
Handrail Quantity at AB Platform (Lm)	1782.7	1782.7
Weight Kg	58829.1	16044.3
Weight Reduction %		**73%**

This is not to say that GRP has no disadvantages. For example, GRP has a low modulus of elasticity compared to steel, so the material is not rigid as steel and may approach the deflection limit that controls the design. However, this disadvantage can be overcome by providing special design treatment during the fabrication process for areas where stiffness is required. The orientation of the fiber inside the composites is very important and gives the highest mechanical properties in the direction of the fiber. Another way to solve this problem is to increase the thickness of the GRP. Another disadvantage is the high initial cost of the GRP materials, but this is offset by lower construction costs.

Life Cycle Costing

- The results show that the GRP handrails are less than steel handrails in LCC at all times.
- The results show that steel gratings are lower in LCC than GRP grating for a short period less than 6 periods, otherwise GRP gratings are less and more economical.
- The life cycle costing results for the steel gratings over 25 years of service and with interest rates of 5%, 10% and 15% are very high compared to GRP gratings. In fact, the cost of steel gratings is more than double the cost of the GRP gratings for 25mm and 38mm thickness at a 5% interest rate. The cost of steel is from 75% to 100% higher at a 10% interest rate and from 40% to 70% higher at a 15% interest rate.
- The life cycle costing results for the steel gratings over 20 years of service and with interest rates of 5%, 10% and 15% are also very high compared to GRP gratings. In fact, the cost of steel gratings is more than double the

cost of the GRP gratings for 25mm and 38mm thickness at a 5% interest rate. The cost of steel is from 67% to 100% higher at a 10% interest rate and from 37% to 66% higher at a 15% interest rate.

- The life cycle costing results for the steel gratings over 30 years of service and with interest rates of 5%, 10% and 15% are also very high compared to GRP gratings. The cost of steel gratings is more than triple the cost of the GRP gratings for 25mm and 38mm thickness at a 5% interest rate. The cost of steel is from 80% to 100% higher at a 10% interest rate and from 42% to 70% higher at a 15% interest rate.
- Deflation in steel gratings cost has been considered with 5% in materials cost and 10% in offshore installation costs over 25 years and 20 years. The results show that at 25 years of service at a 5% interest rate, the cost of steel gratings is still higher than the GRP alternative (both 25mm and 38mm), ranging from 51% to 82% higher. The steel gratings cost is from 25% to 52% higher at an interest rate of 10% and from 11.5% to 34% higher at a 15% interest rate. At 20 years of service with a 5% interest rate, the steel gratings cost ranges from 46% to 77% higher than the cost of the GRP alternative, from 24% to 50% higher at an interest rate of 10%, and from 11% to 34% higher at a 15% interest rate.
- Deflation in steel gratings cost has also been considered at 10% in materials cost and 10% in offshore installation construction cost over 25 and 20 years. The results show that, at 25 years, with a 5% interest rate,

the cost of steel gratings is still higher than the cost of the GRP alternative (for both 25mm and 38mm), ranging from 38% to 67%, higher by 18% to 43% at an interest rate of 10%, and higher by 7% to 30% at a 15% interest rate. At 20 years, with a 5% interest rate, the cost of steel gratings remains higher than the GRP alternative cost by 36-64%, higher by17-42% at an interest rate of 10%, and higher by 15-29% at a15% interest rate.

- Two approaches have been considered for the steel handrails. The first approach assumes the maintenance is applied every 5 years, while the second approach assumes maintenance is ignored and the handrails are replaced every 12 years. The results show that the life cycle cost for the "replacement" approach is always more economical.
- Life cycle costing for the steel handrails over 25 years of service and at 5% interest rate shows that the cost of steel handrails is more than double the cost of the GRP alternatives when the "maintenance" approach is used and higher by 79% when the "replacement" approach is used.
- Life cycle costing for the steel handrails over 25 years of service and at 10% interest rate shows that the cost of steel handrails is higher than GRP alternatives cost by 95% when the "maintenance" approach is used and higher by 54% when the "replacement" approach is used.
- Life cycle costing for the steel handrails over 25 years of service and at 15% interest rate shows that the cost of steel handrails is 67% more than

the cost of the GRP alternatives when the "maintenance" approach is used and higher by 34% when the "replacement" approach is used.

- Life cycle costing for the steel handrails over 20 years of service and at 5% interest rate shows that the cost of steel handrails is more than double the cost of the GRP alternatives when the "maintenance" approach is used and higher by 79% when the "replacement" approach is used.
- Life cycle costing for the steel handrails over 20 years of service and at 10% interest rate shows that the cost of steel handrails is higher than GRP alternatives cost by 86% when the "maintenance" approach is used and higher by 50% when the "replacement" approach is used.
- Life cycle costing for the steel handrails over 20 years of service and at 15% interest rate shows that the cost of steel handrails is 63% higher than the cost of the GRP alternatives when the "maintenance" approach is used and higher by 34% when the "replacement" approach is used.
- Life cycle costing for the steel handrails over 30 years of service and at 5% interest rate shows that the cost of steel handrails is more than double the cost of the GRP alternatives when either the "maintenance" approach or the "replacement" approach is used.
- Life cycle costing for the steel handrails over 30 years of service and at 10% interest rate shows that the cost of steel handrails is more than double the cost of the GRP alternatives when the "maintenance" approach is used and higher by 62% when the "replacement" approach is used.

- Life cycle costing for the steel handrails over 30 years of service and at 15% interest rate shows that the cost of steel handrails is 69% higher than the cost of the GRP alternatives when the “maintenance” approach is used and higher by 38% when the “replacement” approach is used.
- Deflation by 5% in steel materials cost and 10% in the cost of offshore installation construction has been carried out for steel handrails using the “replacement” approach over 25 years of service and at 5%, 10% and 15% interest rates. Results show that steel handrails are still more expensive by 48%, 32% and 24%, respectively.
- Deflation by 10% in steel materials cost and 10% in the cost of offshore installation construction has been carried out for steel handrails using “replacement” approach over 25 years of service and at 5%, 10% and 15% interest rates. Results show that steel handrails are still more expensive by 46%, 31% and 23%, respectively.
- Deflation by 5% in steel materials cost and 10% in the cost of offshore installation construction has been carried out for steel handrails using the “replacement” approach over 20 years of service and at 5%, 10% and 15% interest rates. Results show that steel handrails are still more expensive by 48%, 33% and 24%, respectively.
- Deflation by 10% in steel materials cost and 10% in the cost of offshore installation construction has been carried out for steel handrails using “replacement” approach over 20 years of service and at 5%, 10% and 15%

interest rates. Results show that steel handrails are still more expensive by 46%, 31% and 24%, respectively.

6.3 RECOMMENDATION

Recommendation for Offshore Industries:

Based on what has been presented the following recommendations are made by the author:

- It will be recommended to use GRP grating and handrails at offshore platforms where corrosion resistant materials are always required.
- It will be recommended to use GRP where there are weight issue problem on platform. The weight of the GRP almost third of the steel weight.
- Offshore installation cost is one of the major expenses in oil and gas industry, it will be recommended to use GRP gratings and handrails for their easily offshore installation with simple tools and easy lifting equipments unlike steel materials.
- Because the GRP has low modulus of elasticity compare to steel, so deflection is controlling design factor. It will be recommended to use steel gratings in areas where grating penetrations are big.
- Also, it will be recommended to use steel gratings for a short period less than 6 years.
- It will be recommended to use GRP handrails from the beginning of any projects since LCC for the GRP handrail is less than the steel handrail at all times.

Recommendation for Further Study:

- The Control of deflection is a main concern because of the low modulus of elasticity of the GRP products, so load deflection behavior of grating panels compare to steel is needed further studies.
- GRP products offers excellent durability, however, there is no data available regarding their long term durability after exposure to different natural environmental conditions like change in temperature, moisture, humidity, sea water, salt water immersion and crude oil. It will be recommended to study effect of the natural environments on the GRP gratings and handrails for long term at offshore.
- What are the barriers behind not using the GRP in the main structures? This question needs further study.

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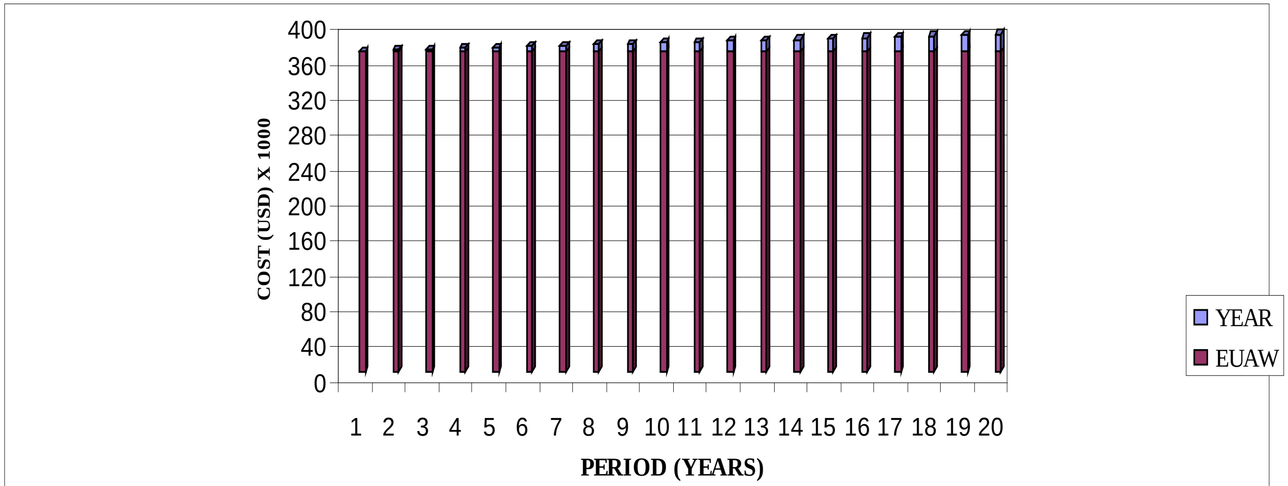
APPENDIX A

CASH FLOWS ANALYSIS FOR THE

GRATINGS FOR A PERIOD OF 20 YEARS

Table A1: LCC Components for Steel Grating@ 5%

Material Type	Steel Grating 25mm as a base material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	4,526,660.53
Equivalent Uniform Annual Worth (EUAW)	363,230.95



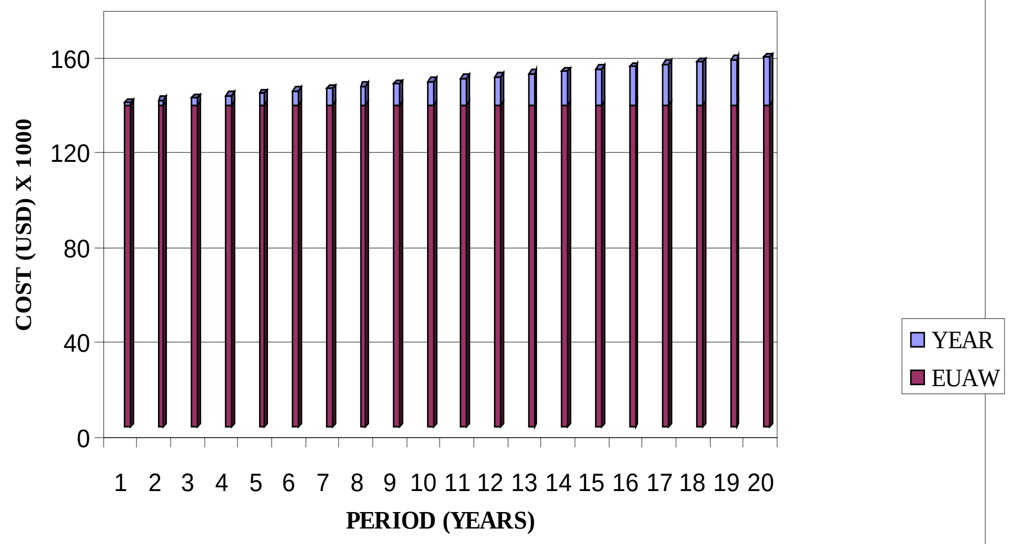
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	363.2	363.2	363.2	363.2	363.2	363.2	363.2	363.2	363.2	363.2	363.2	363.2	363.2	363.2	363.2	363.2	363.2	363.2	363.2	363.2

Figure A1: EUAW for Steel Grating @ 5%

Table A2: LCC Components for Polyester Grating 25mm @ 5%

Material Type	GRP Grating (Polyester)25 mm
Capital Cost	
Initial Cost	613,672.80
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,696,624.80
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	1,696,624.80
Equivalent Uniform Annual Worth (EUAW)	136,141.56

EUAW For GRP Grating/Polyester Type (25mm THK) @ 5%

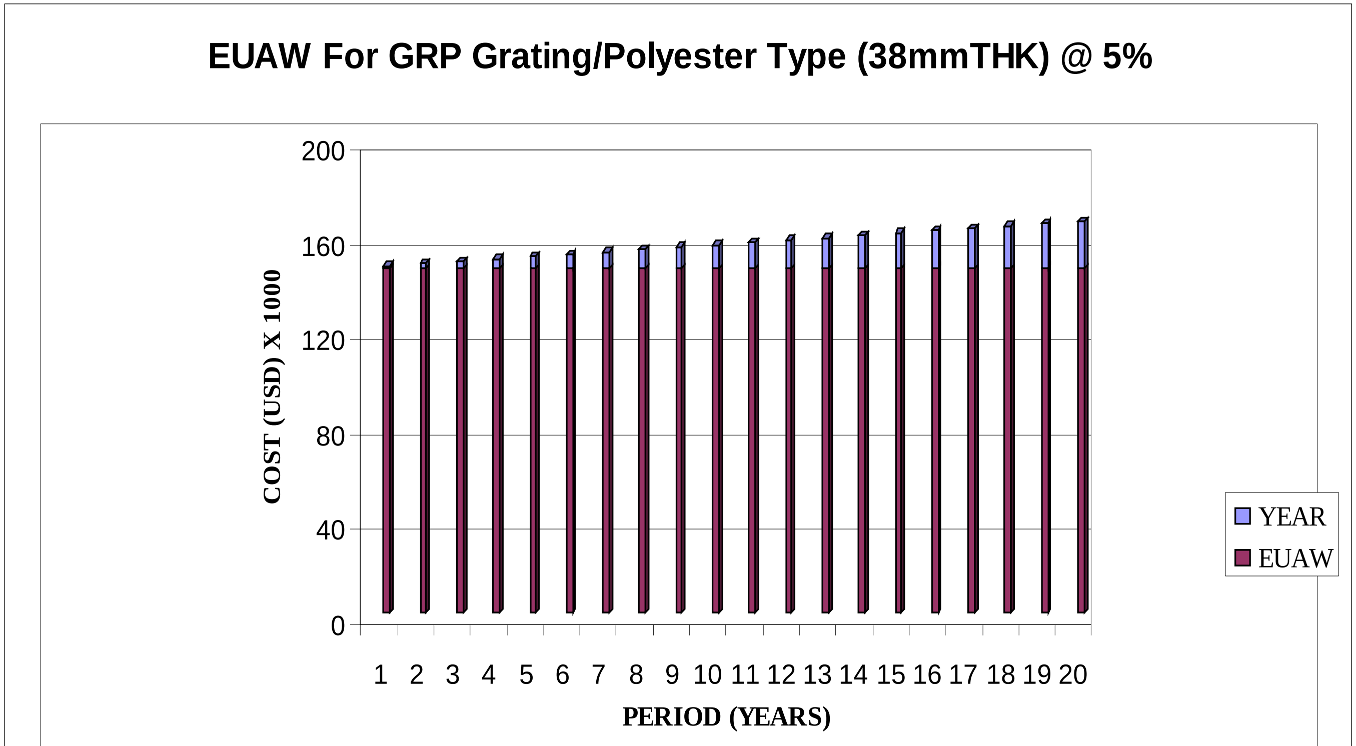


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	136.1	136.1	136.1	136.1	136.1	136.1	136.1	136.1	136.1	136.1	136.1	136.1	136.1	136.1	136.1	136.1	136.1	136.1	136.1	136.1

Figure A2: EUAW for Polyester Grating 25mm @ 5%

Table A3: LCC Components for Polyester Grating 38mm @ 5%

Material Type	GRP Grating (Polyester)38 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	145,555.61

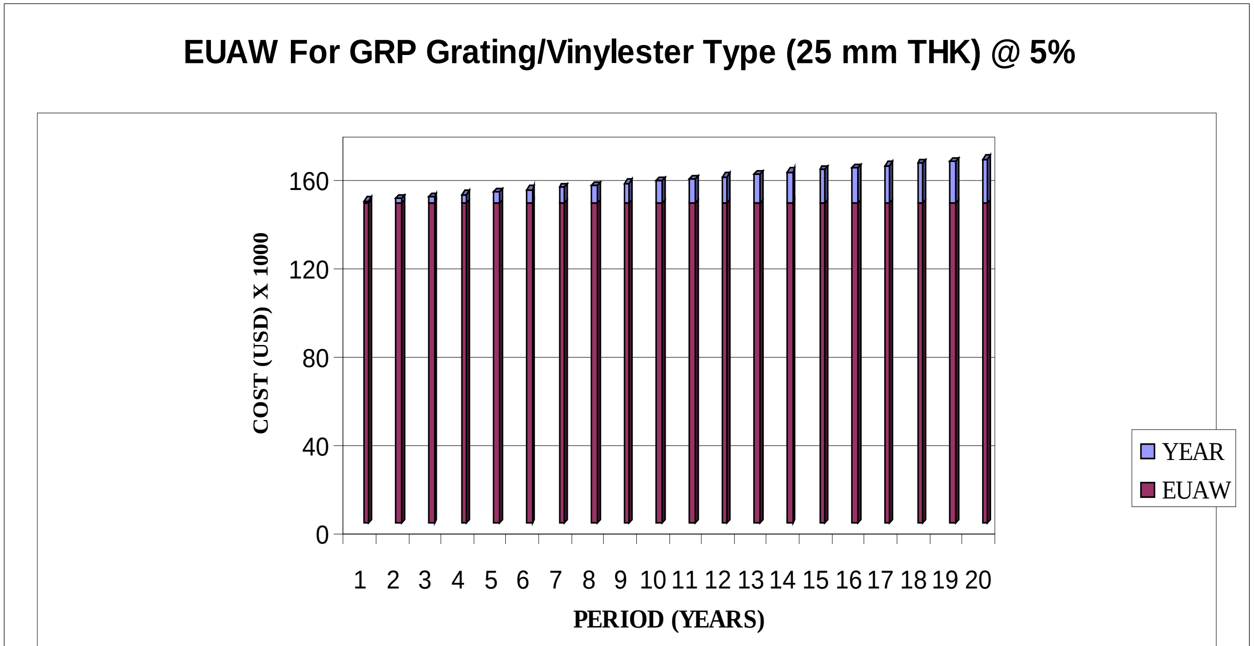


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6

Figure A3: EUAW for Polyester Grating 38mm @ 5%

Table A4: LCC Components for Vinylester Grating 25mm @ 5%

Material Type	GRP Grating (Vinylester)25 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	145,555.61



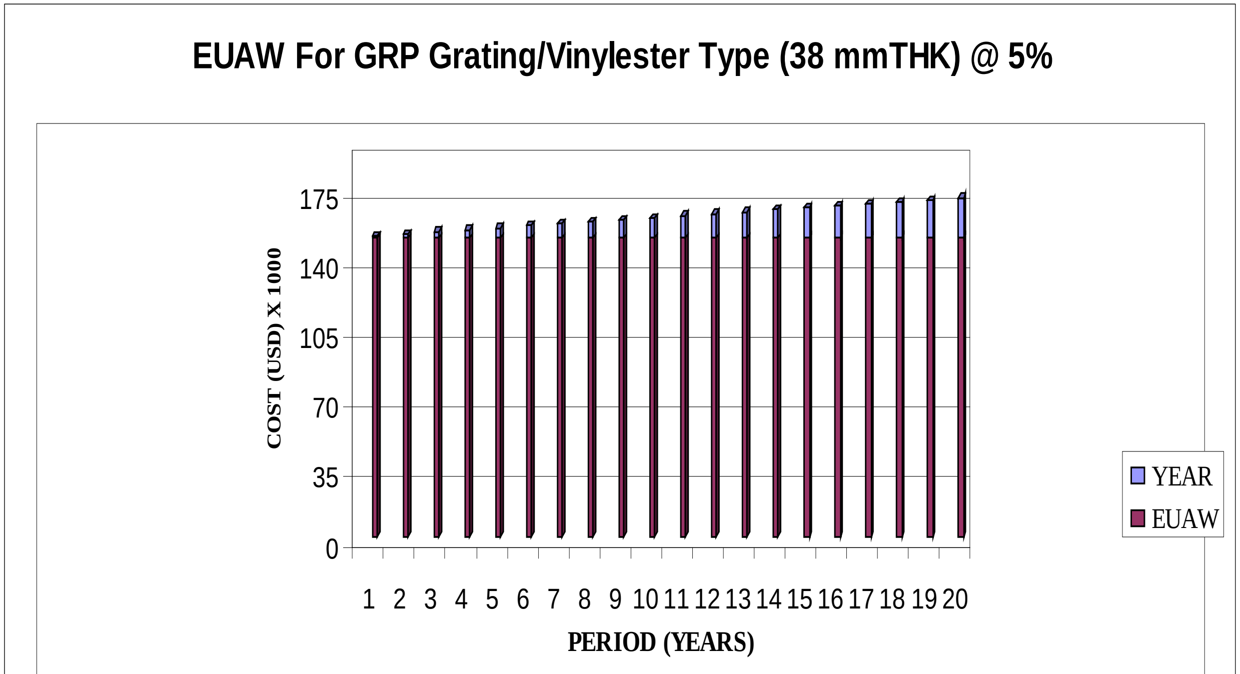
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6	145.6

Figure A4: EUAW for Vinylester Grating 25mm @ 5%

Table A5: LCC Components for Vinylester Grating 38mm @ 5%

Material Type	GRP Grating (Vinylester)38 mm
Capital Cost	
Initial Cost	789,652.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,872,604.50
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	1,872,604.50
Equivalent Uniform Annual Worth (EUAW)	150,262.63

Note : Cost in USD



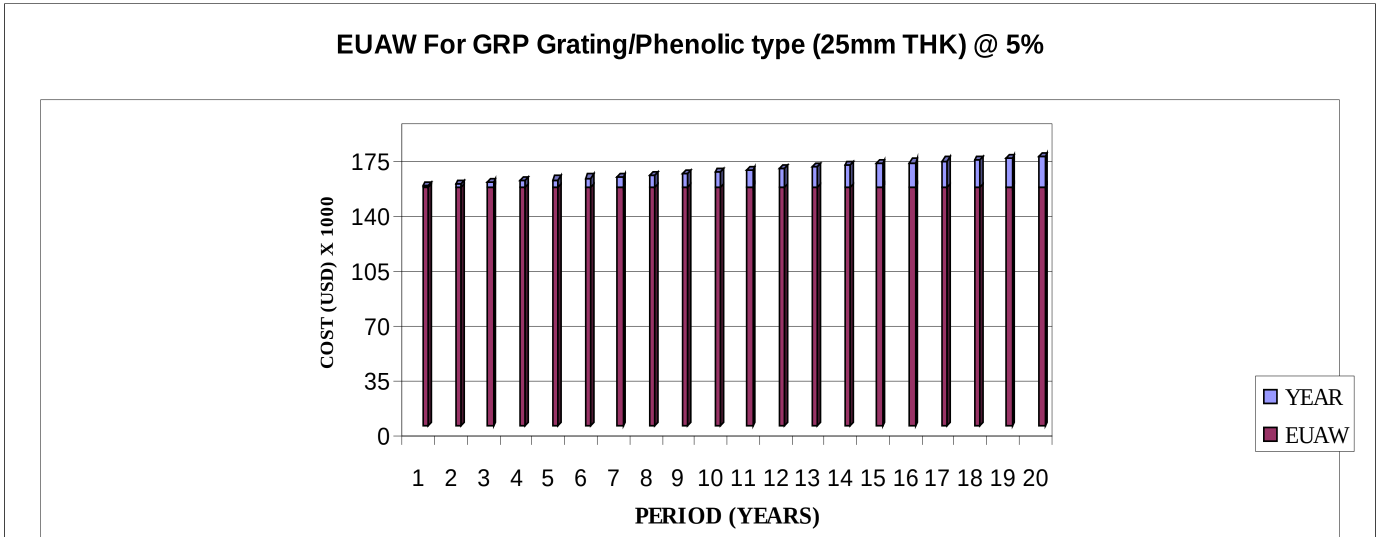
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	150.3	150.3	150.3	150.3	150.3	150.3	150.3	150.3	150.3	150.3	150.3	150.3	150.3	150.3	150.3	150.3	150.3	150.3	150.3	150.3

Figure A5: EUAW for Vinylester Grating 38mm @ 5%

Table A6: LCC Components for Phenolic Grating 25mm @ 5%

Material Type	**GRP Grating (Phenolic)25 mm**
Capital Cost	
Initial Cost	821,238.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,904,190.60
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	1,904,190.60
Equivalent Uniform Annual Worth (EUAW)	152,797.18

Note: Cost in USD



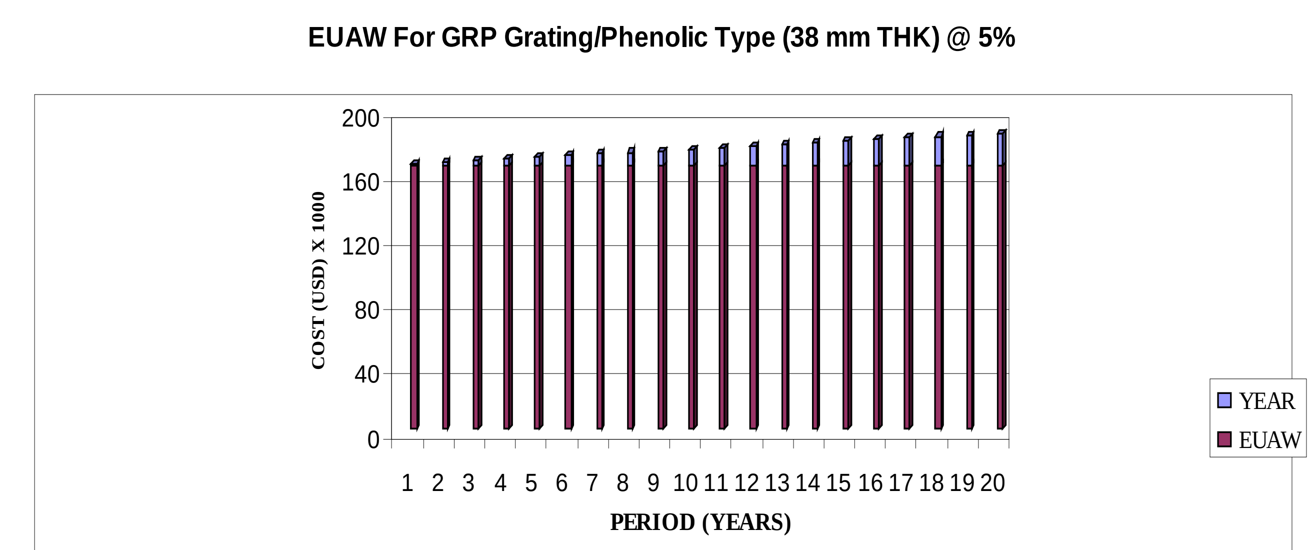
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	152.8	152.8	152.8	152.8	152.8	152.8	152.8	152.8	152.8	152.8	152.8	152.8	152.8	152.8	152.8	152.8	152.8	152.8	152.8	152.8

Figure A6: EUAW for Phenolic Grating 25mm @ 5%

Table A7: LCC Components for Phenolic Grating 38mm @ 5%

Material Type	GRP Grating (Phenolic)38 mm
Capital Cost	
Initial Cost	970,144.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	2,053,096.50
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	2,053,096.50
Equivalent Uniform Annual Worth (EUAW)	164,745.77

Note: Cost in USD



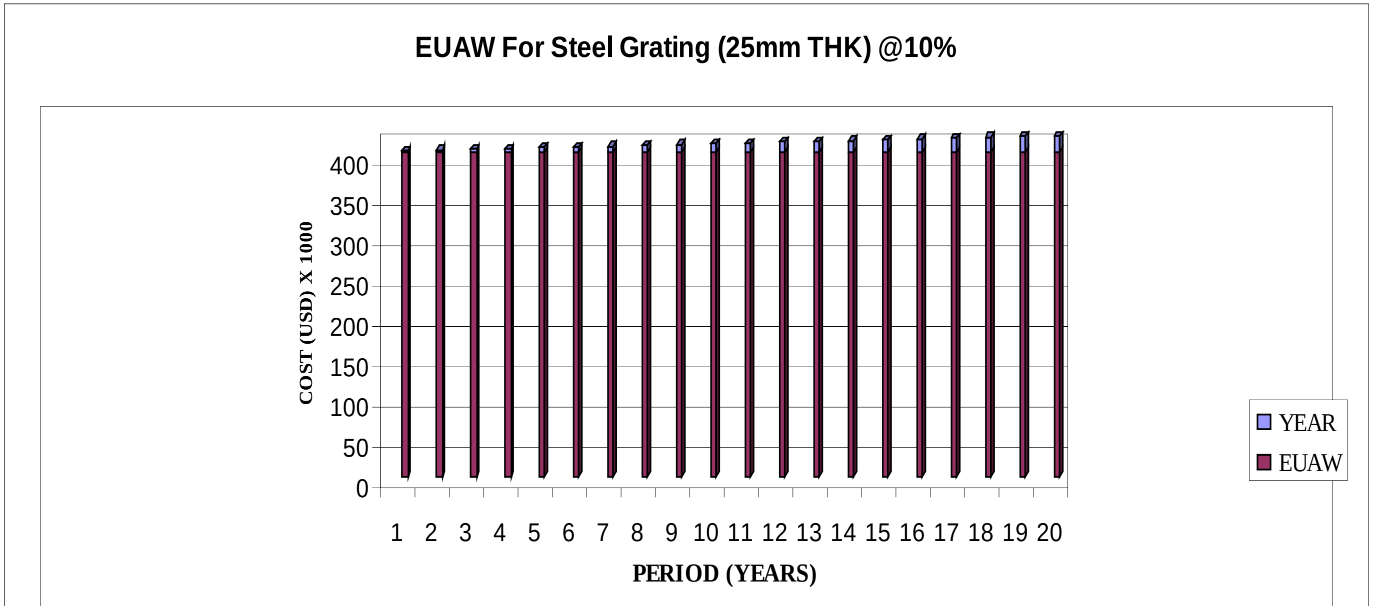
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	164.7	164.7	164.7	164.7	164.7	164.7	164.7	164.7	164.7	164.7	164.7	164.7	164.7	164.7	164.7	164.7	164.7	164.7	164.7	164.7

Figure A7: EUAW for Phenolic Grating 38mm @ 5%

Table A8: LCC Components for Steel Grating @ 10%

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial Cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	3,435,013.15
Equivalent Uniform Annual Worth (EUAW)	403,475.36

Note: Cost in USD



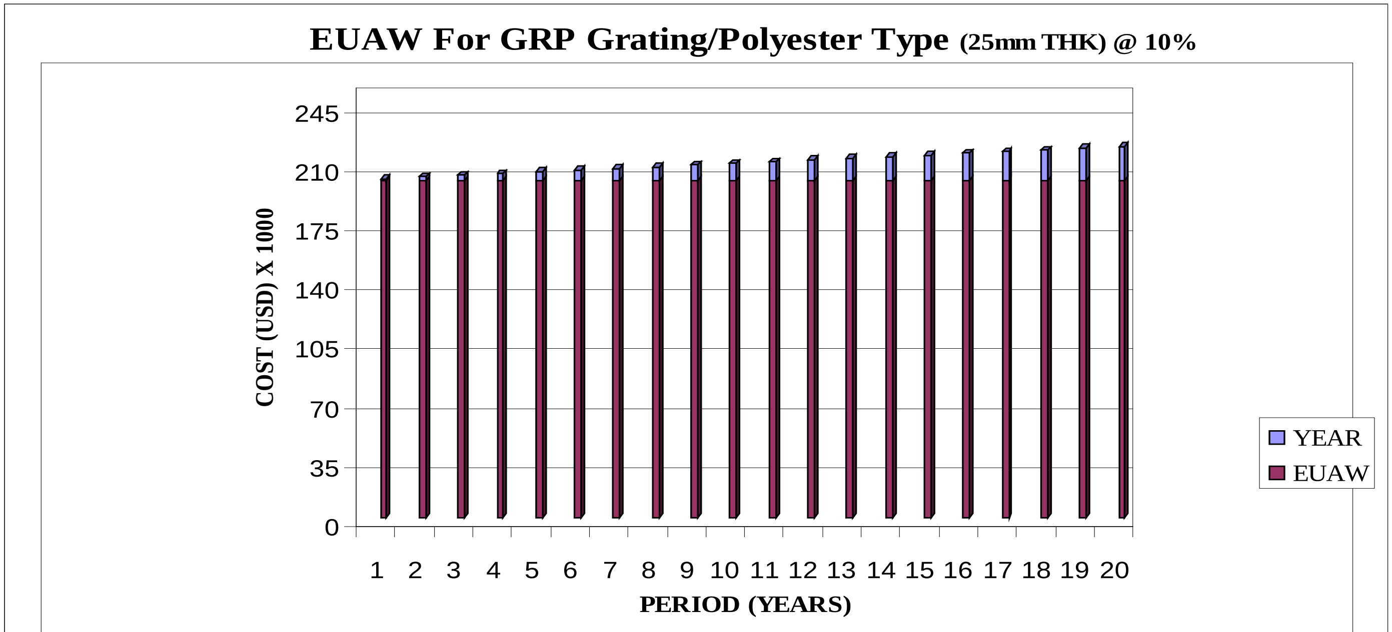
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	403.5	403.5	403.5	403.5	403.5	403.5	403.5	403.5	403.5	403.5	403.5	403.5	403.5	403.5	403.5	403.5	403.5	403.5	403.5	403.5

Figure A8: EUAW for Steel Grating @ 10%

Table A9: LCC Components for Polyester Grating 25mm @ 10%

Material Type	**GRP Grating (Polyester)25 mm**
Capital Cost	
Initial Cost	613,672.80
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,696,624.80
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	1,696,624.80
Equivalent Uniform Annual Worth (EUAW)	199,284.91

Note: Cost in USD



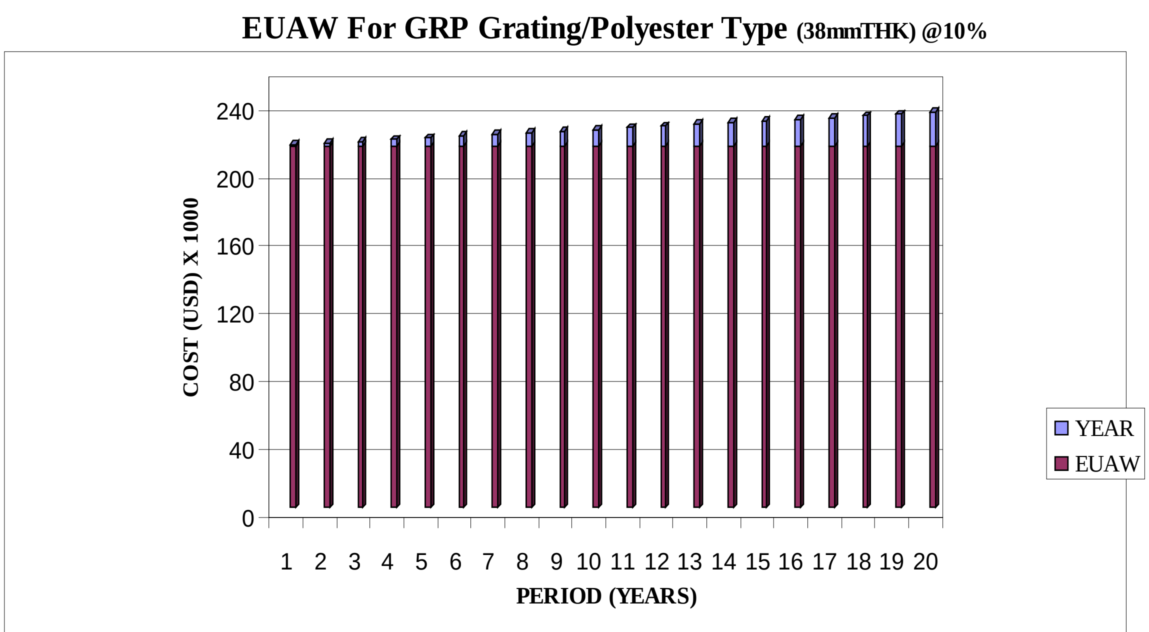
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	199.3	199.3	199.3	199.3	199.3	199.3	199.3	199.3	199.3	199.3	199.3	199.3	199.3	199.3	199.3	199.3	199.3	199.3	199.3	199.3

Figure A9: EUAW for Polyester Grating 25mm @ 10%

Table A10: LCC Components for Polyester Grating 38mm @ 10%

Material Type	GRP Grating (Polyester)38 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	213,065.25

Note: Cost in USD



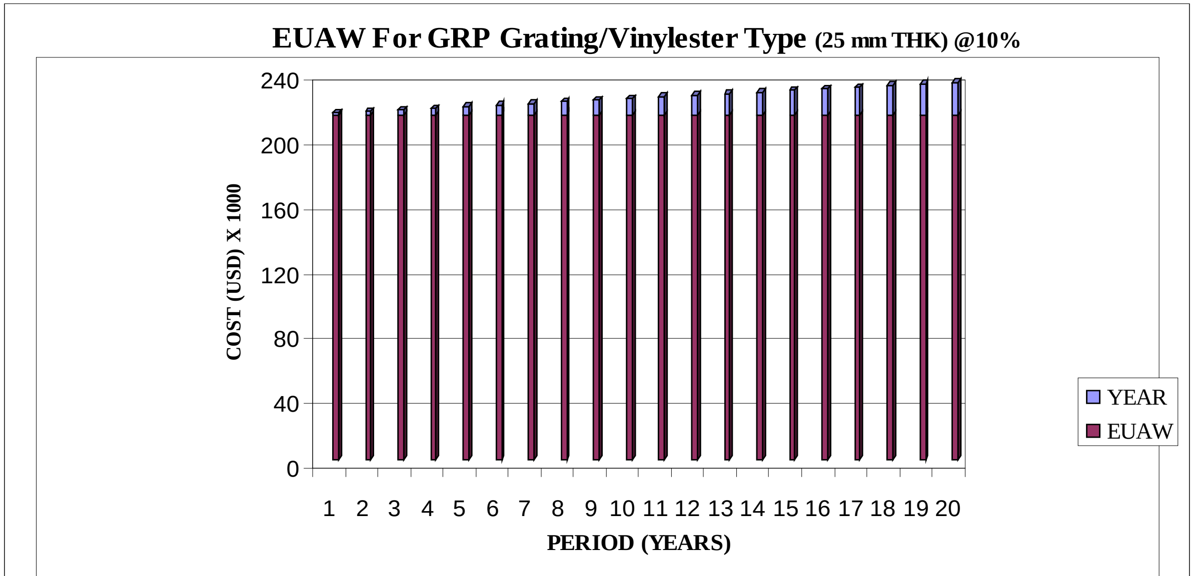
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1

Figure A10: EUAW for Polyester Grating 38mm @ 10%

Table A11: LCC Components for Vinylester Grating 25mm @ 10%

Material Type	**GRP Grating (Vinylester)25 mm**
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	213,065.25

Note: Cost in USD



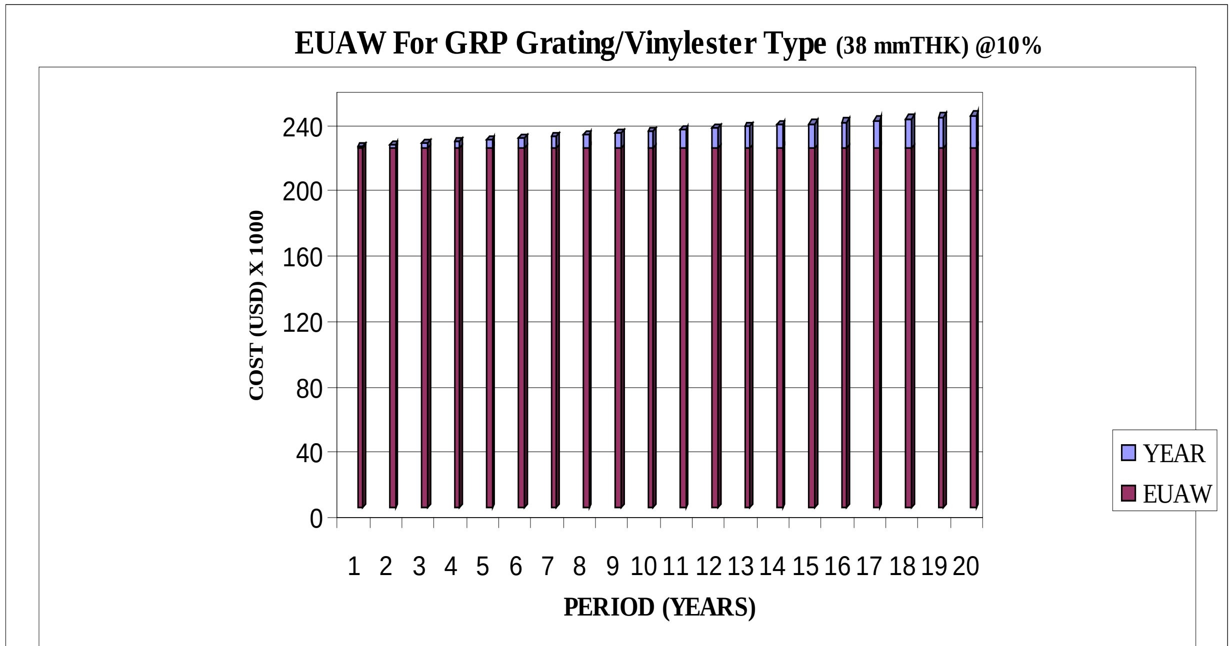
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1	213.1

Figure A11: EUAW for Vinylester Grating 25mm @ 10%

Table A12: LCC Components for Vinylester Grating 38mm @ 10%

Material Type	GRP Grating (Vinylester)38 mm
Capital Cost	
Initial Cost	789,652.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,872,604.50
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	1,872,604.50
Equivalent Uniform Annual Worth (EUAW)	219,955.42

Note: Cost in USD



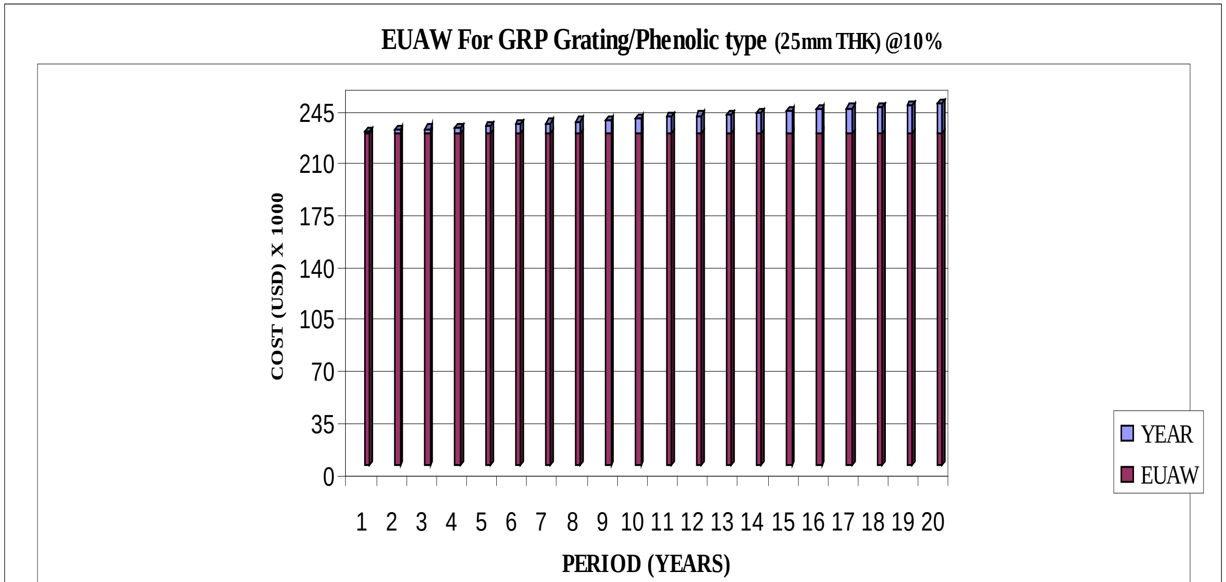
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220

Figure A12: EUAW for Vinylester Grating 38mm @ 10%

Table A13: LCC Components for Phenolic Grating 25mm @ 10%

Material Type	GRP Grating (Phenolic)25 mm
Capital Cost	
Initial Cost	821,238.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,904,190.60
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	1,904,190.60
Equivalent Uniform Annual Worth (EUAW)	223,665.51

Note: Cost in USD



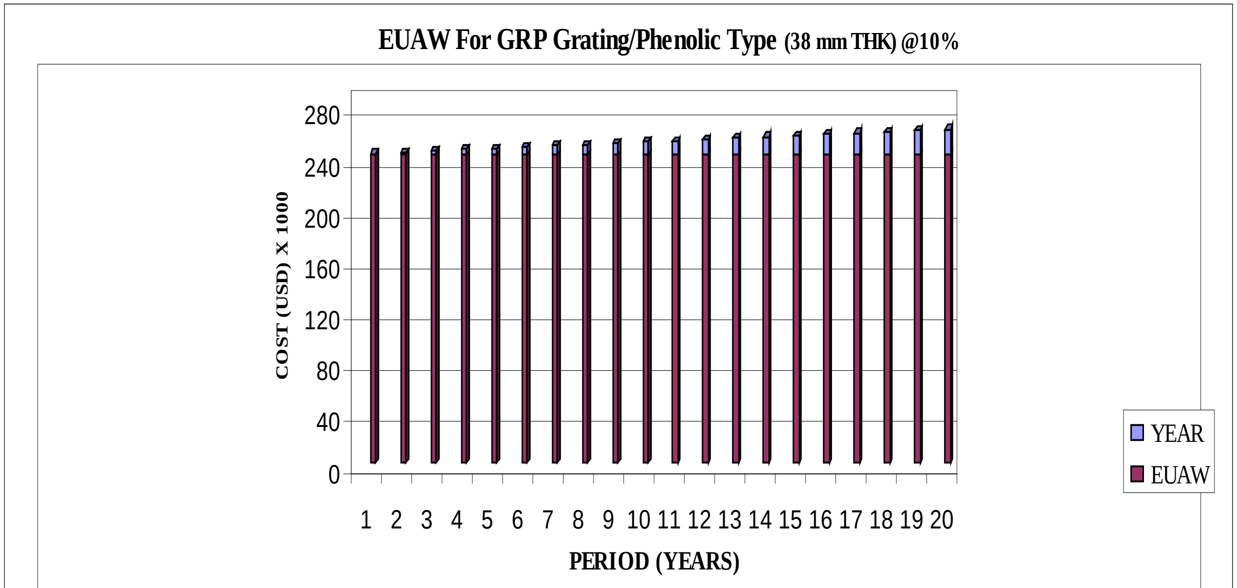
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7	223.7

Figure A13: EUAW for Phenolic Grating 25mm @ 10%

Table A14: LCC Components for Phenolic Grating 38mm @ 10%

Material Type	GRP Grating (Phenolic)38 mm
Capital Cost	
Initial Cost	970,144.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	2,053,096.50
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,053,096.50
Equivalent Uniform Annual Worth (EUAW)	241,155.94

Note: Cost in USD



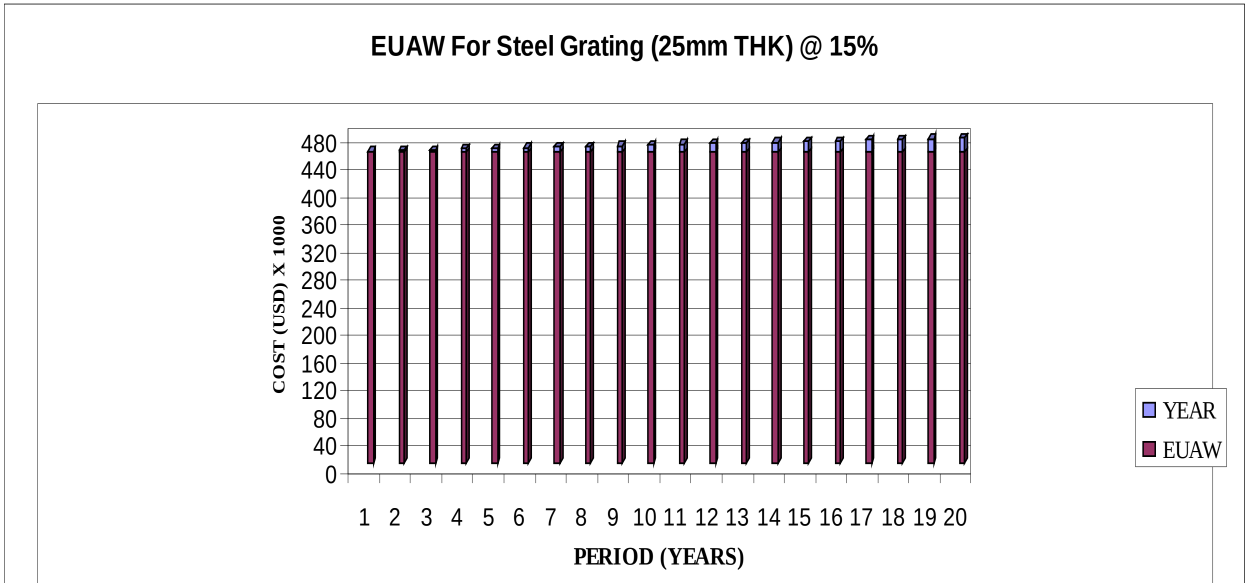
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	241.2	241.2	241.2	241.2	241.2	241.2	241.2	241.2	241.2	241.2	241.2	241.2	241.2	241.2	241.2	241.2	241.2	241.2	241.2	241.2

Figure A14: EUAW for Phenolic Grating 38mm @ 10%

Table A15: LCC Components for Steel Grating @ 15%

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,830,713.77
Equivalent Uniform Annual Worth (EUAW)	452,238.99

Note: Cost in USD



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	452.2	452.2	452.2	452.2	452.2	452.2	452.2	452.2	452.2	452.2	452.2	452.2	452.2	452.2	452.2	452.2	452.2	452.2	452.2	452.2

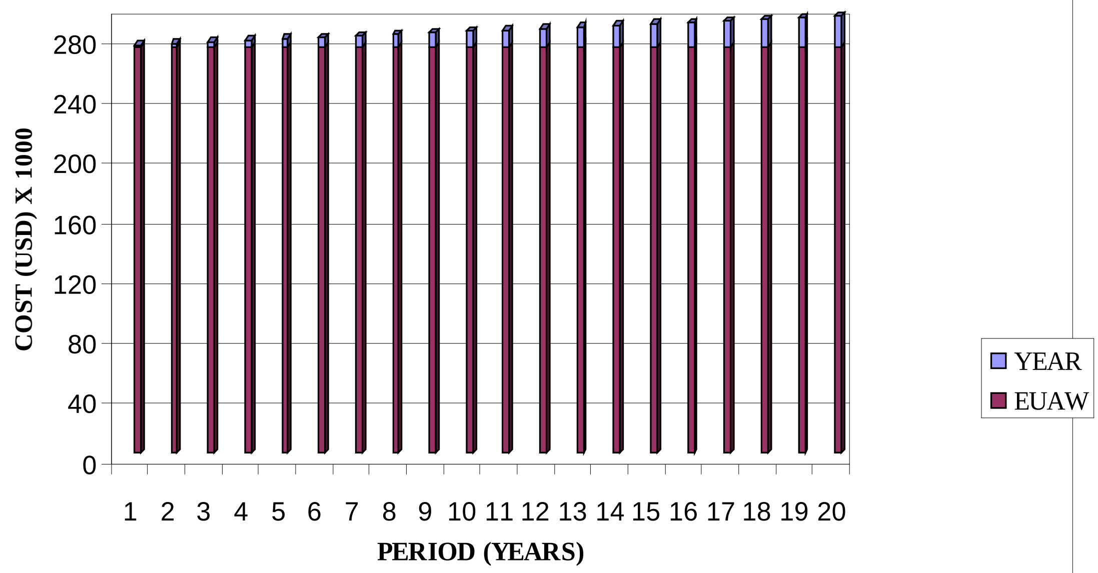
Figure A15: EUAW for Steel Grating @ 15%

Table A16: LCC Components for Polyester Grating 25mm @ 15%

Material Type	GRP Grating (Polyester)25 mm
Capital Cost	
Initial Cost	613,672.80
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,696,624.80
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	1,696,624.80
Equivalent Uniform Annual Worth (EUAW)	271,055.27

Note: Cost in USD

EUAW For GRP Grating/Polyester Type (25mm THK) @15%



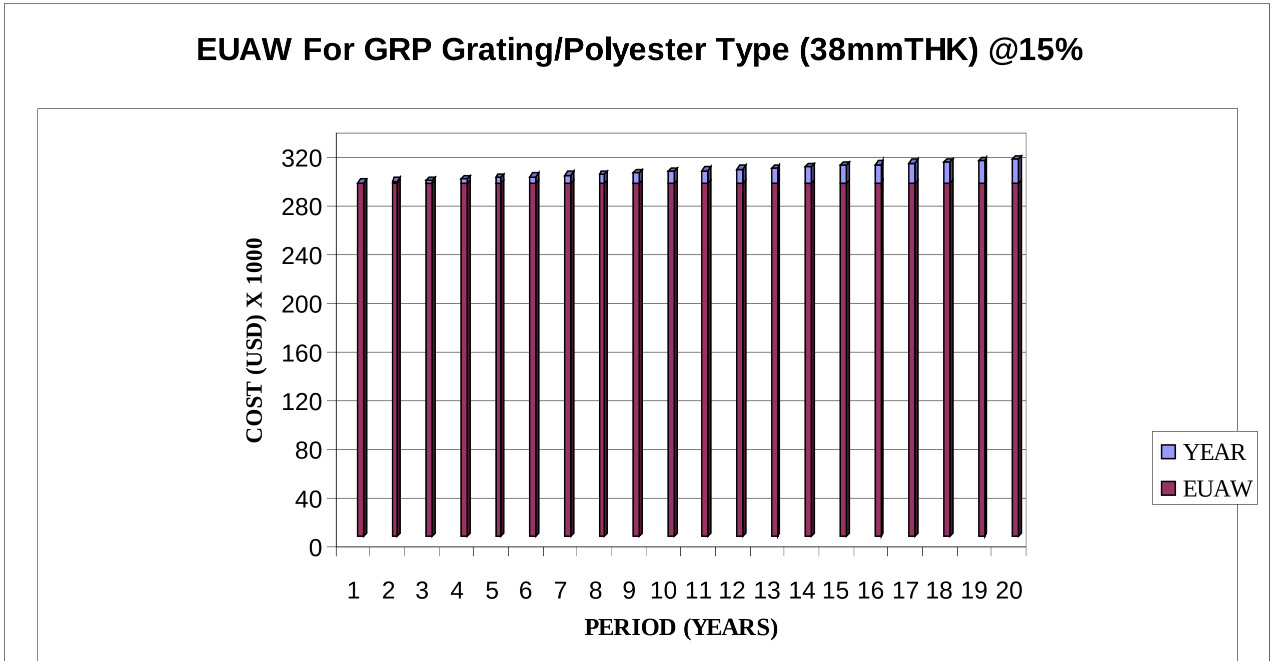
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	271.1	271.1	271.1	271.1	271.1	271.1	271.1	271.1	271.1	271.1	271.1	271.1	271.1	271.1	271.1	271.1	271.1	271.1	271.1	271.1

Figure A16: EUAW for Polyester Grating 25mm @ 15%

Table A17: LCC Components for Polyester Grating 38mm @ 15%

Material Type	GRP Grating (Polyester)38 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	289,798.46

Note: Cost in USD



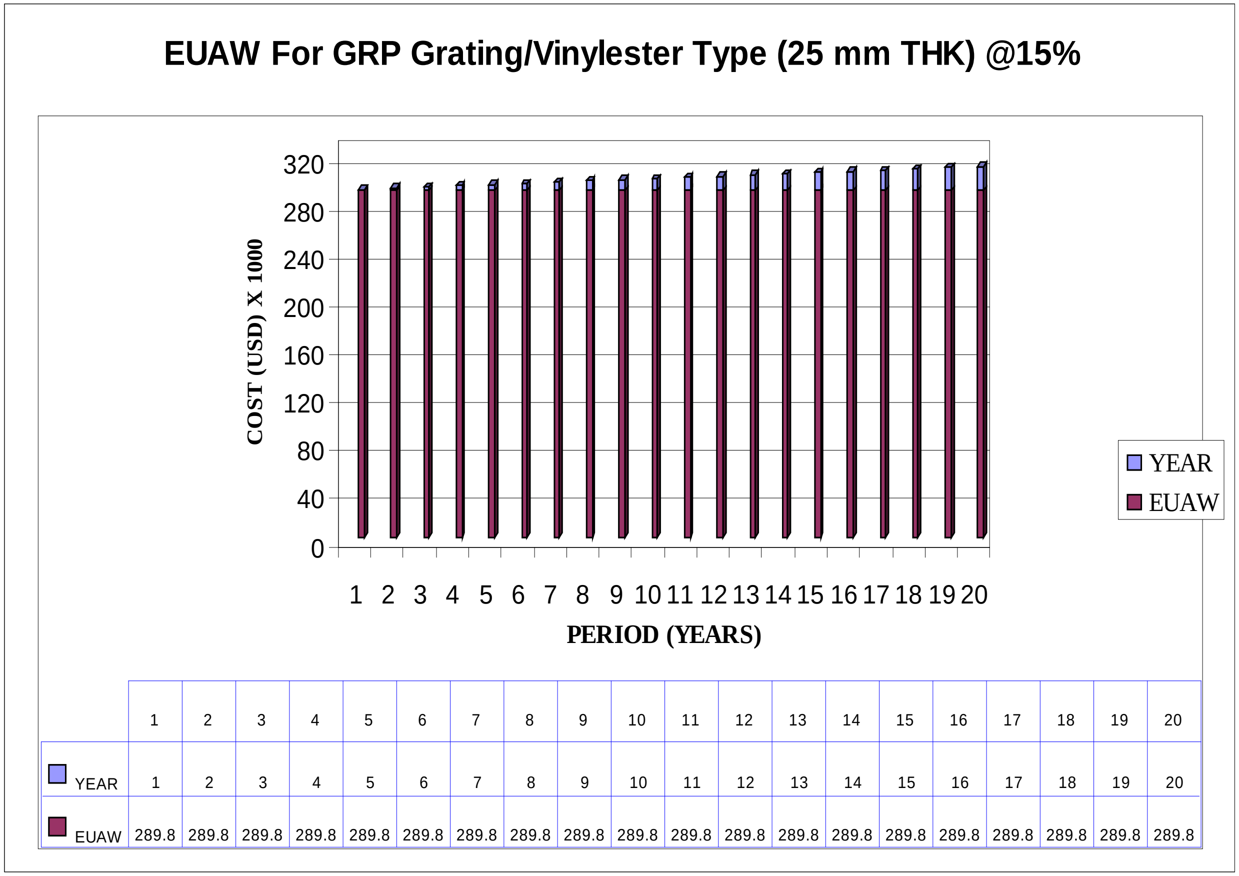
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8

Figure A17: EUAW for Polyester Grating 38mm @ 15%

Table A18: LCC Components for Vinylester Grating 25mm @ 15%

Material Type	GRP Grating (Vinylester)25 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	289,798.46

Note: Cost in USD



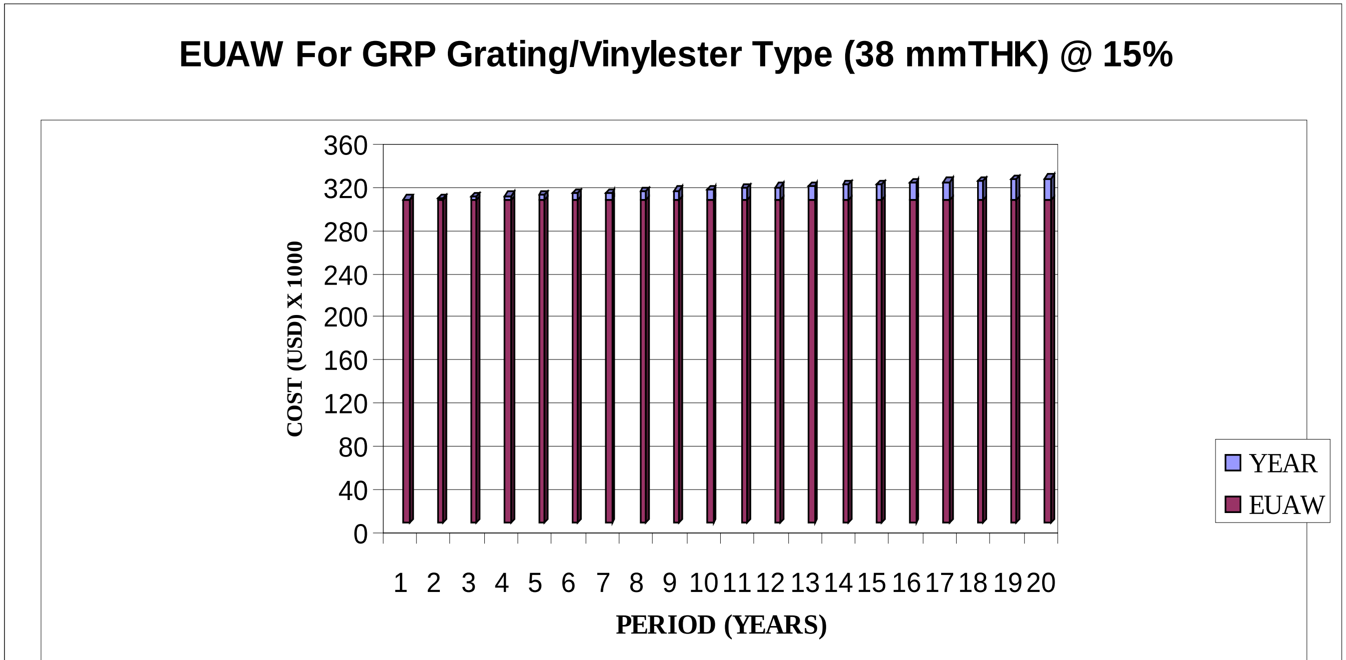
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8	289.8

Figure A18: EUAW for Vinylester Grating 25mm @ 15%

Table A19: LCC Components for Vinylester Grating 38mm @ 15%

Material Type	GRP Grating (Vinylester)38 mm
Capital Cost	
Initial Cost	789,652.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,872,604.50
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	1,872,604.50
Equivalent Uniform Annual Worth (EUAW)	299,170.05

Note: Cost in USD



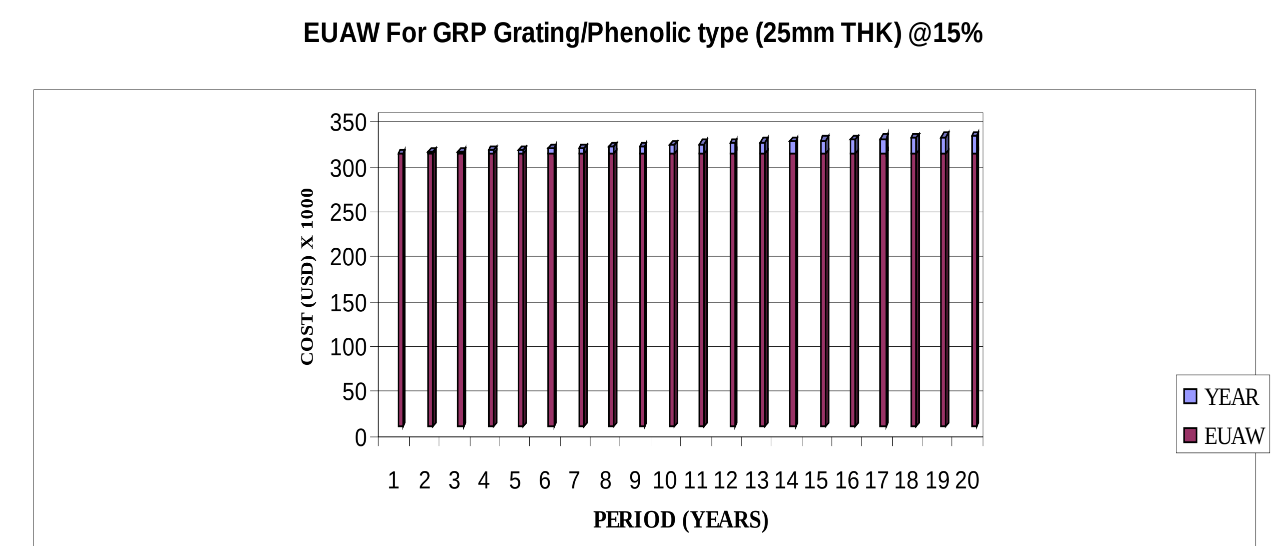
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2

Figure A19: EUAW for Vinylester Grating 38mm @ 15%

Table A20: LCC Components for Phenolic Grating 25mm @ 15%

Material Type	GRP Grating (Phenolic)25 mm
Capital Cost	
Initial Cost	821,238.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,904,190.60
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	1,904,190.60
Equivalent Uniform Annual Worth (EUAW)	304,216.29

Note: Cost in USD



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	304.3	304.3	304.3	304.3	304.3	304.3	304.3	304.3	304.3	304.3	304.3	304.3	304.3	304.3	304.3	304.3	304.3	304.3	304.3	304.3

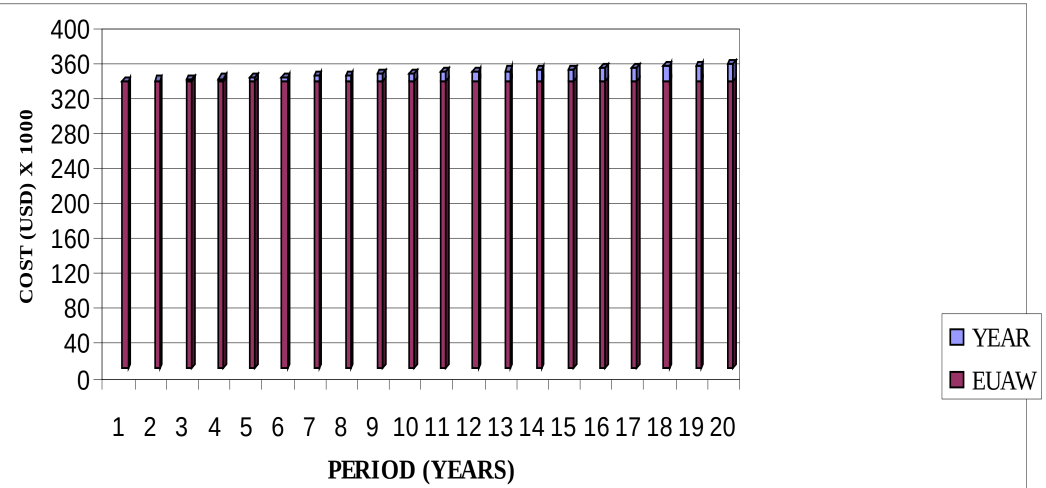
Figure A20: EUAW for Phenolic Grating 25mm @ 15%

Table A21: LCC Components for Phenolic Grating 38mm @ 15%

Material Type	GRP Grating (Phenolic)38 mm
Capital Cost	
Initial Cost	970,144.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	2,053,096.50
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,053,096.50
Equivalent Uniform Annual Worth (EUAW)	328,005.72

Note: Cost in USD

EUAW For GRP Grating/Phenolic Type (38 mm THK) @ 15%



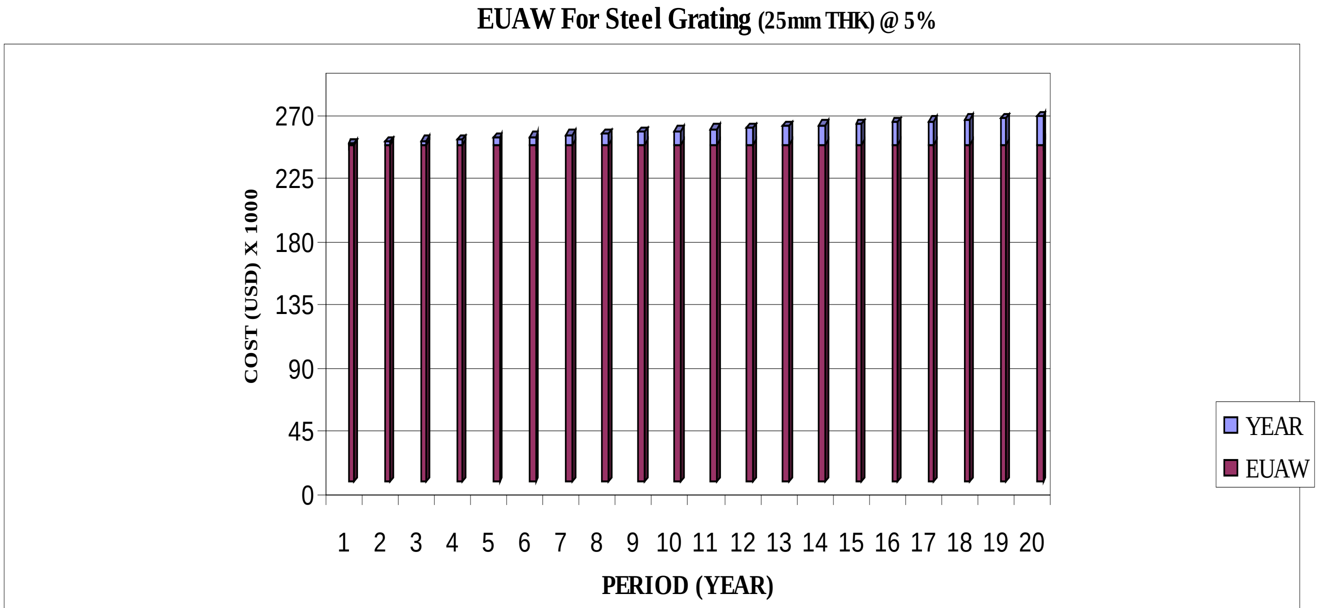
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	328	328	328	328	328	328	328	328	328	328	328	328	328	328	328	328	328	328	328	328

Figure A21: EUAW for Phenolic Grating 38mm @ 15%

Table A22: LCC Components Steel Grating (Deflated 5% in Material and 10% in Installation Cost) at 5% Interest Rate

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	2,999,472.61
Equivalent Uniform Annual Worth (EUAW)	240,685.44

Note: Cost in USD



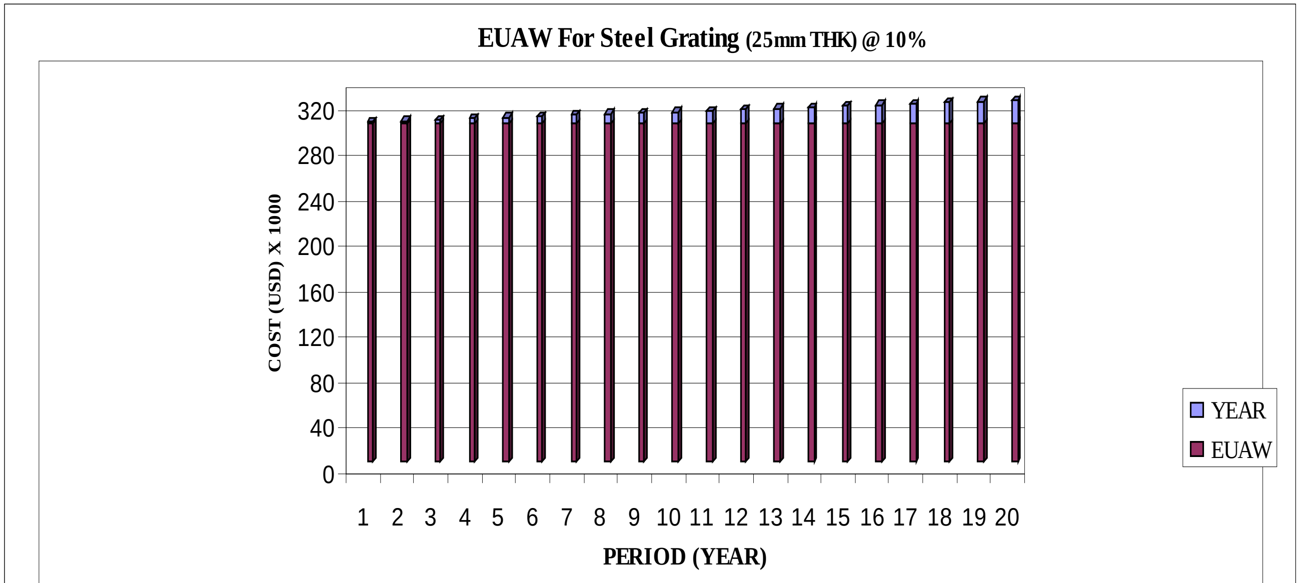
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	240.7	240.7	240.7	240.7	240.7	240.7	240.7	240.7	240.7	240.7	240.7	240.7	240.7	240.7	240.7	240.7	240.7	240.7	240.7	240.7

Figure A22: EUAW for Steel Grating (Deflated) @ 5%

Table A23: LCC Components Steel Grating (Deflated 5% in Material and 10% in Installation Cost) at 10% Interest Rate

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,547,115.66
Equivalent Uniform Annual Worth (EUAW)	299,183.25

Note: Cost in USD

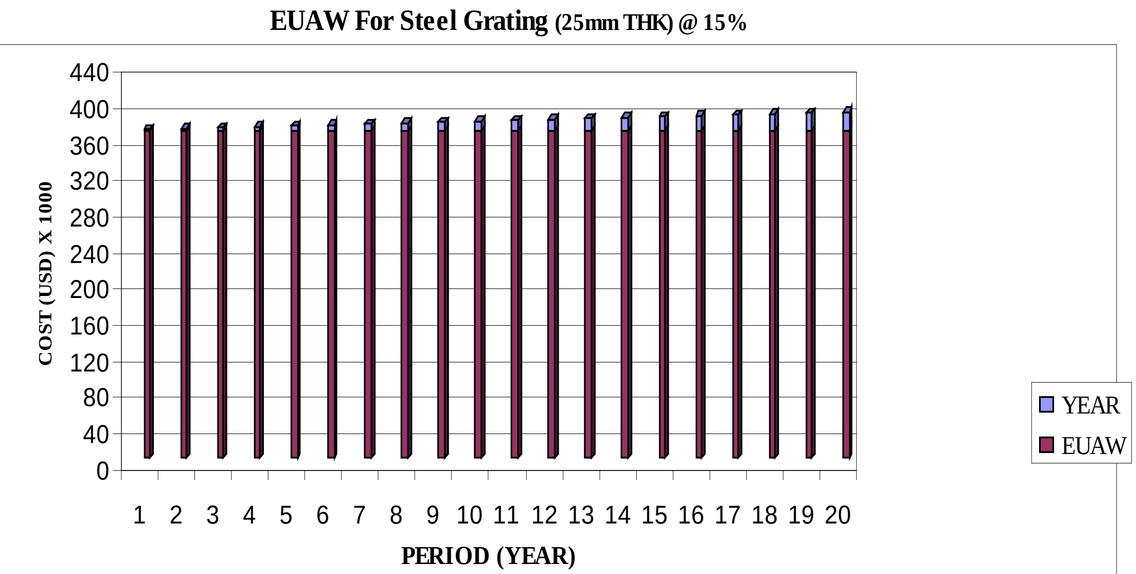


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2	299.2

Figure A23: EUAW for Steel Grating (Deflated) @ 10%

Table A24: LCC Components Steel Grating (Deflated 5% in Material and 10% in Installation Cost) at 15% Interest Rate

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1083000
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1665086.7
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,277,529.40
Equivalent Uniform Annual Worth (EUAW)	363861.4465



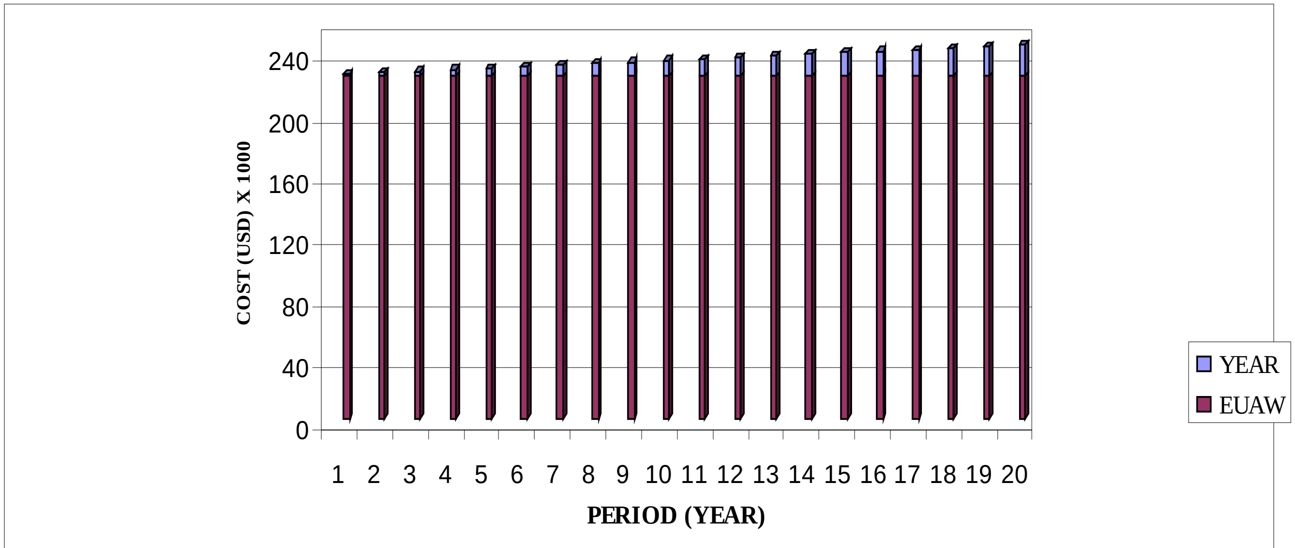
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	363.9	363.9	363.9	363.9	363.9	363.9	363.9	363.9	363.9	363.9	363.9	363.9	363.9	363.9	363.9	363.9	363.9	363.9	363.9	363.9

Figure A24: EUAW for Steel Grating (Deflated) @ 15%

Table A25: LCC Components Steel Grating (Deflated 10% in Both Material & Installation Cost) at 5% Interest Rate

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	2,786,322.35
Equivalent Uniform Annual Worth (EUAW)	223,581.71

Note: Cost in USD



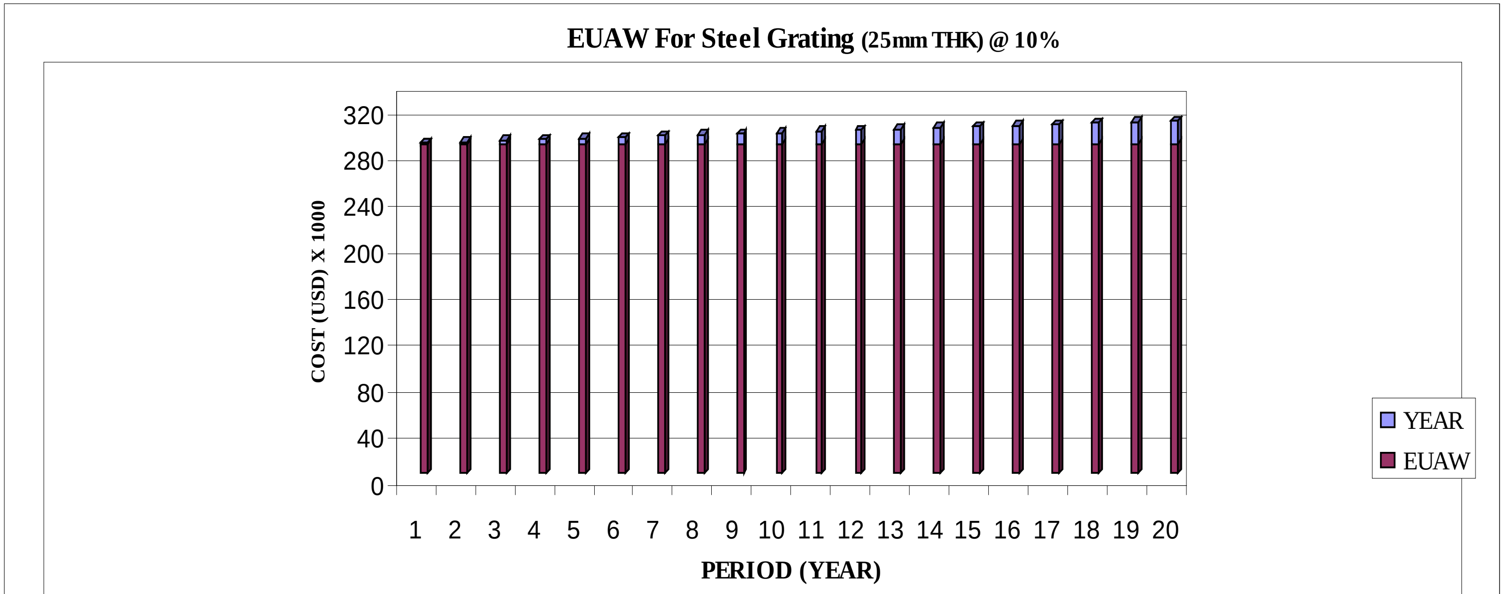
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	223.6	223.6	223.6	223.6	223.6	223.6	223.6	223.6	223.6	223.6	223.6	223.6	223.6	223.6	223.6	223.6	223.6	223.6	223.6	223.6

Figure A25: EUAW for Steel Grating (Deflated 10%) @ 5%

Table A26: LCC Components Steel Grating (Deflated 10% in Both Material & Installation Cost) at 10% Interest Rate

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,418,547.76
Equivalent Uniform Annual Worth (EUAW)	284,081.7119

Note: Cost in USD



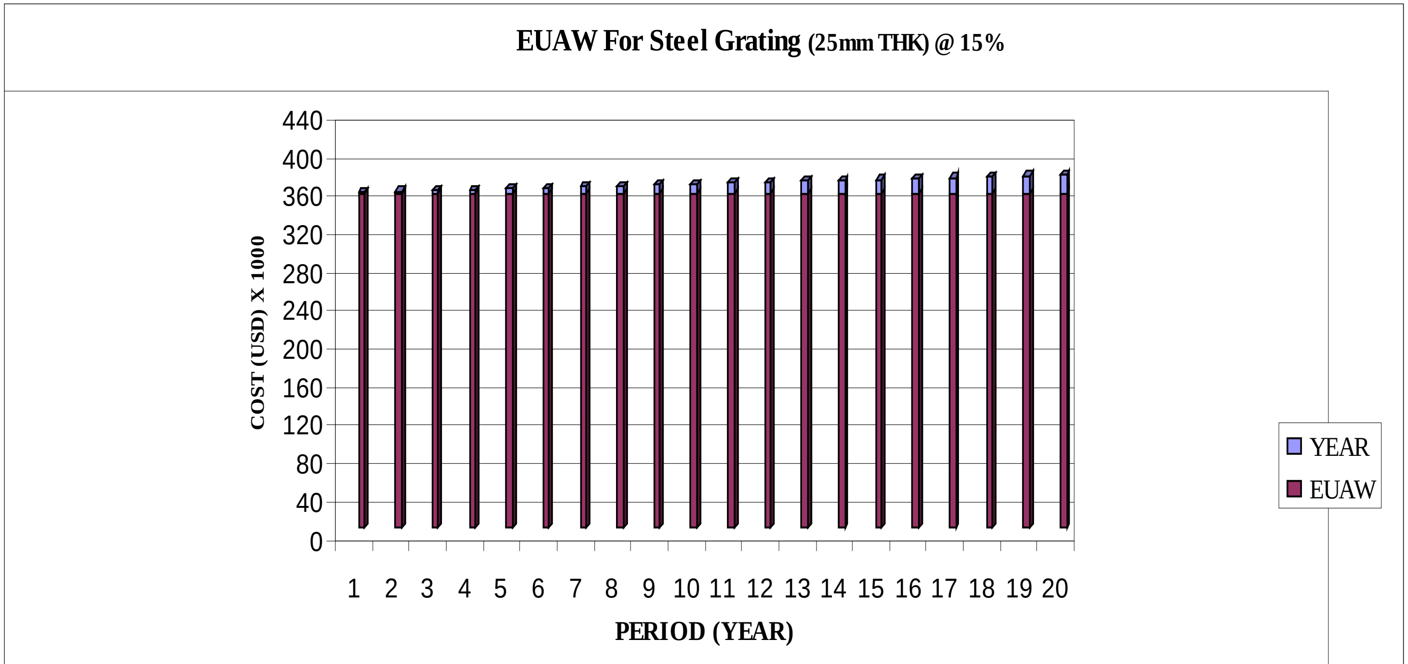
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1

Figure A26: EUAW for Steel Grating (Deflated 10%) @ 10%

Table A27: LCC Components Steel Grating (Deflated 10% in Both Material & Installation Cost) at 15% Interest Rate

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,194,793.32
Equivalent Uniform Annual Worth (EUAW)	350,643.41

Note: Cost in USD



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	350.7	350.7	350.7	350.7	350.7	350.7	350.7	350.7	350.7	350.7	350.7	350.7	350.7	350.7	350.7	350.7	350.7	350.7	350.7	350.7

Figure A27: EUAW for Steel Grating (Deflated 10%) @ 15%

APPENDIX B

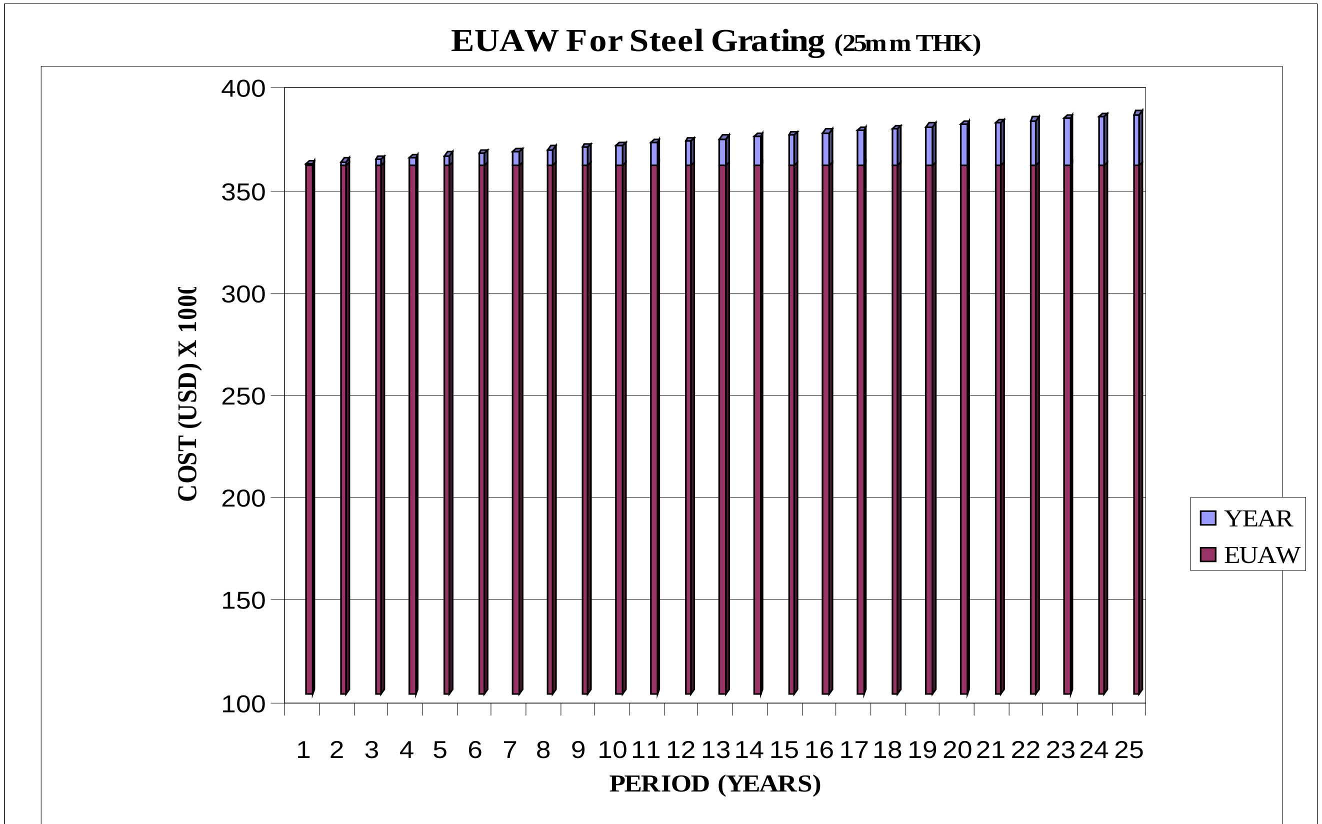
CASH FLOWS ANALYSIS FOR THE GRATINGS

FOR A PERIOD OF 25 YEARS

Table B1: LCC Components for Steel Grating@ 5%

Material Type	**Steel Grating 25mm as a Base Material**
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	5,042,950.48
Equivalent Uniform Annual Worth (EUAW)	357,809.73

Note: Cost in USD



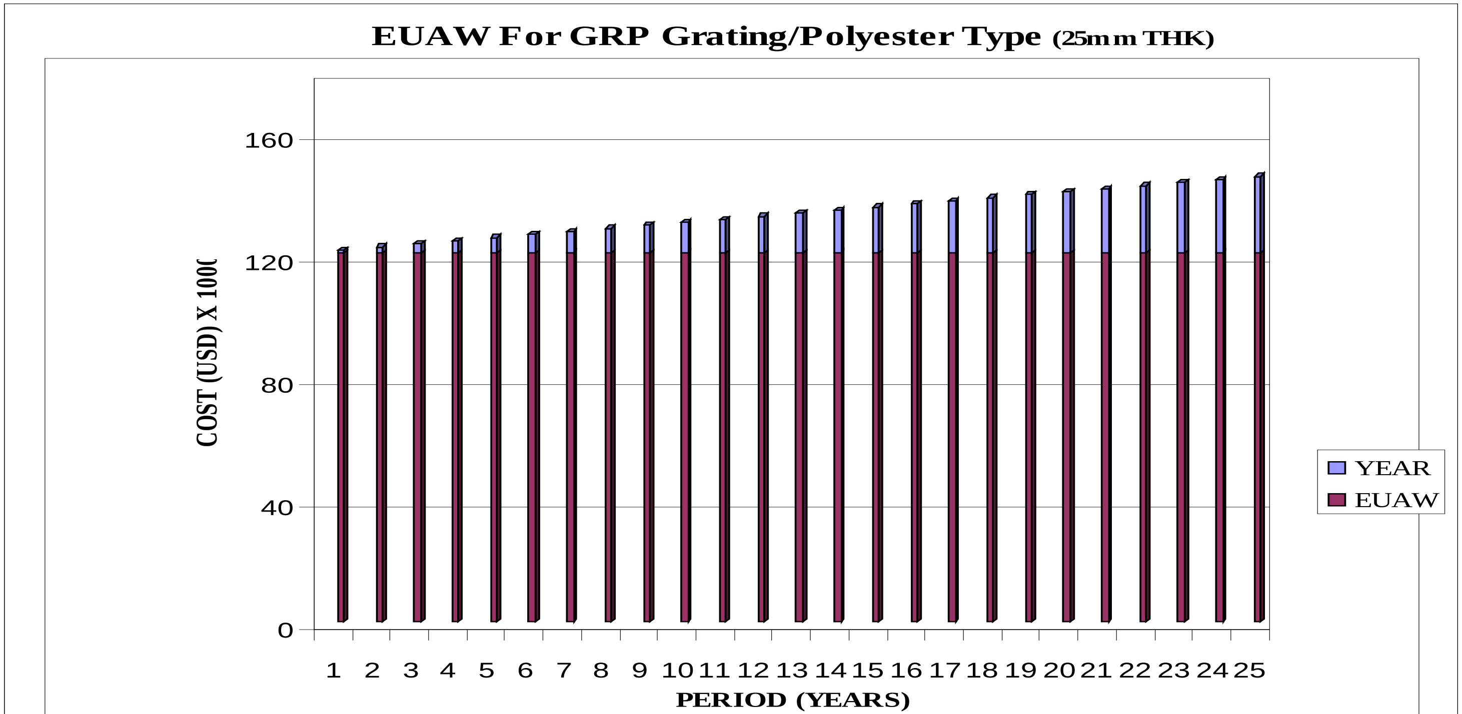
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8

Figure B1: EUAW for Steel Grating @ 5%

Table B2: LCC Components for Polyester Grating 25mm @ 5%

Material Type	GRP Grating (Polyester)25 mm
Capital Cost	
Initial Cost	613,672.80
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,696,624.80
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	1,696,624.80
Equivalent Uniform Annual Worth (EUAW)	120,379.70

Note: Cost in USD



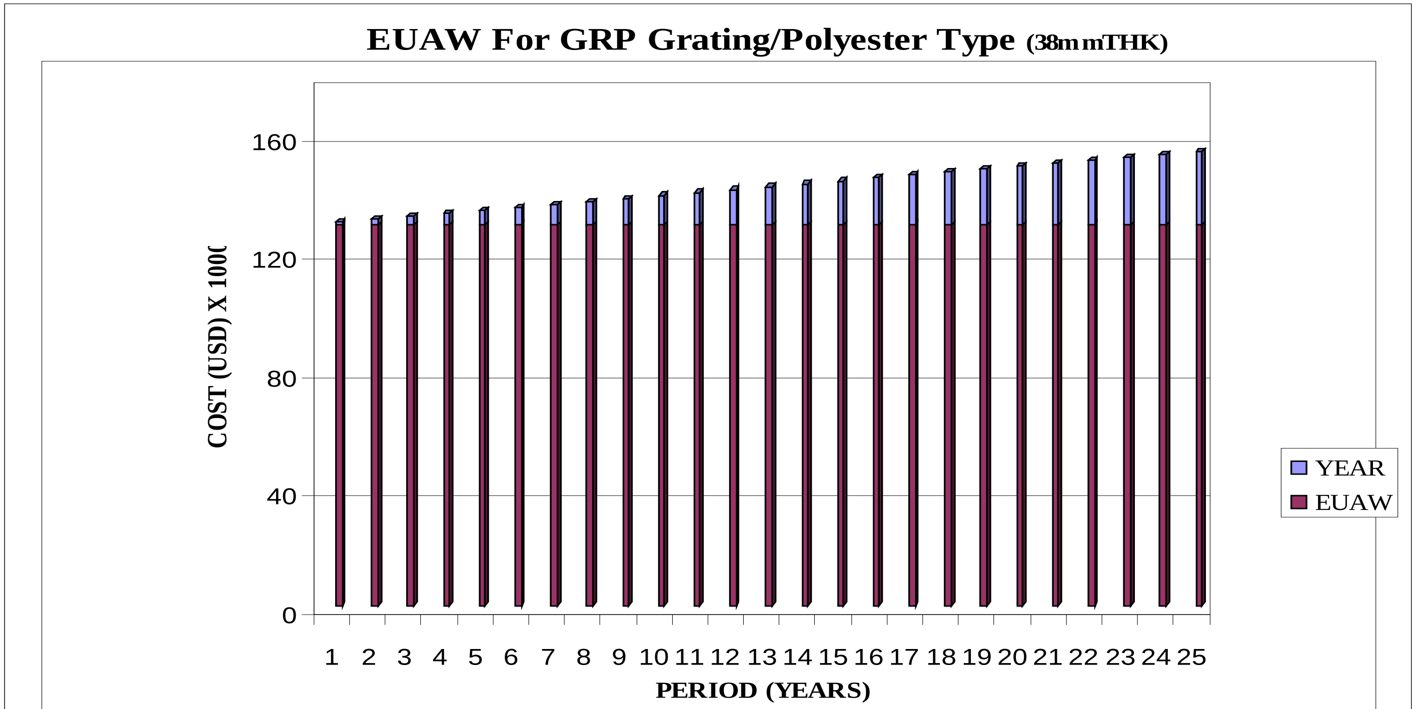
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4

Figure B2: EUAW for Polyester Grating 25mm @ 5%

Table B3: LCC Components for Polyester Grating 38mm @ 5%

Material Type	GRP Grating (Polyester)38 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	128,703.83

Note: Cost in USD



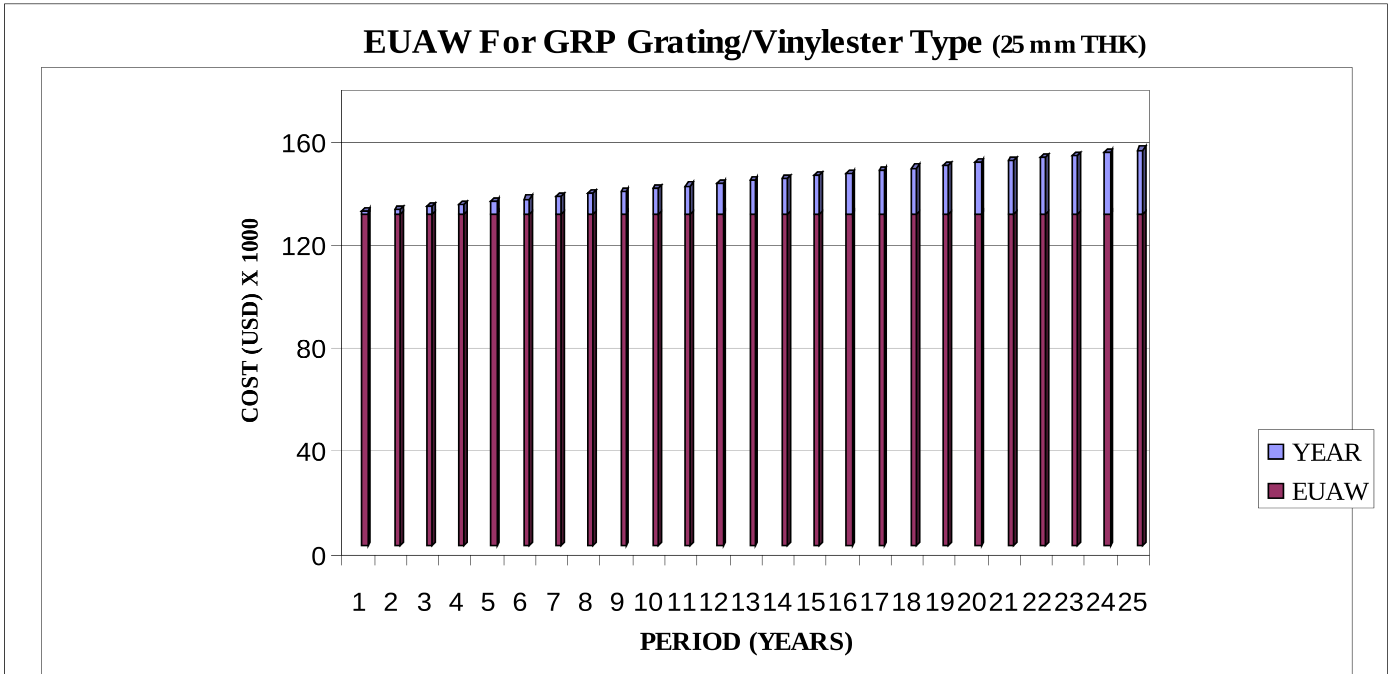
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7

Figure B3: EUAW for Polyester Grating 38mm @ 5%

Table B4: LCC Components for Vinylester Grating 25mm @ 5%

Material Type	GRP Grating (Vinylester)25 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	128,703.83

Note: Cost in USD



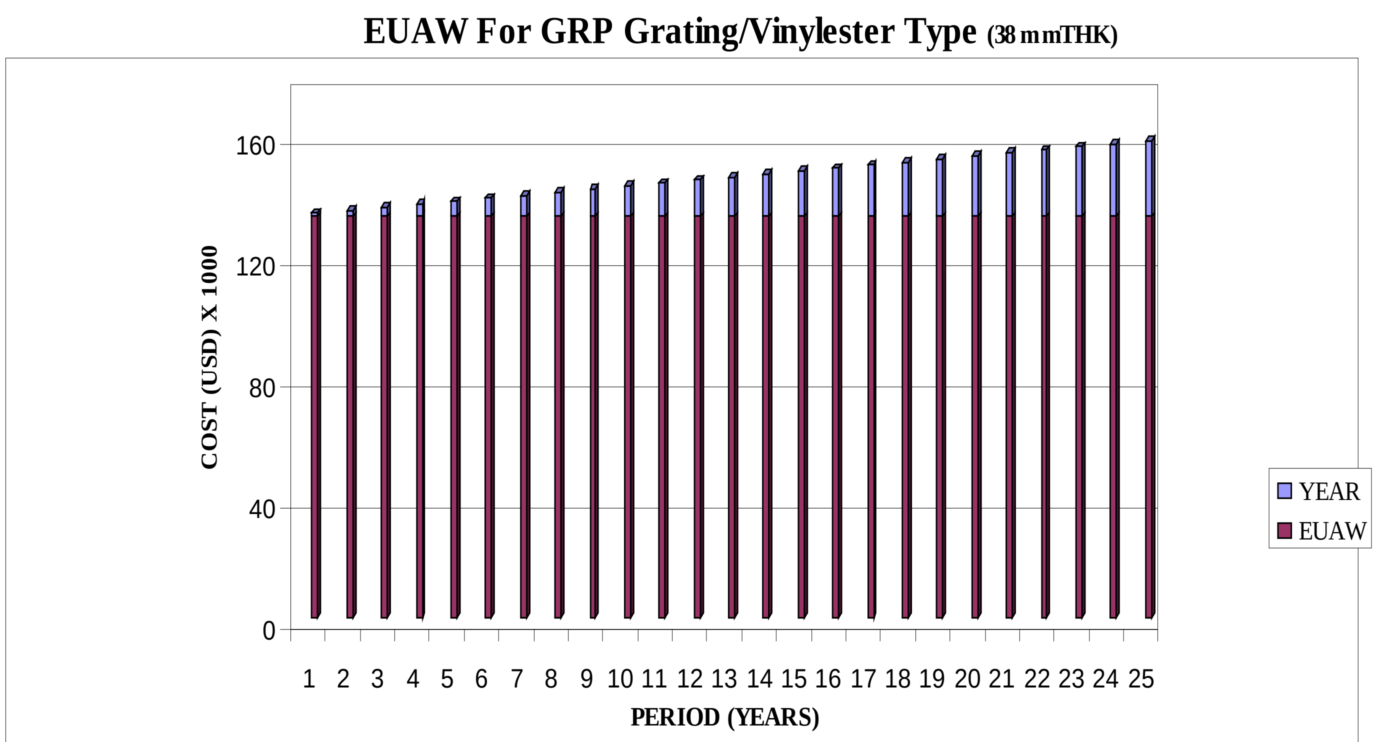
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7

Figure B4: EUAW for Vinylester Grating 25mm @ 5%

Table B5: LCC Components for Vinylester Grating 38mm @ 5%

Material Type	GRP Grating (Vinylester)38 mm
Capital Cost	
Initial Cost	789,652.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,872,604.50
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	1,872,604.50
Equivalent Uniform Annual Worth (EUAW)	132,865.89

Note: Cost in USD



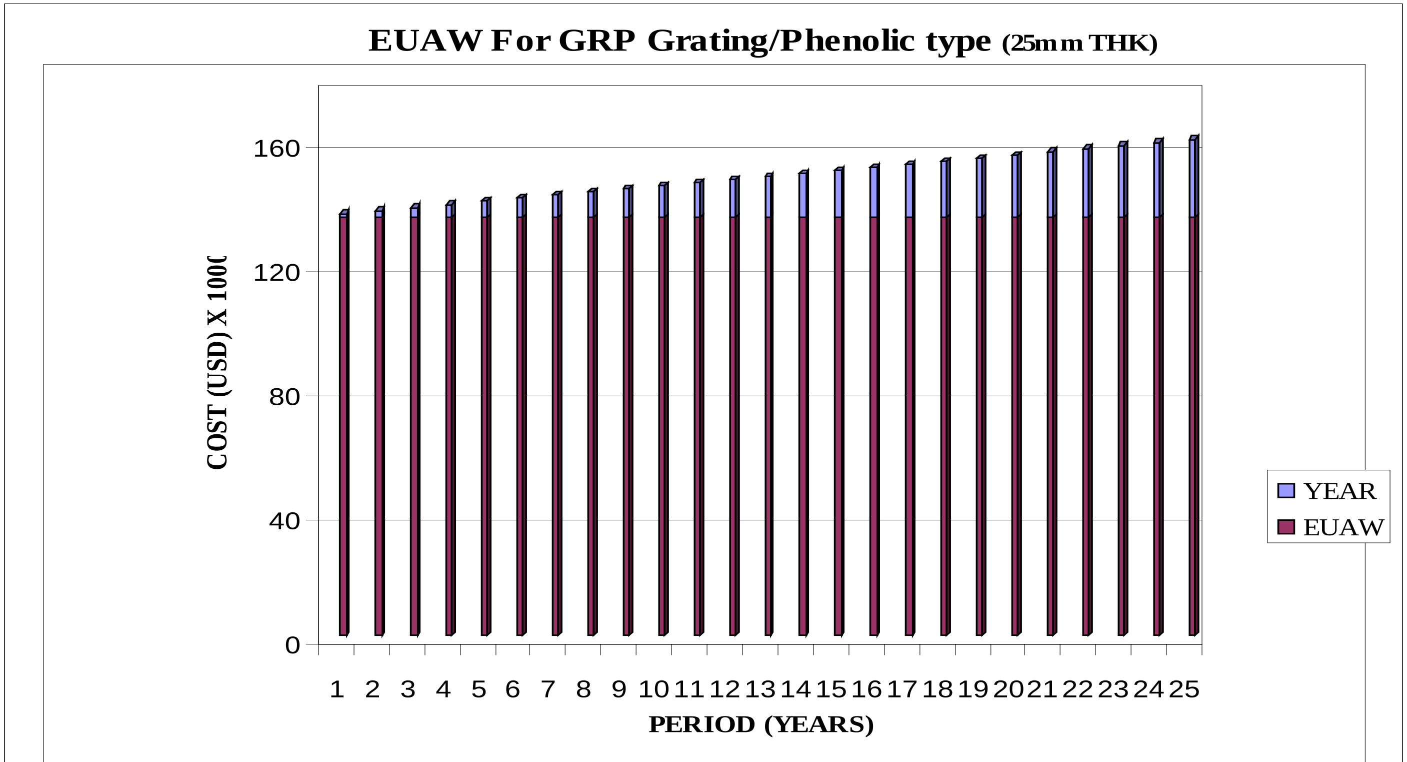
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9	132.9

Figure B5: EUAW for Vinylester Grating 38mm @ 5%

Table B6: LCC Components for Phenolic Grating 25mm @ 5%

Material Type	**GRP Grating (Phenolic)25 mm**
Capital Cost	
Initial Cost	821,238.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,904,190.60
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	1,904,190.60
Equivalent Uniform Annual Worth (EUAW)	135,107.00

Note: Cost in USD

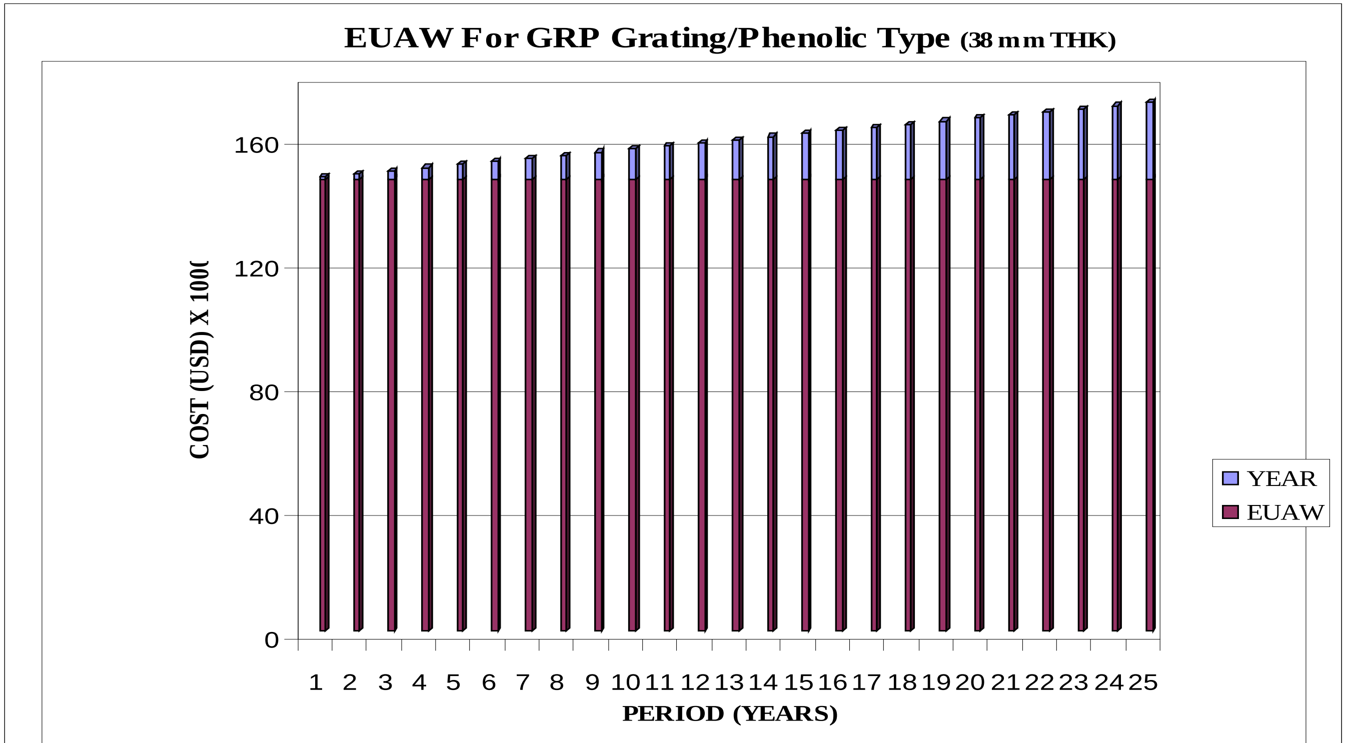


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1	135.1

Figure B6: EUAW for Phenolic Grating 25mm @ 5%

Table B7: LCC Components for Phenolic Grating 38mm @ 5%

Material Type	GRP Grating (Phenolic)38 mm
Capital Cost	
Initial Cost	970,144.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	2,053,096.50
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	2,053,096.50
Equivalent Uniform Annual Worth (EUAW)	145,672.24



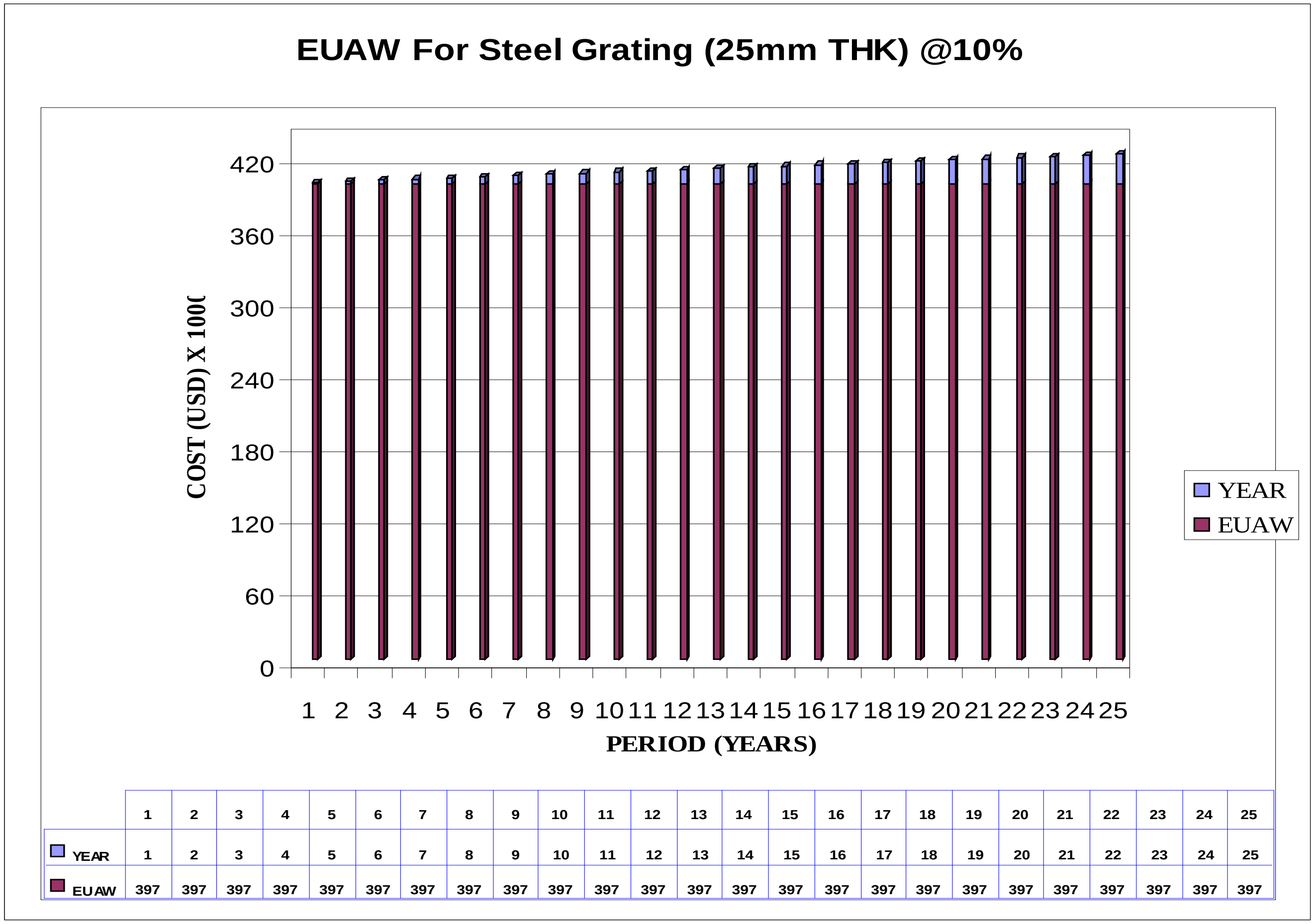
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7	145.7

Figure B7: EUAW for Phenolic Grating 38mm @ 5%

Table B8: LCC Components for Steel Grating @ 10%

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	3,604,062.07
Equivalent Uniform Annual Worth (EUAW)	397,052.57

Note: Cost in USD



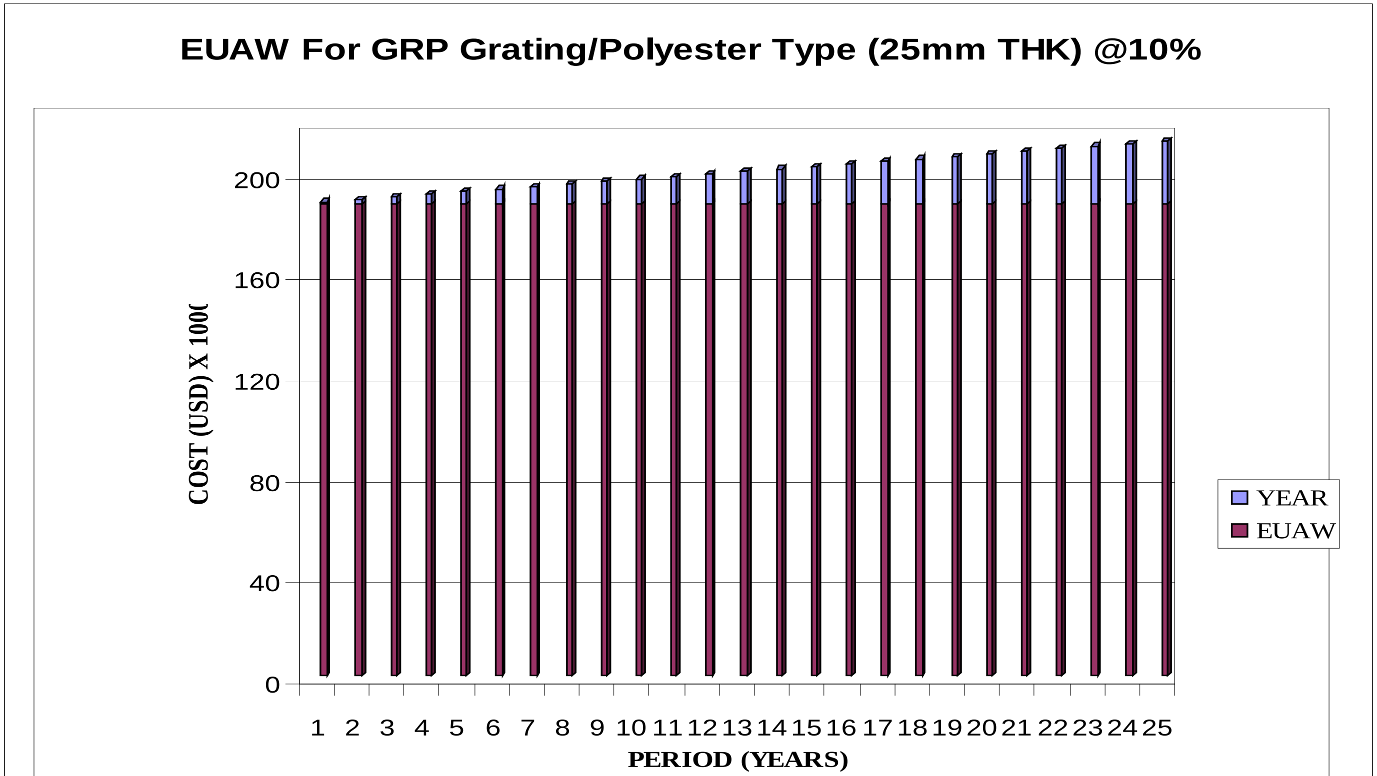
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	397	397	397	397	397	397	397	397	397	397	397	397	397	397	397	397	397	397	397	397	397	397	397	397	397

Figure B8: EUAW for Steel Grating @ 10%

Table B9: LCC Components for Polyester Grating 25mm @ 10%

Material Type	GRP Grating (Polyester)25 mm
Capital Cost	
Initial Cost	613,672.80
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,696,624.80
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	1,696,624.80
Equivalent Uniform Annual Worth (EUAW)	186,913.88

Note: Cost in USD



	1	2	3	4	5	6	7	8	9	10	11	12	13
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13
EUAW	186.9	186.9	186.9	186.9	186.9	186.9	186.9	186.9	186.9	186.9	186.9	186.9	186.9

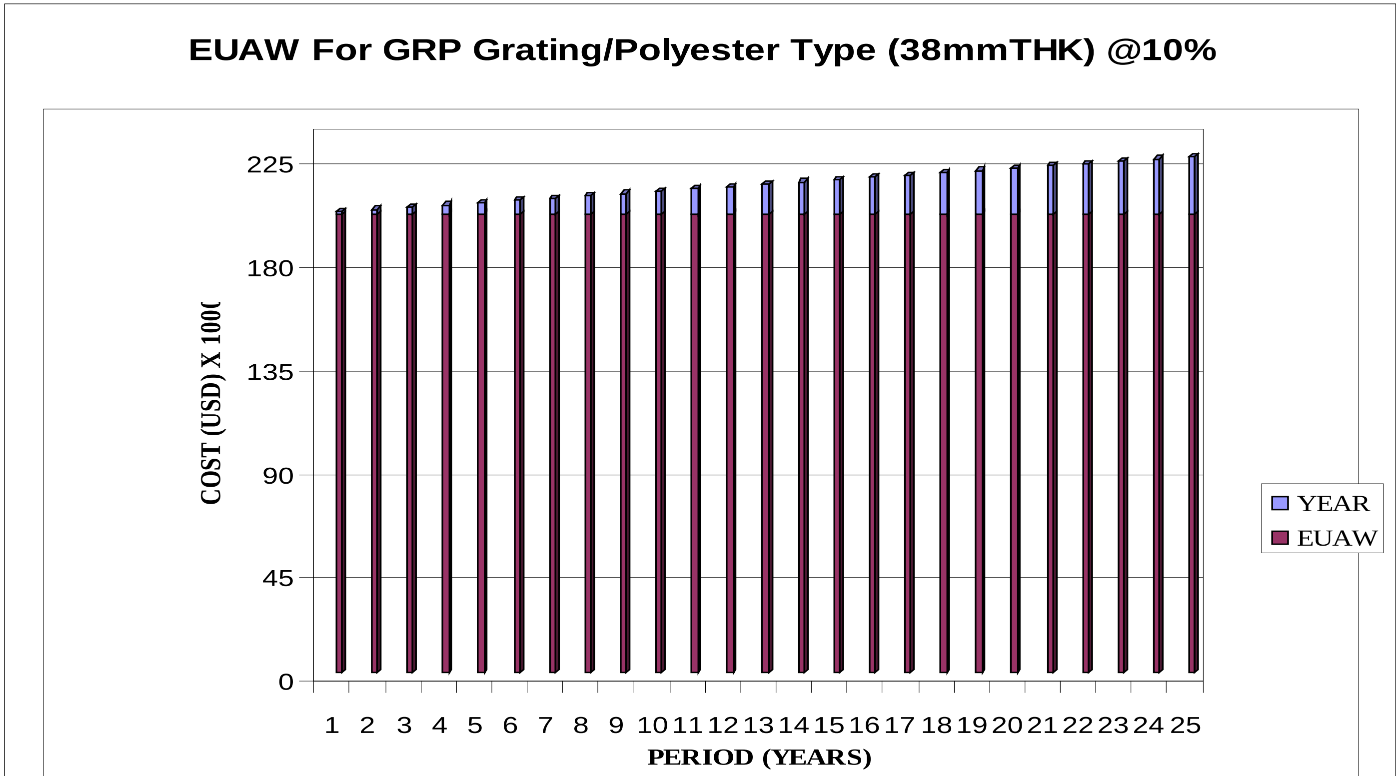
	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	186.9	186.9	186.9	186.9	186.9	186.9	186.9	186.9	186.9	186.9	186.9	186.9

Figure B9: EUAW for Polyester Grating 25mm @ 10%

Table B10: LCC Components for Polyester Grating 38mm @ 10%

Material Type	GRP Grating (Polyester)38 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	199,838.78

Note: Cost in USD



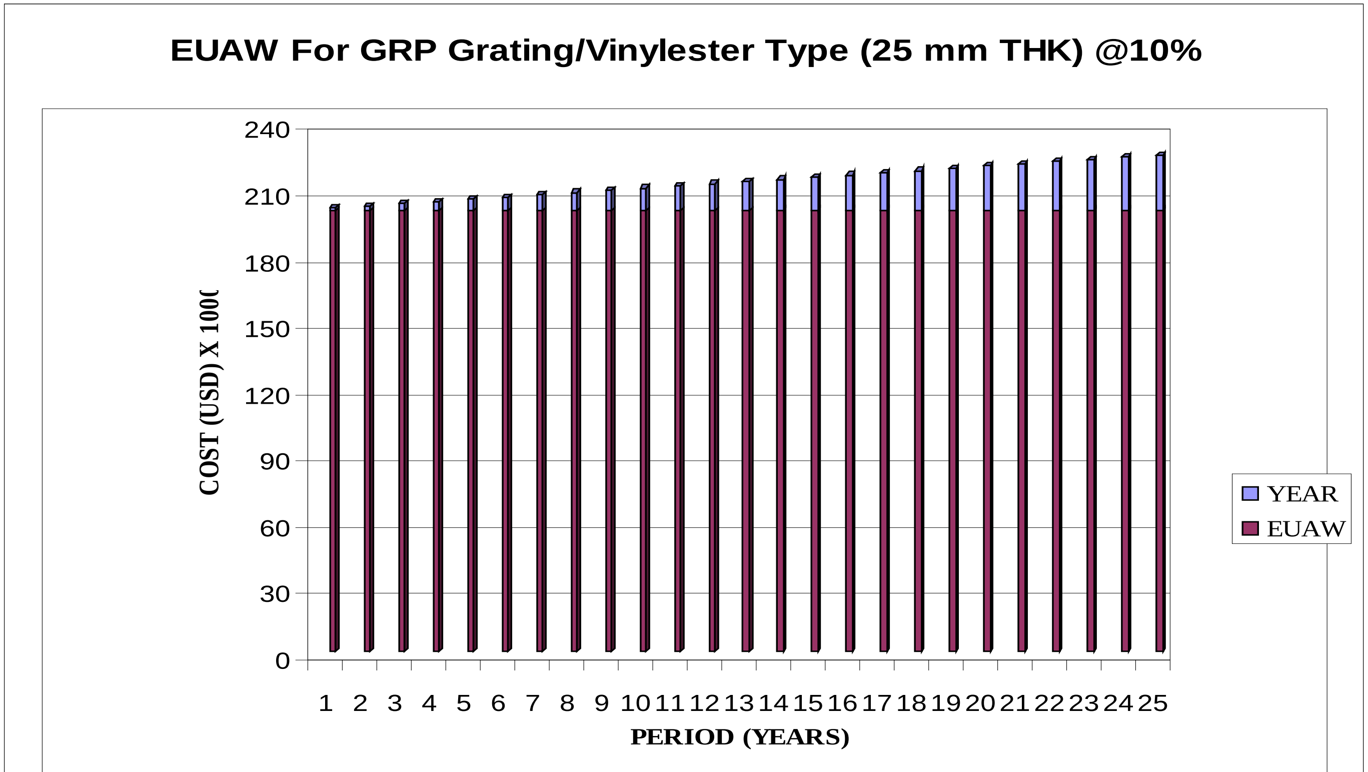
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8

Figure B10: EUAW for Polyester Grating 38mm @ 10%

Table B11: LCC Components for Vinylester Grating 25mm @ 10%

Material Type	GRP Grating (Vinylester)25 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	199,838.78

Note: Cost in USD



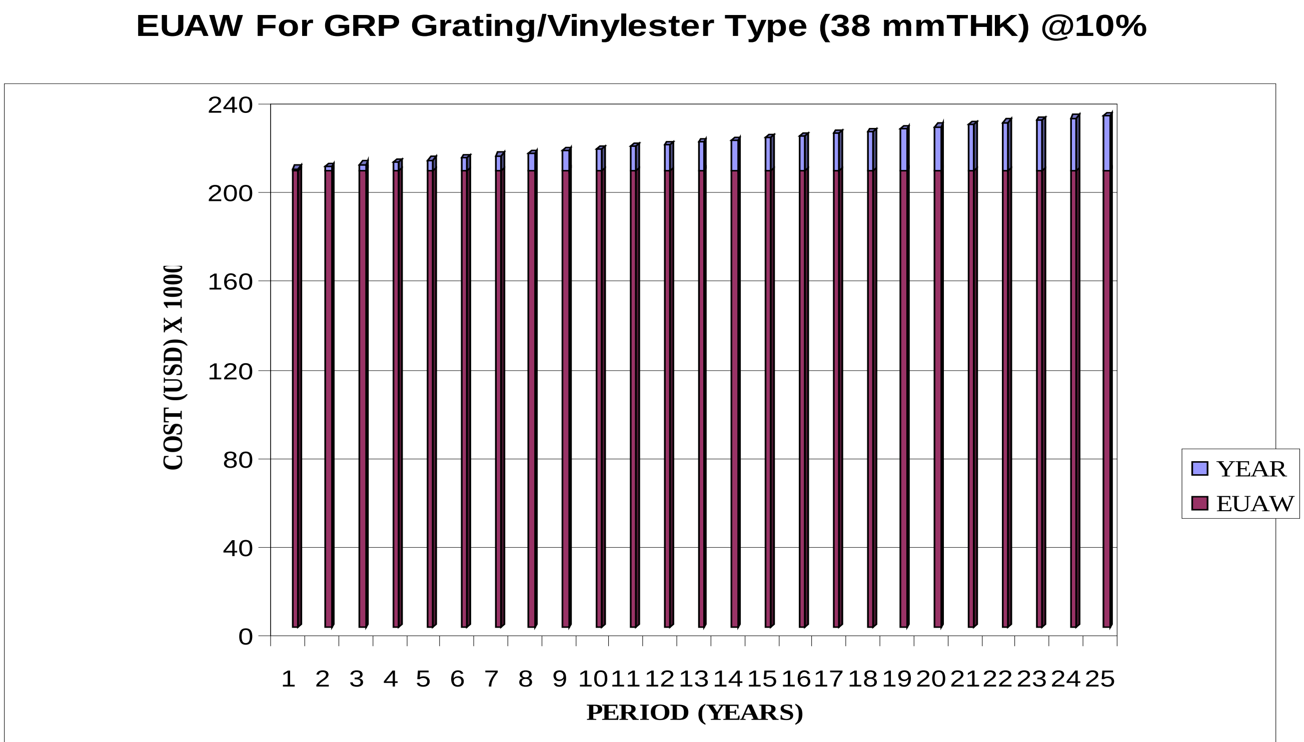
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8	199.8

Figure B11: EUAW for Vinylester Grating 25mm @ 10%

Table B12: LCC Components for Vinylester Grating 38mm @ 10%

Material Type	GRP Grating (Vinylester)38 mm
Capital Cost	
Initial Cost	789,652.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,872,604.50
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	1,872,604.50
Equivalent Uniform Annual Worth (EUAW)	206,301.23

Note: Cost in USD



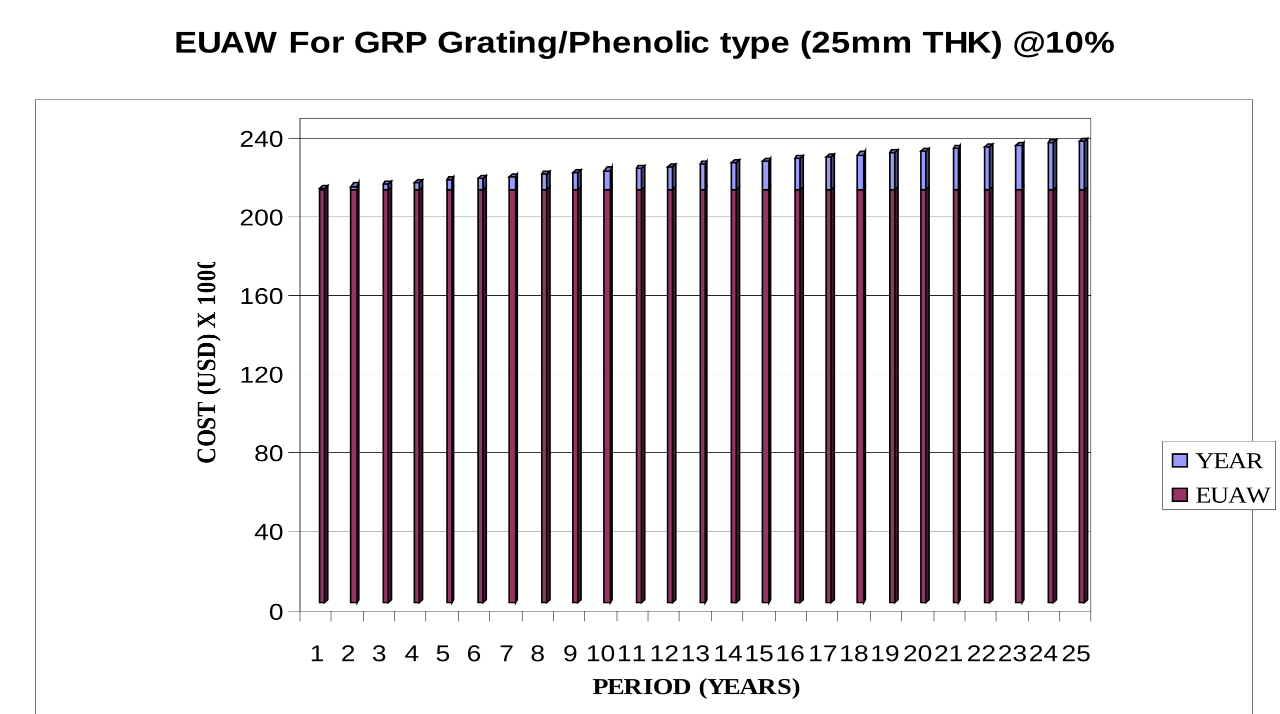
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3	206.3

Figure B12: EUAW for Vinylester Grating 38mm @ 10%

Table B13: LCC Components for Phenolic Grating 25mm @ 10%

Material Type	GRP Grating (Phenolic)25 mm
Capital Cost	
Initial Cost	821,238.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,904,190.60
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	1,904,190.60
Equivalent Uniform Annual Worth (EUAW)	209,781.01

Note: Cost in USD



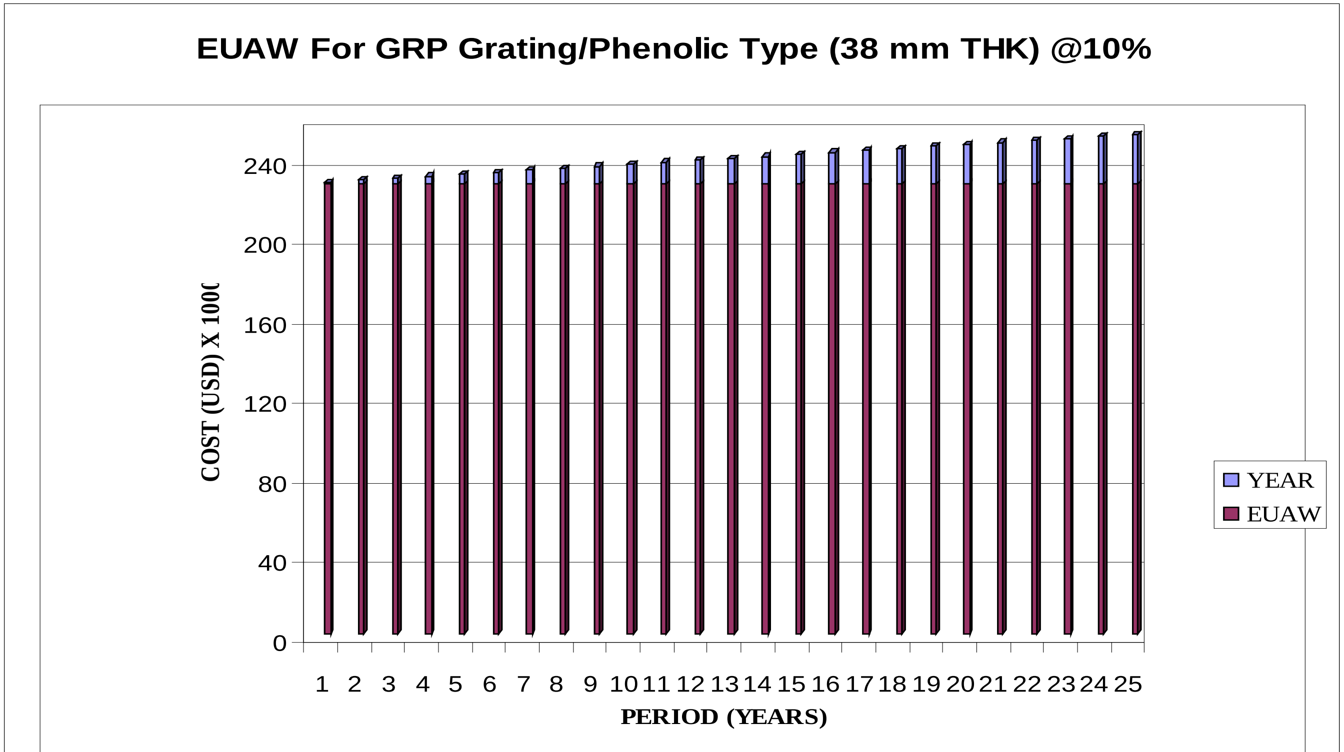
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8	209.8

Figure B13: EUAW for Phenolic Grating 25mm @ 10%

Table B14: LCC Components for Phenolic Grating 38mm @ 10%

Material Type	GRP Grating (Phenolic)38 mm
Capital Cost	
Initial Cost	970,144.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	2,053,096.50
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,053,096.50
Equivalent Uniform Annual Worth (EUAW)	226,185.68

Note: Cost in USD



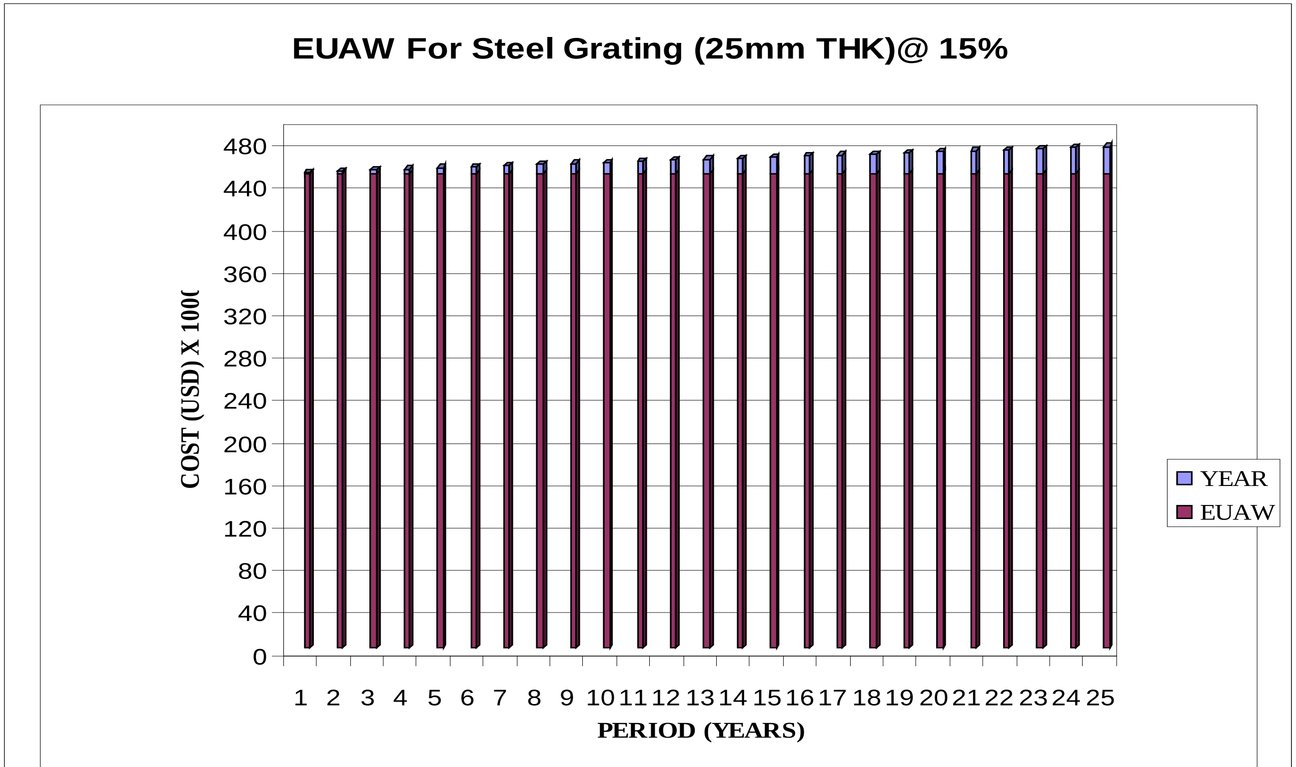
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2	226.2

Figure B14: EUAW for Phenolic Grating 38mm @ 10%

Table B15: LCC Components for Steel Grating @ 15%

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,888,882.38
Equivalent Uniform Annual Worth (EUAW)	446,908.38

Note: Cost in USD



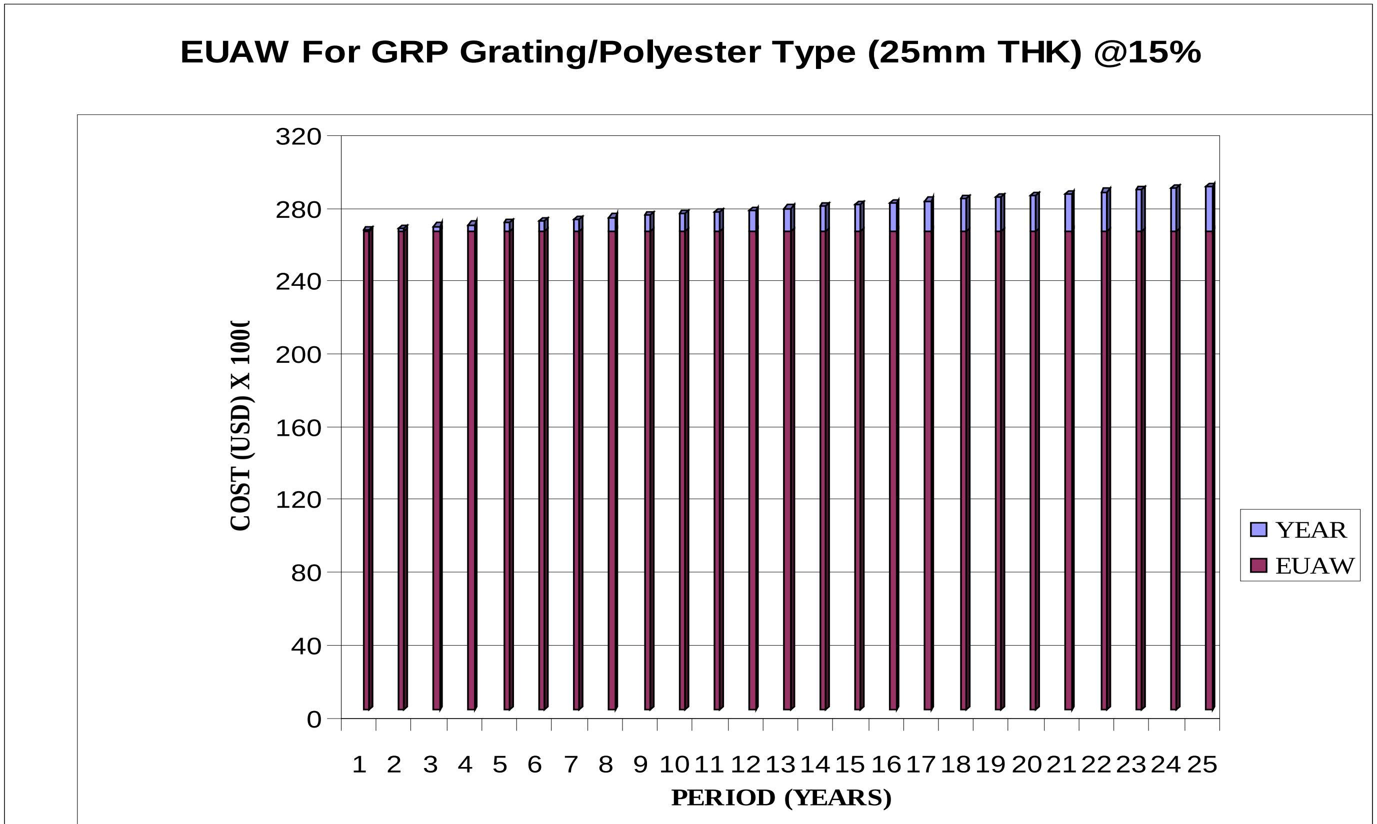
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9	446.9

Figure B15: EUAW for Steel Grating @ 15%

Table B16: LCC Components for Polyester Grating 25mm @ 15%

Material Type	**GRP Grating (Polyester)25 mm**
Capital Cost	
Initial Cost	613,672.80
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,696,624.80
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	1,696,624.80
Equivalent Uniform Annual Worth (EUAW)	262,466.84

Note: Cost in USD



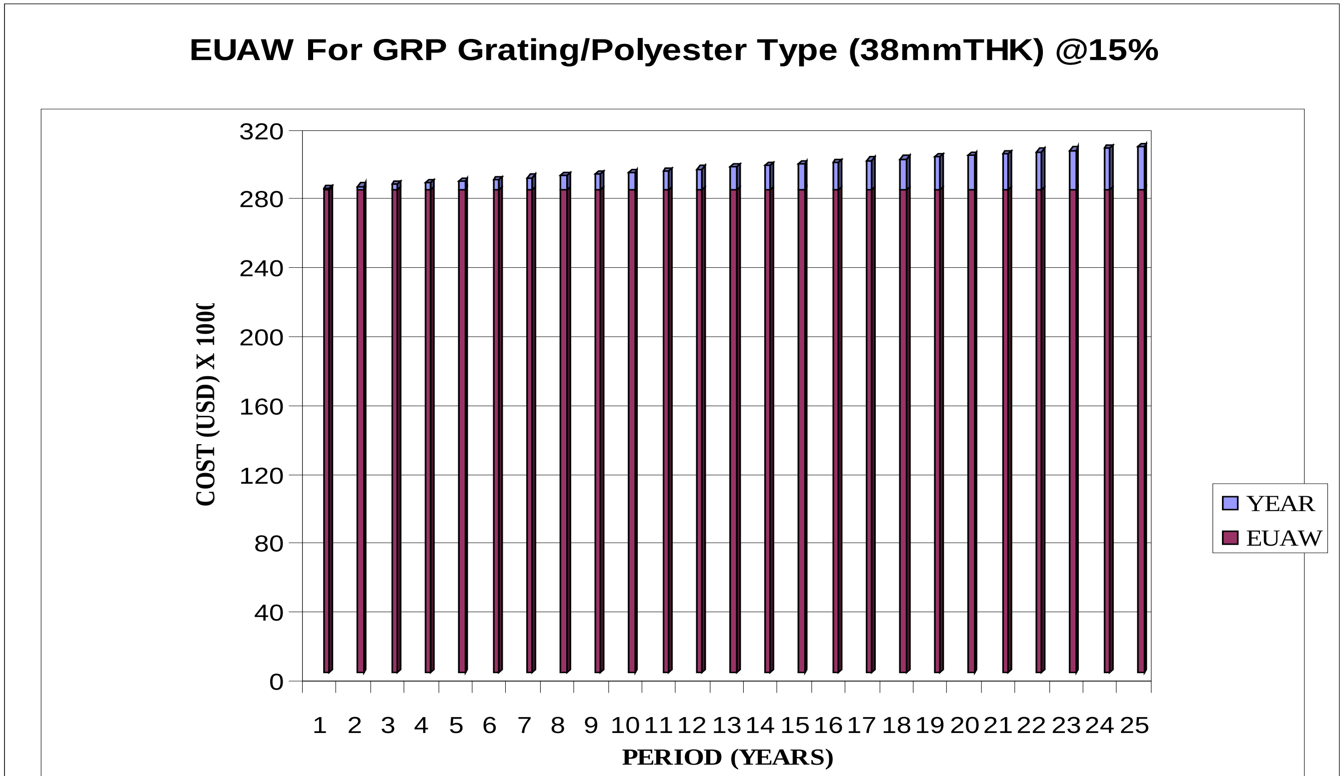
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5	262.5

Figure B16: EUAW for Polyester Grating 25mm @ 15%

Table B17: LCC Components for Polyester Grating 38mm @ 15%

Material Type	GRP Grating (Polyester)38 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	280,616.15

Note: Cost in USD



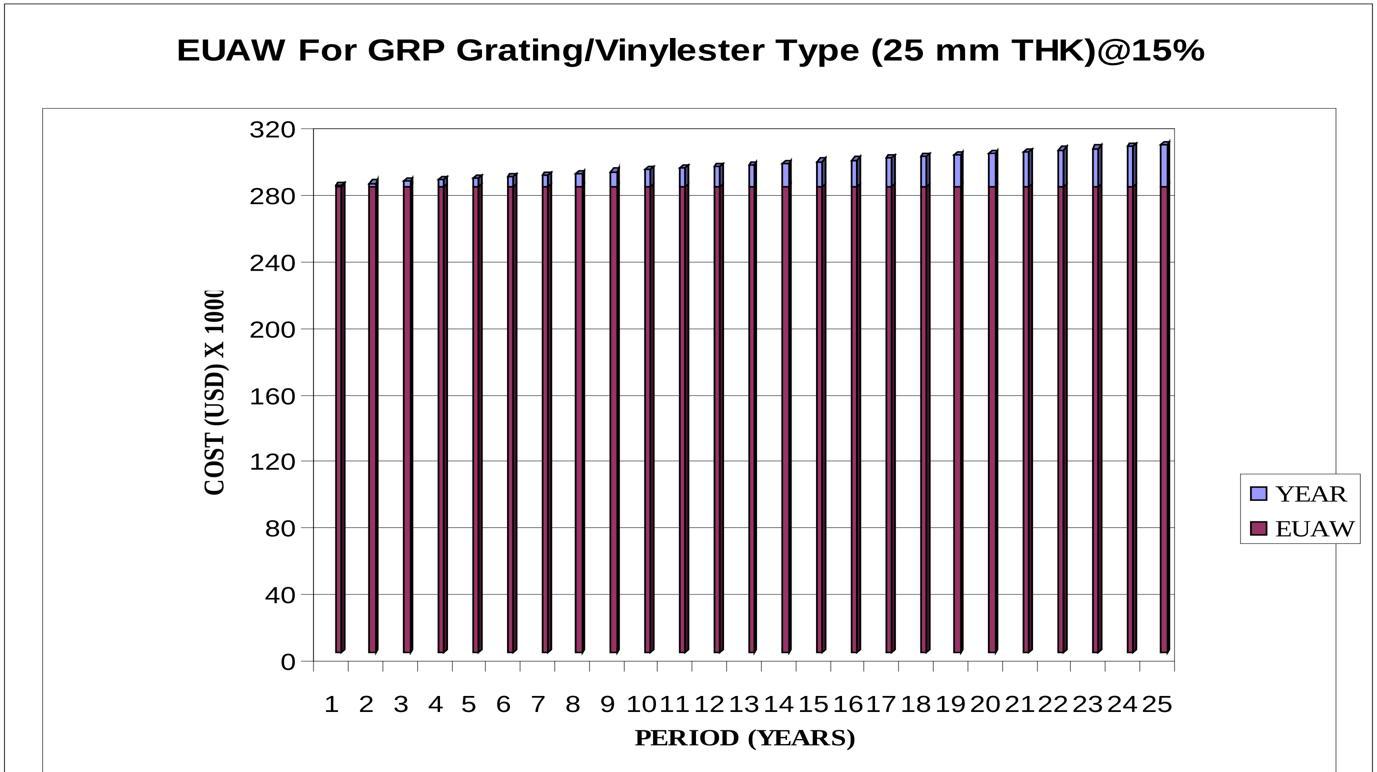
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6

Figure B17: EUAW for Polyester Grating 38mm @ 15%

Table B18: LCC Components for Vinylester Grating 25mm @ 15%

Material Type	GRP Grating (Vinylester)25 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	280,616.15

Note: Cost in USD



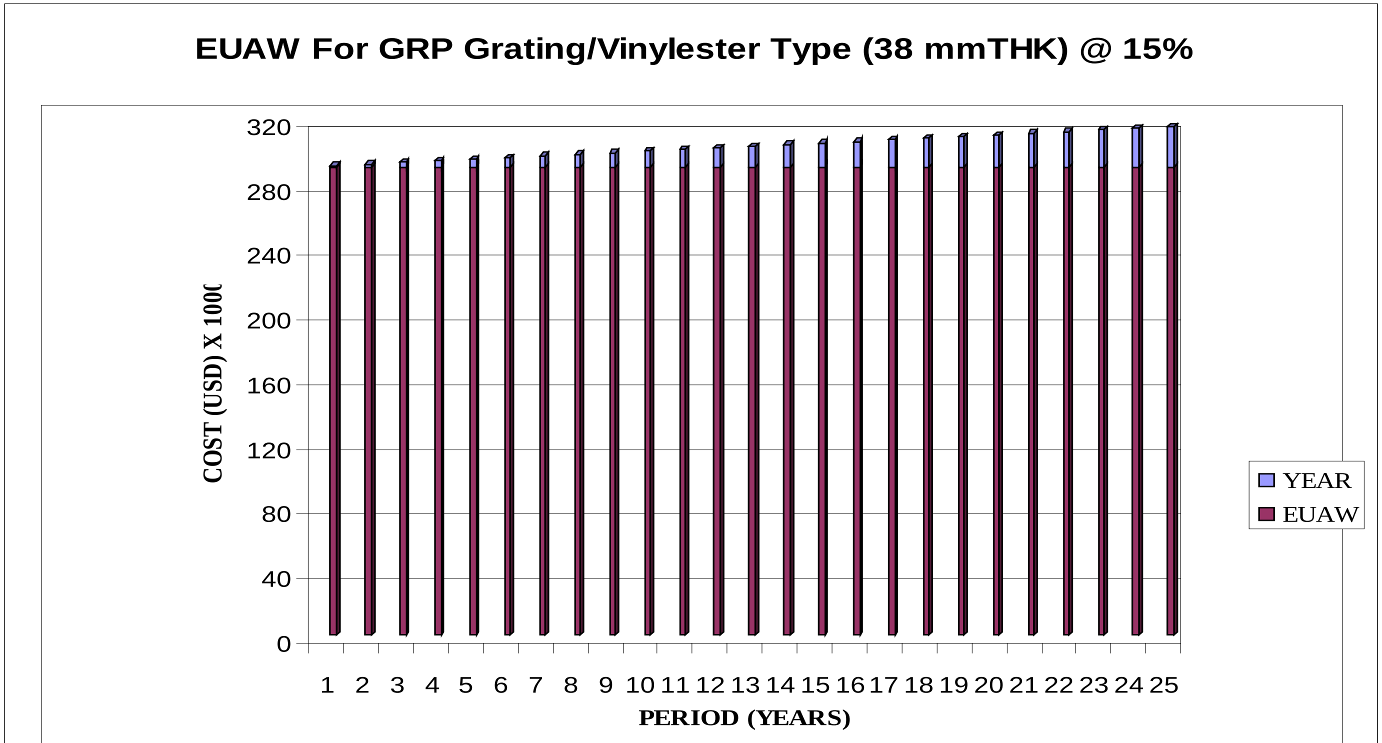
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6	280.6

Figure B18: EUAW for Vinylester Grating 25mm @ 15%

Table B19: LCC Components for Vinylester Grating 38mm @ 15%

Material Type	GRP Grating (Vinylester) 38 mm
Capital Cost	
Initial Cost	789,652.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,872,604.50
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	1,872,604.50
Equivalent Uniform Annual Worth (EUAW)	289,690.80

Note: Cost in USD



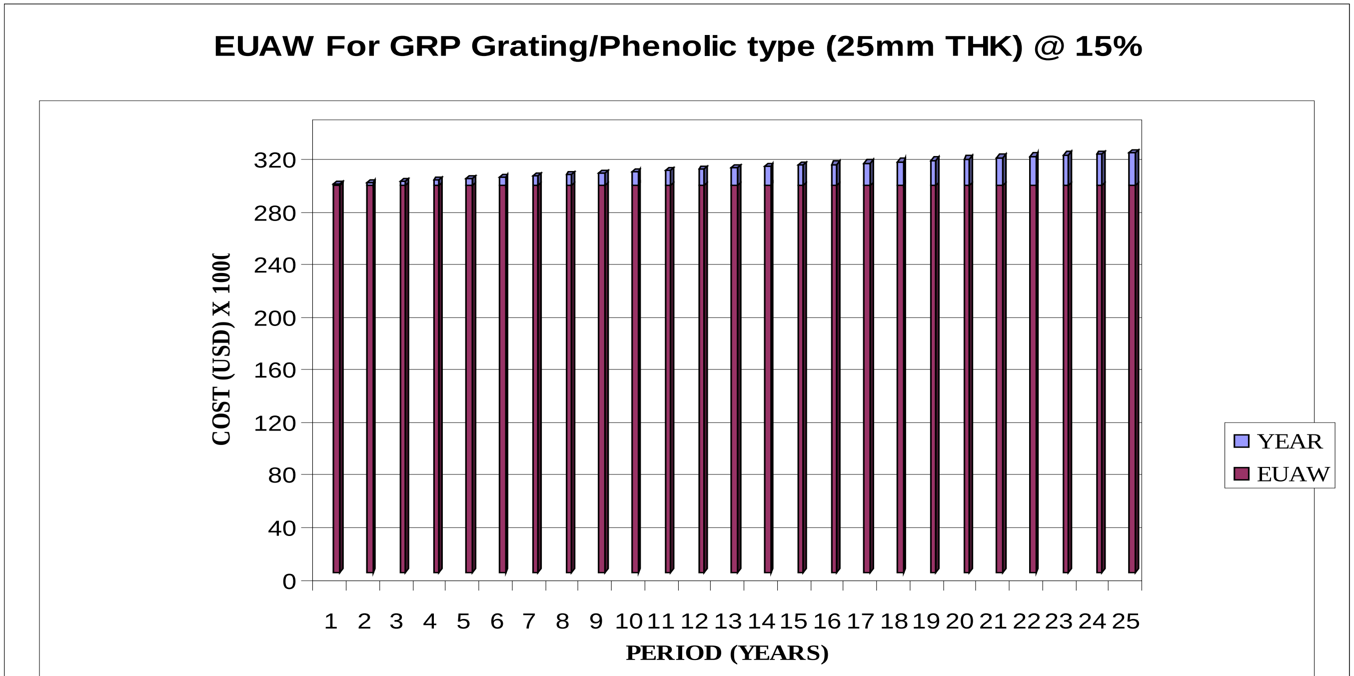
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7	289.7

Figure B19: EUAW for Vinylester Grating 38mm @ 15%

Table B20: LCC Components for Phenolic Grating 25mm @ 15%

Material Type	GRP Grating (Phenolic)25 mm
Capital Cost	
Initial Cost	821,238.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,904,190.60
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	1,904,190.60
Equivalent Uniform Annual Worth (EUAW)	294,577.15

Note: Cost in USD



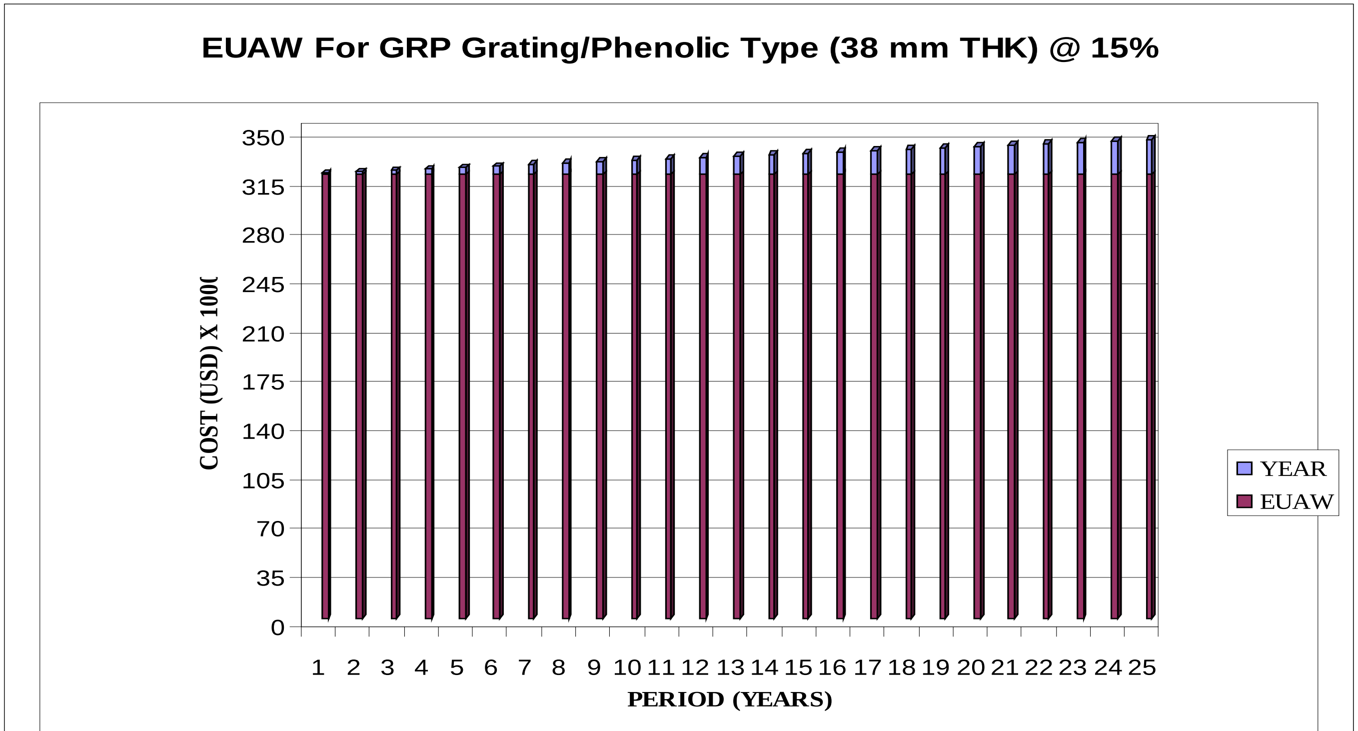
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6	294.6

Figure B20: EUAW for Phenolic Grating 25mm @ 15%

Table B21: LCC Components for Phenolic Grating 38mm @ 15%

Material Type	GRP Grating (Phenolic)38 mm
Capital Cost	
Initial Cost	970,144.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	2,053,096.50
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,053,096.50
Equivalent Uniform Annual Worth (EUAW)	317,612.80

Note: Cost in USD



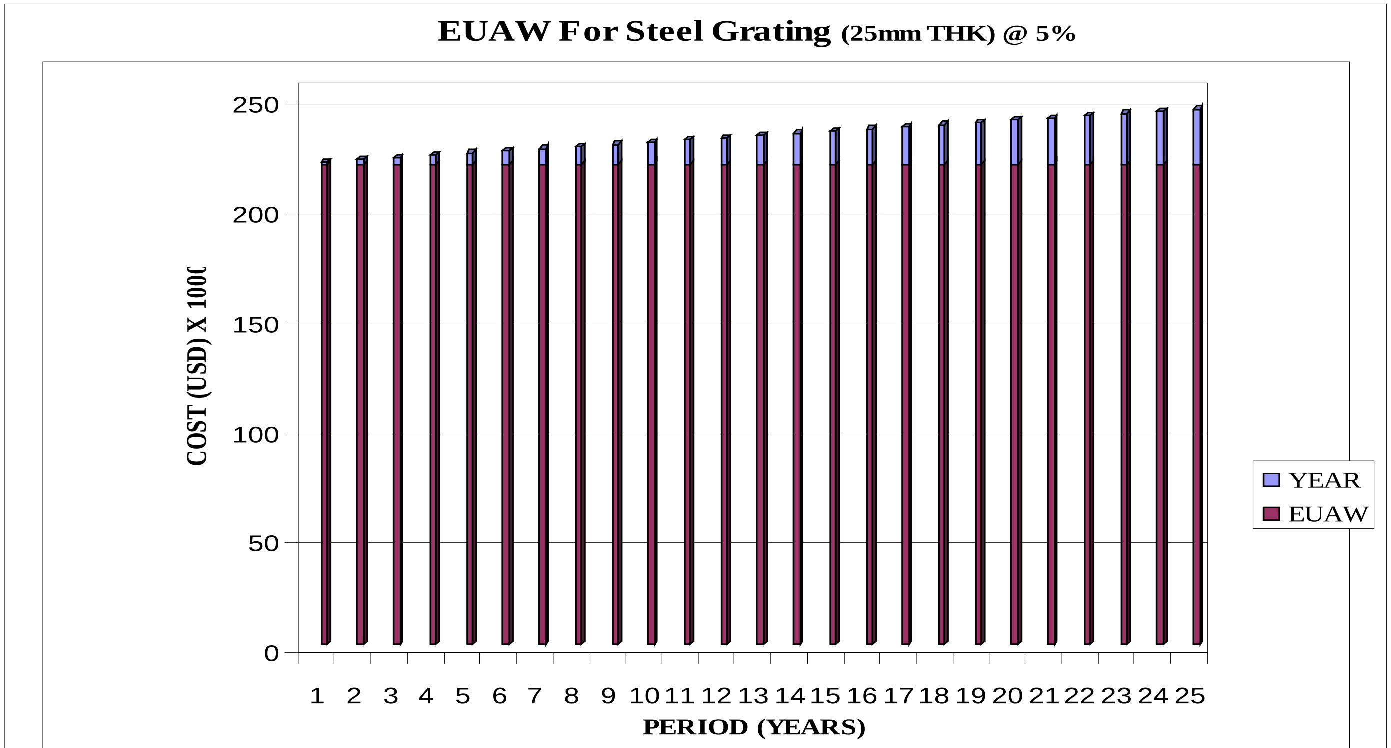
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6	317.6

Figure B21: EUAW for Phenolic Grating 38mm @ 15%

Table B22: LCC Components Steel Grating (Deflated 5% in Material and 10% in Installation Cost) at 5% Interest Rate

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	3,089,528.31
Equivalent Uniform Annual Worth (EUAW)	219,209.63

Note: Cost in USD



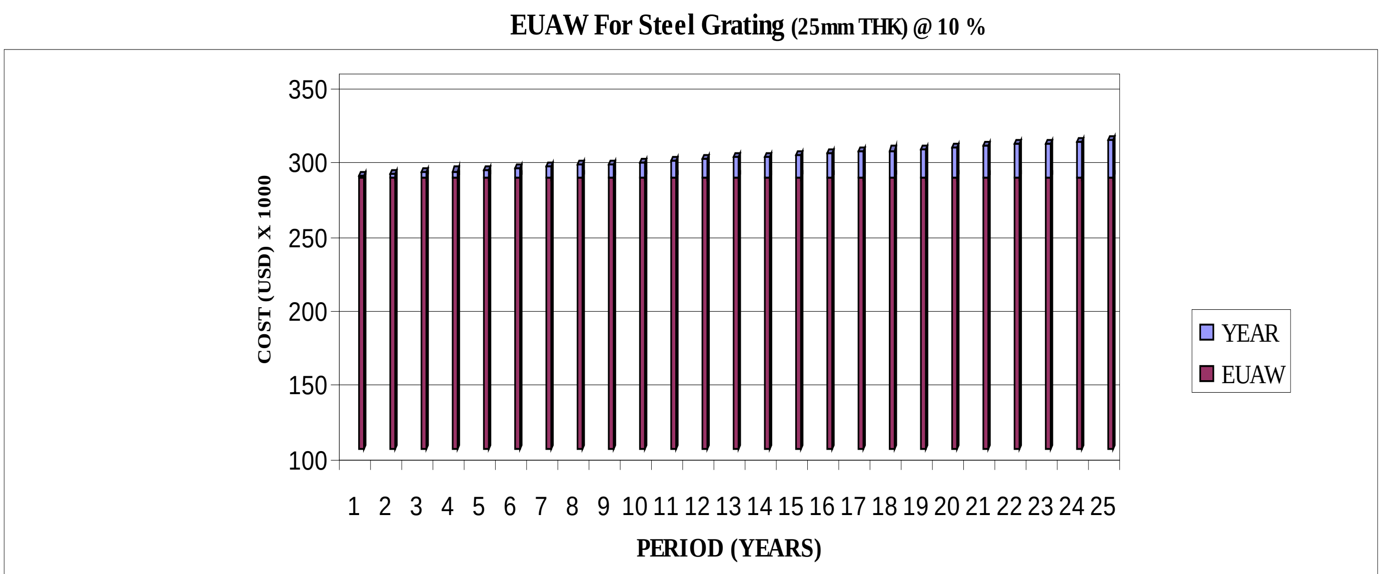
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2	219.2

Figure B22: EUAW for Steel Grating (Deflated) @ 5%

Table B23: LCC Components Steel Grating (Deflated 5% in Material and 10% in Installation Cost) at 10% Interest Rate

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,576,602.61
Equivalent Uniform Annual Worth (EUAW)	283,859.34

Note: Cost in USD



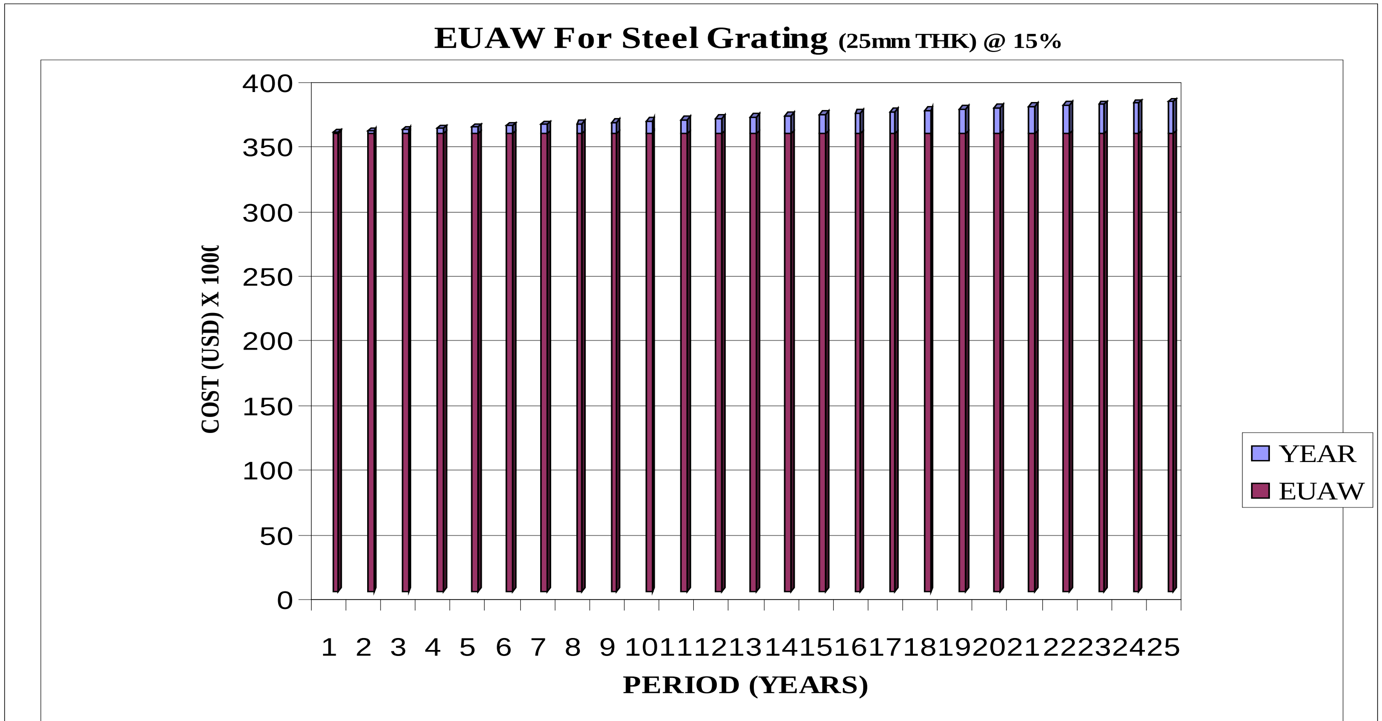
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9	283.9

Figure B23: EUAW for Steel Grating (Deflated) @ 10%

Table B24: LCC Components Steel Grating (Deflated 5% in Material and 10% in Installation Cost) at 10% Interest Rate

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,287,675.67
Equivalent Uniform Annual Worth (EUAW)	353,902.06

Note: Cost in USD



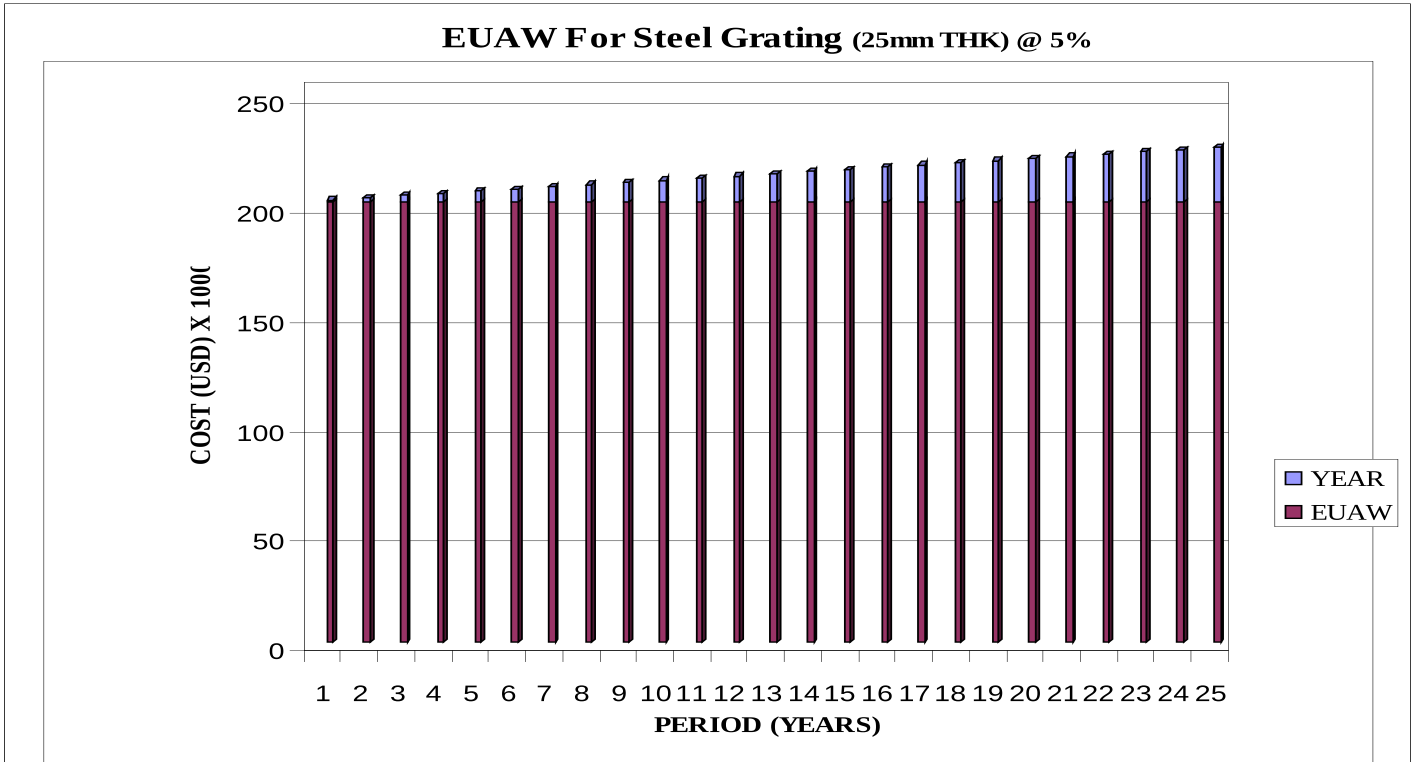
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9	353.9

Figure B24: EUAW for Steel Grating (Deflated) @ 15%

Table B25: LCC Components Steel Grating (Deflated 10% in Both Installations & Material Cost) at 5% Interest Rate

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	2,838,739.00
Equivalent Uniform Annual Worth (EUAW)	201,415.51

Note: Cost in USD



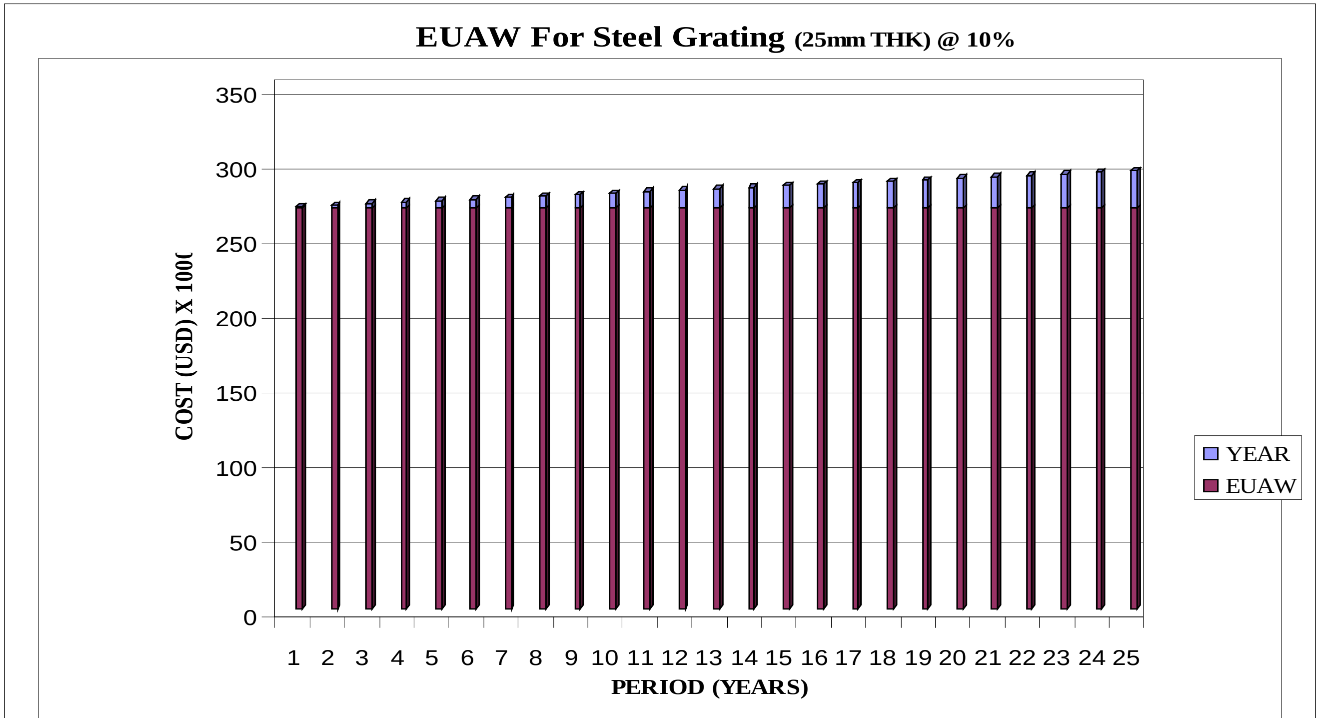
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4	201.4

Figure B25: EUAW for Steel Grating (Deflated 10%) @ 5%

Table B26: LCC Components Steel Grating (Deflated 10% in Both Installation & Material Cost) at 10% Interest Rate

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,435,710.55
Equivalent Uniform Annual Worth (EUAW)	268,337.54

Note: Cost in USD



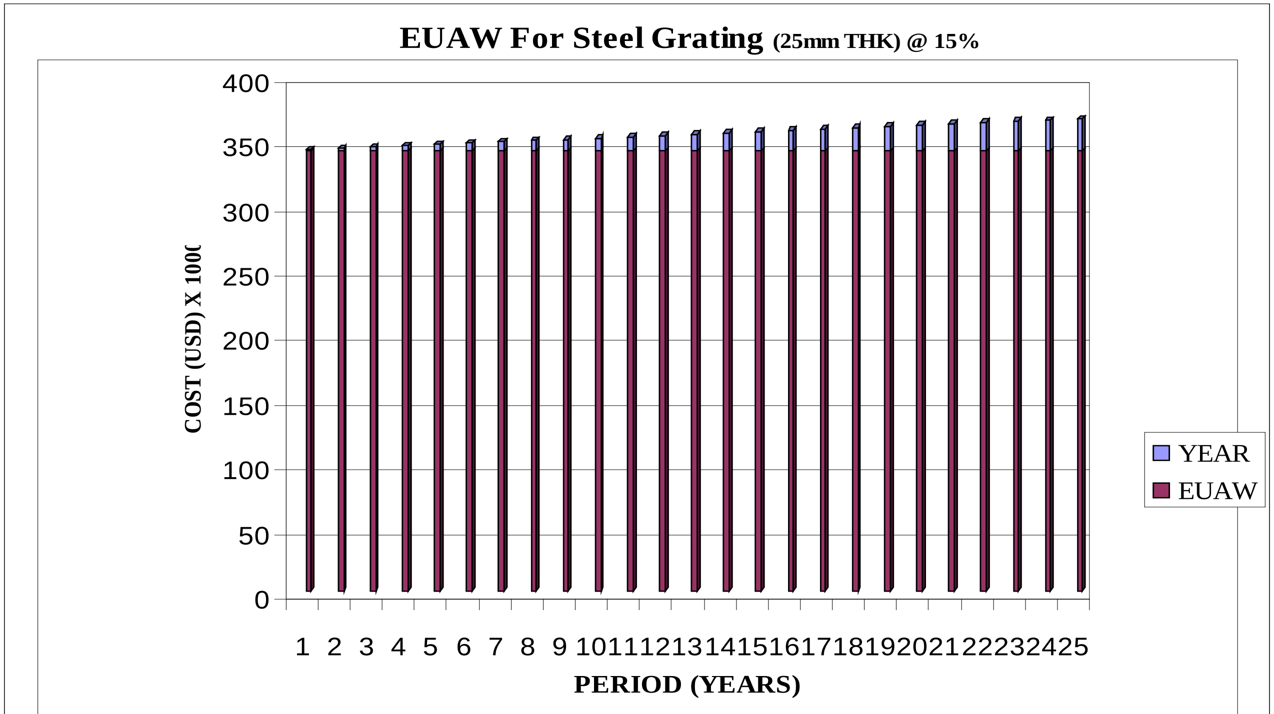
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4

Figure B26: EUAW for Steel Grating (Deflated 10%) @ 10%

Table B27: LCC Components Steel Grating (Deflated 10% in Both Installation & Material Cost) at 15% Interest Rate

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,200,698.92
Equivalent Uniform Annual Worth (EUAW)	340,446.81

Note: Cost in USD



	1	2	3	4	5	6	7	8	9	10	11	12	13
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13
EUAW	340.5	340.5	340.5	340.5	340.5	340.5	340.5	340.5	340.5	340.5	340.5	340.5	340.5

	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	340.5	340.5	340.5	340.5	340.5	340.5	340.5	340.5	340.5	340.5	340.5	340.5

Figure B27: EUAW for Steel Grating (Deflated 10%) @ 15%

APPENDIX C

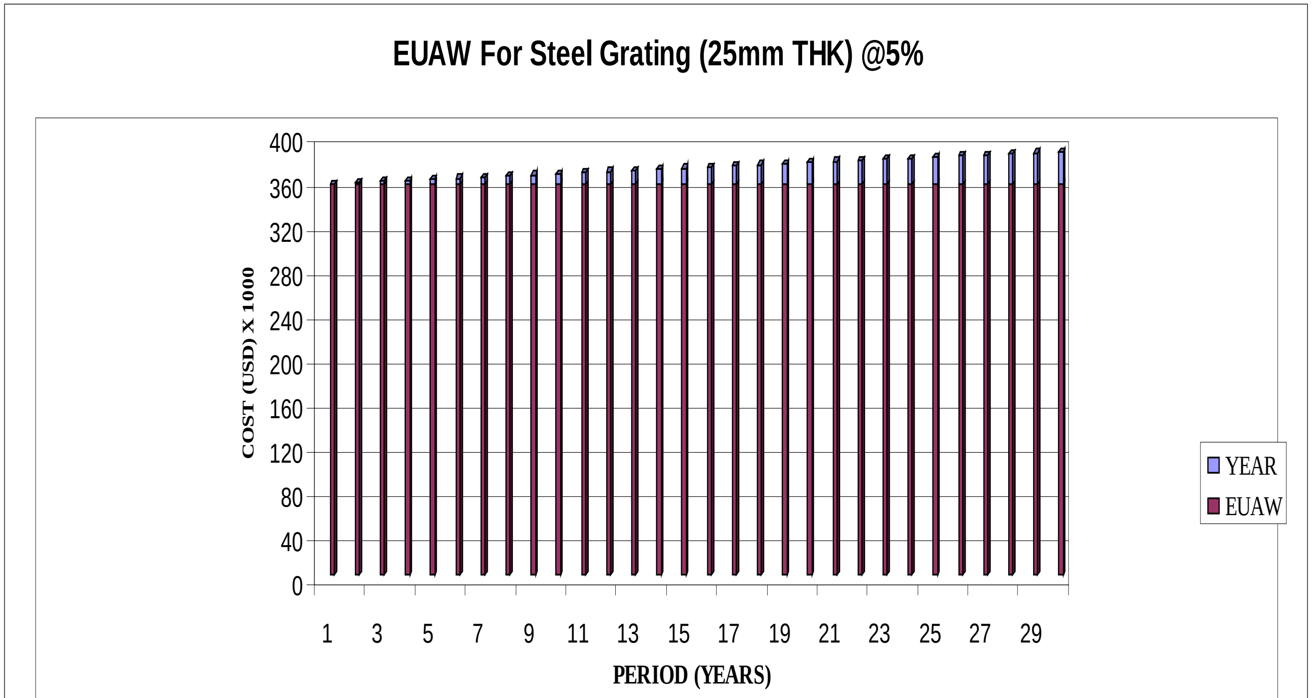
CASH FLOWS ANALYSIS FOR THE GRATINGS

FOR A PERIOD OF 30 YEARS

Table C1: LCC Components for Steel Grating@ 5%

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial Cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
30 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	5,428,213.99
Equivalent Uniform Annual Worth (EUAW)	353,113.11

Note: Cost in USD



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1

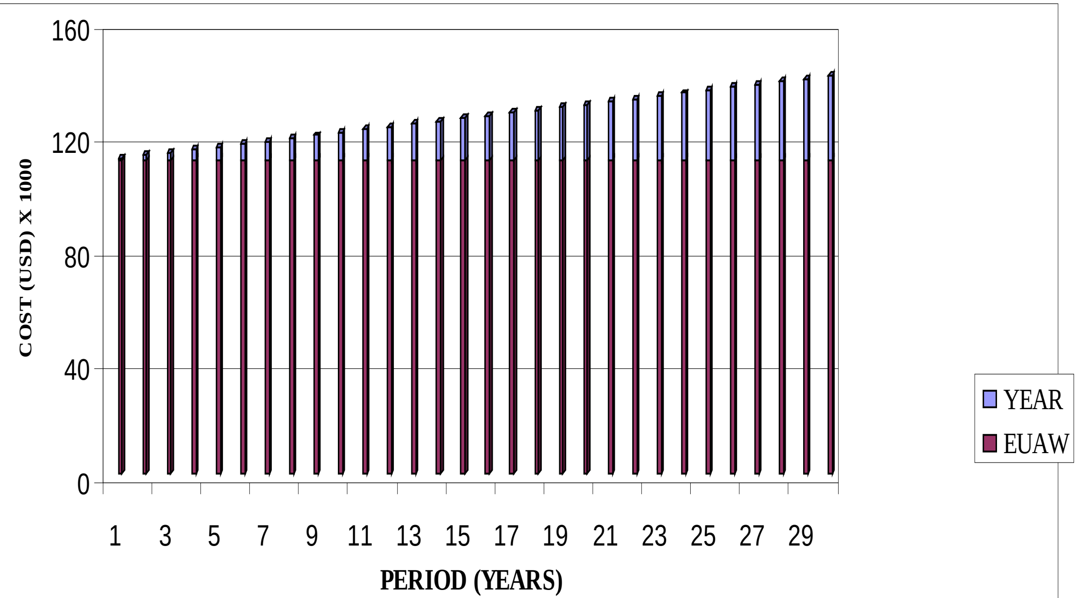
Figure C1: EUAW for Steel Grating @ 5%

Table C2: LCC Components for Polyester Grating 25mm @ 5%

Material Type	GRP Grating (Polyester)25 mm
Capital Cost	
Initial Cost	613,672.80
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,696,624.80
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	1,696,624.80
Equivalent Uniform Annual Worth (EUAW)	110,367.88

Note: Cost in USD

EUAW For GRP Grating/Polyester Type (25mm THK) @ 5 %



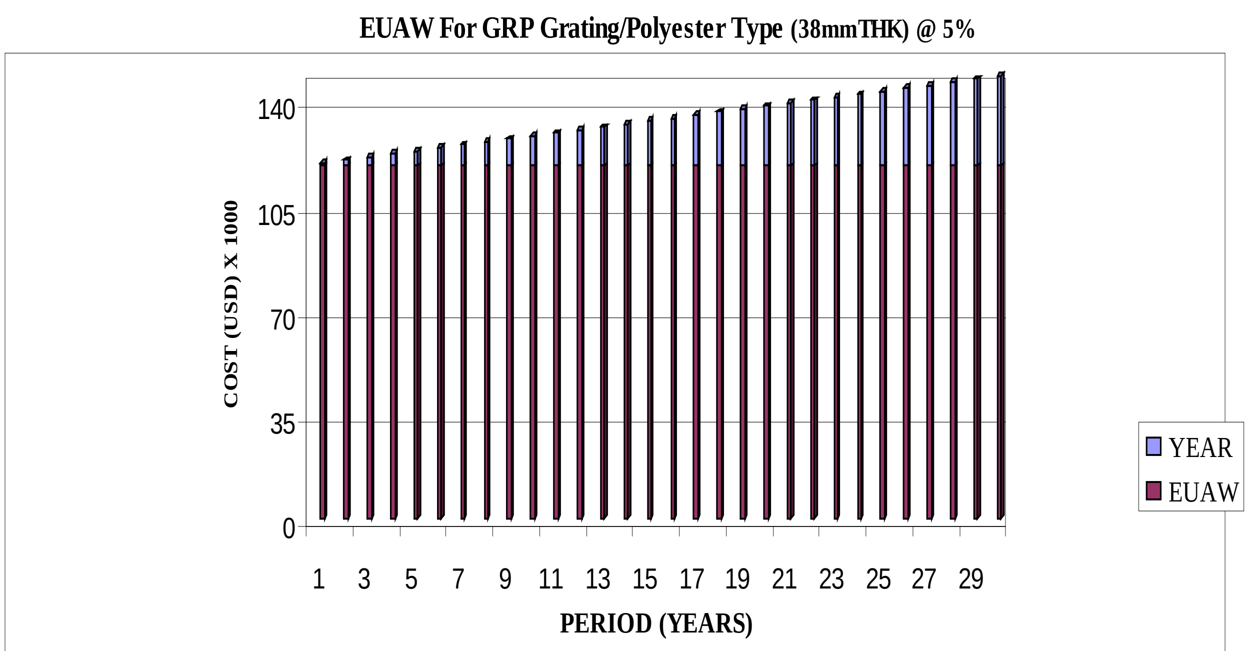
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4	110.4

Figure C2: EUAW for Polyester Grating 25mm @ 5%

Table C3: LCC Components for Polyester Grating 38mm @ 5%

Material Type	GRP Grating (Polyester)38 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	117,999.70

Note: Cost in USD



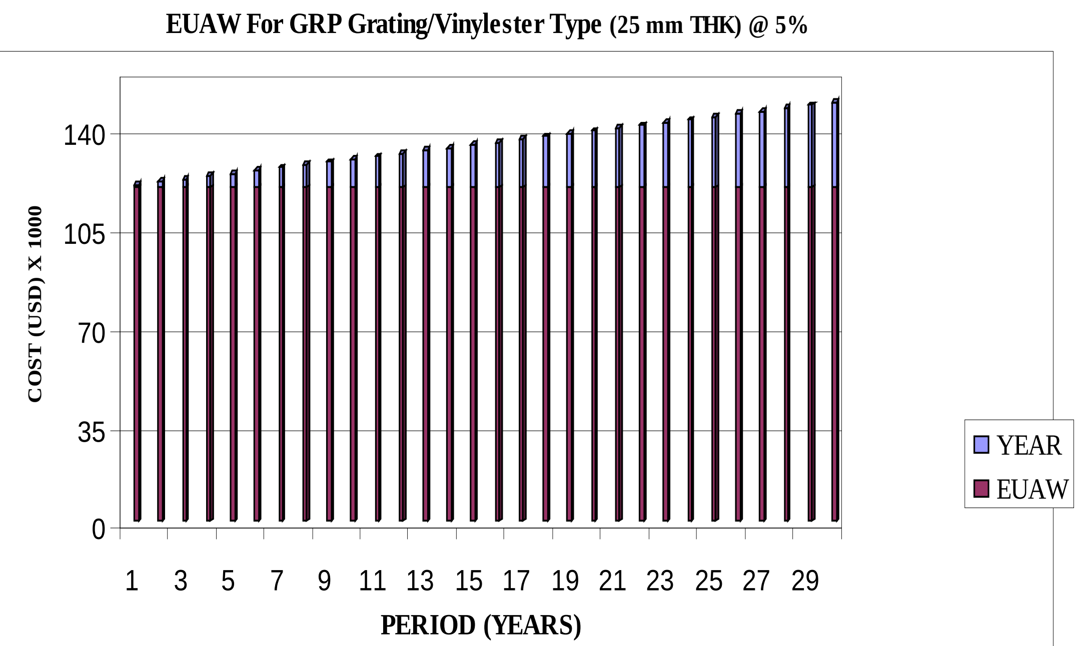
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118

Figure C3: EUAW for Polyester Grating 38mm @ 5%

Table C4: LCC Components for Vinylester Grating 25mm @ 5%

Material Type	GRP Grating (Vinylester) 25 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	117,999.70

Note: Cost in USD



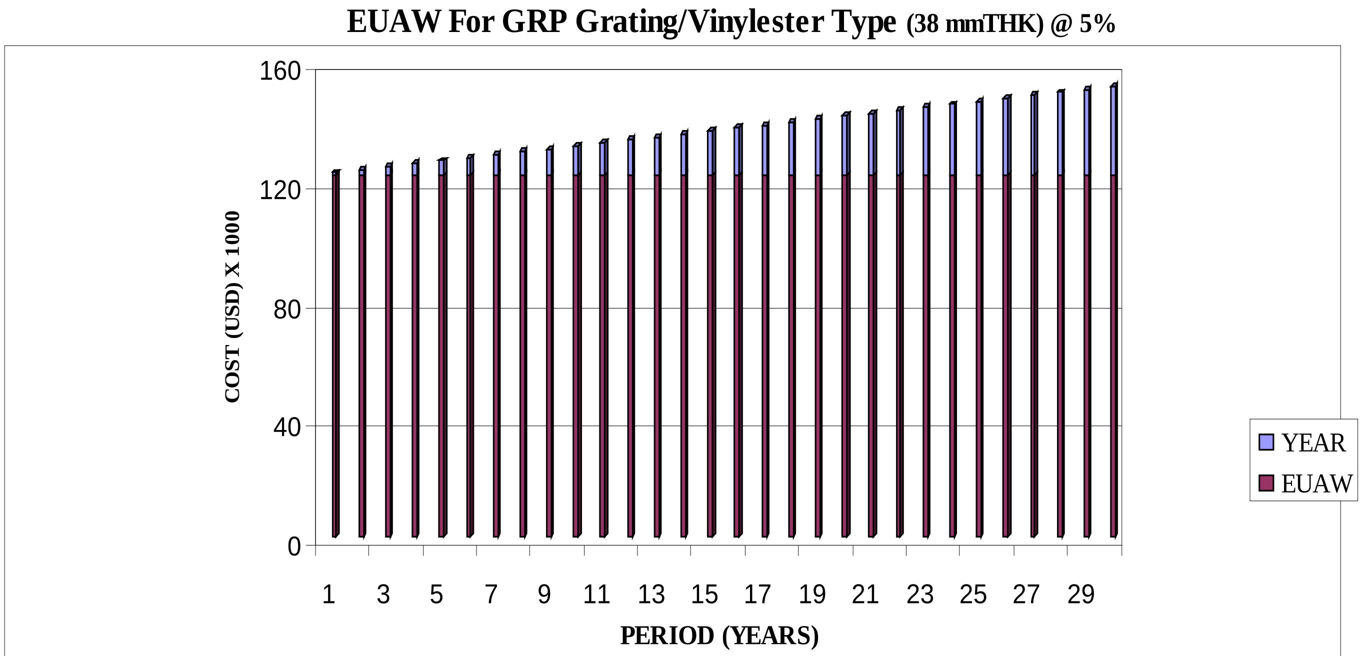
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118	118

Figure C4: EUAW for Vinylester Grating 25mm @ 5%

Table C5: LCC Components for Vinylester Grating 38mm @ 5%

Material Type	GRP Grating (Vinylester)38 mm
Capital Cost	
Initial Cost	789,652.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,872,604.50
Replacement Cost	
Replacement Cost	0.00
Period	
30years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	1,872,604.50
Equivalent Uniform Annual Worth EUAW)	121,815.61

Note: Cost in USD

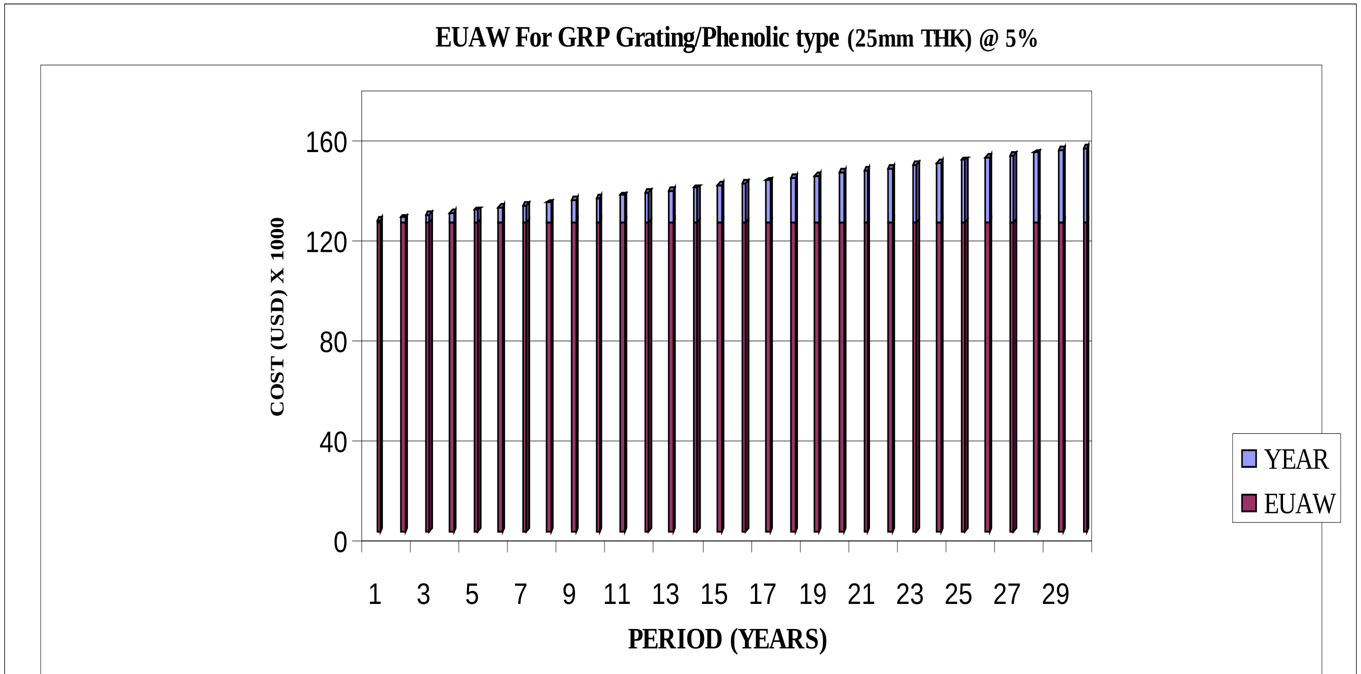


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8	121.8

Figure C5: EUAW for Vinylester Grating 38mm @ 5%

Table C6: LCC Components for Phenolic Grating 25mm @ 5%

Material Type	GRP Grating (Phenolic)25 mm
Capital Cost	
Initial Cost	821,238.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,904,190.60
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	1,904,190.60
Equivalent Uniform Annual Worth (EUAW)	123,870.33

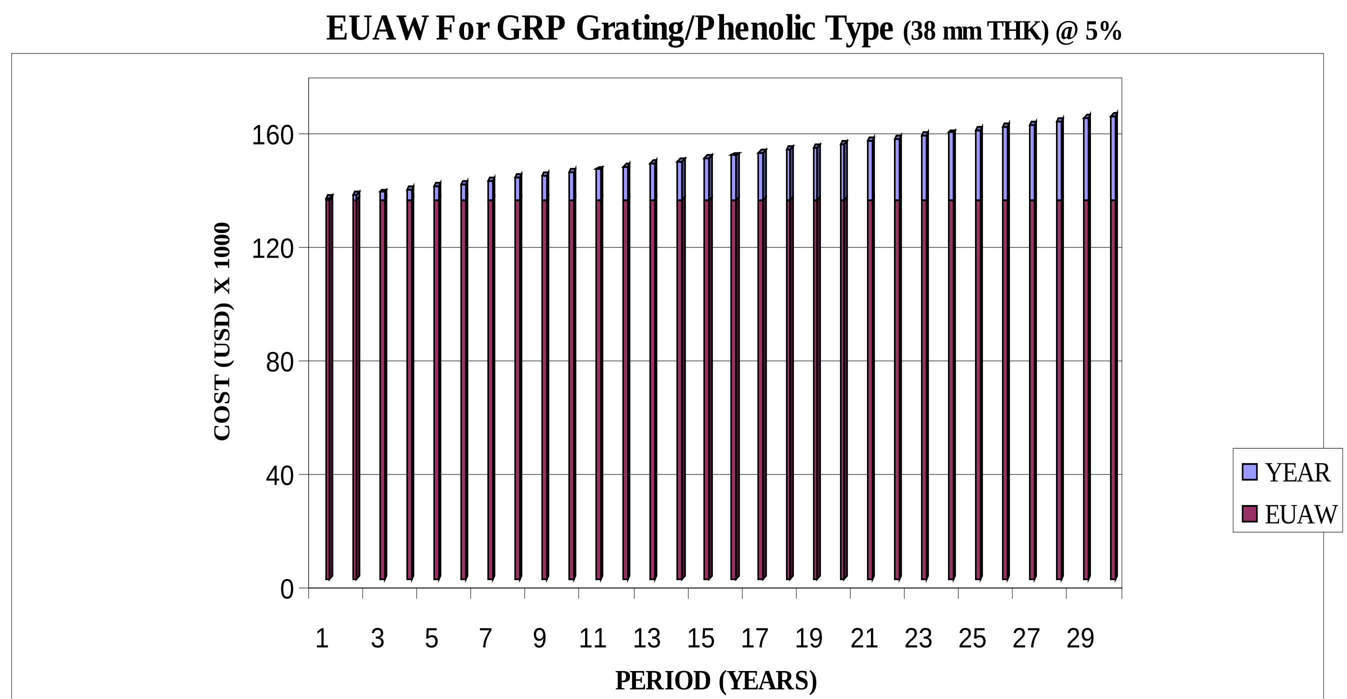


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9	123.9

Figure C6: EUAW for Phenolic Grating 25mm @ 5%

Table C7: LCC Components for Phenolic Grating 38mm @ 5%

Material Type	GRP Grating (Phenolic)38 mm
Capital Cost	
Initial Cost	970,144.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	2,053,096.50
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	2,053,096.50
Equivalent Uniform Annual Worth (EUAW)	133,556.87

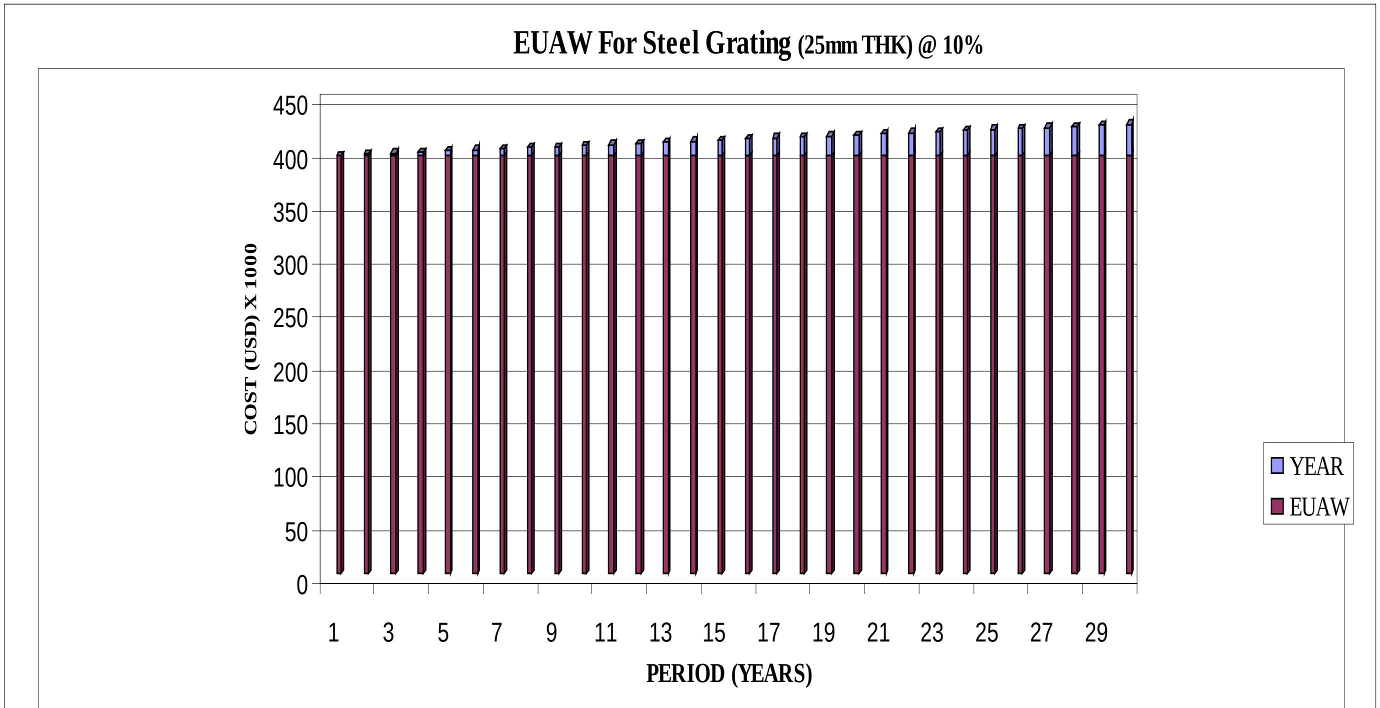


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6

Figure C7: EUAW for Phenolic Grating 38mm @ 5%

Table C8: LCC Components for Steel Grating @ 10%

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
30 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	3,699,485.78
Equivalent Uniform Annual Worth (EUAW)	392,438.67

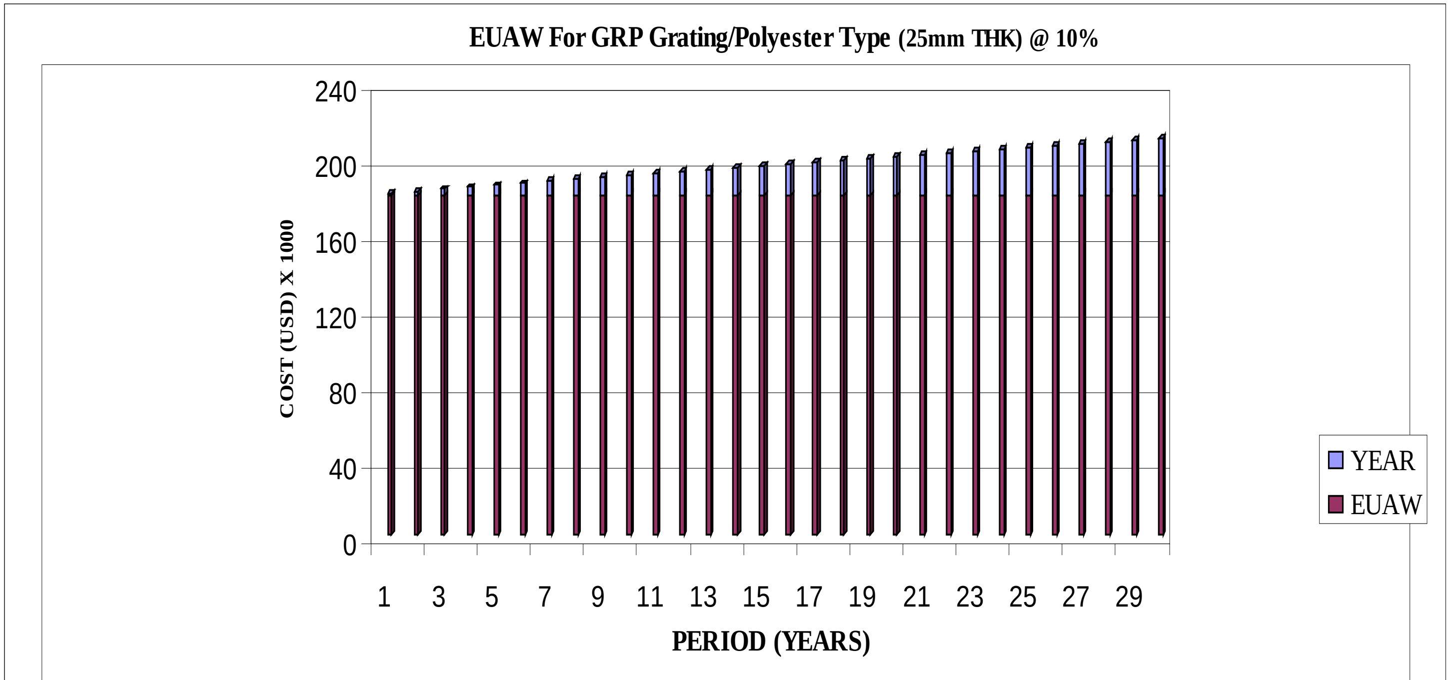


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4	392.4

Figure C8: EUAW for Steel Grating @ 10%

Table C9: LCC Components for Polyester Grating 25mm @ 10%

Material Type	GRP Grating (Polyester)25 mm
Capital Cost	
Initial Cost	613,672.80
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,696,624.80
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	1,696,624.80
Equivalent Uniform Annual Worth (EUAW)	179,976.68

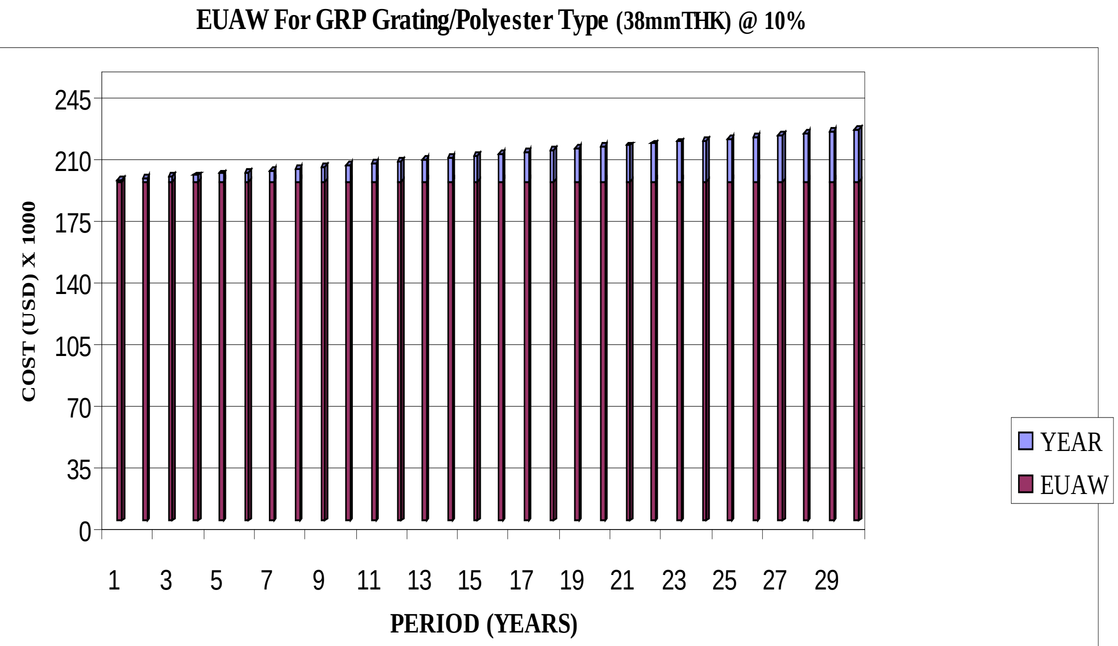


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180

Figure C9: EUAW for Polyester Grating 25mm @ 10%

Table C10: LCC Components for Polyester Grating 38mm @ 10%

Material Type	GRP Grating (Polyester)38 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	192,421.88

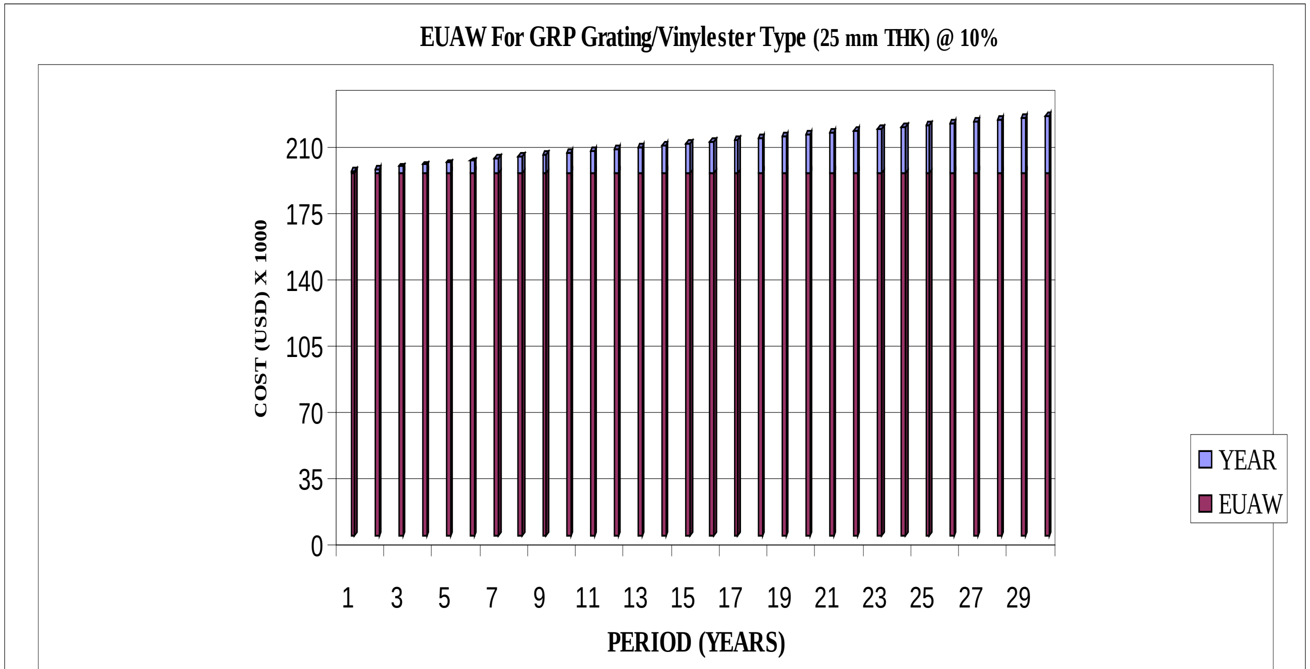


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4

Figure C10: EUAW for Polyester Grating 38mm @ 10%

Table C11: LCC Components for Vinylester Grating 25mm @ 10%

Material Type	GRP Grating (Vinylester)25 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	192,421.88

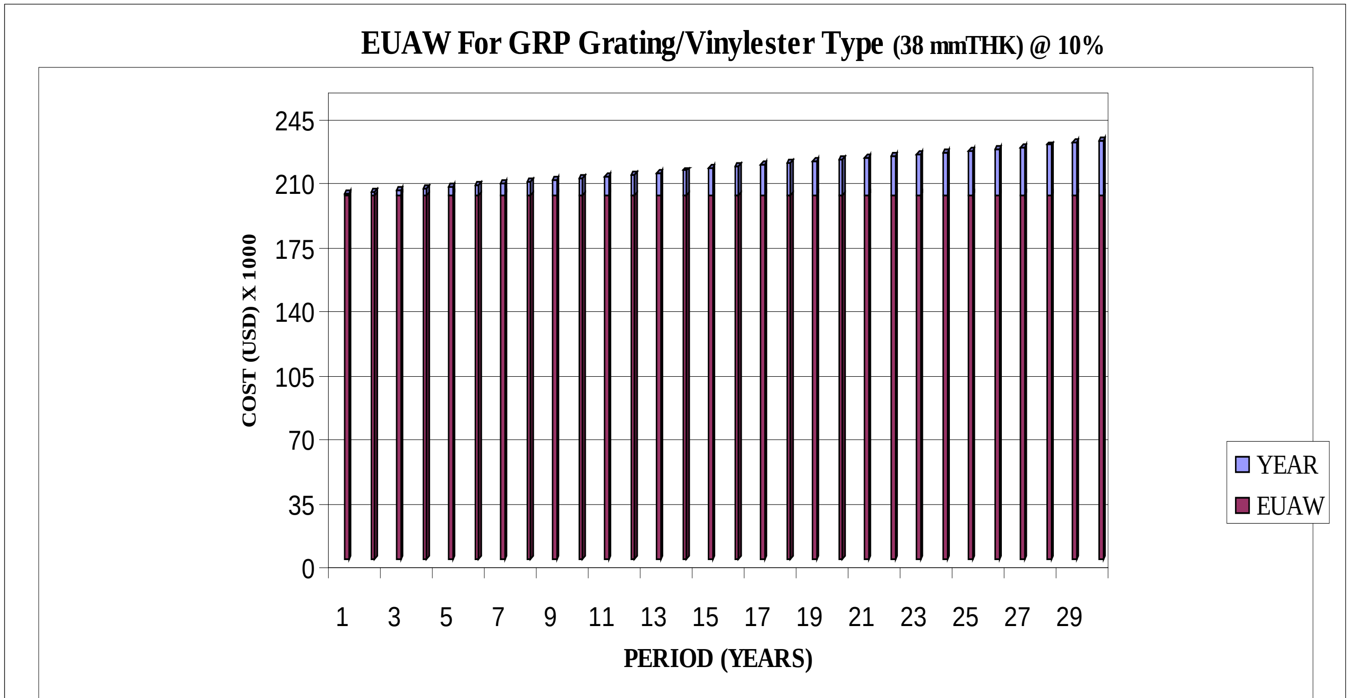


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4

Figure C11: EUAW for Vinylester Grating 25mm @ 10%

Table C12: LCC Components for Vinylester Grating 38mm @ 10%

Material Type	GRP Grating (Vinylester)38 mm
Capital Cost	
Initial Cost	789,652.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,872,604.50
Replacement Cost	
Replacement Cost	0.00
Period	
30years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	1,872,604.50
Equivalent Uniform Annual Worth(EUAW)	198,644.48

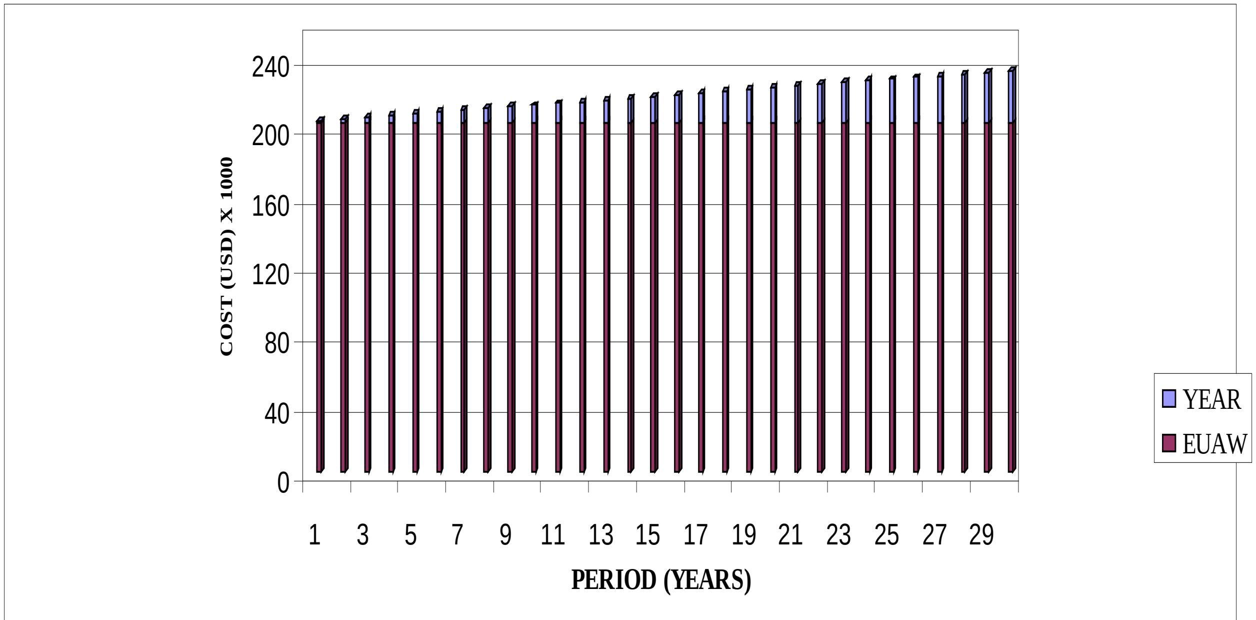


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7	198.7

Figure C12: EUAW for Vinylester Grating 38mm @ 10%

Table C13: LCC Components for Phenolic Grating 25mm @ 10%

Material Type	GRP Grating (Phenolic)25 mm
Capital Cost	
Initial Cost	821,238.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,904,190.60
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	1,904,190.60
Equivalent Uniform Annual Worth(EUAW)	201,995.11



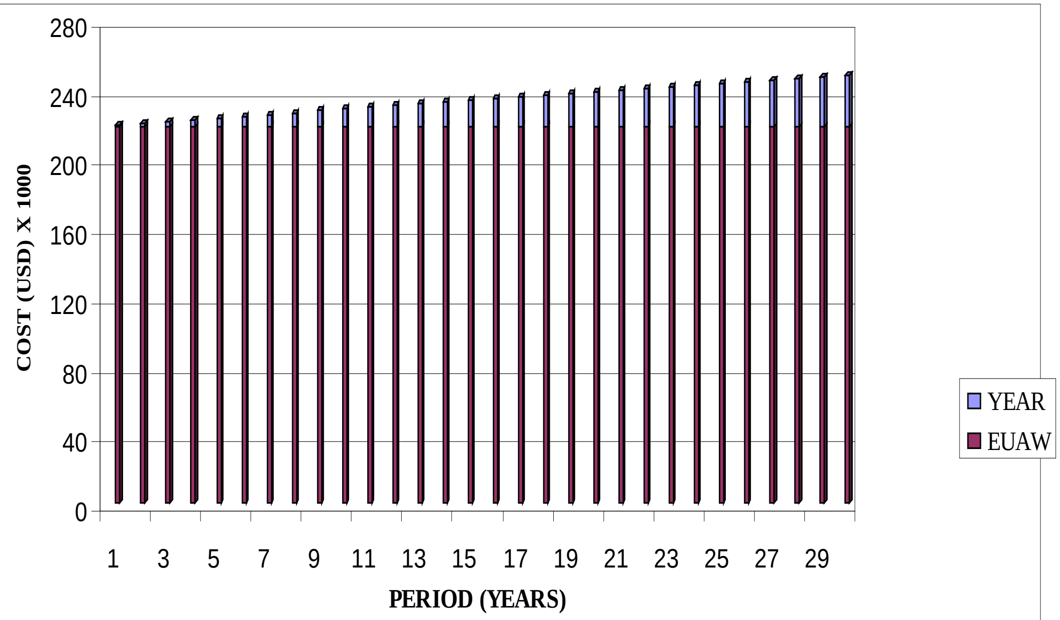
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202	202

Figure C13: EUAW for Phenolic Grating 25mm @ 10%

Table C14: LCC Components for Phenolic Grating 38mm @ 10%

Material Type	GRP Grating (Phenolic)38 mm
Capital Cost	
Initial Cost	970,144.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	2,053,096.50
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,053,096.50
Equivalent Uniform Annual Worth (EUAW)	217,790.93

EUAW For GRP Grating/Phenolic Type (38 mm THK) @ 10%

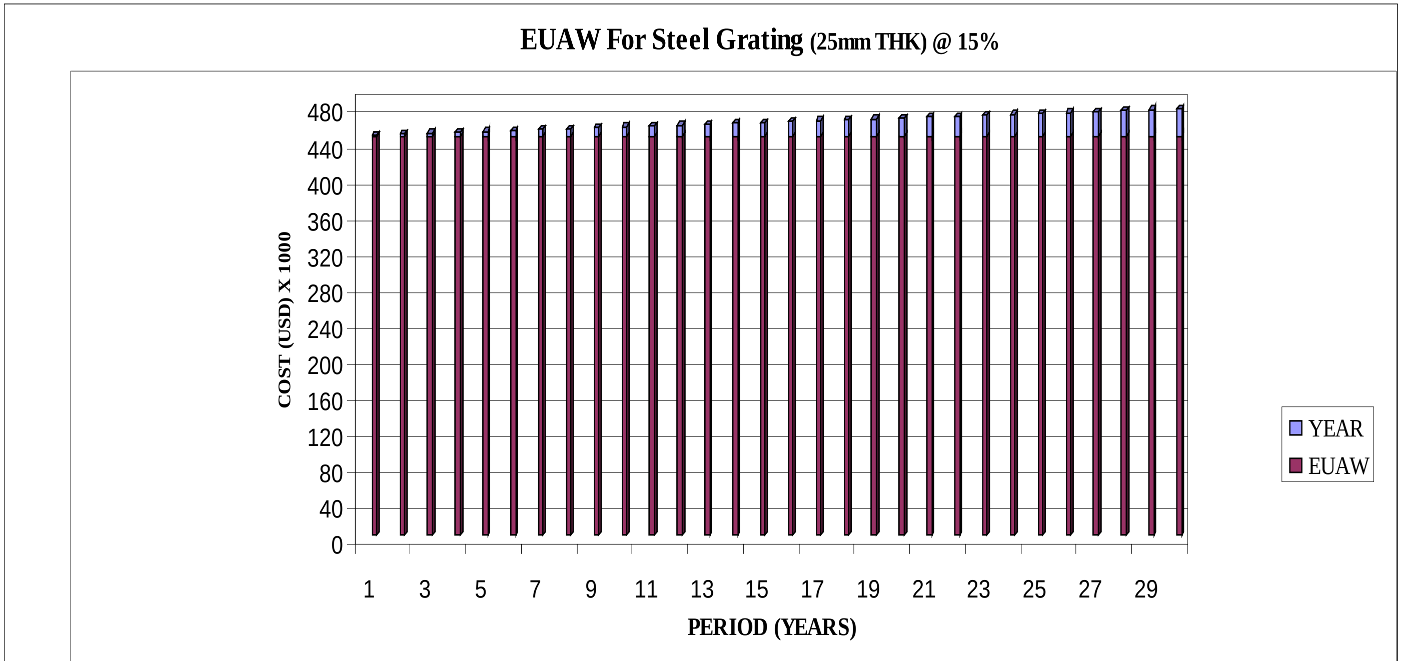


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8	217.8

Figure C14: EUAW for Phenolic Grating 38mm @ 10%

Table C15: LCC Components for Steel Grating @ 15%

Material Type	Steel Grating 25mm as a Base Material
Capital Cost	
Initial cost	388,057.80
Prefabrication Cost	194,028.90
Installation Cost	1,083,000.00
Total Capital Cost	1,665,086.70
Replacement Cost	
Replacement Cost every 6 years	1,665,086.70
Period	
30 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,914,030.27
Equivalent Uniform Annual Worth (EUAW)	443,807.39

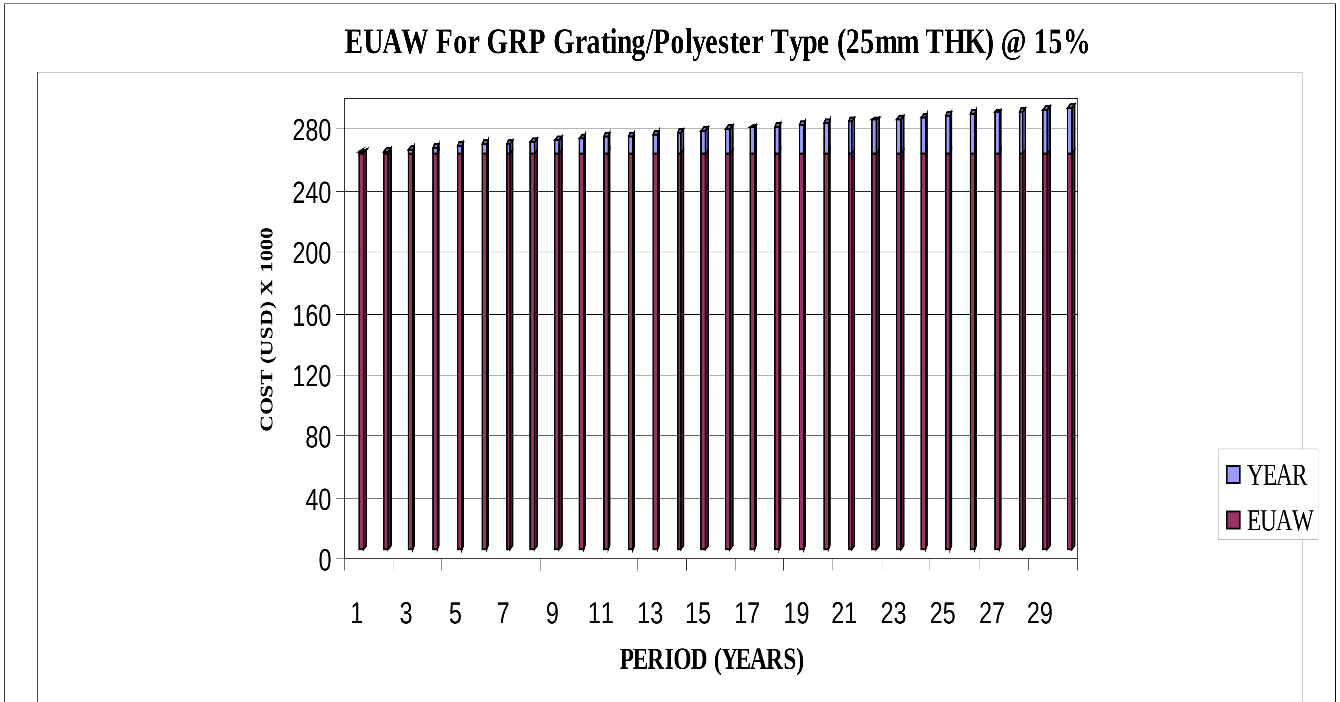


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8	443.8

Figure C15: EUAW for Steel Grating @ 15%

Table C16: LCC Components for Polyester Grating 25mm @ 15%

Material Type	GRP Grating (Polyester)25 mm
Capital Cost	
Initial Cost	613,672.80
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,696,624.80
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	1,696,624.80
Equivalent Uniform Annual Worth(EUAW)	258,396.29

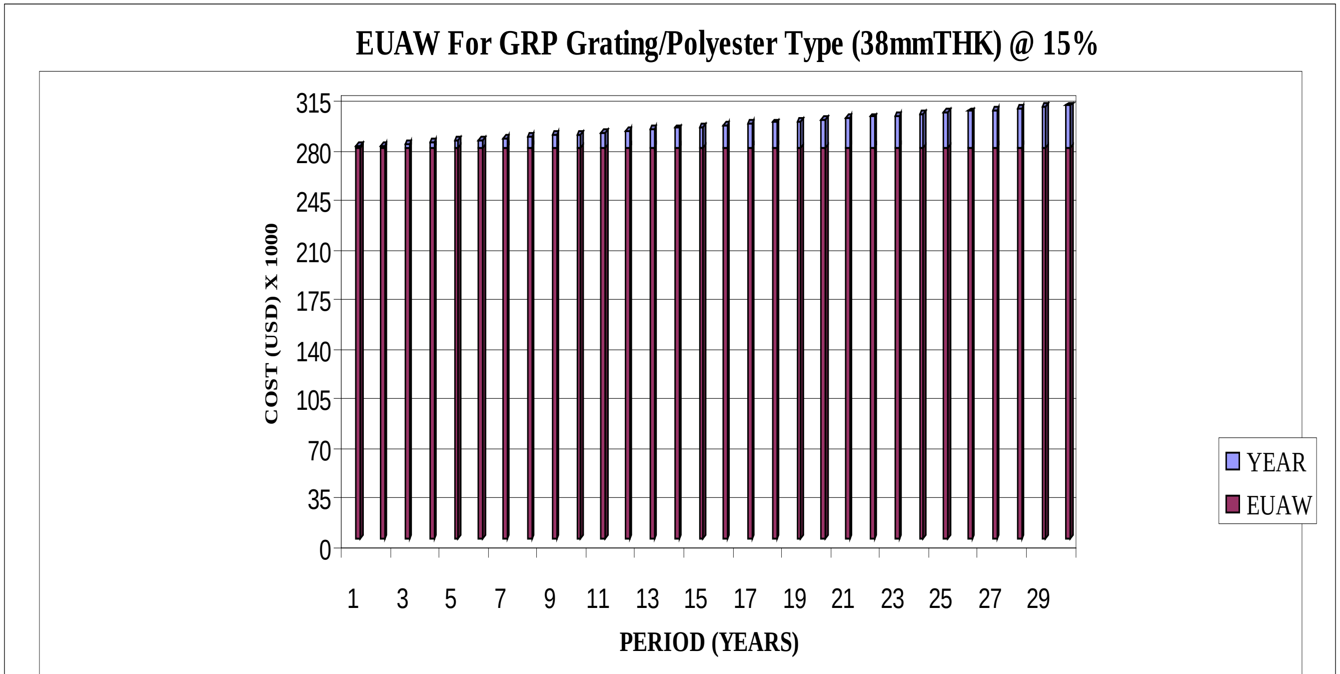


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4	258.4

Figure C16: EUAW for Polyester Grating 25mm @ 15%

Table C17: LCC Components for Polyester Grating 38mm @ 15%

Material Type	GRP Grating (Polyester)38 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	276,264.12

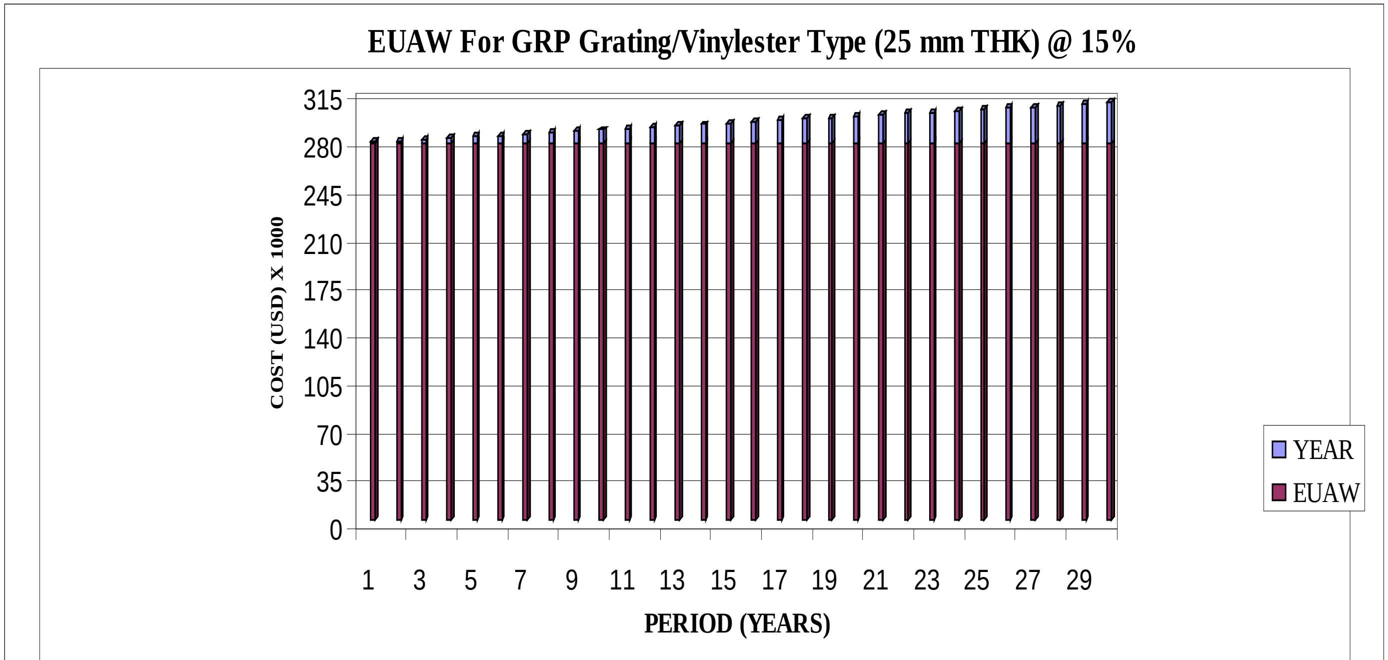


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3

Figure C17: EUAW for Polyester Grating 38mm @ 15%

Table C18: LCC Components for Vinylester Grating 25mm @ 15%

Material Type	GRP Grating (Vinylester)25 mm
Capital Cost	
Initial Cost	730,992.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,813,944.60
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	1,813,944.60
Equivalent Uniform Annual Worth (EUAW)	276,264.12

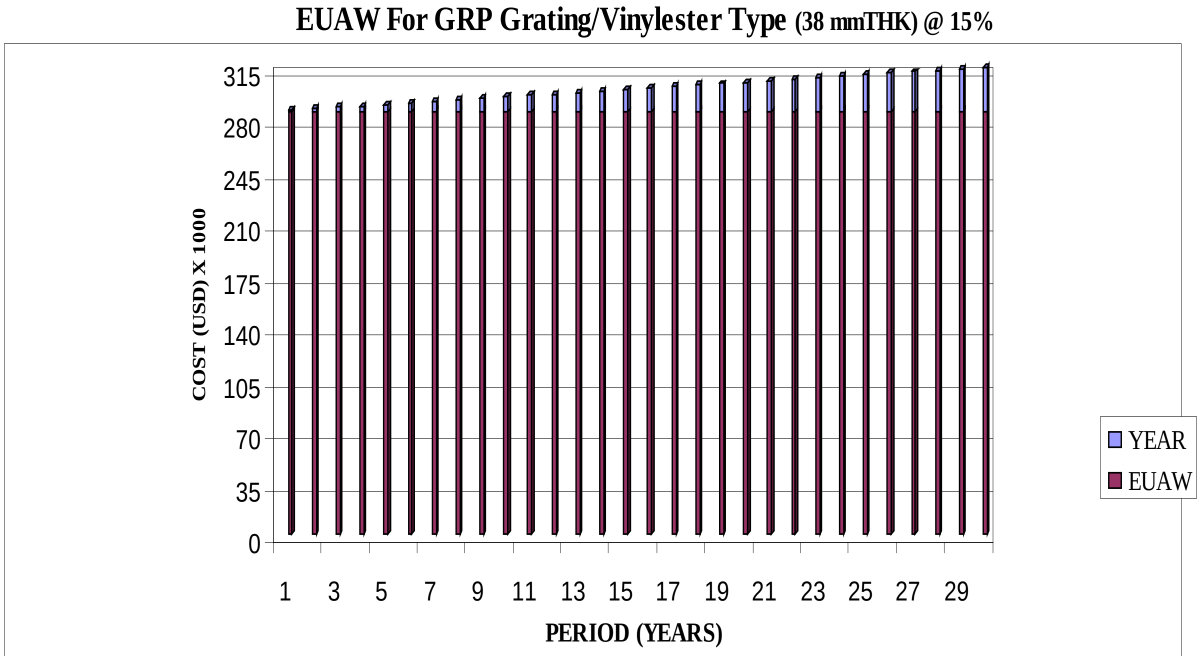


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3	276.3

Figure C18: EUAW for Vinylester Grating 25mm @ 15%

Table C19: LCC Components for Vinylester Grating 38mm @ 15%

Material Type	GRP Grating (Vinylester)38 mm
Capital Cost	
Initial Cost	789,652.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,872,604.50
Replacement Cost	
Replacement Cost	0.00
Period	
30years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	1,872,604.50
Equivalent Uniform Annual Worth(EUAW)	285,198.04



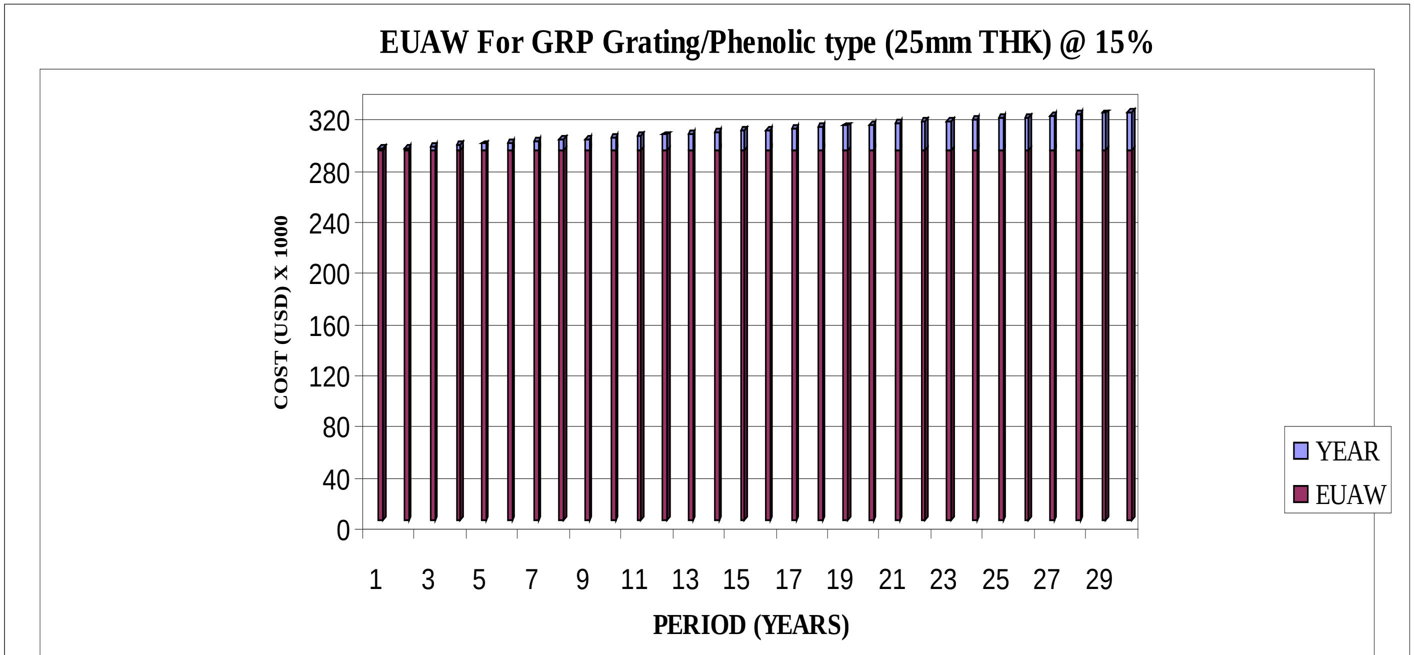
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
EUAW	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2	285.2

Figure C19: EUAW for Vinylester Grating 38mm @ 15%

Table C20: LCC Components for Phenolic Grating 25mm @ 15%

Material Type	GRP Grating (Phenolic)25 mm
Capital Cost	
Initial Cost	821,238.60
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	1,904,190.60
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	1,904,190.60
Equivalent Uniform Annual Worth (EUAW)	290,008.61

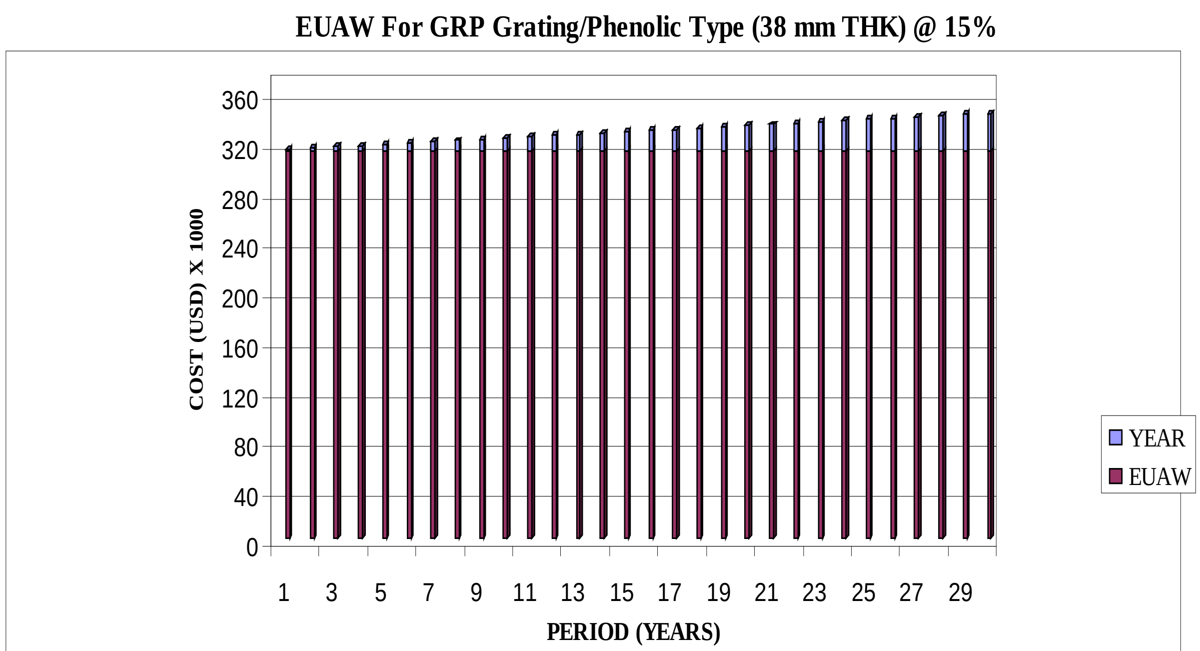


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290

Figure C19: EUAW for Phenolic Grating 25mm @ 15%

Table C21: LCC Components for Phenolic Grating 38mm @ 15%

Material Type	GRP Grating (Phenolic)38 mm
Capital Cost	
Initial Cost	970,144.50
Prefabrication Cost	0.00
Installation Cost	1,082,952.00
Total Capital Cost	2,053,096.50
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,053,096.50
Equivalent Uniform Annual Worth(EUAW)	312,687.00



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
EUAW	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7	312.7

Figure C21: EUAW for Phenolic Grating 38mm @ 15%

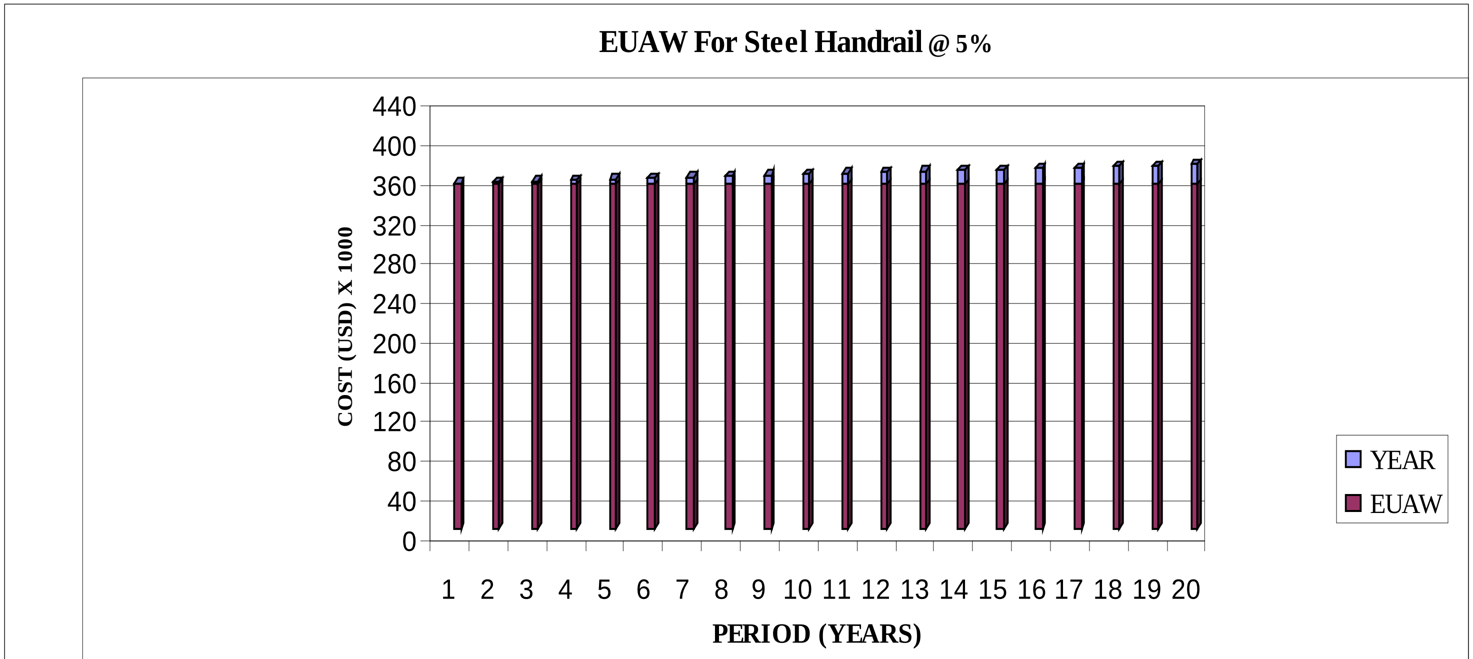
APPENDIX D

CASH FLOWS ANALYSIS FOR THE HANDRAILS

FOR A PERIOD OF 20 YEARS

Table D1: LCC Components for Steel Handrail (Replacement) @ 5%

Material Type	Steel Handrail (Replacement)
Capital Cost	
Initial cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Maintenance Cost	
Replacement Cost every12 years	2,935,822.0
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	4,356,577.54
Equivalent Uniform Annual Worth(EUAW)	349,583.05

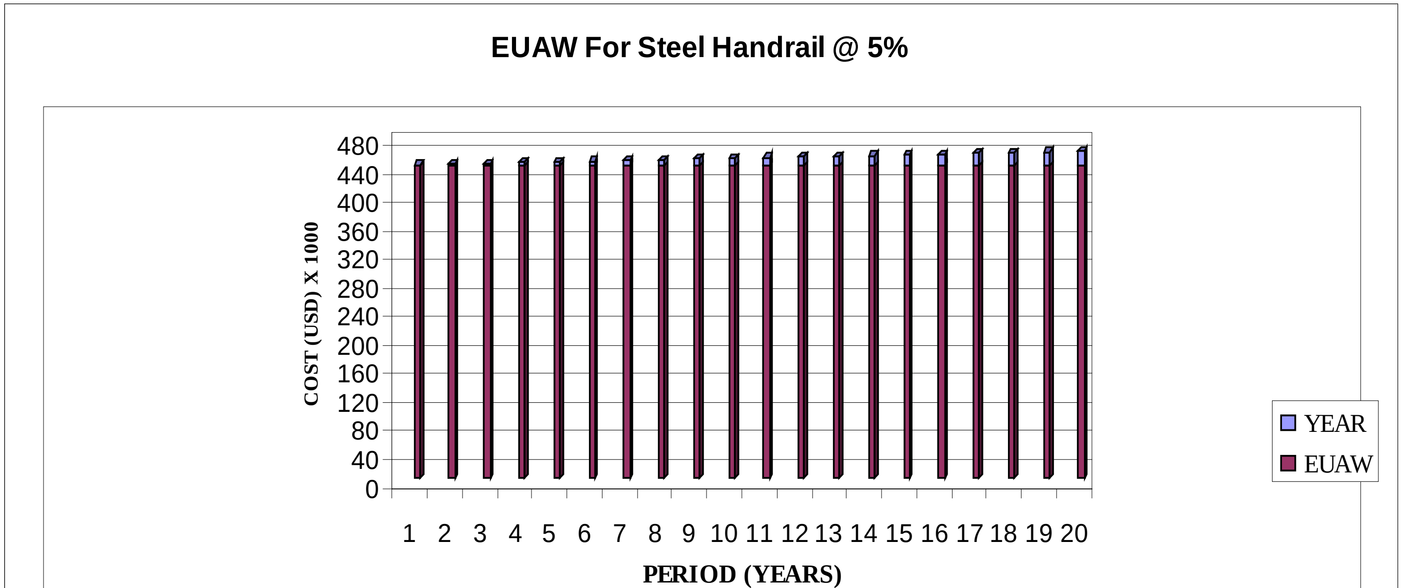


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	349.6	349.6	349.6	349.6	349.6	349.6	349.6	349.6	349.6	349.6	349.6	349.6	349.6	349.6	349.6	349.6	349.6	349.6	349.6	349.6

Figure D1: EUAW Steel Handrail @ 5%

Table D2: LCC Components for Steel Handrail (Maintenance) @ 5%

Material Type	Steel Handrail (Maintenance)
Capital Cost	
Initial cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Maintenance Cost	
Maintenance Cost every 5 years	1,461,814.00
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	5,467,756.04
Equivalent Uniform Annual Worth(EUAW)	438,746.89



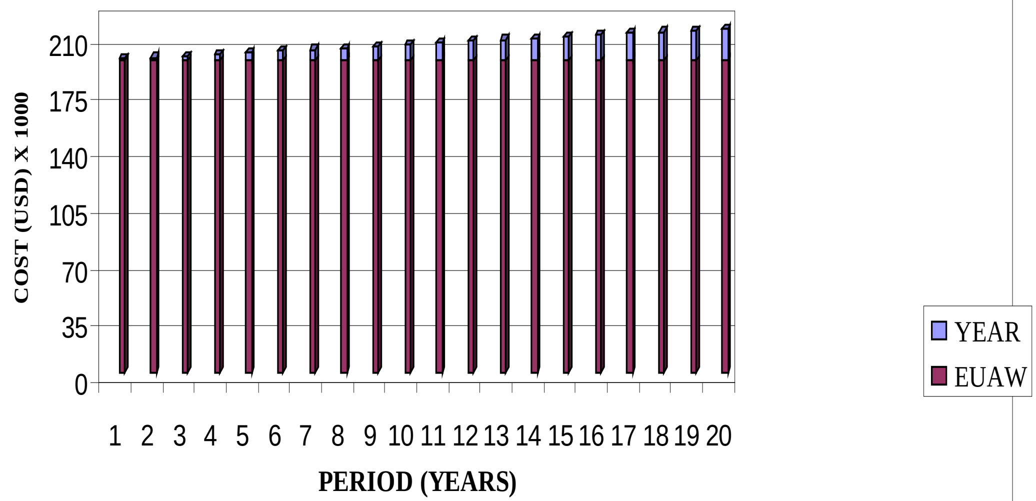
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	438.7	438.7	438.7	438.7	438.7	438.7	438.7	438.7	438.7	438.7	438.7	438.7	438.7	438.7	438.7	438.7	438.7	438.7	438.7	438.7

Figure D2: EUAW Steel Handrail (Maintenance) @ 5%

Table D3: LCC Components for Polyester Handrail @ 5%

Material Type	GRP Handrail (Polyester)
Capital Cost	
Initial Cost	178,270.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,400,916.00
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	2,400,916.00
Equivalent Uniform Annual Worth(EUAW)	192,655.71

EUAW For GRP Handrail (Polyester Type) @ 5%

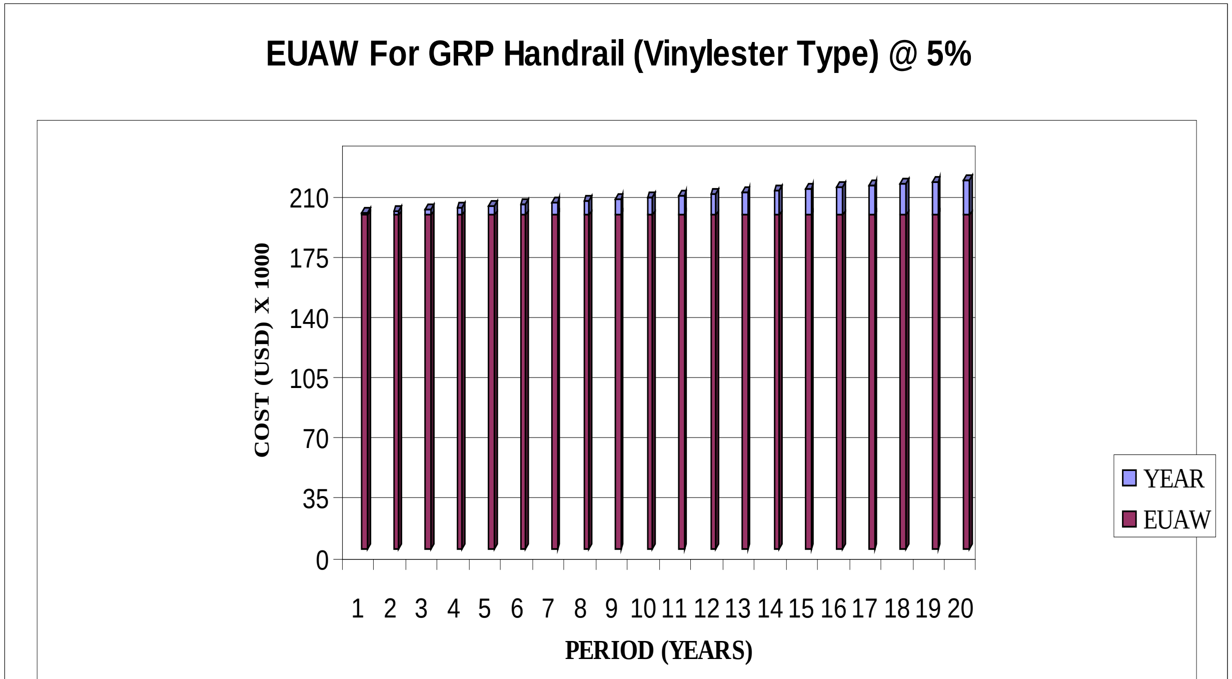


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	192.7	192.7	192.7	192.7	192.7	192.7	192.7	192.7	192.7	192.7	192.7	192.7	192.7	192.7	192.7	192.7	192.7	192.7	192.7	192.7

Figure D3: EUAW Polyester Handrail @ 5%

Table D4: LCC Components for Vinylester Handrail @ 5%

Material Type	GRP Handrail (Vinylester)
Capital Cost	
Initial Cost	196,097.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,418,743.00
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	2,418,743.00
Equivalent Uniform Annual Worth(EUAW)	194,086.20

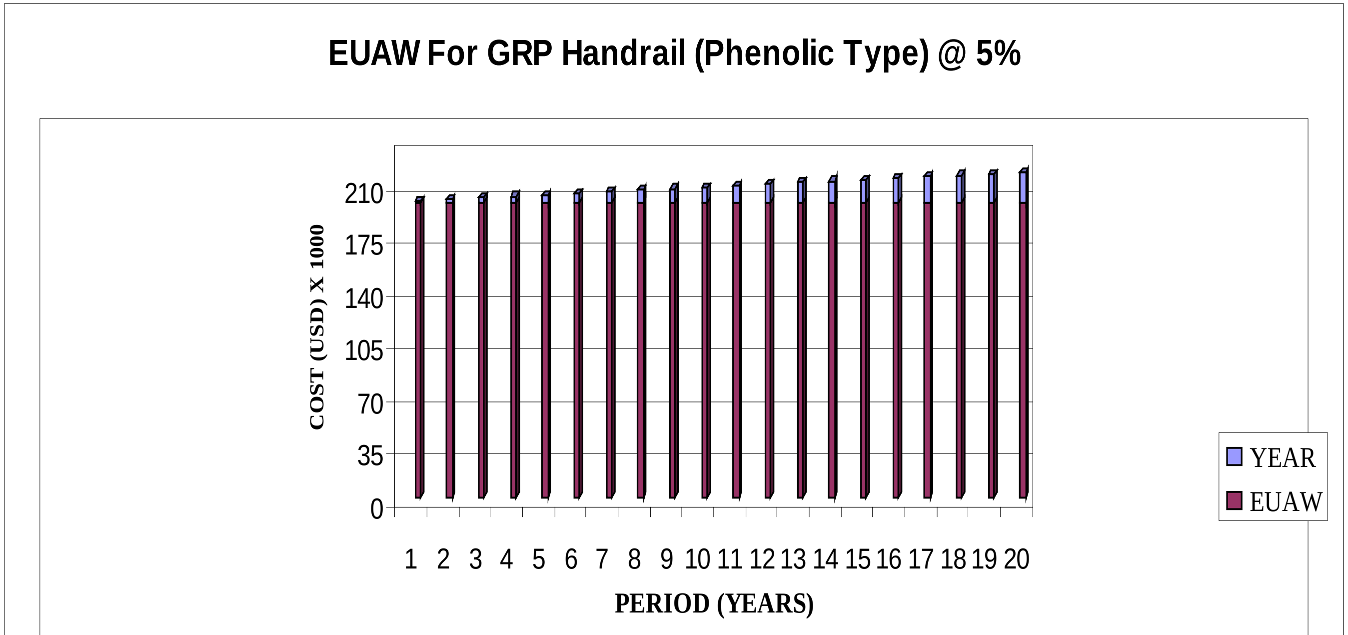


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1	194.1

Figure D4: EUAW Vinylester Handrail @ 5%

Table D5: LCC Components for Phenolic Handrail @ 5%

Material Type	GRP Handrail (Phenolic)
Capital Cost	
Initial Cost	213,924.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,436,570.00
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	2,436,570.00
Equivalent Uniform Annual Worth(EUAW)	195,516.68

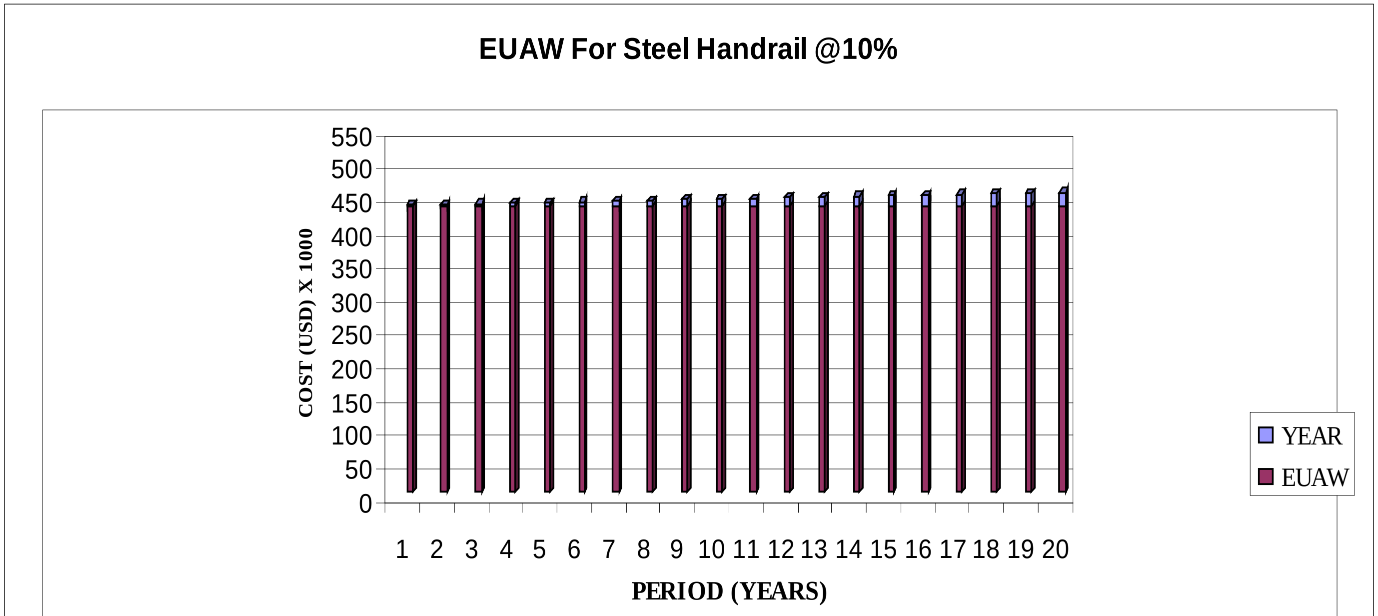


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	195.5	195.5	195.5	195.5	195.5	195.5	195.5	195.5	195.5	195.5	195.5	195.5	195.5	195.5	195.5	195.5	195.5	195.5	195.5	195.5

Figure D5: EUAW Phenolic Handrail @ 5%

Table D6: LCC Components for Steel Handrail (Replacement) @ 10%

Material Type	Steel Handrail (Replacement)
Capital Cost	
Initial Cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	3,657,245.36
Equivalent Uniform Annual Worth(EUAW)	429,578.67

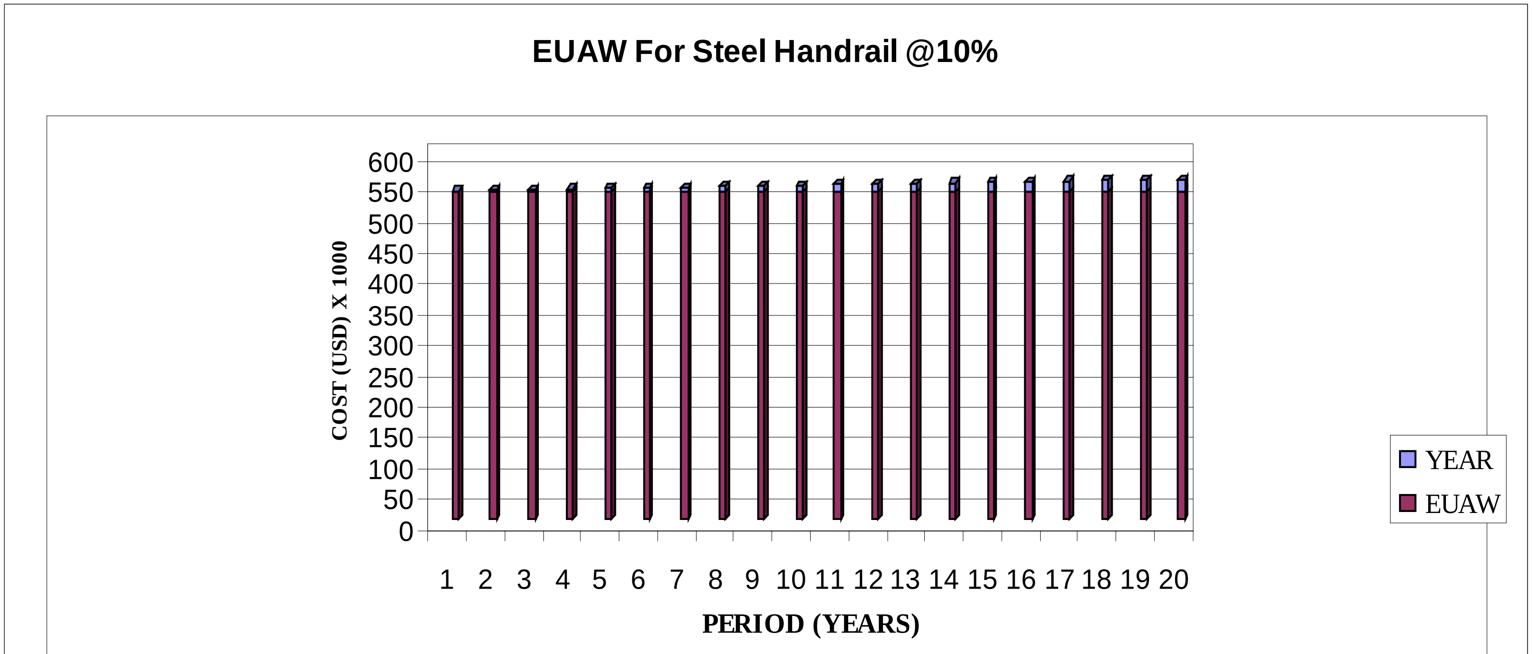


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	429.6	429.6	429.6	429.6	429.6	429.6	429.6	429.6	429.6	429.6	429.6	429.6	429.6	429.6	429.6	429.6	429.6	429.6	429.6	429.6

Figure D6: EUAW for Steel Handrail (Replacement) @ 10%

Table D7: LCC Components for Steel Handrail (Maintenance) @ 10%

Material Type	Steel Handrail (Maintenance)
Capital Cost	
Initial Cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Maintenance Cost	
Maintenance Cost every 5 years	1,461,814.0
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	4,543,012.71
Equivalent Uniform Annual Worth(EUAW)	533,620.57

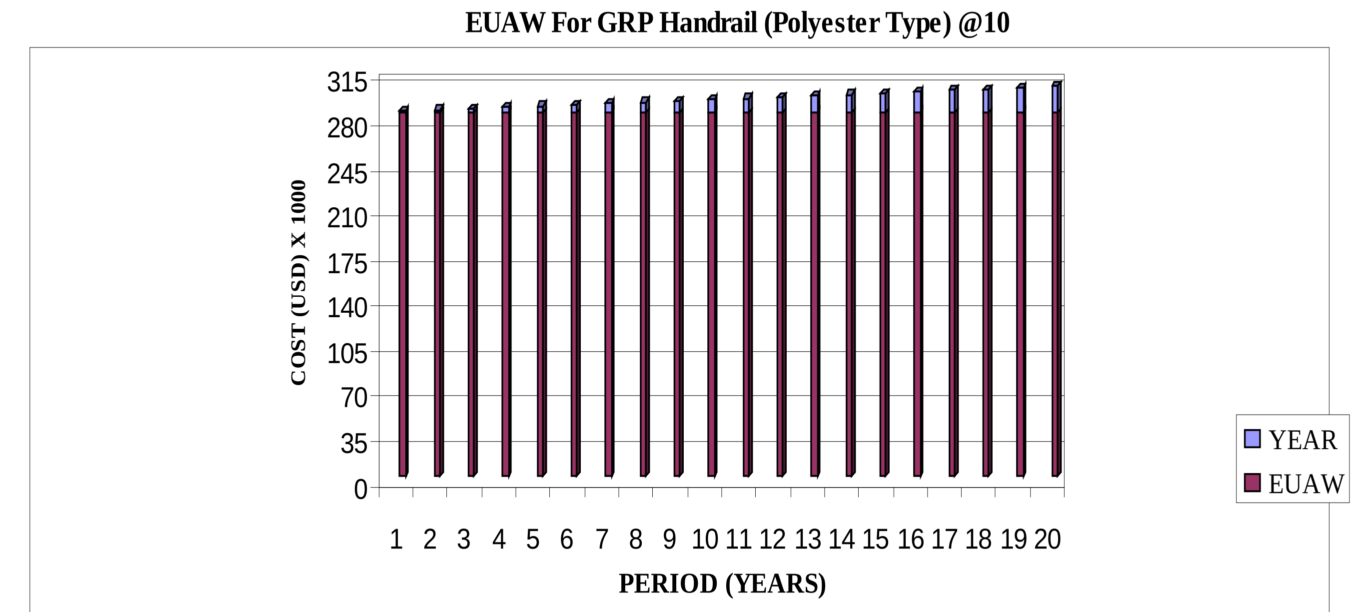


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	533.6	533.6	533.6	533.6	533.6	533.6	533.6	533.6	533.6	533.6	533.6	533.6	533.6	533.6	533.6	533.6	533.6	533.6	533.6	533.6

Figure D7: EUAW for Steel Handrail (Maintenance) @ 10%

Table D8: LCC Components for Polyester Handrail @ 10%

Material Type	GRP Handrail (Polyester)
Capital Cost	
Initial Cost	178,270.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,400,916.00
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,400,916.00
Equivalent Uniform Annual Worth(EUAW)	282,010.69

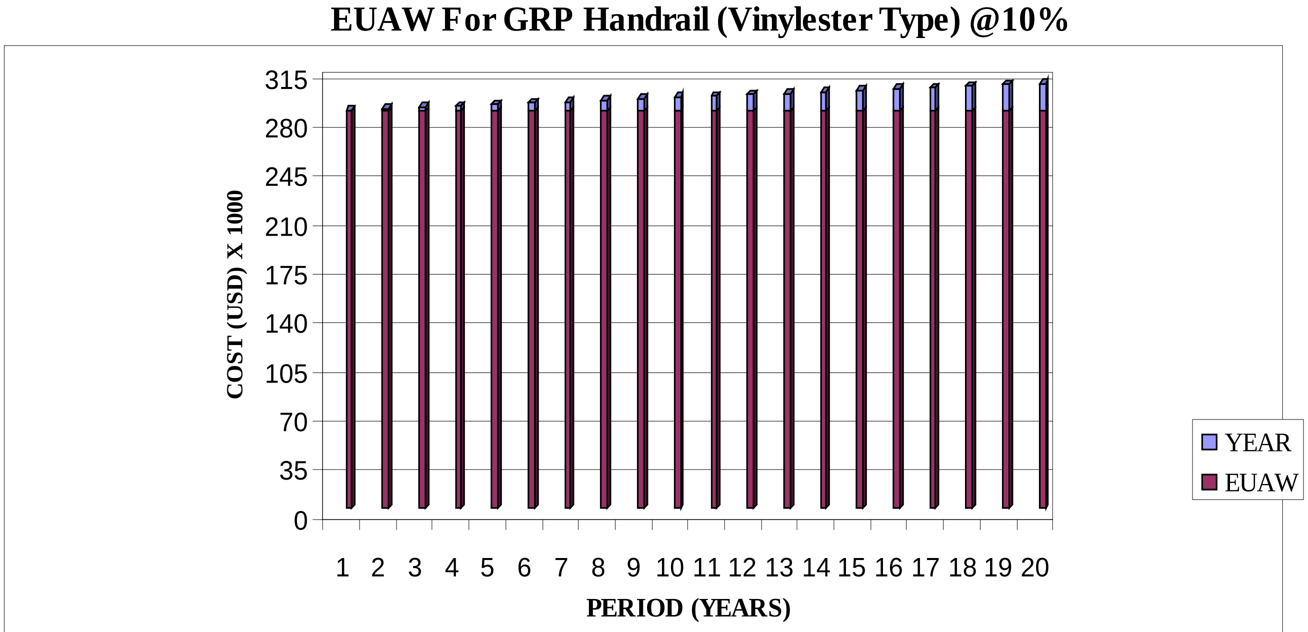


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	282.1	282.1	282.1	282.1	282.1	282.1	282.1	282.1	282.1	282.1	282.1	282.1	282.1	282.1	282.1	282.1	282.1	282.1	282.1	282.1

Figure D8: EUAW for Polyester Handrail @ 10%

Table D9: LCC Components for Vinylester Handrail @ 10%

Material Type	GRP Handrail (Vinylester)
Capital Cost	
Initial Cost	196,097.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,418,743.00
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,418,743.00
Equivalent Uniform Annual Worth(EUAW)	284,104.65

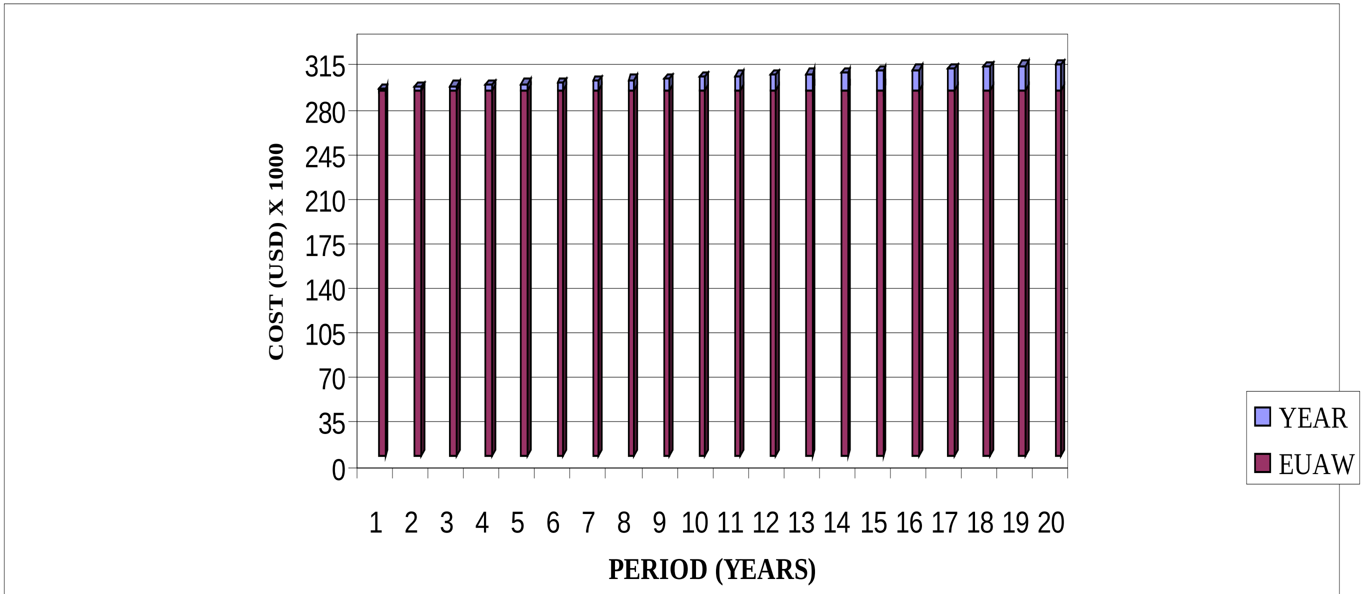


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1	284.1

Figure D9: EUAW for Vinylester Handrail @ 10%

Table D10: LCC Components for Phenolic Handrail @ 10%

Material Type	GRP Handrail (Phenolic)
Capital Cost	
Initial Cost	213,924.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,436,570.00
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,436,570.00
Equivalent Uniform Annual Worth(EUAW)	286,198.60

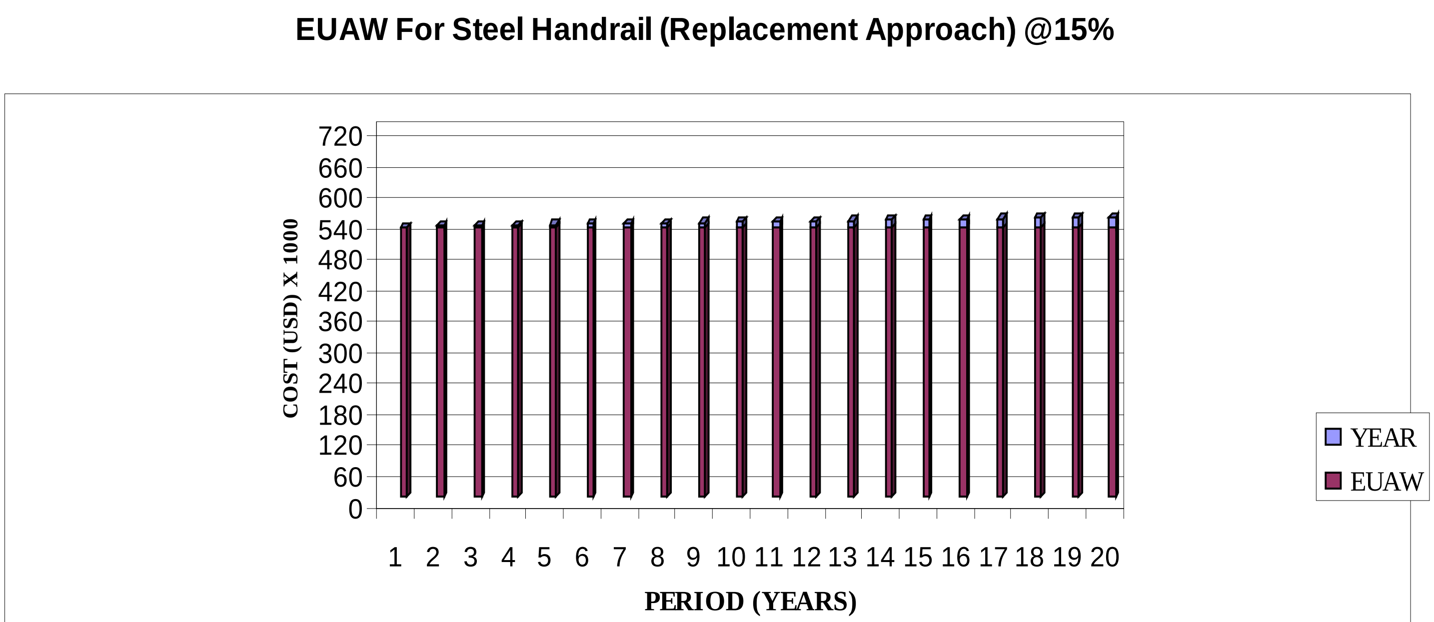


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2

Figure D10: EUAW for Phenolic Handrail @ 10%

Table D11: LCC Components for Steel Handrail (Replacement) @ 15%

Material Type	Steel Handrail (Replacement)
Capital Cost	
Initial Cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	3,270,528.12
Equivalent Uniform Annual Worth(EUAW)	522,504.38

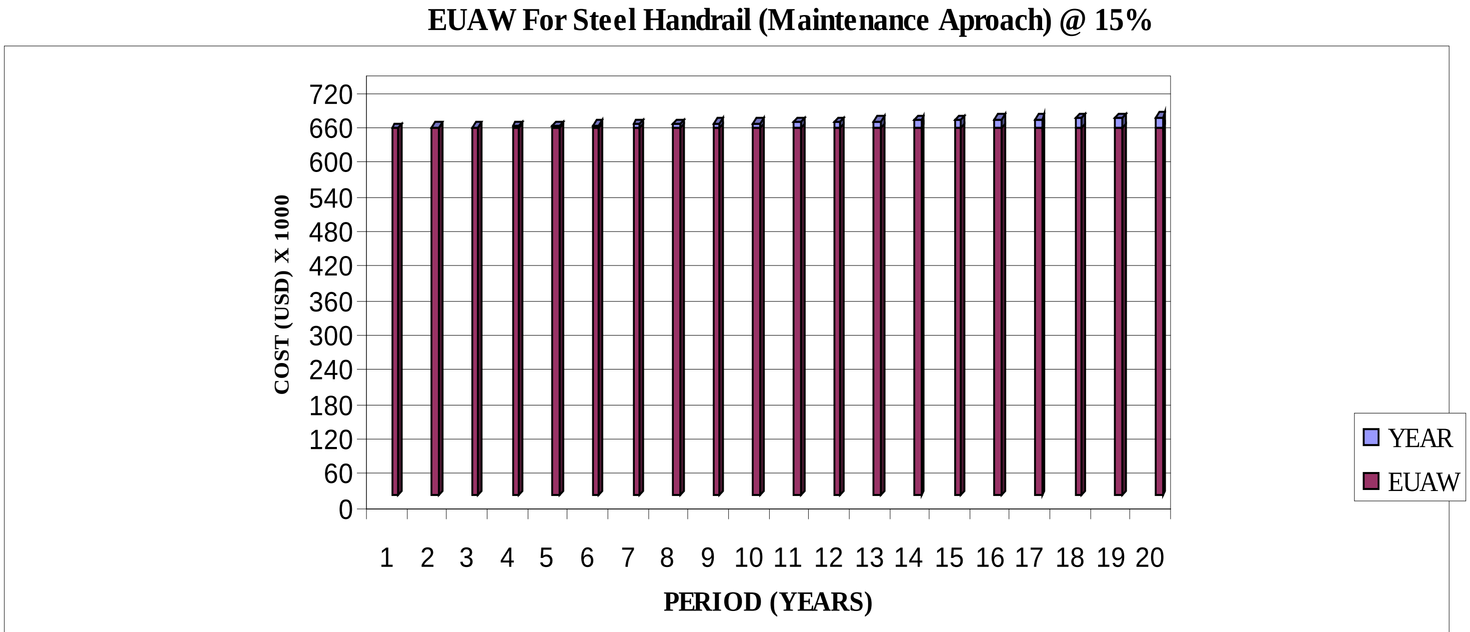


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	522.5	522.5	522.5	522.5	522.5	522.5	522.5	522.5	522.5	522.5	522.5	522.5	522.5	522.5	522.5	522.5	522.5	522.5	522.5	522.5

Figure D11: EUAW for Steel Handrail (Replacement) @ 15%

Table D12: LCC Components for Steel Handrail (Maintenance) @ 15%

Material Type	Steel Handrail (Maintenance Approach)
Capital Cost	
Initial Cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Maintenance Cost	
Maintenance Cost every 5 years	1,461,814.0
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	3,989,568.86
Equivalent Uniform Annual Worth(EUAW)	637,379.39

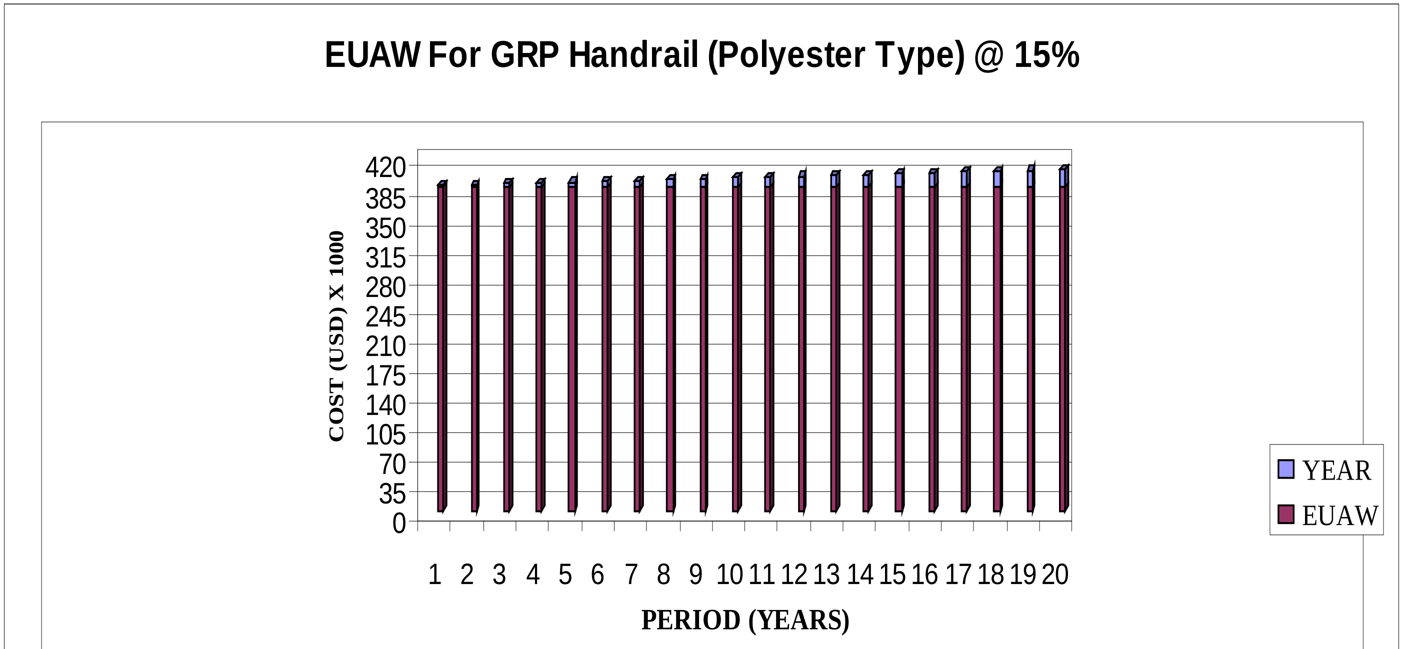


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	637.4	637.4	637.4	637.4	637.4	637.4	637.4	637.4	637.4	637.4	637.4	637.4	637.4	637.4	637.4	637.4	637.4	637.4	637.4	637.4

Figure D12: EUAW for Steel Handrail (Maintenance) @ 15%

Table D13: LCC Components for Polyester Handrail @ 15%

Material Type	GRP Handrail (Polyester)
Capital Cost	
Initial Cost	178,270.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,400,916.00
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,400,916.00
Equivalent Uniform Annual Worth(EUAW)	383,573.87

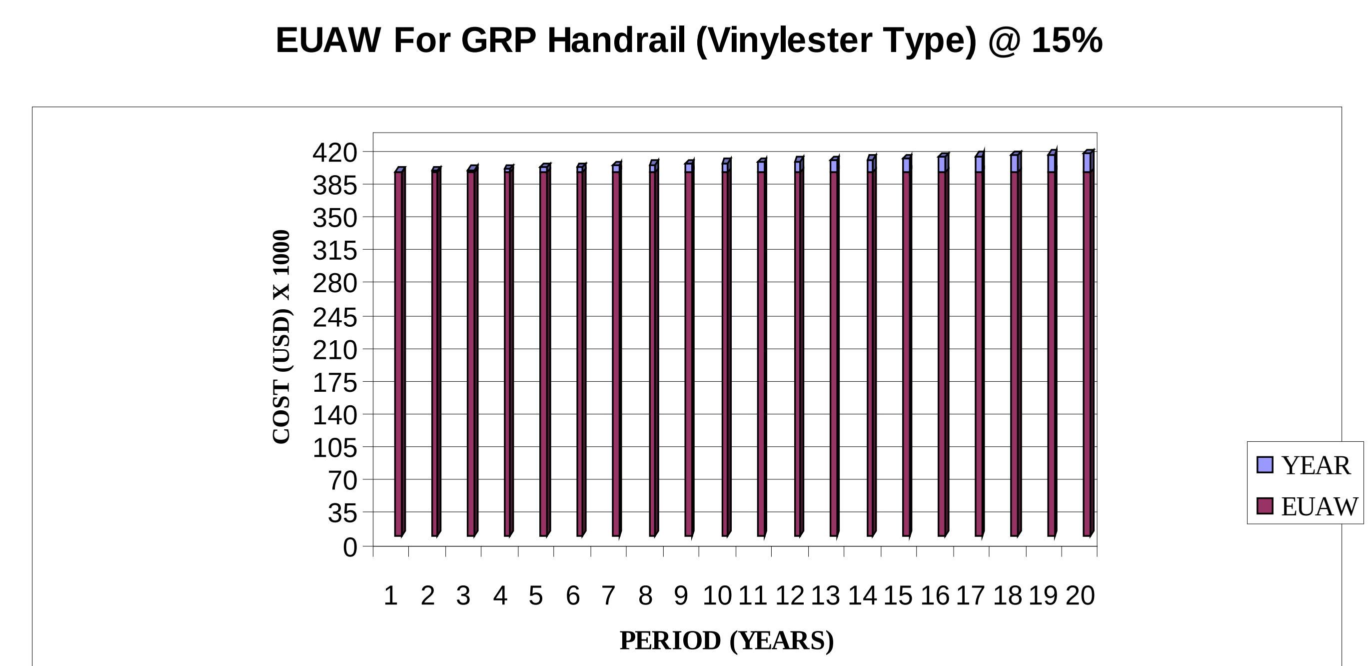


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	383.6	383.6	383.6	383.6	383.6	383.6	383.6	383.6	383.6	383.6	383.6	383.6	383.6	383.6	383.6	383.6	383.6	383.6	383.6	383.6

Figure D13: EUAW for Polyester Handrail @ 15%

Table D14: LCC Components for Vinylester Handrail @ 15%

Material Type	GRP Handrail (Vinylester)
Capital Cost	
Initial Cost	196,097.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,418,743.00
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,418,743.00
Equivalent Uniform Annual Worth(EUAW)	386,421.94

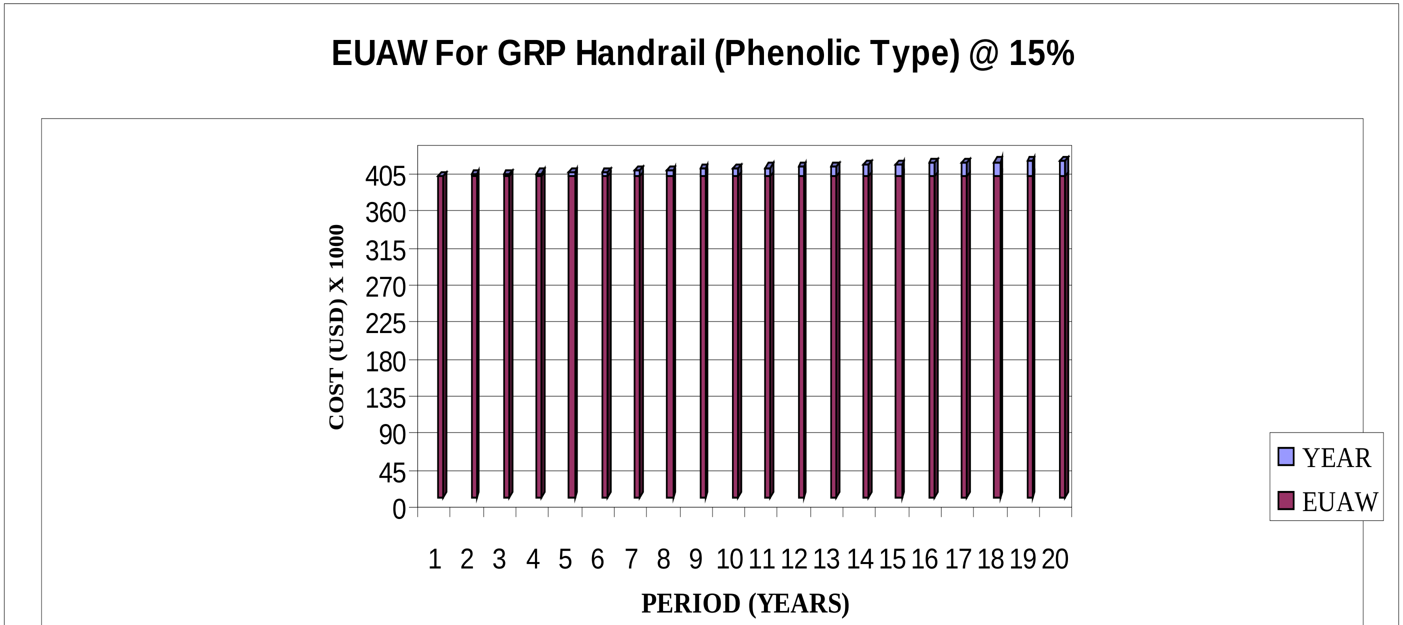


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	386.4	386.4	386.4	386.4	386.4	386.4	386.4	386.4	386.4	386.4	386.4	386.4	386.4	386.4	386.4	386.4	386.4	386.4	386.4	386.4

Figure D14: EUAW for Vinylester Handrail @ 15%

Table D15: LCC Components for Phenolic Handrail @ 15%

Material Type	GRP Handrail (Phenolic)
Capital Cost	
Initial Cost	213,924.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,436,570.00
Replacement Cost	
Replacement Cost	0.00
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,436,570.00
Equivalent Uniform Annual Worth(EUAW)	389,270.01



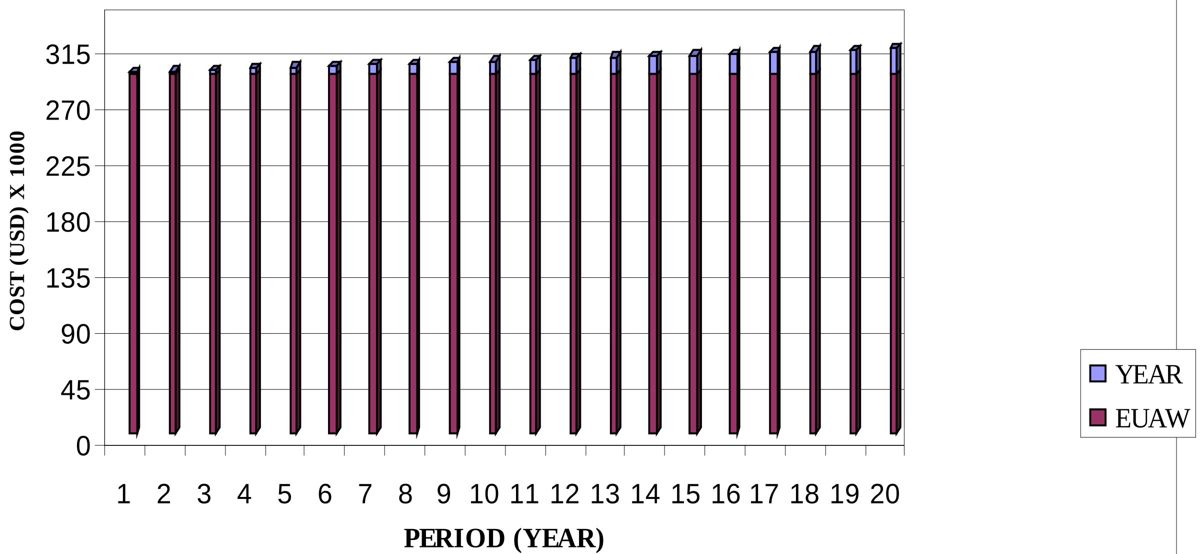
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	389.3	389.3	389.3	389.3	389.3	389.3	389.3	389.3	389.3	389.3	389.3	389.3	389.3	389.3	389.3	389.3	389.3	389.3	389.3	389.3

Figure D15: EUAW for Phenolic Handrail @ 15%

Table D16: LCC Components for Steel Handrail (Replacement-deflated) @ 5%

Material Type	Steel Handrail
Capital Cost	
Initial cost	356,540.00
Demolishing Cost	214,020.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	3,613,775.87
Equivalent Uniform Annual Worth(EUAW)	289,978.73

EUAW For Steel Handrail @ 5%

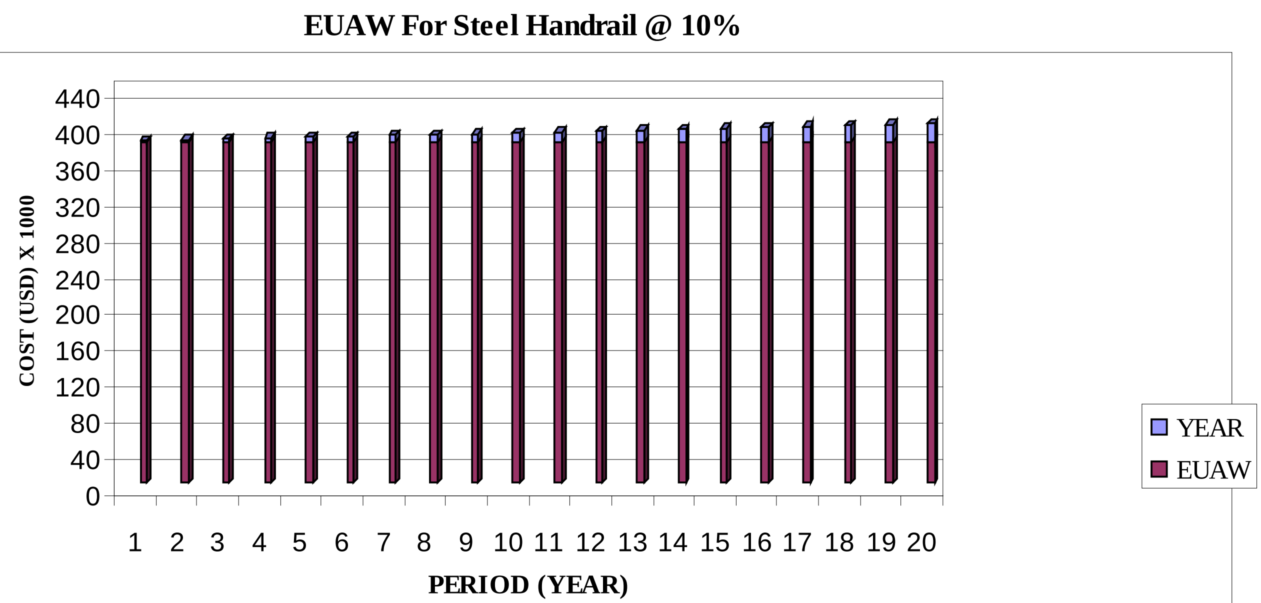


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290

Figure D16: EUAW for Steel Handrail (Replacement-deflated) @ 5%

Table D17: LCC Components for Steel Handrail (Replacement-deflated) @ 10%

Material Type	Steel Handrail
Capital Cost	
Initial cost	356,540.00
Demolishing Cost	214,020.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	3,232,202.98
Equivalent Uniform Annual Worth(EUAW)	379,653.35

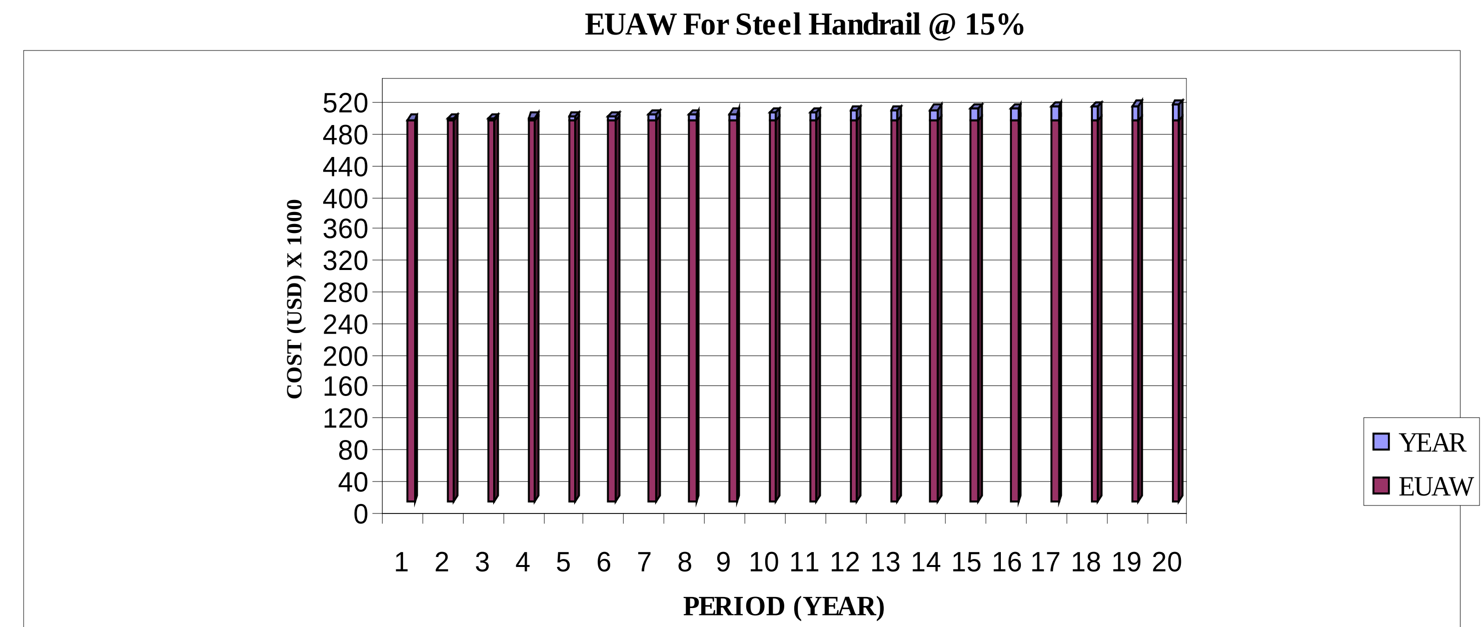


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	379.6	379.6	379.6	379.6	379.6	379.6	379.6	379.6	379.6	379.6	379.6	379.6	379.6	379.6	379.6	379.6	379.6	379.6	379.6	379.6

Figure D17: EUAW for Steel Handrail (Replacement-deflated) @ 10%

Table D18: LCC Components for Steel Handrail (Replacement-deflated) @ 15%

Material Type	Steel Handrail
Capital Cost	
Initial cost	356,540.00
Prefabrication Cost	214,020.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	3,021,200.51
Equivalent Uniform Annual Worth(EUAW)	482,671.44

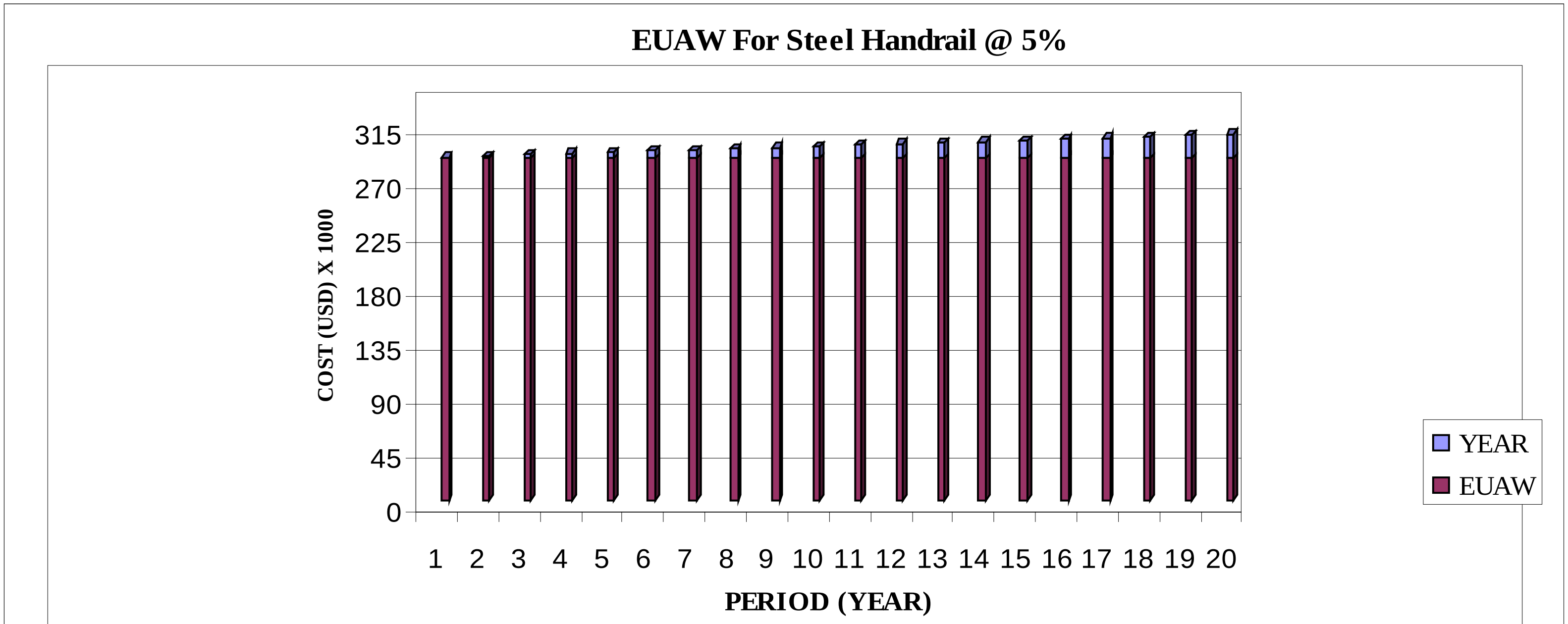


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	482.7	482.7	482.7	482.7	482.7	482.7	482.7	482.7	482.7	482.7	482.7	482.7	482.7	482.7	482.7	482.7	482.7	482.7	482.7	482.7

Figure D18: EUAW for Steel Handrail (Replacement-deflated) @ 15%

Table D19: LCC Components for Steel Handrail (Replacement-deflated 10%) @ 5%

Material Type	Steel Handrail
Capital Cost	
Initial cost	356,540.00
Demolishing Cost	214,020.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
20 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	3,566,483.57
Equivalent Uniform Annual Worth(EUAW)	286,183.87



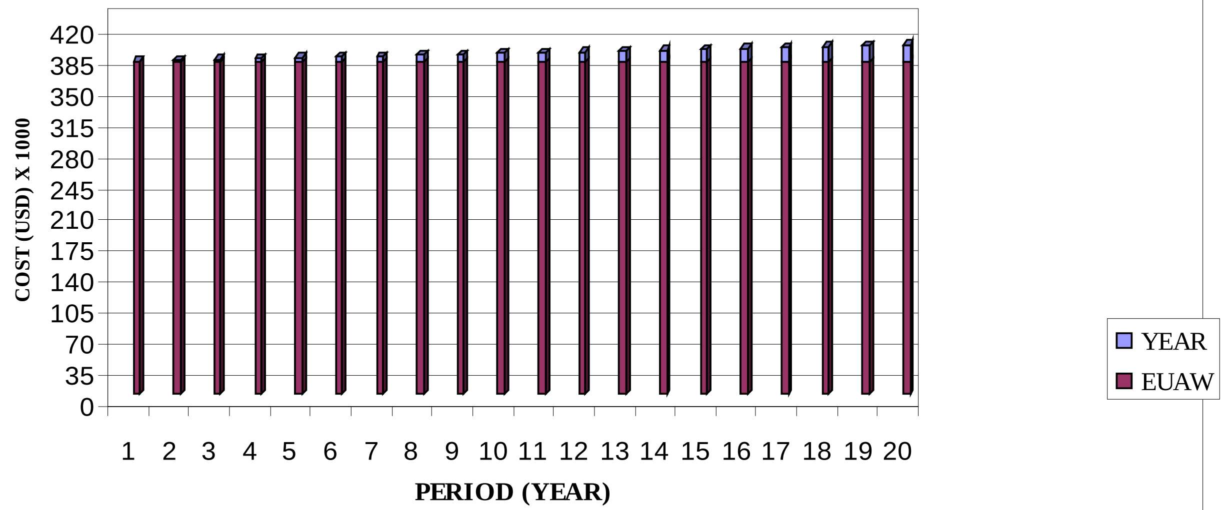
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2	286.2

Figure D19: EUAW for Steel Handrail (Replacement-deflated 10%) @ 5%

Table D20: LCC Components for Steel Handrail (Replacement-deflated 10%) @ 10%

Material Type	Steel Handrail
Capital Cost	
Initial cost	356,540.00
Demolishing Cost	214,020.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
20 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	3,205,141.61
Equivalent Uniform Annual Worth(EUAW)	376,474.73

EUAW For Steel Handrail @ 10%

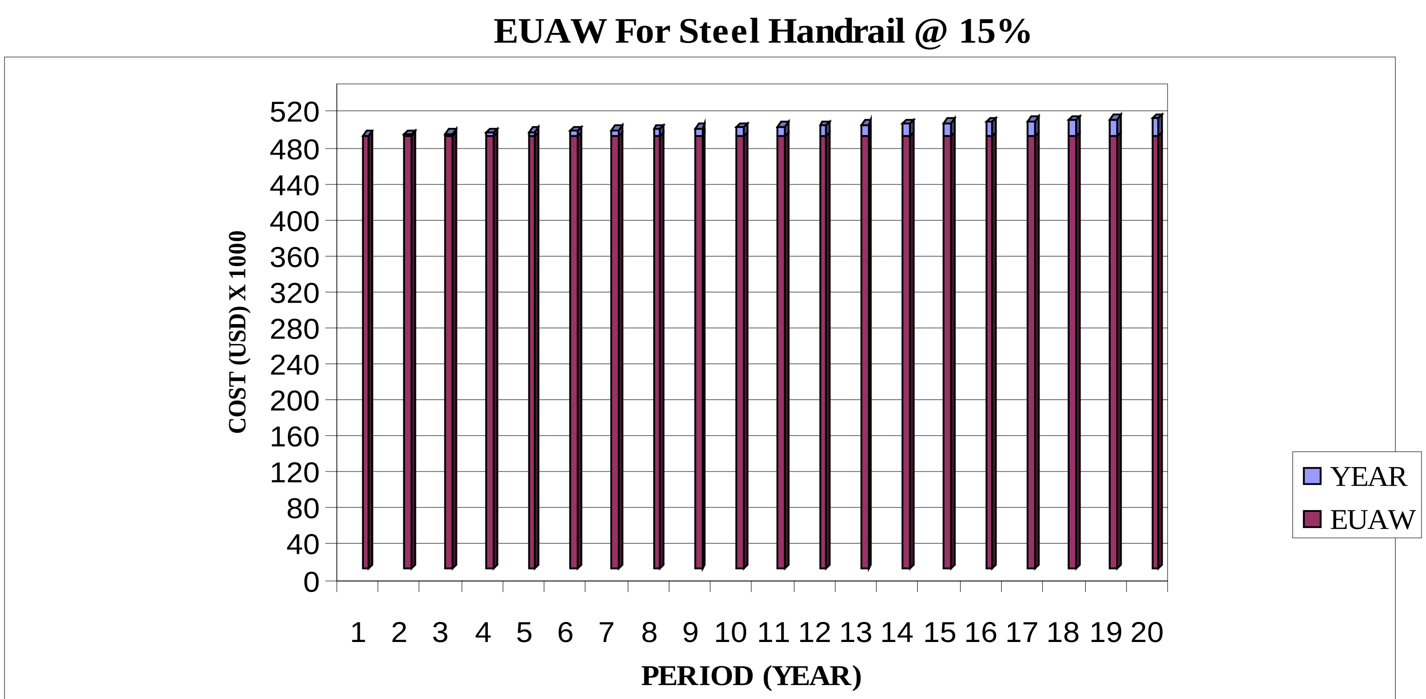


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	376.5	376.5	376.5	376.5	376.5	376.5	376.5	376.5	376.5	376.5	376.5	376.5	376.5	376.5	376.5	376.5	376.5	376.5	376.5	376.5

Figure D20: EUAW for Steel Handrail (Replacement-deflated 10%) @ 10%

Table D21: LCC Components for Steel Handrail (Replacement-deflated 10%) @ 15%

Material Type	Steel Handrail
Capital Cost	
Initial cost	356,540.00
Prefabrication Cost	214,020.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
20 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	3,005,326.45
Equivalent Uniform Annual Worth(EUAW)	480,135.37



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EUAW	480.1	480.1	480.1	480.1	480.1	480.1	480.1	480.1	480.1	480.1	480.1	480.1	480.1	480.1	480.1	480.1	480.1	480.1	480.1	480.1

Figure D21: EUAW for Steel Handrail (Replacement-deflated 10%) @1 5%

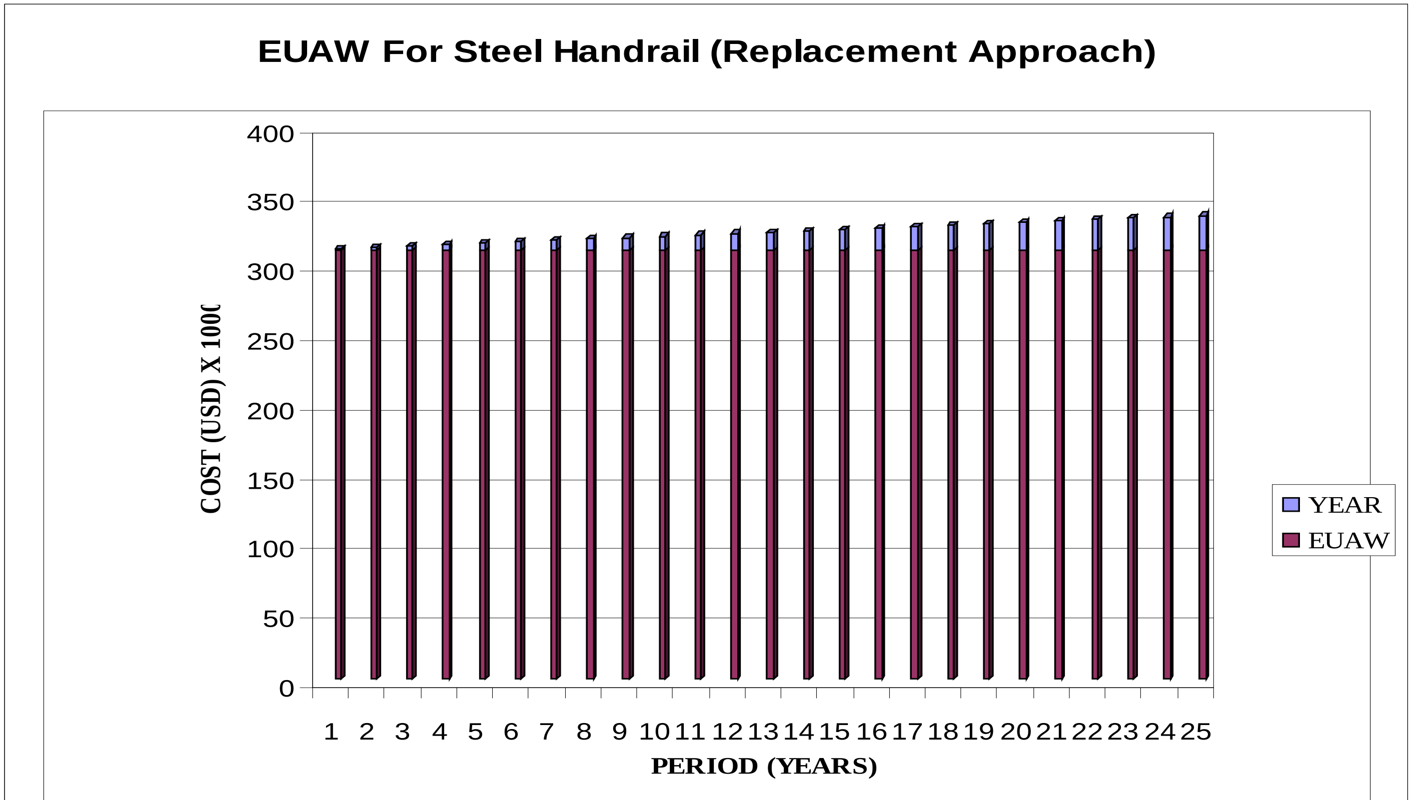
APPENDIX E

CASH FLOWS ANALYSIS FOR THE HANDRAILS

FOR A PERIOD OF 25 YEARS

Table E1: LCC Components for Steel Handrail (Replacement) @ 5%

Material Type	Steel Handrail (Replacement)
Capital Cost	
Initial cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	4,356,577.54
Equivalent Uniform Annual Worth(EUAW)	309,109.88

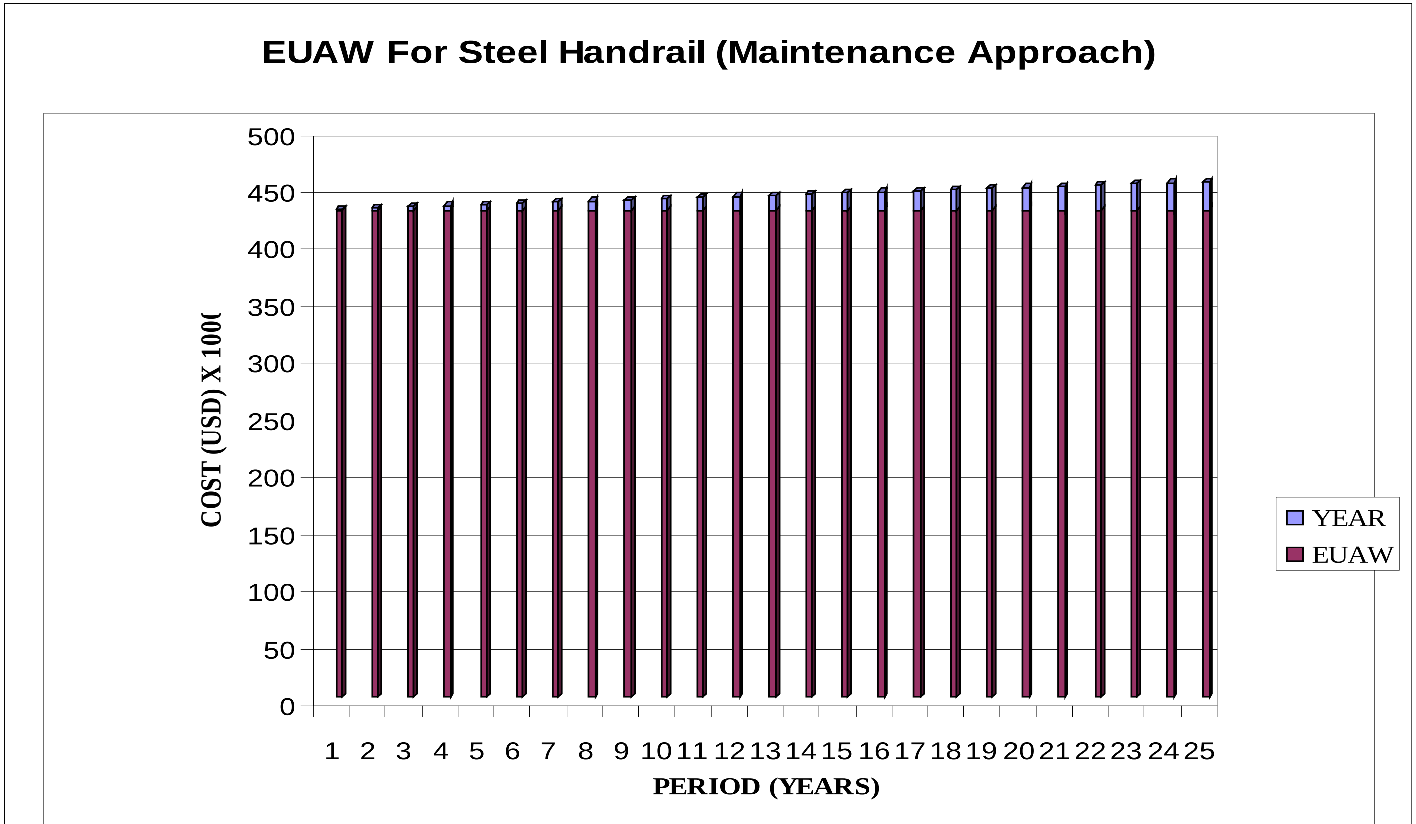


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1	309.1

Figure E1: EUAW for Steel Handrail (Replacement) @5%

Table E2: LCC Components for Steel Handrail (Maintenance @ 5%

Material Type	Steel Handrail (Maintenance)
Capital Cost	
Initial cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Maintenance Cost	
Maintenance Cost every 5 years	1,461,814.00
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	6,018,698.36
Equivalent Uniform Annual Worth (EUAW)	427,041.44

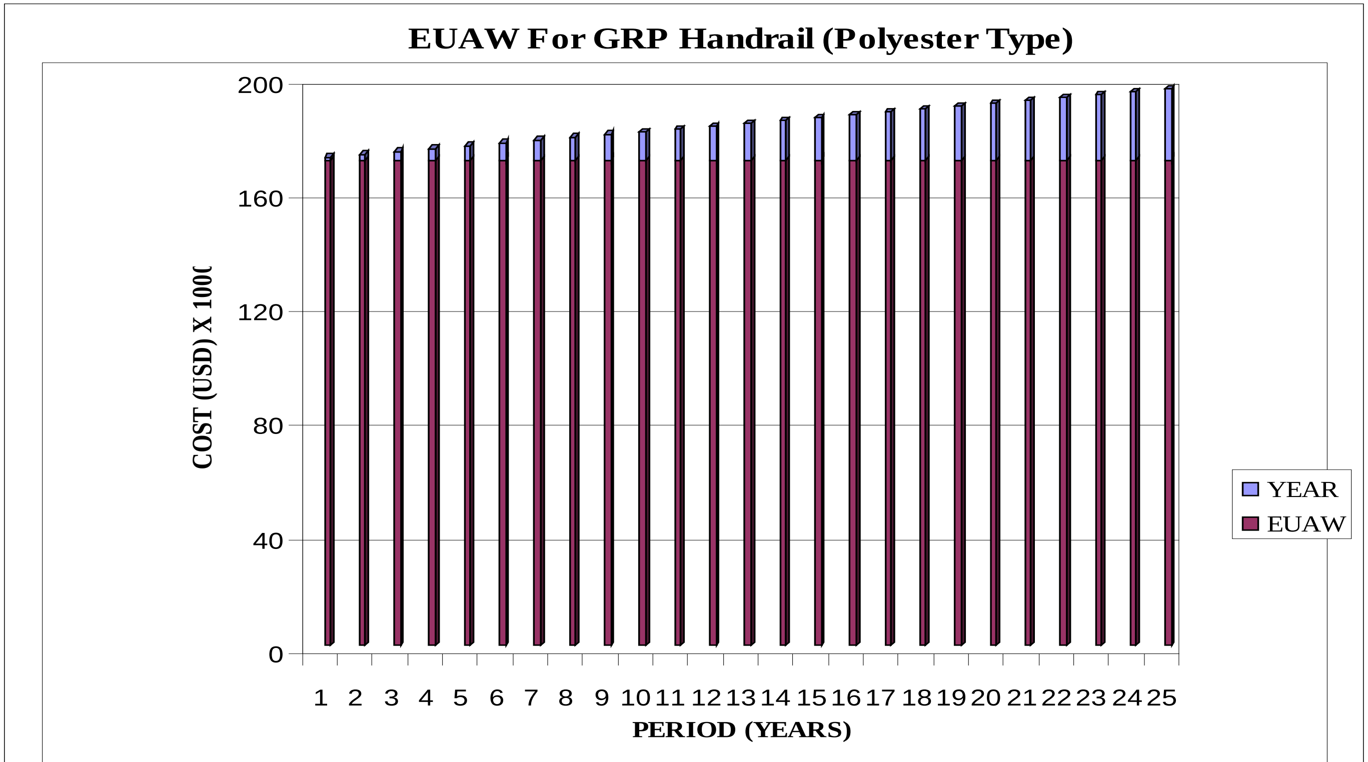


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427

Figure E2: EUAW for Steel Handrail (Maintenance) @ 5%

Table E3: LCC Components for Polyester Handrail @ 5%

Material Type	GRP Handrail (Polyester)
Capital Cost	
Initial Cost	178,270.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,400,916.00
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	2,400,916.00
Equivalent Uniform Annual Worth(EUAW)	170,350.89

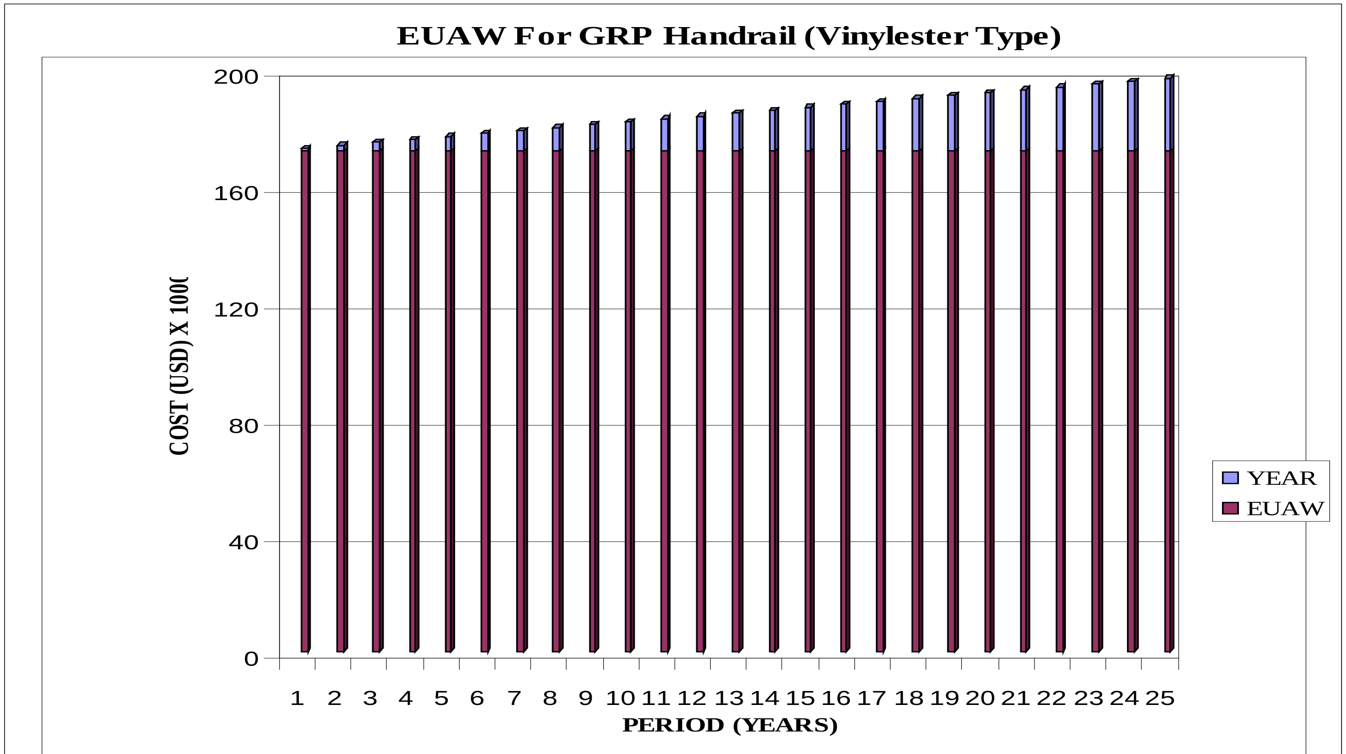


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4	170.4

Figure E3: EUAW for Polyester Handrail @ 5%

Table E4: LCC Components for Vinylester Handrail @ 5%

Material Type	GRP Handrail (Vinylester)
Capital Cost	
Initial Cost	196,097.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,418,743.00
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	2,418,743.00
Equivalent Uniform Annual Worth(EUAW)	171,615.76

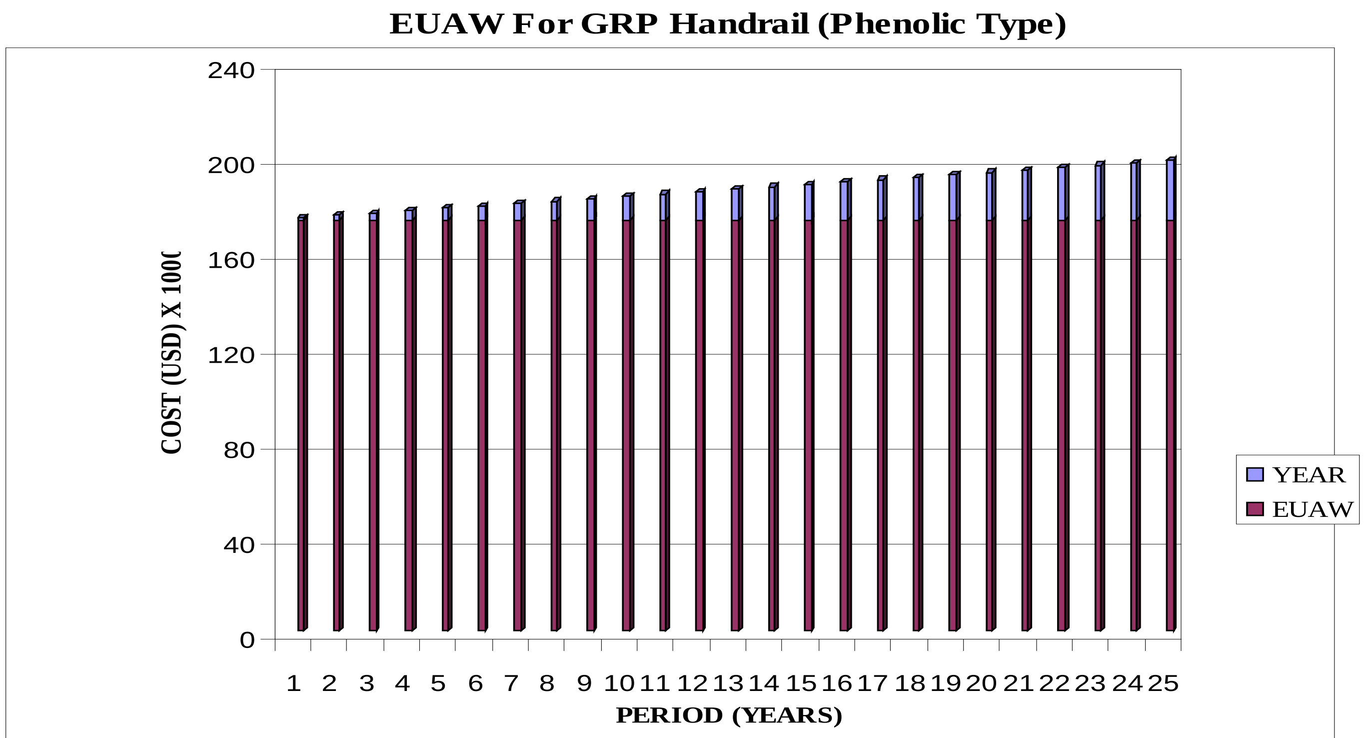


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6

Figure E4: EUAW for Vinylester Handrail @ 5%

Table E5: LCC Components for Phenolic Handrail @ 5%

Material Type	GRP Handrail (Phenolic)
Capital Cost	
Initial Cost	213,924.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,436,570.00
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	2,436,570.00
Equivalent Uniform Annual Worth(EUAW)	172,880.63

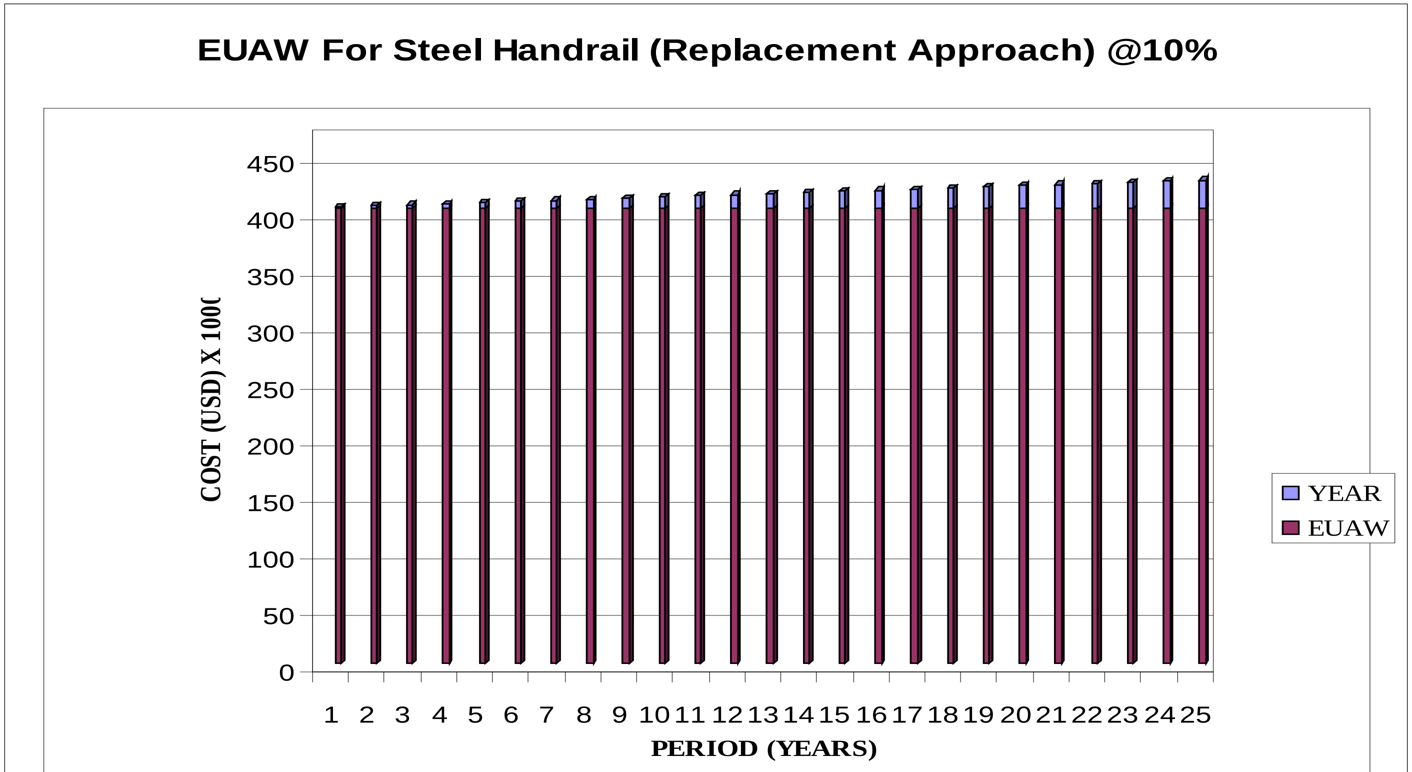


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9

Figure E5: EUAW for Phenolic Handrail @ 5%

Table E6: LCC Components for Steel Handrail (Replacement) @ 10%

Material Type	Steel Handrail (Replacement)
Capital Cost	
Initial cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	3,657,245.36
Equivalent Uniform Annual Worth(EUAW)	402,911.67

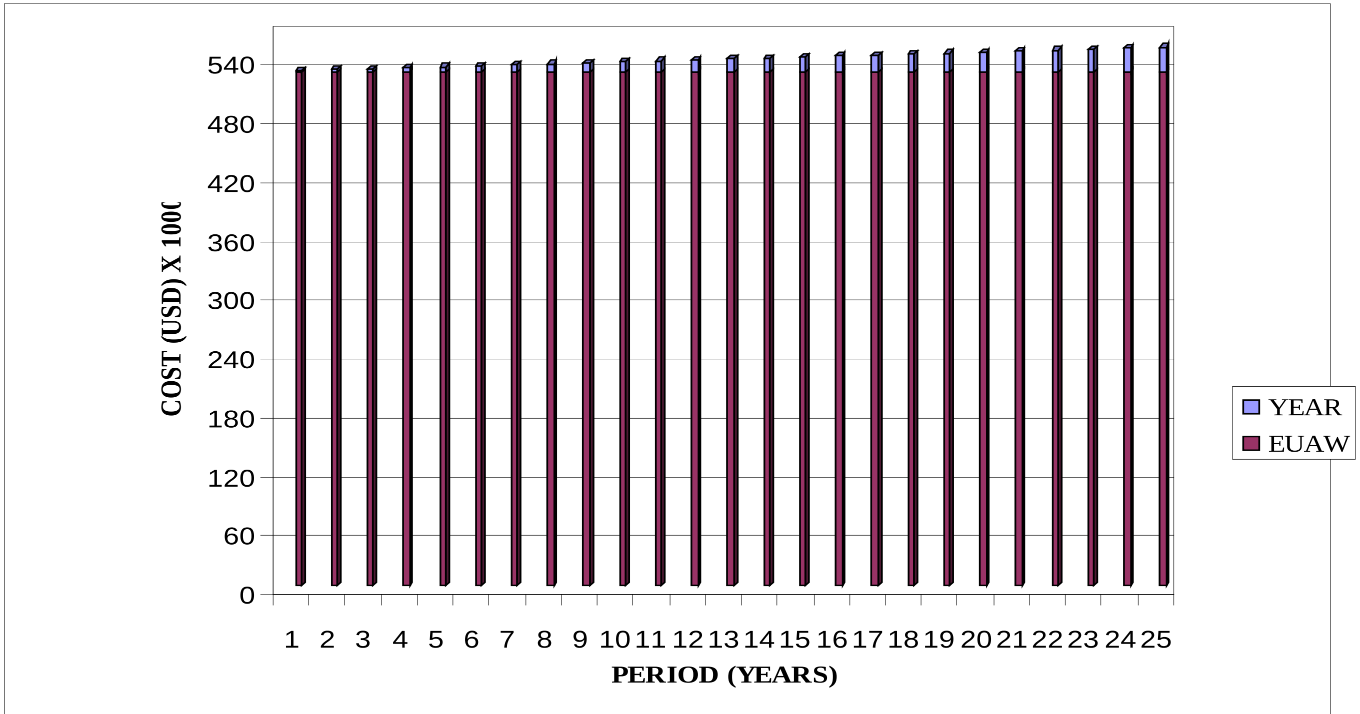


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9	402.9

Figure E6: EUAW for Steel Handrail (Replacement) @ 10%

Table E7: LCC Components for Steel Handrail (Maintenance) @ 10%

Material Type	Steel Handrail
Capital Cost	
Initial cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Maintenance Cost	
Maintenance Cost every 5 years	1,461,814.00
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	4,760,302.05
Equivalent Uniform Annual Worth(EUAW)	524,433.30

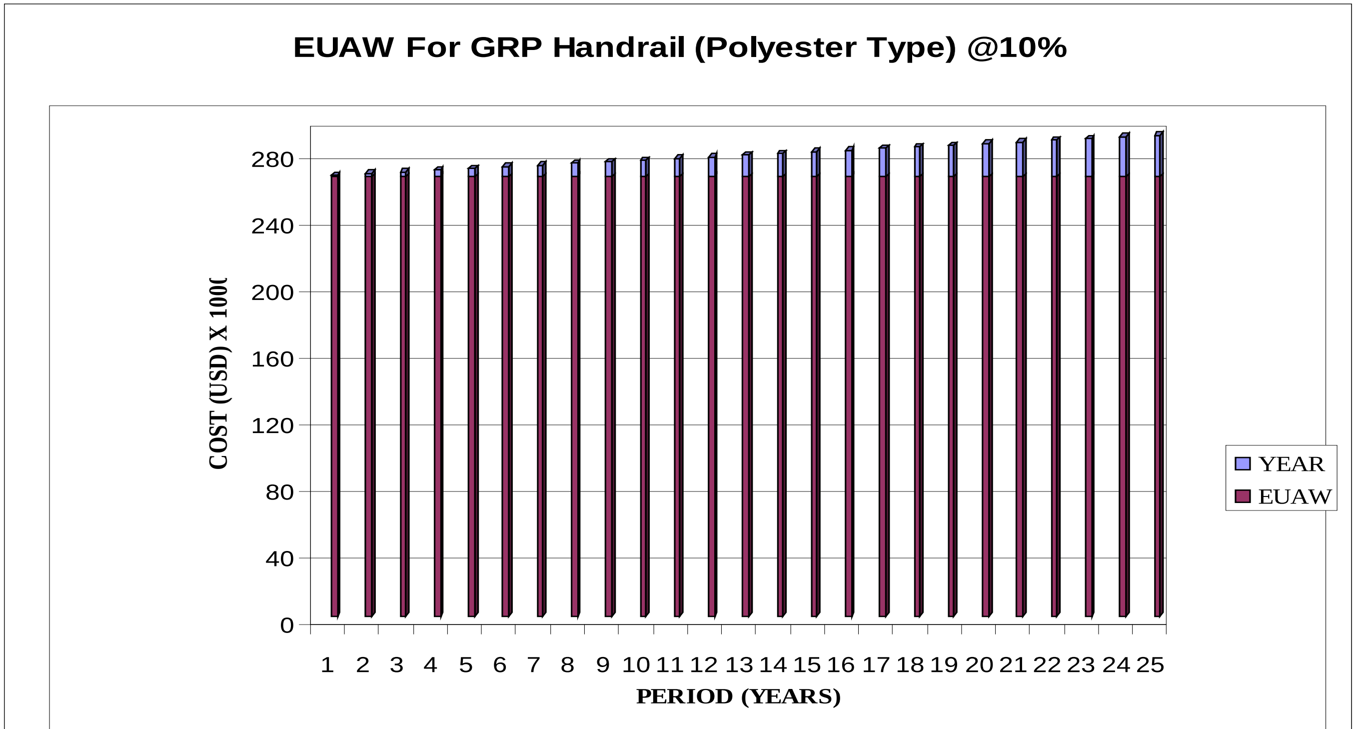


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4	524.4

Figure E7: EUAW for Steel Handrail (Maintenance) @ 10%

Table E8: LCC Components for Polyester Handrail @ 10%

Material Type	GRP Handrail (Polyester)
Capital Cost	
Initial Cost	178,270.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,400,916.00
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,400,916.00
Equivalent Uniform Annual Worth(EUAW)	264,504.29

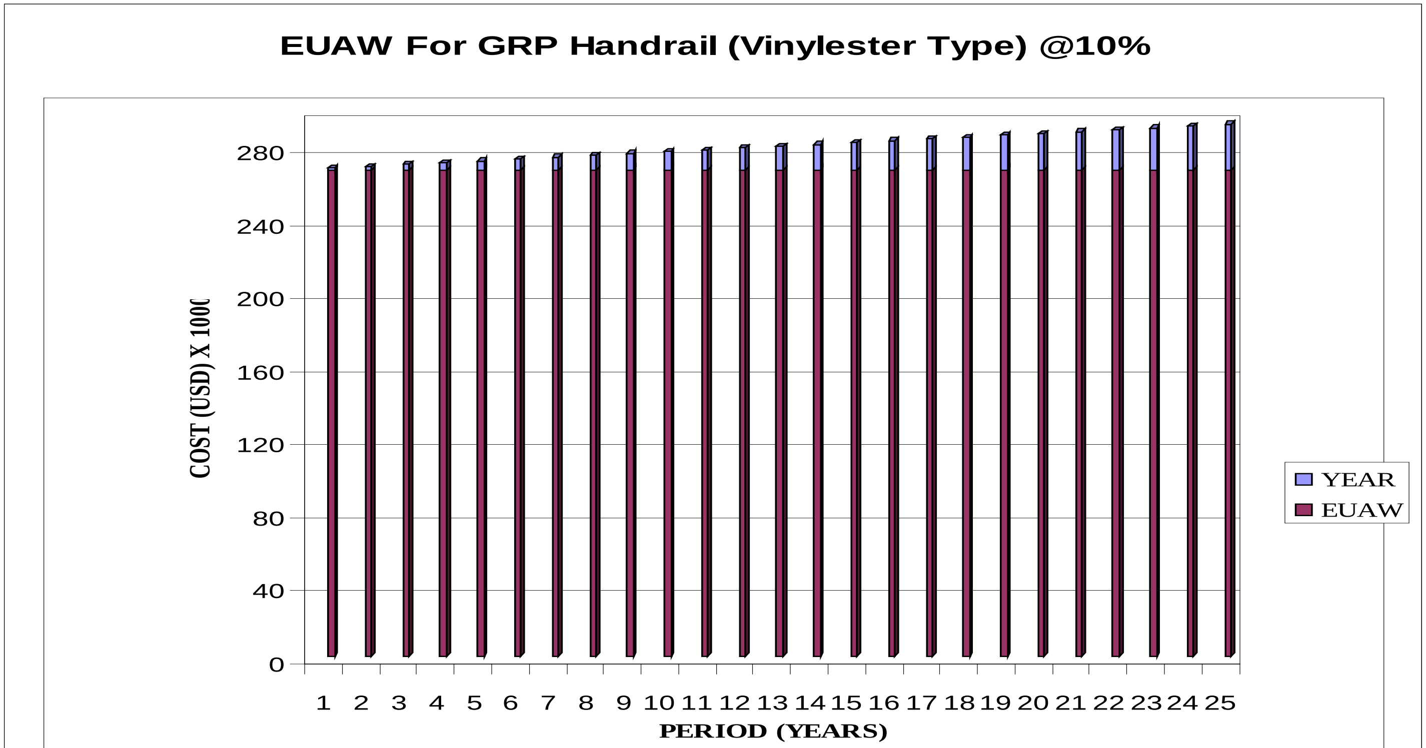


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5	264.5

Figure E8: EUAW for Polyester Handrail @ 10%

Table E9: LCC Components for Vinylester Handrail @ 10%

Material Type	GRP Handrail (Vinylester)
Capital Cost	
Initial Cost	196,097.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,418,743.00
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,418,743.00
Equivalent Uniform Annual Worth(EUAW)	266,468.25

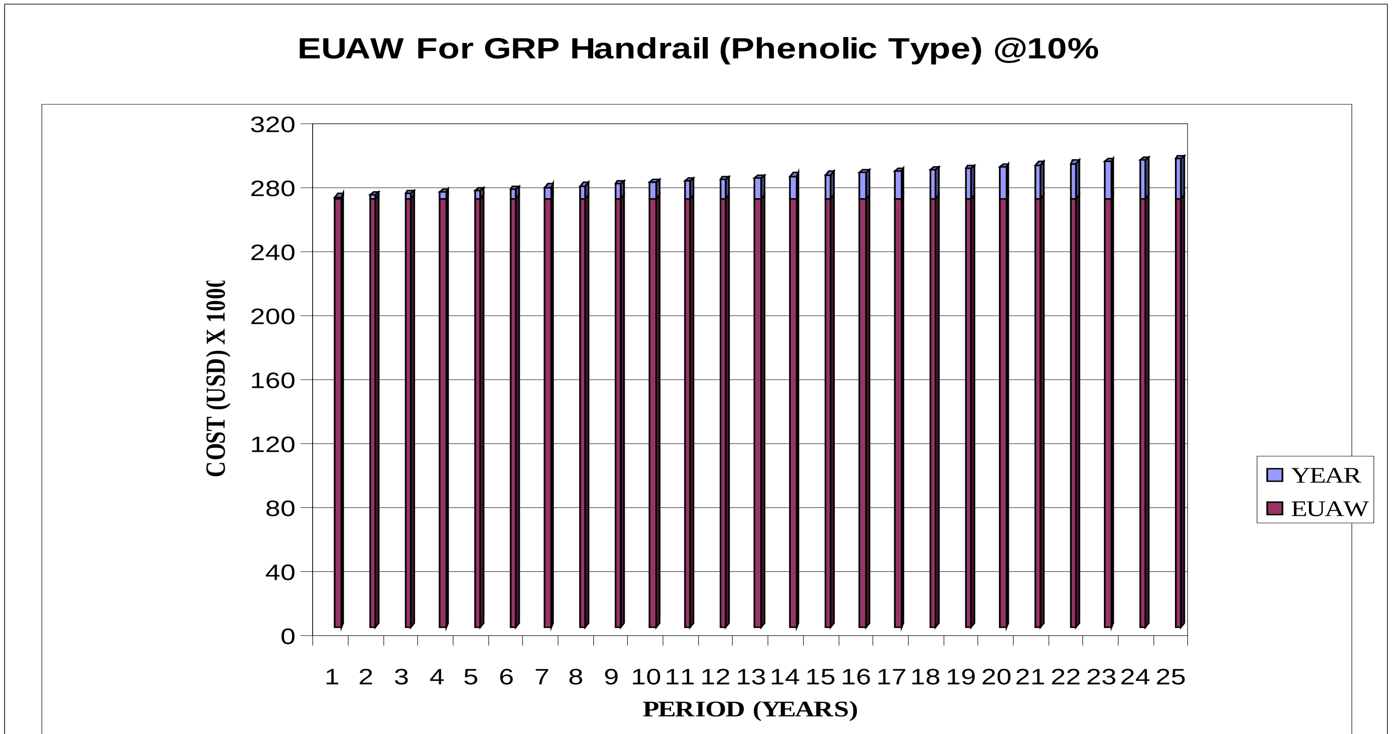


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5	266.5

Figure E9: EUAW for Vinylester Handrail @ 10%

Table E10: LCC Components for Phenolic Handrail @ 10%

Material Type	GRP Handrail (Phenolic)
Capital Cost	
Initial Cost	213,924.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,436,570.00
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,436,570.00
Equivalent Uniform Annual Worth(EUAW)	268,432.22

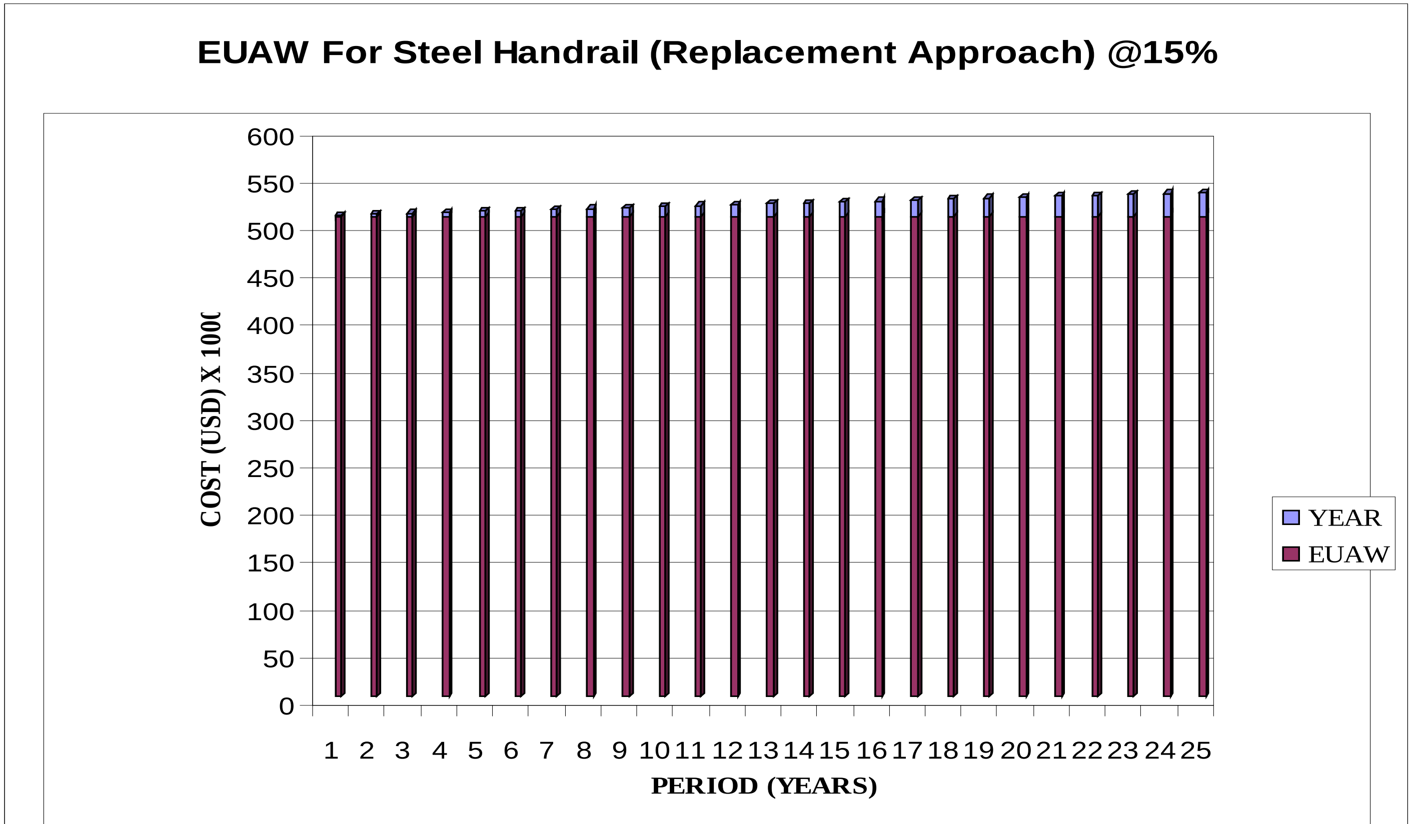


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4	268.4

Figure E10: EUAW for Phenolic Handrail @ 10%

Table E11: LCC Components for Steel Handrail (Replacement) @ 15%

Material Type	Steel Handrail (Replacement)
Capital Cost	
Initial cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	3,270,528.12
Equivalent Uniform Annual Worth(EUAW)	505,984.75

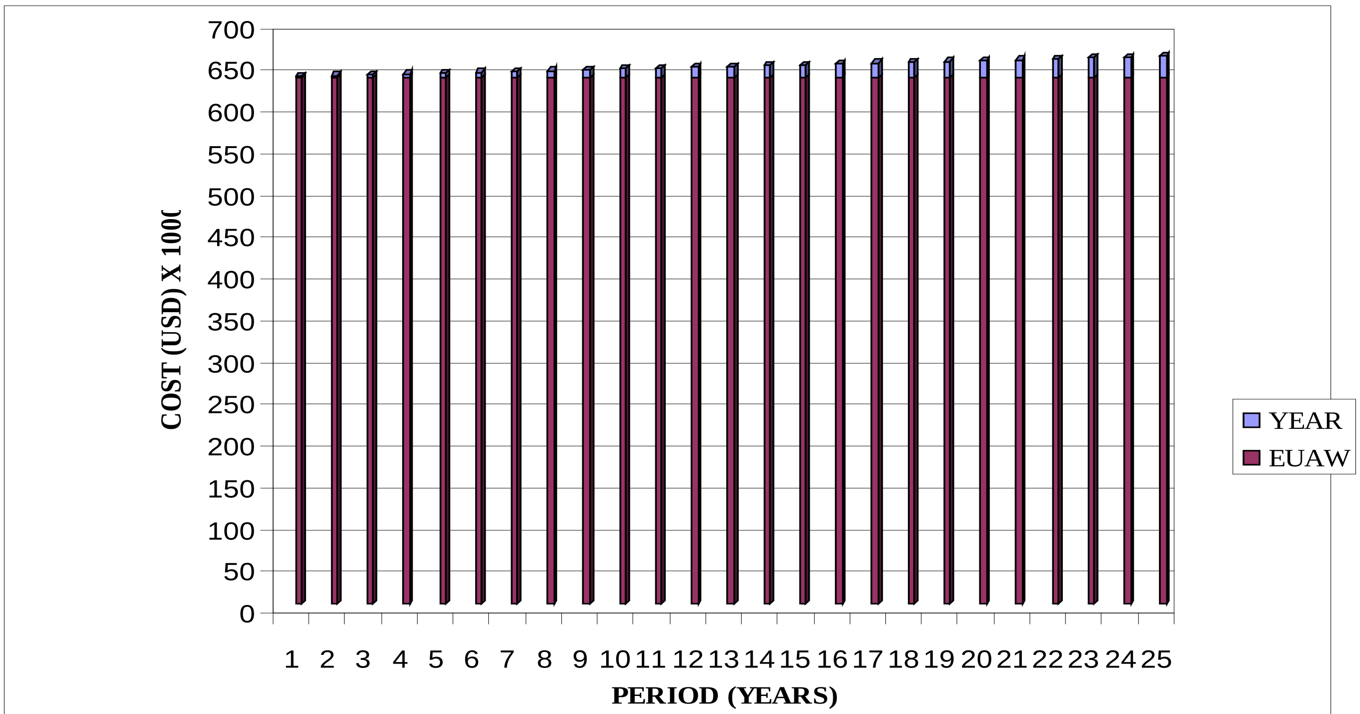


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	506	506	506	506	506	506	506	506	506	506	506	506	506	506	506	506	506	506	506	506	506	506	506	506	506

Figure E11: EUAW for Steel Handrail (Replacement) @ 15%

Table E12: LCC Components for Steel Handrail (Maintenance) @ 15%

Material Type	Steel Handrail (Maintenance)
Capital Cost	
Initial cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Maintenance Cost	
Maintenance cost every 5 years	1,461,814.00
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	4,078,886.10
Equivalent Uniform Annual Worth (EUAW)	631,001.24



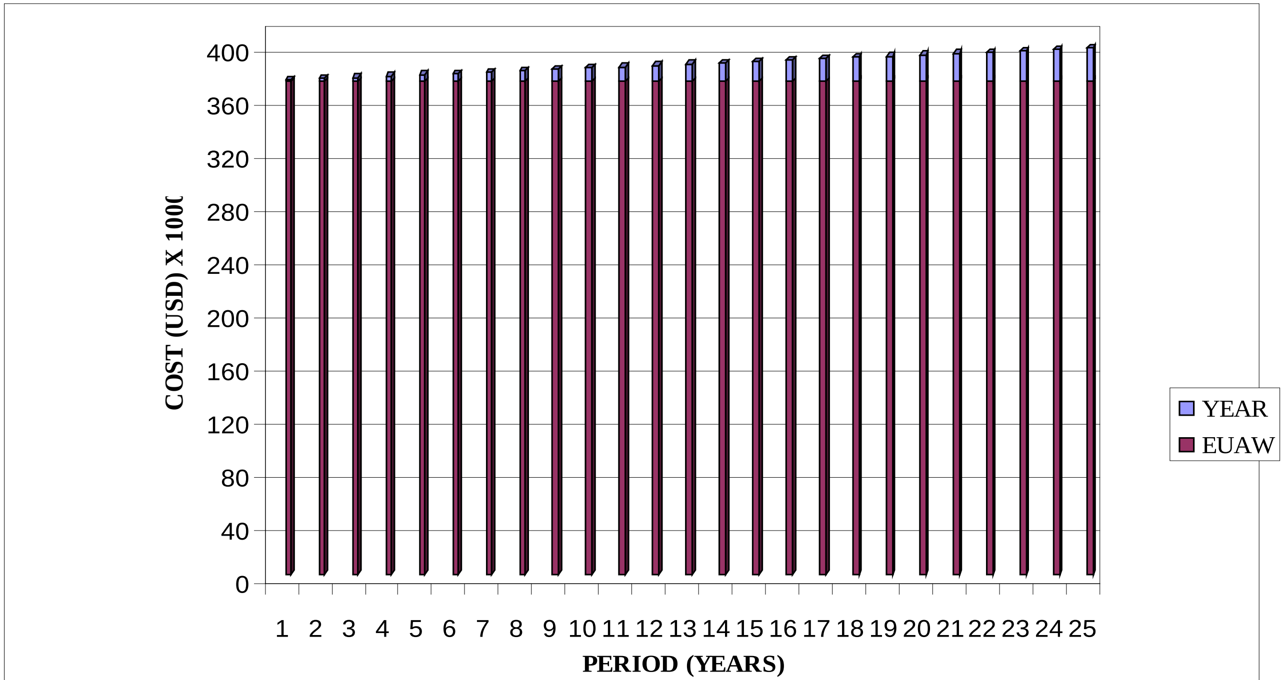
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	631	631	631	631	631	631	631	631	631	631	631	631	631	631	631	631	631	631	631	631	631	631	631	631	631

Figure E12: EUAW for Steel Handrail (Maintenance) @ 15%

Table E13: LCC Components for Polyester Handrail @ 15%

Material Type	GRP Handrail (Polyester)
Capital Cost	
Initial Cost	178,270.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,400,916.00
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,400,916.00
Equivalent Uniform Annual Worth(EUAW)	371,420.27

EUAW For GRP Handrail (Polyester Type) @ 15%

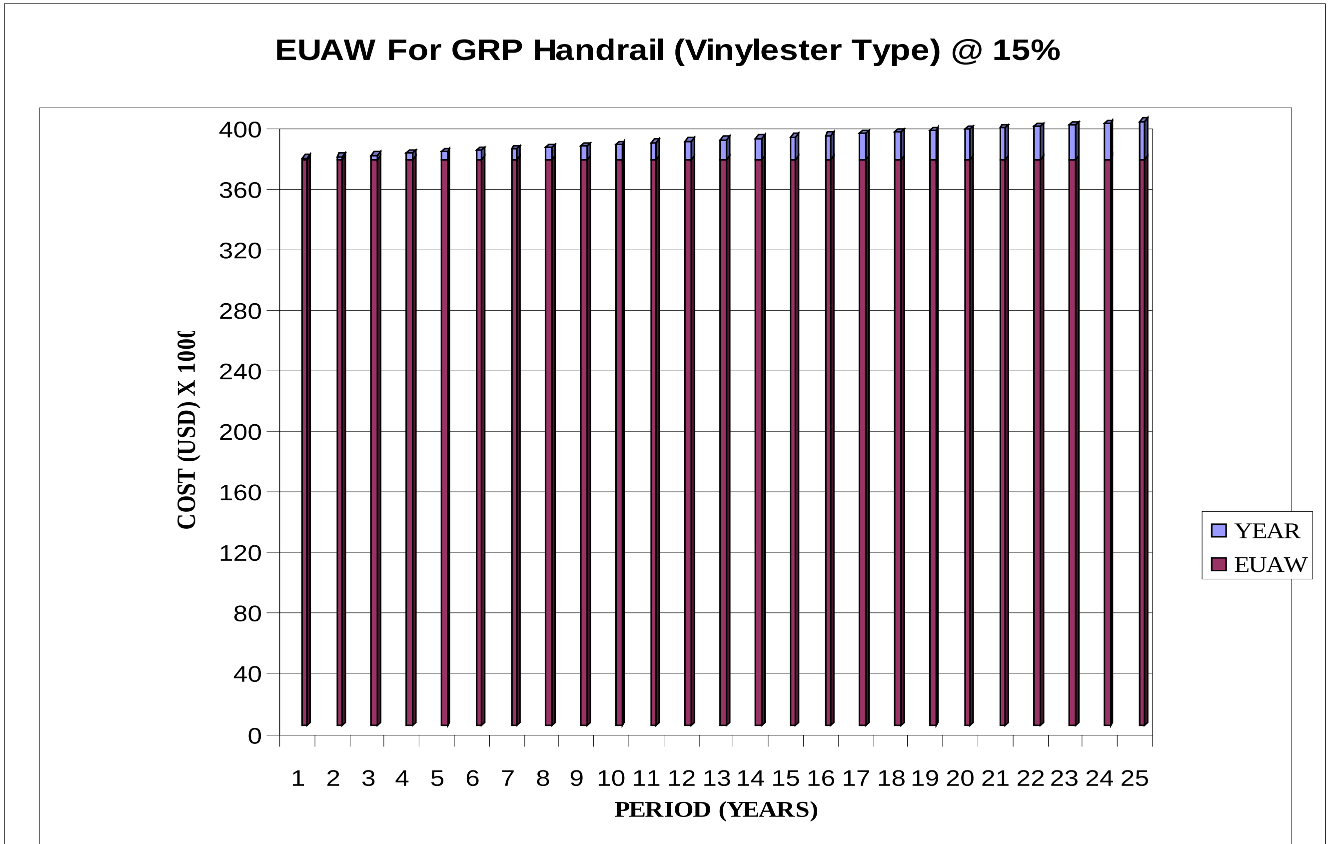


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4	371.4

Figure E13: EUAW for Polyester Handrail @ 15%

Table E14: LCC Components for Vinylester Handrail @ 15%

Material Type	GRP Handrail (Vinylester)
Capital Cost	
Initial Cost	196,097.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,418,743.00
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,418,743.00
Equivalent Uniform Annual Worth(EUAW)	374,178.10

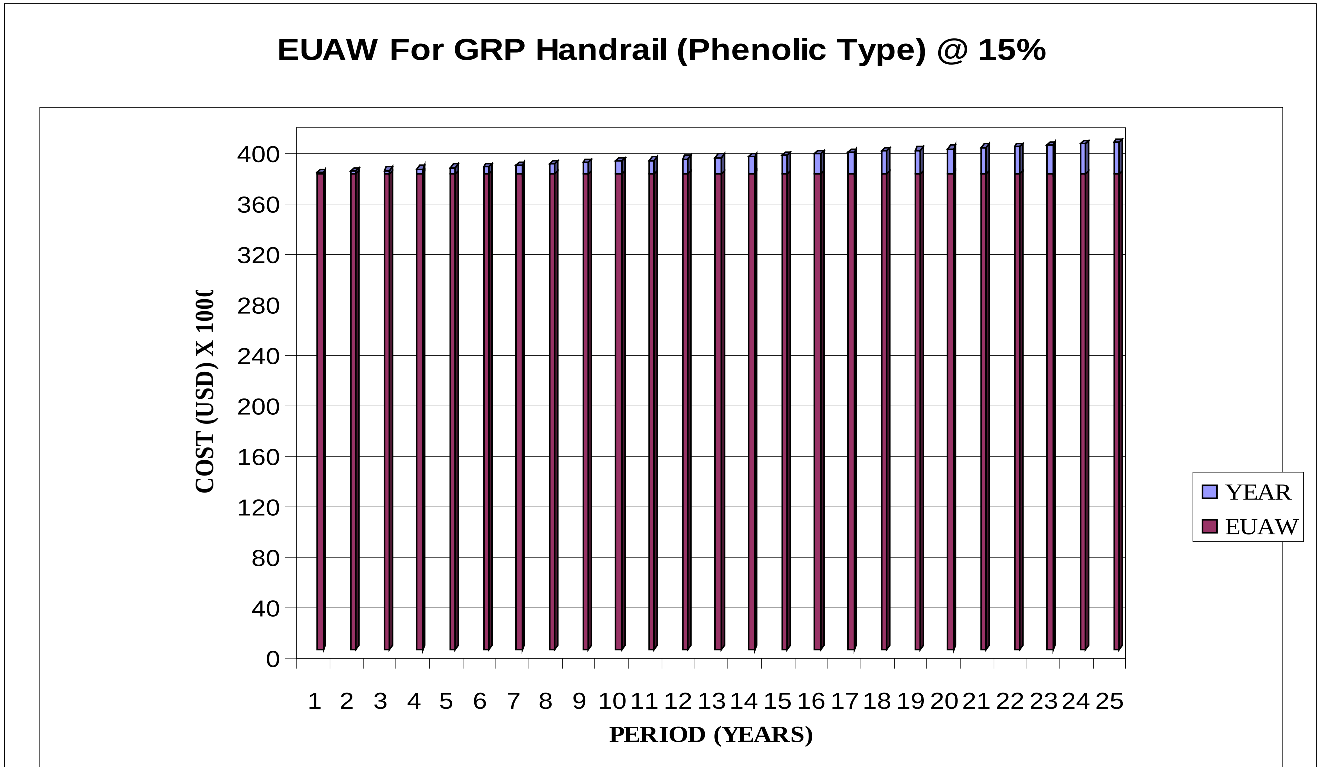


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2	374.2

Figure E14: EUAW for Vinylester Handrail @ 15%

Table E15: LCC Components for Phenolic Handrail @ 15%

Material Type	GRP Handrail (Phenolic)
Capital Cost	
Initial Cost	213,924.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,436,570.00
Replacement Cost	
Replacement Cost	0.00
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,436,570.00
Equivalent Uniform Annual Worth(EUAW)	376,935.92

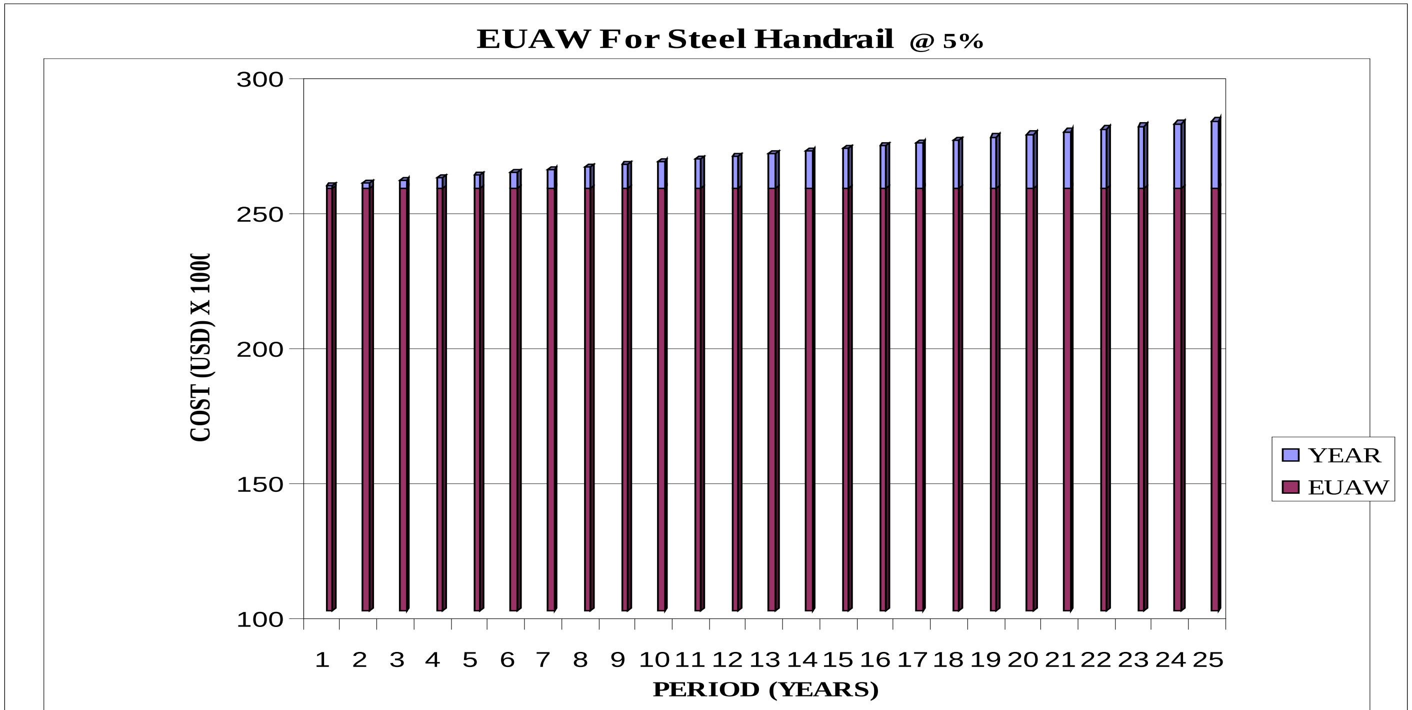


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	377	377	377	377	377	377	377	377	377	377	377	377	377	377	377	377	377	377	377	377	377	377	377	377	377

Figure E15: EUAW for Phenolic Handrail @ 15%

Table E16: LCC Components for Steel Handrail (Replacement-Deflated) @ 5%

Material Type	Steel Handrail
Capital Cost	
Initial cost	356,540.00
Demolishing Cost of Existing Handrail	214,020.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	3,613,775.87
Equivalent Uniform Annual Worth(EUAW)	256,406.28

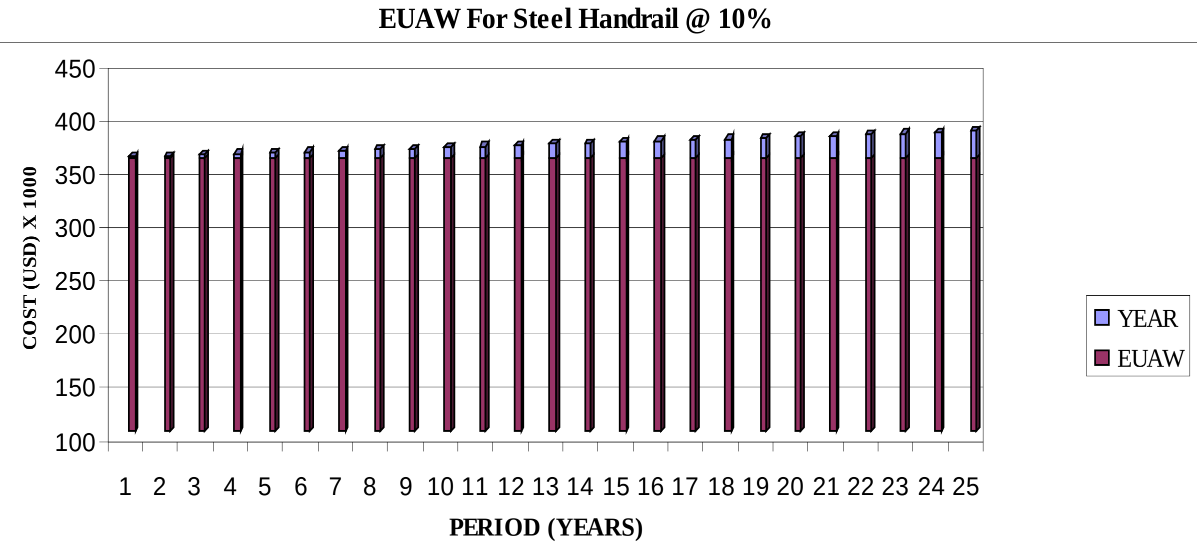


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4	256.4

Figure E16: EUAW for Steel Handrail (Replacement-Deflated) @ 5%

Table E17: LCC Components for Steel Handrail (Replacement-Deflated) @ 10%

Material Type	Steel Handrail
Capital Cost	
Initial cost	356,540.00
demolishing Cost	214,020.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	3,232,202.98
Equivalent Uniform Annual Worth(EUAW)	356,085.57

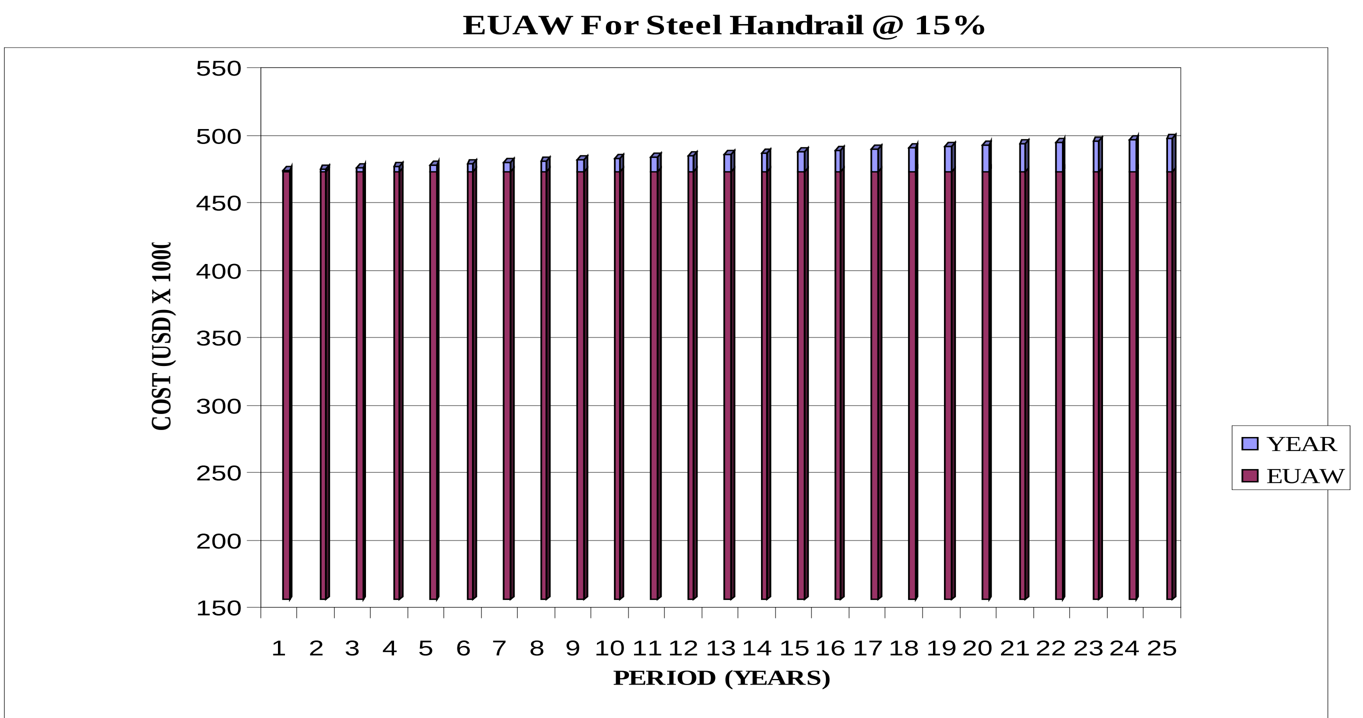


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1	356.1

Figure E17: EUAW for Steel Handrail (Replacement-Deflated) @ 10%

Table E18: LCC Components for Steel Handrail (Replacement-Deflated) @ 15%

Material Type	**Steel Handrail**
Capital Cost	
Initial Cost	356,540.00
demolishing cost	214,020.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	3,021,200.51
Equivalent Uniform Annual Worth(EUAW)	467,377.91

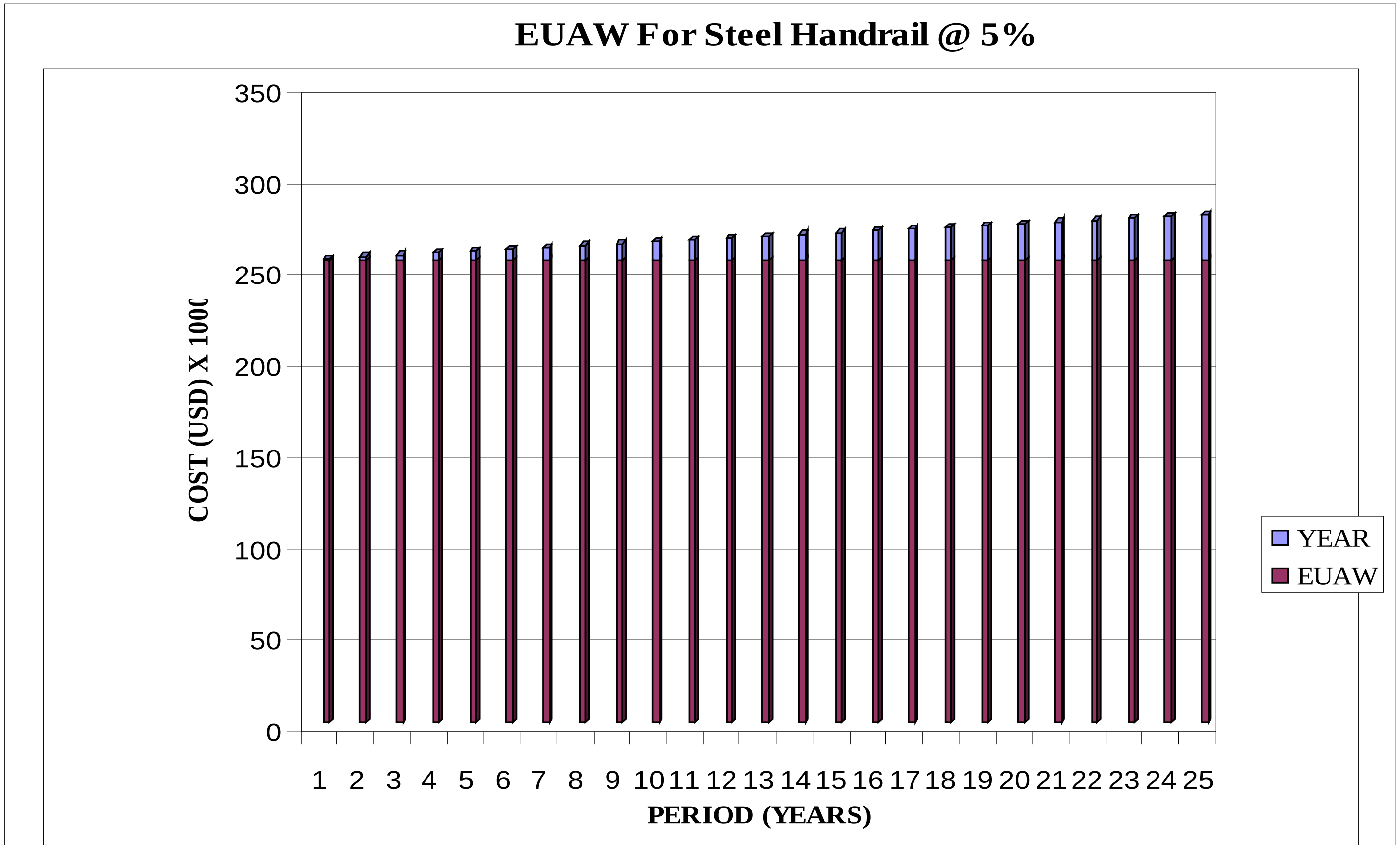


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4	467.4

Figure E18: EUAW for Steel Handrail (Replacement-Deflated) @ 15%

Table E19: LCC Components for Steel Handrail (Replacement-Deflated 10%) @ 5%

Material Type	Steel Handrail
Capital Cost	
Initial cost	356,540.00
demolishing Cost	214,202.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	3,566,515.86
Equivalent Uniform Annual Worth(EUAW)	253,053.06

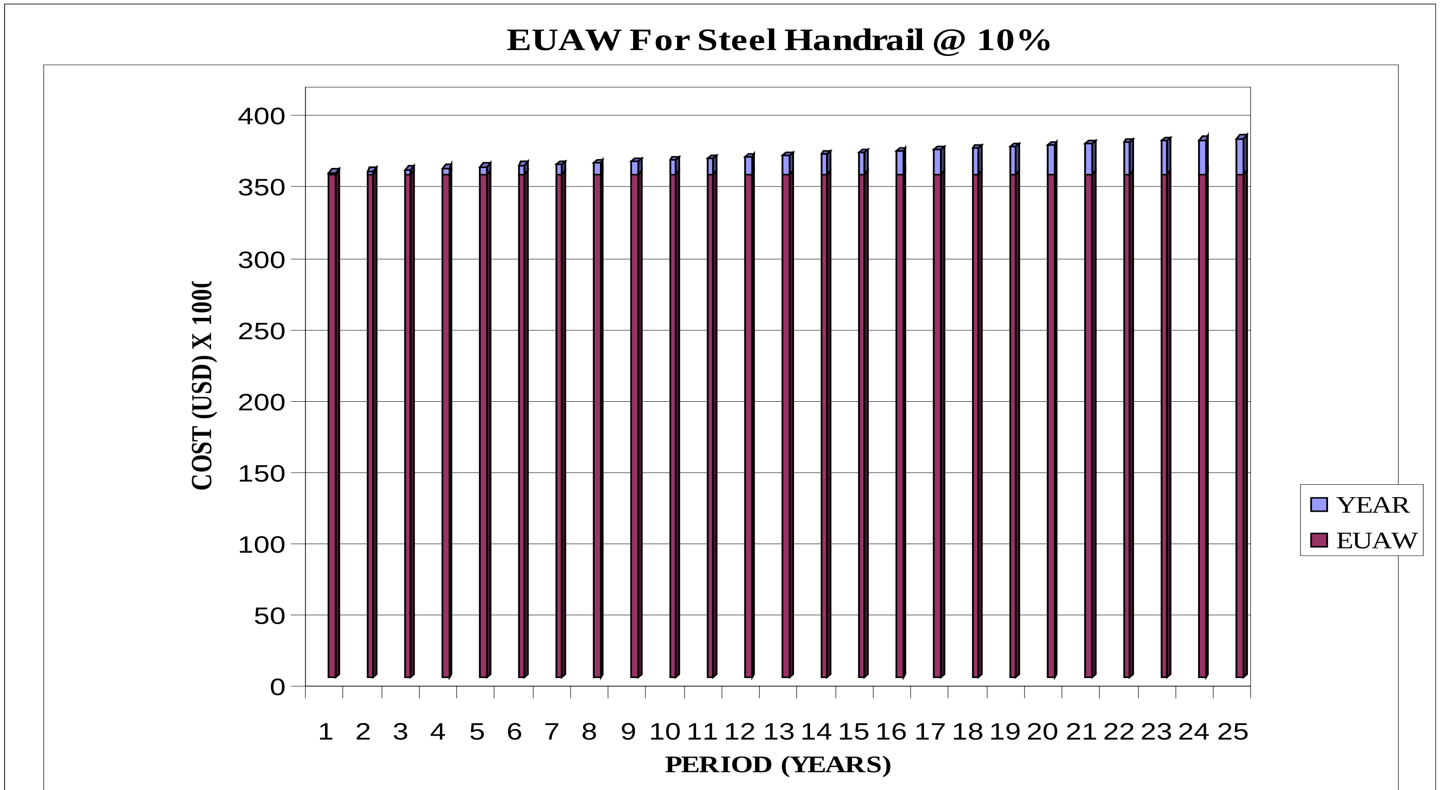


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1	253.1

Figure E19: EUAW for Steel Handrail (Replacement-Deflated 10%) @ 5%

Table E20: LCC Components for Steel Handrail (Replacement-Deflated 10%) @ 10%

Material Type	Steel Handrail
Capital Cost	
Initial Cost	356,540.00
Prefabrication Cost	214,020.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
25 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	3,205,141.61
Equivalent Uniform Annual Worth (EUAW)	353,104.27

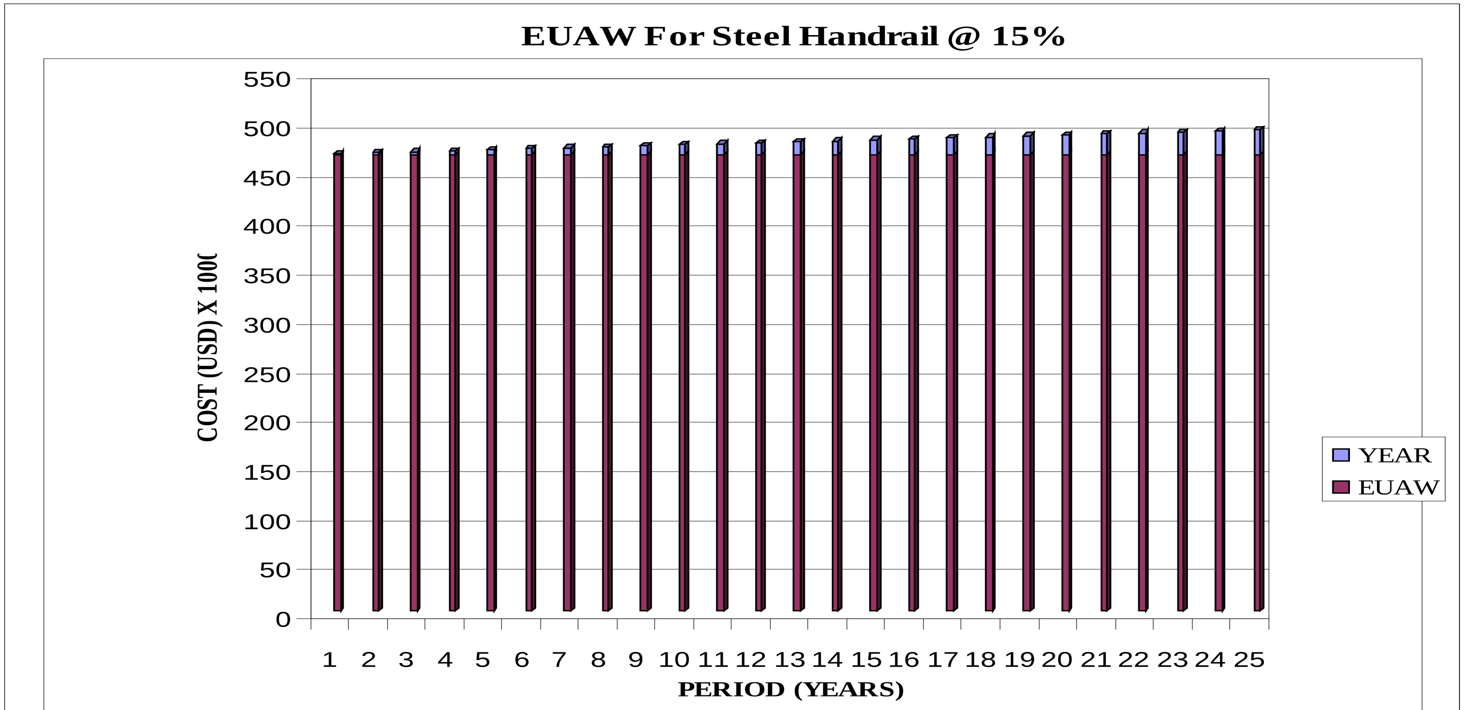


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1	353.1

Figure E20: EUAW for Steel Handrail (Replacement-Deflated 10%) @10%

Table E21: LCC Components for Steel Handrail (Replacement-Deflated 10%) @ 15%

Material Type	**Steel Handrail**
Capital Cost	
Initial Cost	356,540.00
Prefabrication Cost	214,020.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
25 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	3,005,326.45
Equivalent Uniform Annual Worth(EUAW)	464,922.21



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EUAW	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9	464.9

Figure E21: EUAW for Steel Handrail (Replacement-Deflated 10%) @15%

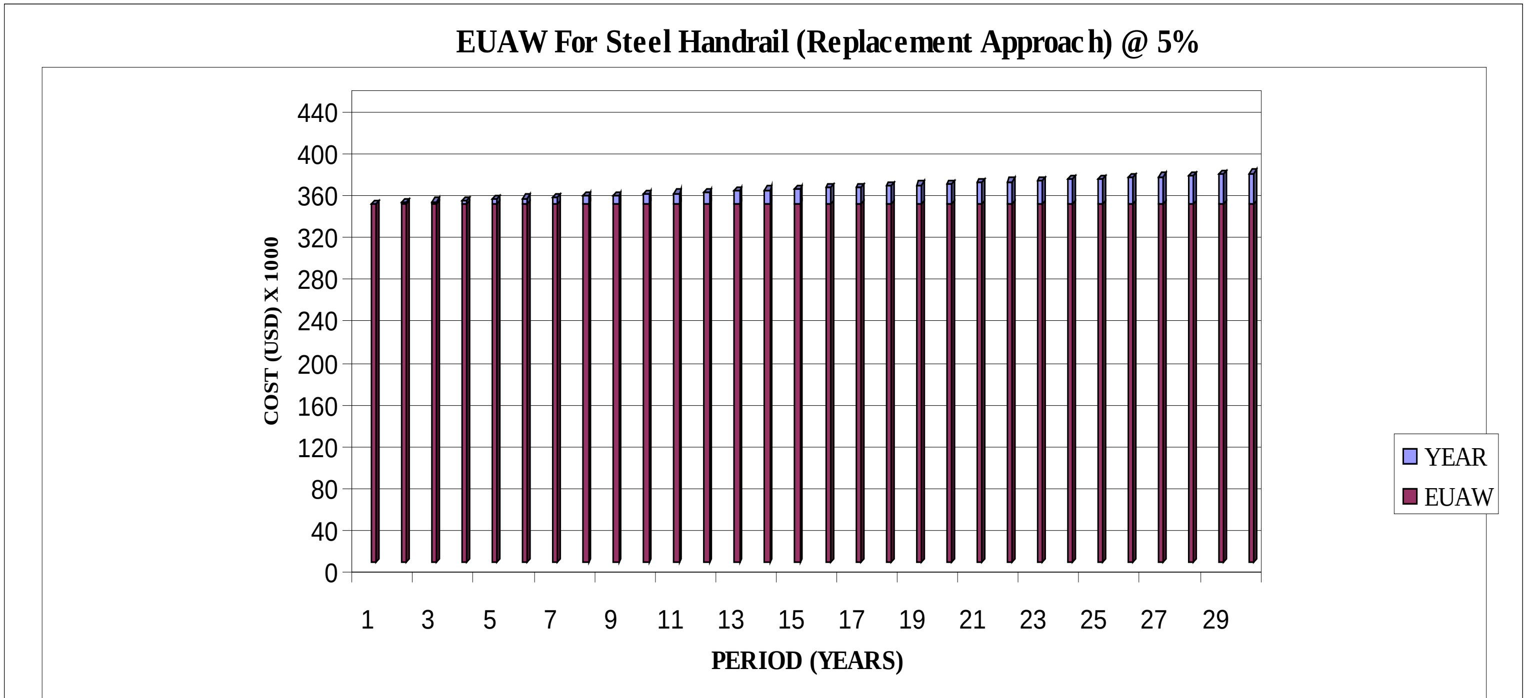
APPENDIX F

CASH FLOWS ANALYSIS FOR THE HANDRAILS

FOR A PERIOD OF 30 YEARS

Table F1: LCC Components for Steel Handrail (Replacement) @ 5%

Material Type	Steel Handrail
Capital Cost	
Initial Cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
25 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	5,266,881.74
Equivalent Uniform Annual Worth(EUAW)	342,618.22

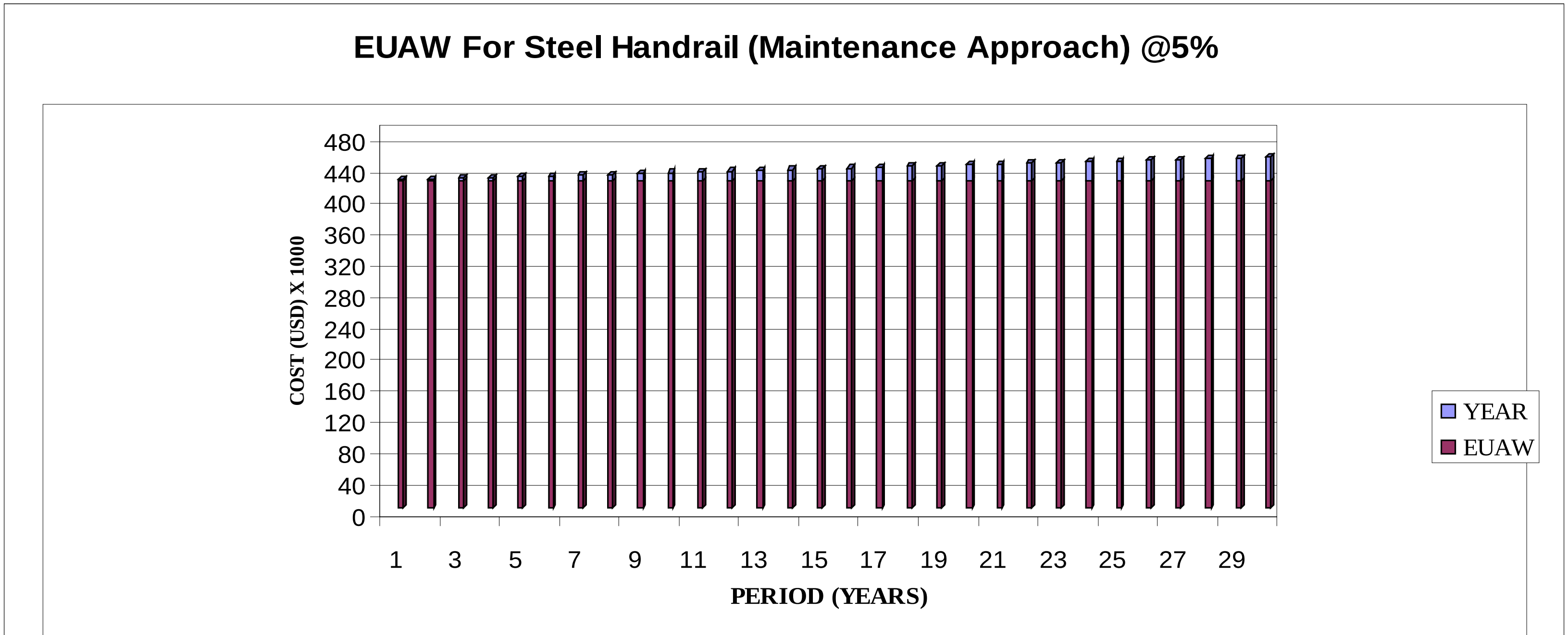


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6	342.6

Figure F1: EUAW for Steel Handrail (Replacement) @ 5%

Table F2: LCC Components for Steel Handrail (Maintenance) @ 5%

Material Type	Steel Handrail (Maintenance)
Capital Cost	
Initial Cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Maintenance Cost	
Maintenance Cost every 5 years	1,461,814.00
Period	
30 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	6,450,376.08
Equivalent Uniform Annual Worth(EUAW)	419,606.22

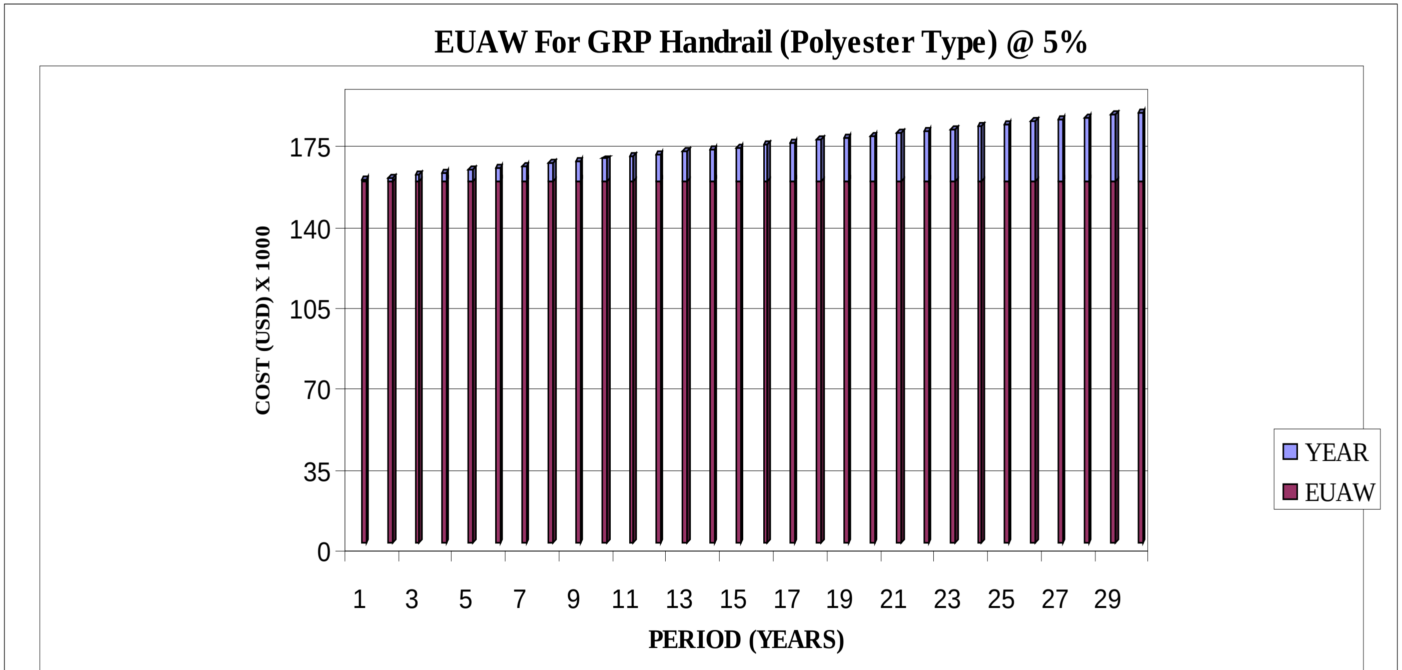


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6

Figure F2: EUAW for Steel Handrail (Maintenance) @ 5%

Table F3: LCC Components for Polyester Handrail @ 5%

Material Type	GRP Handrail (Polyester)
Capital Cost	
Initial Cost	178,270.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,400,916.00
Replacement Cost	
Replacement Cost	0.00
Period	
30years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	2,400,916.00
Equivalent Uniform Annual Worth(EUAW)	156,183.03

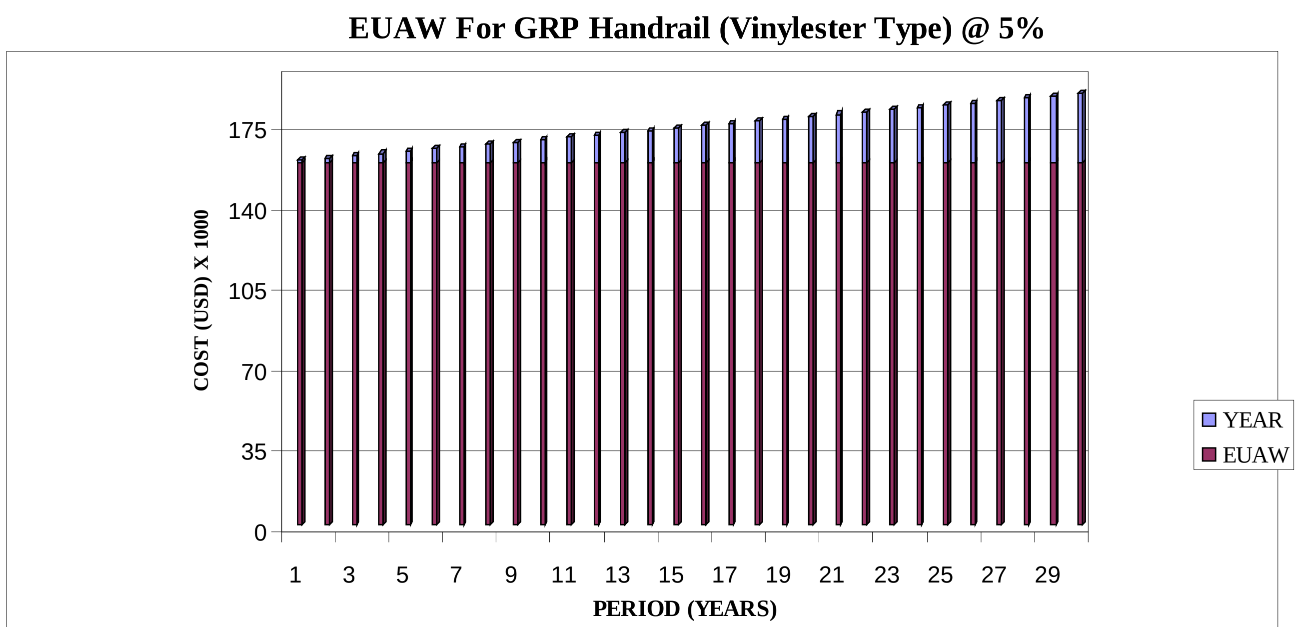


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2	156.2

Figure F3: EUAW for Polyester Handrail @ 5%

Table F4: LCC Components for Vinylester Handrail @ 5%

Material Type	GRP Handrail (Vinylester)
Capital Cost	
Initial Cost	196,097.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,418,743.00
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	2,418,743.00
Equivalent Uniform Annual Worth(EUAW)	157,342.70

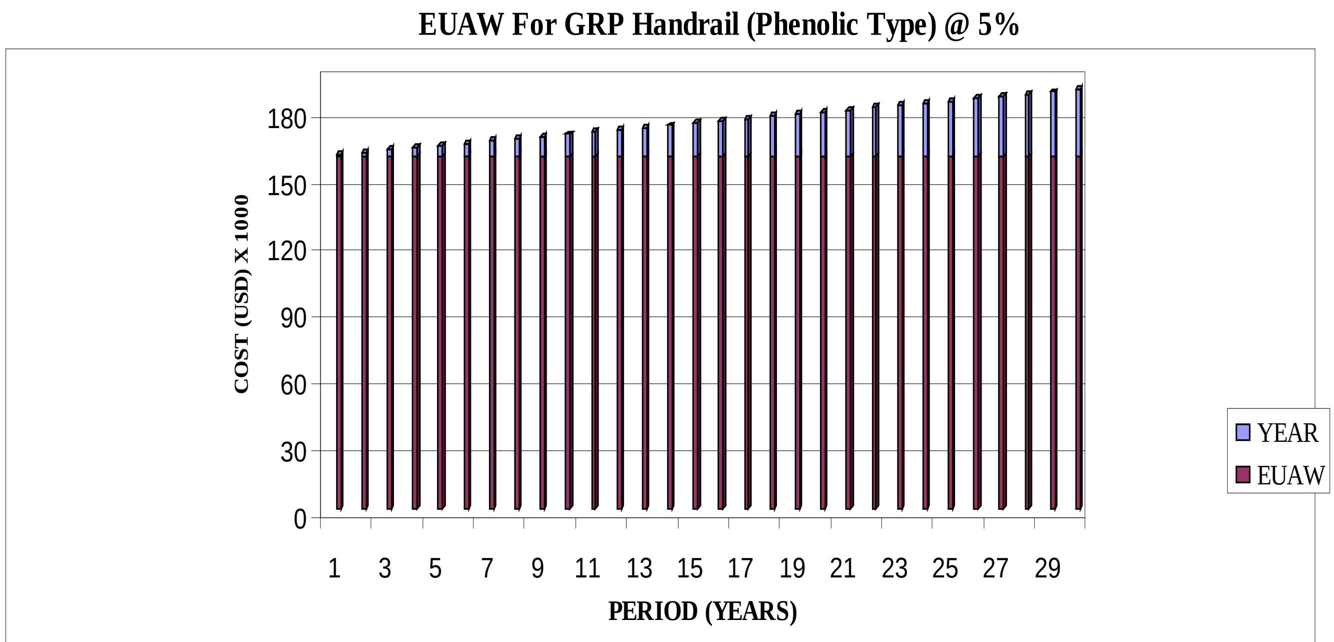


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4	157.4

Figure F4: EUAW for Vinylester Handrail @ 5%

Table F5: LCC Components for Phenolic Handrail @ 5%

Material Type	GRP Handrail (Phenolic)
Capital Cost	
Initial Cost	213,924.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,436,570.00
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
5%	
Result	
Present Value at year 0 (PV)	2,436,570.00
Equivalent Uniform Annual Worth(EUAW)	158,502.38

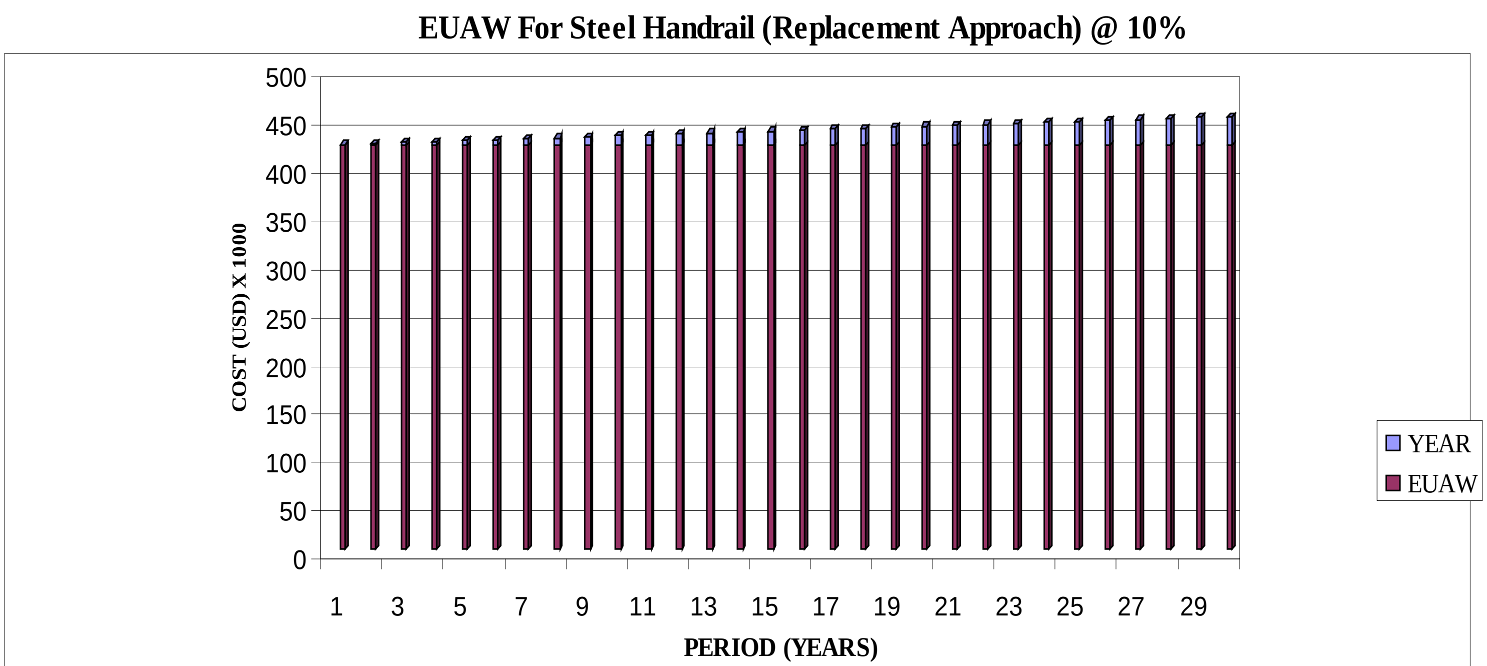


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5	158.5

Figure F5: EUAW for Phenolic Handrail @ 5%

Table F6: LCC Components for Steel Handrail (Replacement) @ 10%

Material Type	Steel Handrail (Replacement)
Capital Cost	
Initial cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
30 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	3,955,306.45
Equivalent Uniform Annual Worth(EUAW)	419,575.93

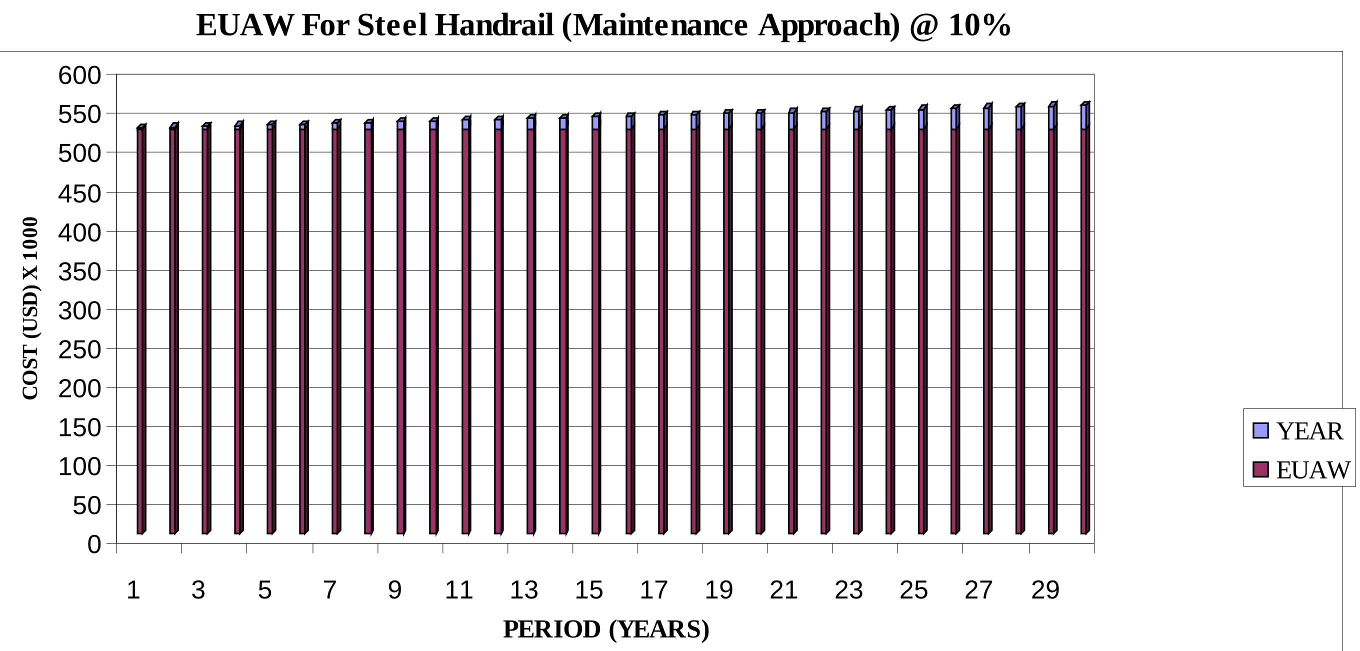


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6	419.6

Figure F6: EUAW for Steel Handrail (Replacement) @ 10%

Table F7: LCC Components for Steel Handrail (Maintenance) @ 10%

Material Type	Steel Handrail (Maintenance)
Capital Cost	
Initial cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Maintenance Cost	
Maintenance Cost every 5 years	1,461,814.00
Period	
30 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	4,895,221.63
Equivalent Uniform Annual Worth(EUAW)	519,281.43

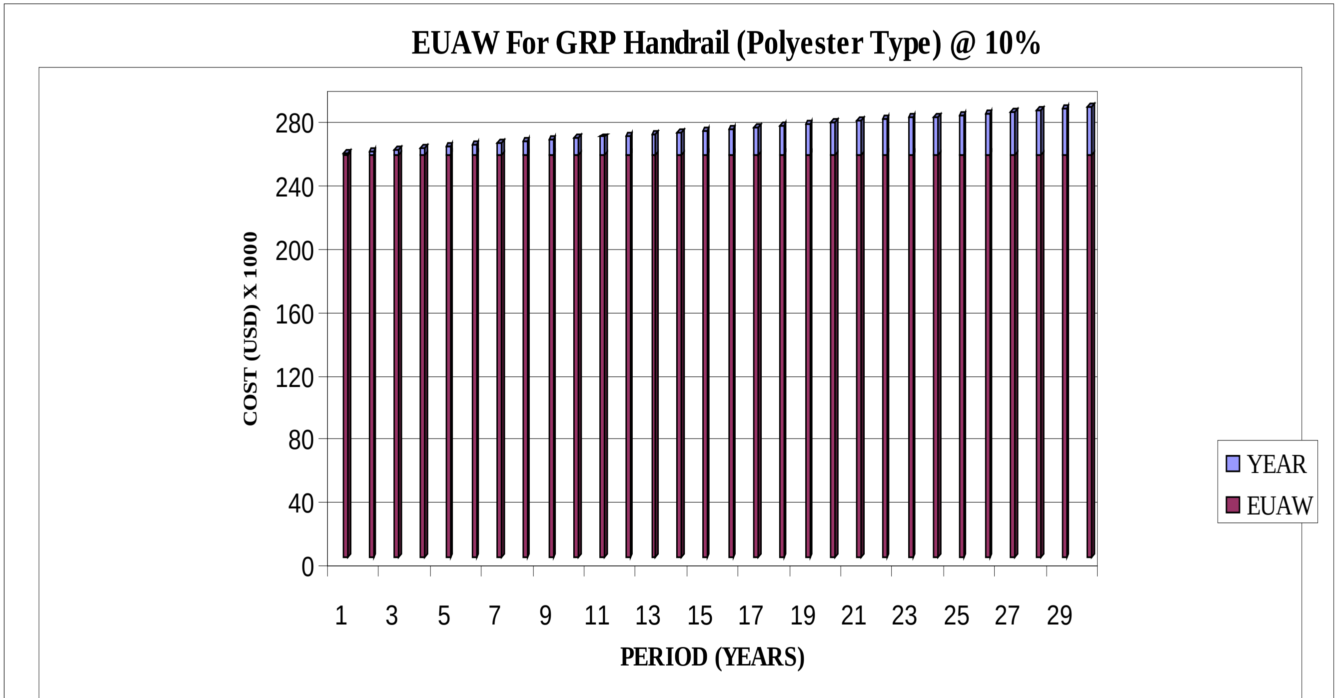


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3	519.3

Figure F7: EUAW for Steel Handrail (Maintenance) @ 10%

Table F8: LCC Components for Polyester Handrail @ 10%

Material Type	GRP Handrail (Polyester)
Capital Cost	
Initial Cost	178,270.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,400,916.00
Replacement Cost	
Replacement Cost	0.00
Period	
30years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,400,916.00
Equivalent Uniform Annual Worth(EUAW)	254,687.36

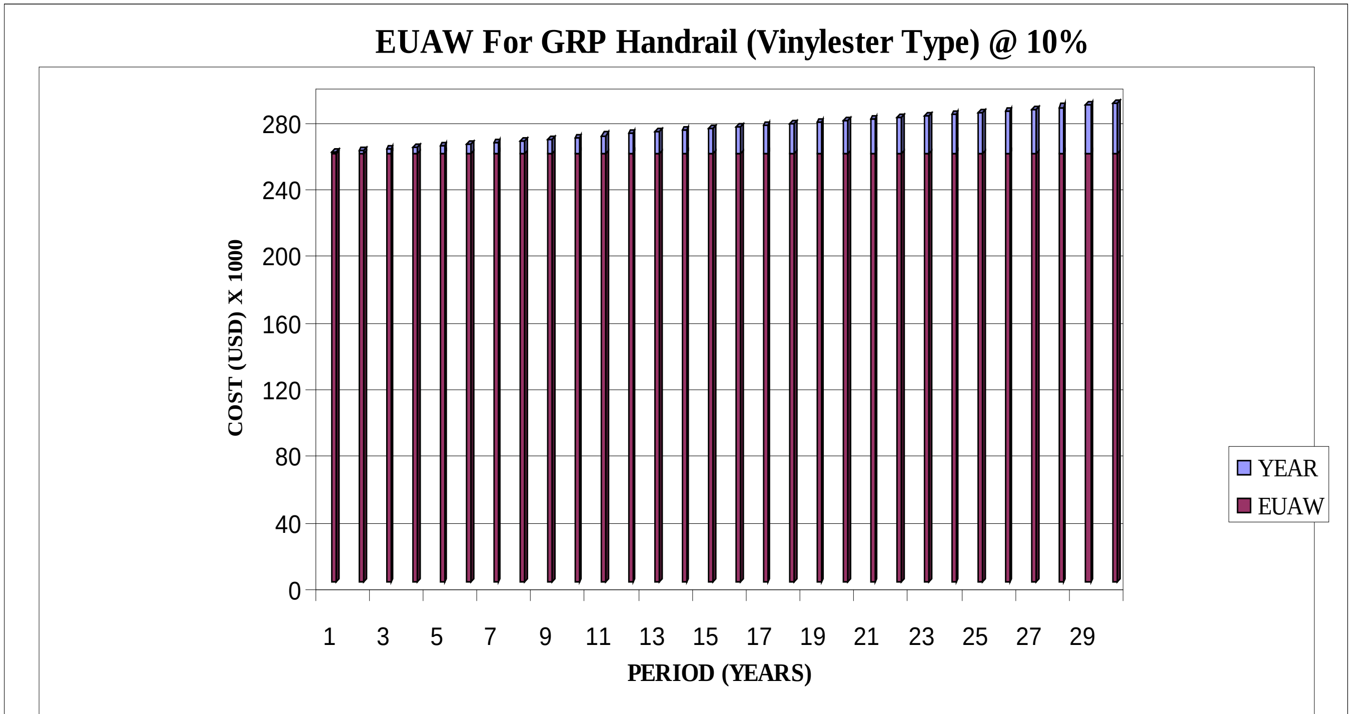


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7	254.7

Figure F8: EUAW for Polyester Handrail @ 10%

Table F9: LCC Components for Vinylester Handrail @ 10%

Material Type	GRP Handrail (Vinylester)
Capital Cost	
Initial Cost	196,097.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,418,743.00
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,418,743.00
Equivalent Uniform Annual Worth(EUAW)	256,578.44

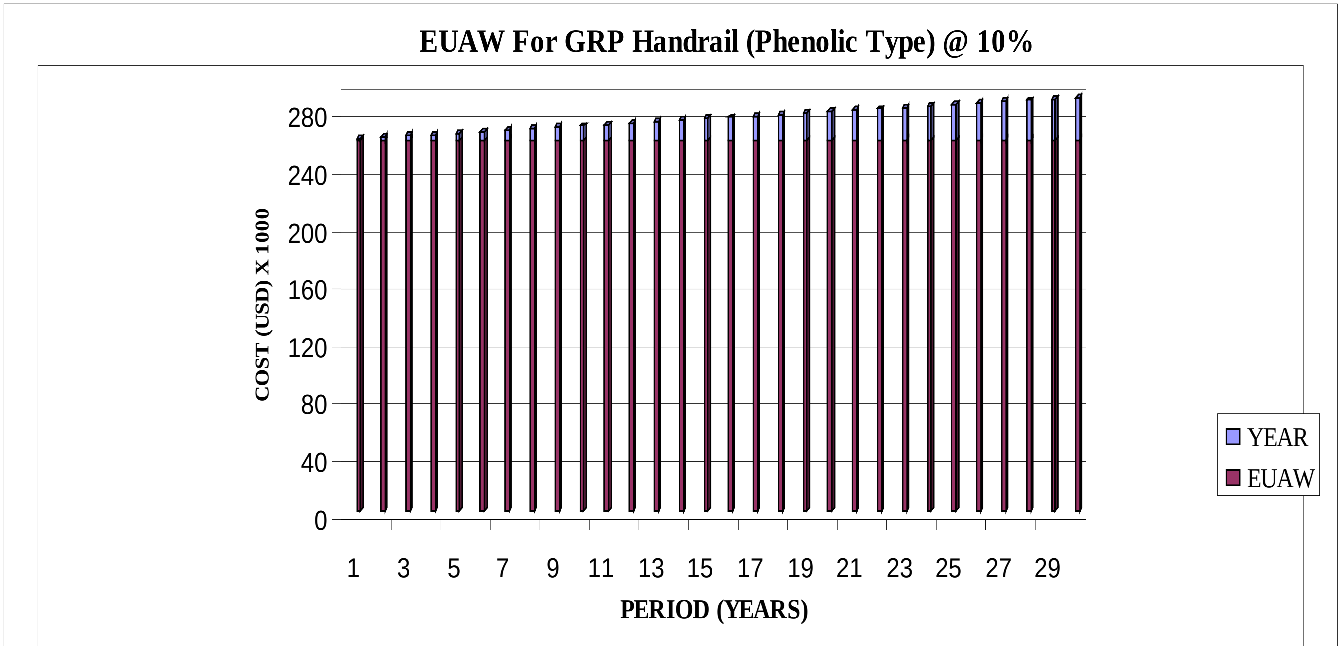


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6	256.6

Figure F9: EUAW for Vinylester Handrail @ 10%

Table F10: LCC Components for Phenolic Handrail @ 10%

Material Type	GRP Handrail (Phenolic)
Capital Cost	
Initial Cost	213,924.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,436,570.00
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
10%	
Result	
Present Value at year 0 (PV)	2,436,570.00
Equivalent Uniform Annual Worth(EUAW)	258,469.51

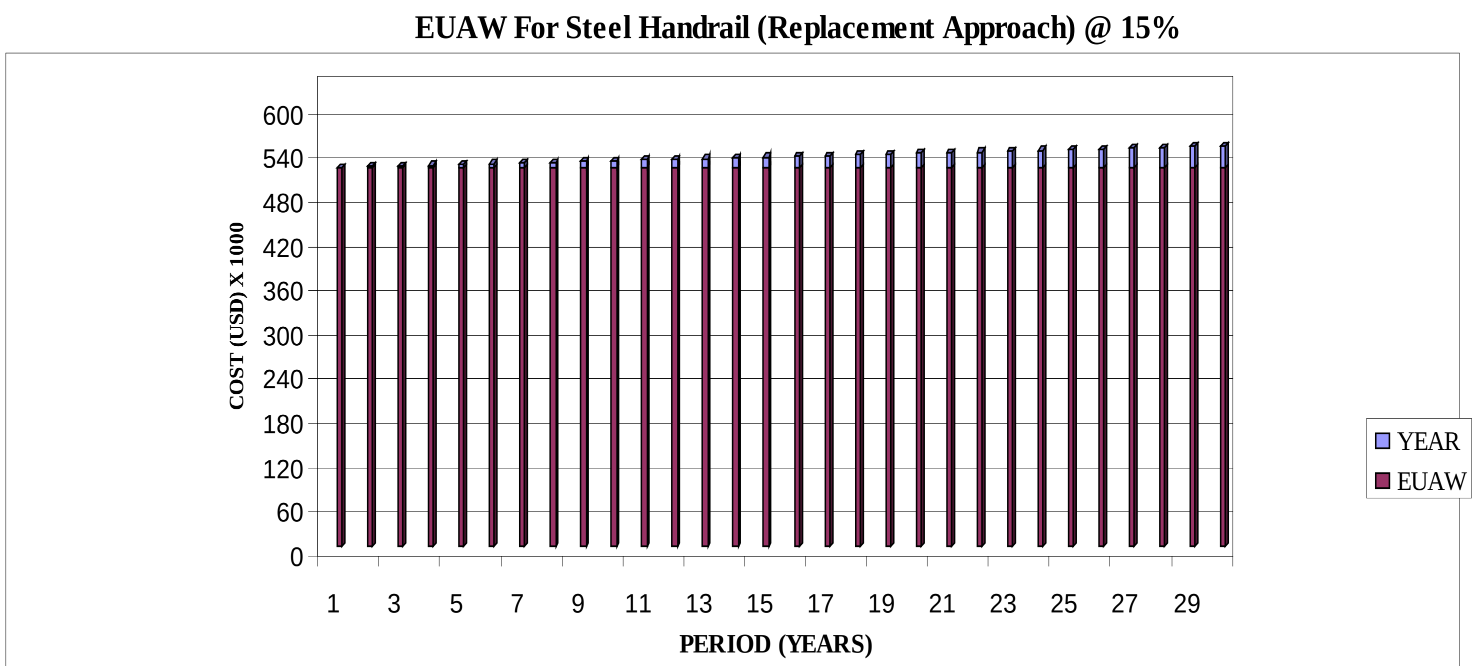


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5	258.5

Figure F10: EUAW for Phenolic Handrail @ 10%

Table F11: LCC Components for Steel Handrail (Replacement) @ 15%

Material Type	Steel Handrail (Replacement)
Capital Cost	
Initial cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Replacement Cost	
Replacement Cost every 12 years	2,935,822.0
Period	
30 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	3,373,088.96
Equivalent Uniform Annual Worth(EUAW)	513,722.12

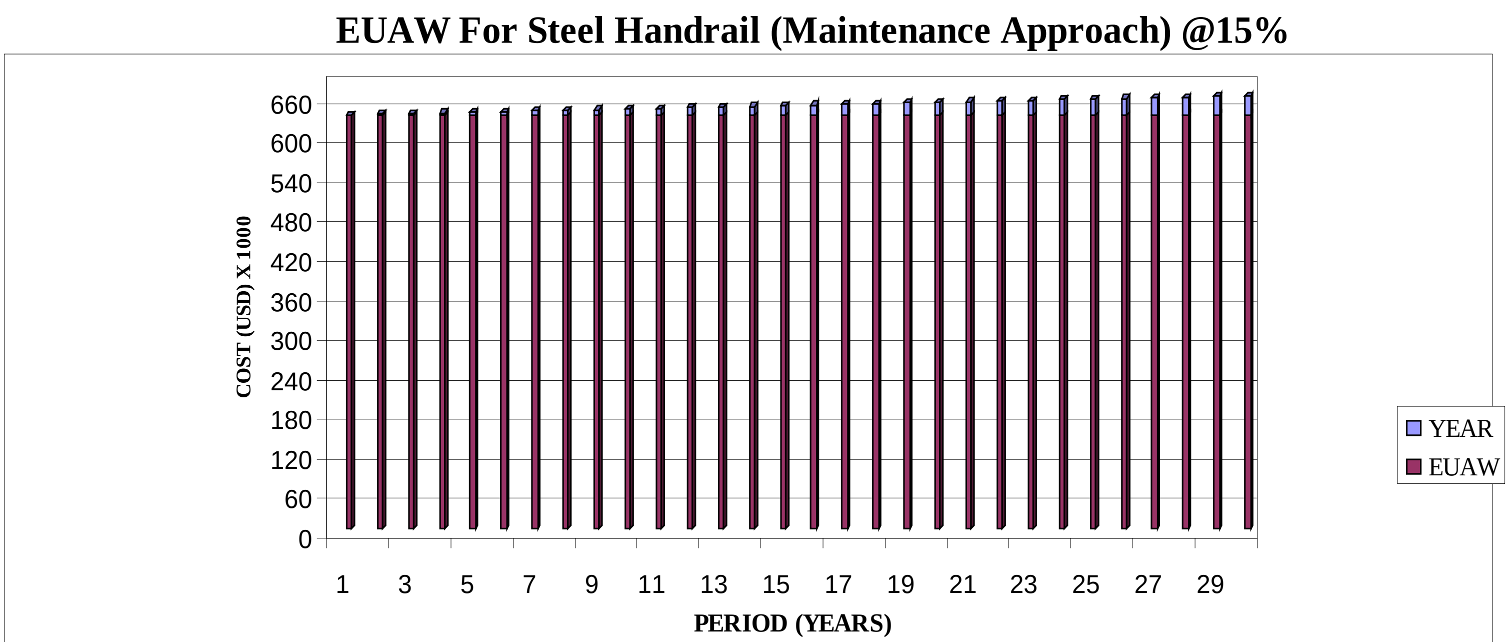


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7	513.7

Figure F11: EUAW for Steel Handrail (Replacement) @ 15%

Table F12: LCC Components for Steel Handrail (Maintenance) @ 15%

Material Type	Steel Handrail (Maintenance)
Capital Cost	
Initial cost	356,540.00
Prefabrication Cost	0.00
Installation Cost	2,365,262.0
Total Capital Cost	2,721,802.0
Maintenance Cost	
Maintenance Cost every 5 years	1,461,814.00
Period	
30 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	4,123,292,55
Equivalent Uniform Annual Worth(EUAW)	627,978.27

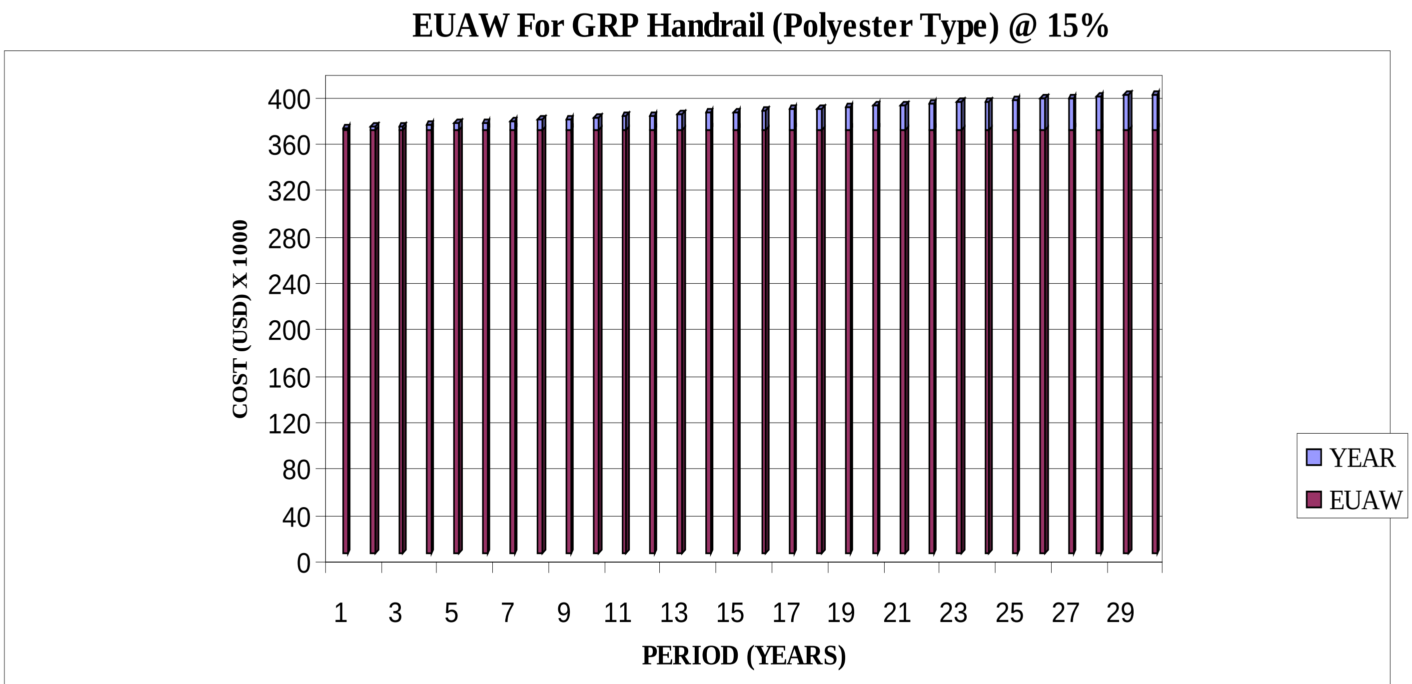


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628	628

Figure F12: EUAW for Steel Handrail (Maintenance) @ 15%

Table F13: LCC Components for Polyester @ 15%

Material Type	GRP Handrail (Polyester)
Capital Cost	
Initial Cost	178,270.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,400,916.00
Replacement Cost	
Replacement Cost	0.00
Period	
30years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,400,916.00
Equivalent Uniform Annual Worth(EUAW)	365,659.98



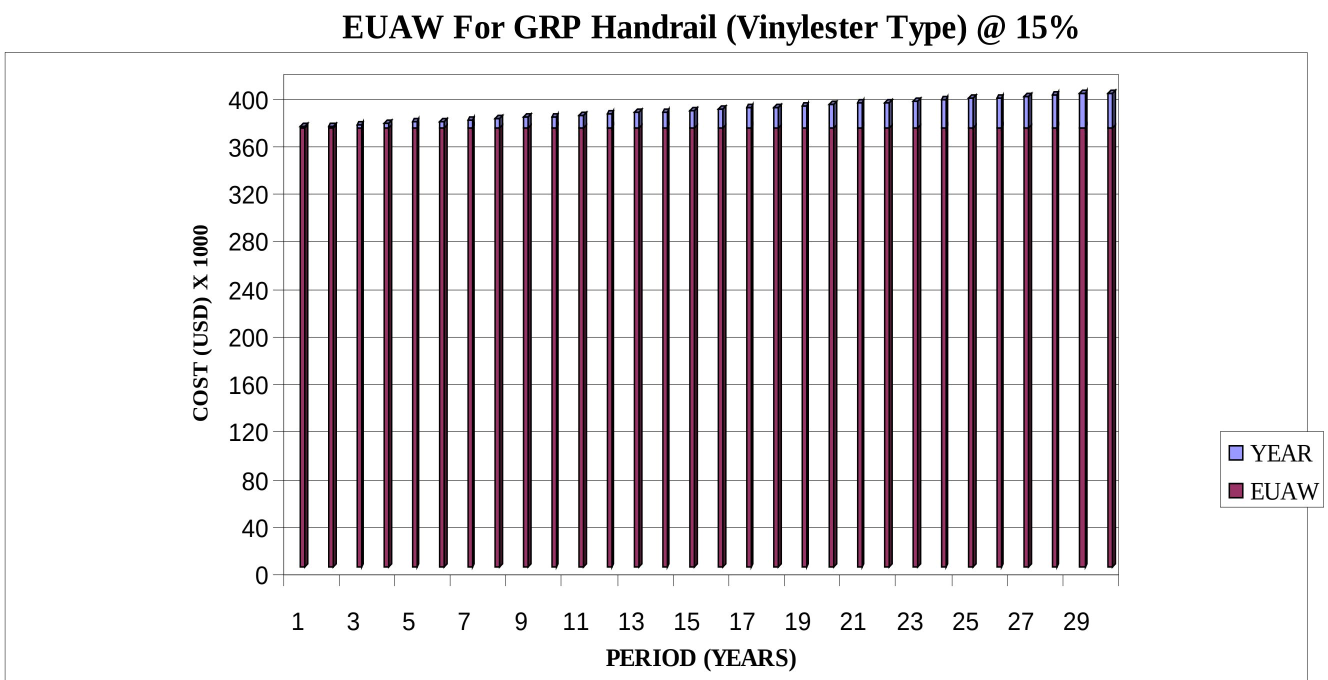
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
EUAW	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7	365.7

Figure F13: EUAW for Polyester Handrail @ 15%

Table F14: LCC Components for Vinylester @ 15%

Material Type	GRP Handrail (Vinylester)
Capital Cost	
Initial Cost	196,097.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,418,743.00
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,418,743.00
Equivalent Uniform Annual Worth(EUAW)	368,375.04

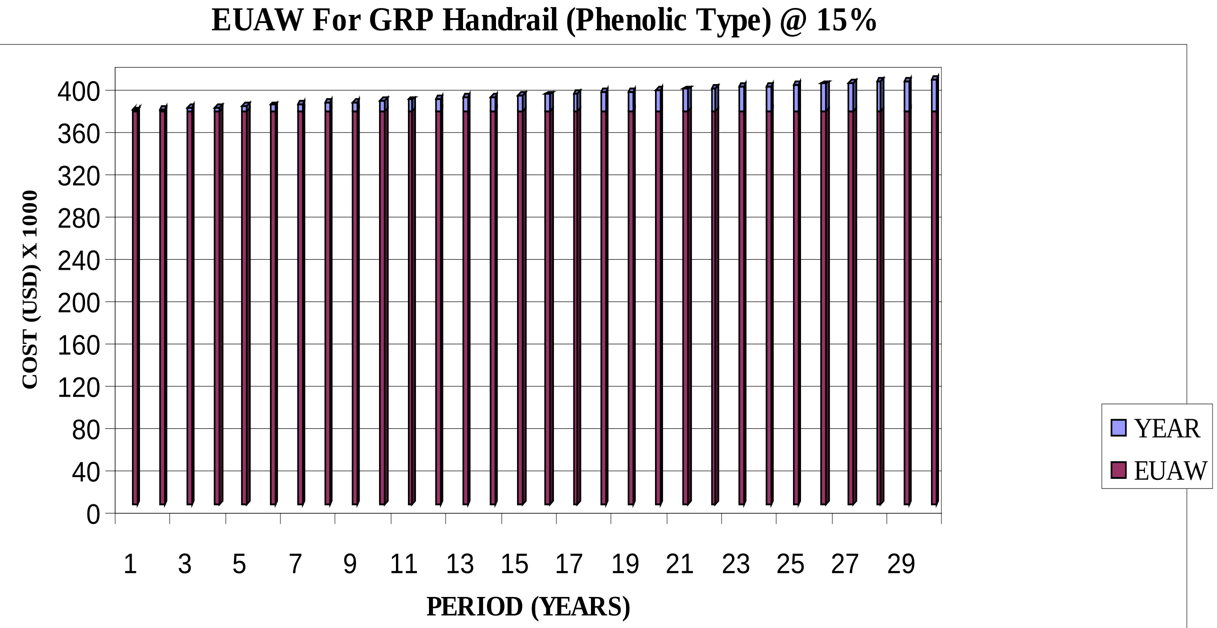


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4	368.4

Figure F14: EUAW for Vinylester Handrail @ 15%

Table F15: LCC Components for Phenolic @ 15%

Material Type	GRP Handrail (Phenolic)
Capital Cost	
Initial Cost	213,924.00
Prefabrication Cost	0.00
Installation Cost	2,222,646.00
Total Capital Cost	2,436,570.00
Replacement Cost	
Replacement Cost	0.00
Period	
30 years	
Interest	
15%	
Result	
Present Value at year 0 (PV)	2,436,570.00
Equivalent Uniform Annual Worth(EUAW)	371,090.09



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EUAW	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1	371.1

Figure F15: EUAW for Phenolic Handrail @ 15%

VITAE

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