ECO FRIENDLY SOLUTIONS FOR GEOSYNTHETICS APPLICATIONS BY EMBODIED ENERGY & CO_2 EMISSION CALCULATIONS

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Abstract— Geosynthetics are the natural or artificial products used along with soil in geotechnical constructions. They have provided innovative solutions to solve difficult problems economically. These are put into application without being aware of their ecological impact. Majority of research in this field is focused on different applications or alternative solutions but there is no analysis of their impact on environment. This paper emphasizes on this critical issue and provides the best available option to go for in order to reduce harm being incurred to nature. This has been brought about by calculating (i) Embodied energy (ii) Carbon dioxide emitted, during manufacture by various methods from several materials.

Index Terms— Geosynthetics, Eco friendly, Embodied energy, CO_2 emission.

I. INTRODUCTION

Geosynthetics have revolutionized the modern construction practices, especially related to Geotechnical engineering. Materials used to prepare these geosynthetics can be either natural or artificial. In this paper artificial materials are focused, as natural materials seldom cause damage to environment. Usage of polymeric materials has advantage in performance but it also has adverse affects on environment in some cases, may not be during application but during manufacturing and extraction. If this damage crosses the threshold then suitable measures have to taken in order to mitigate it. The wide range of geosynthetics includes Geotextile, Geomembrane, Garmats, Gabions, Geotextile tubes, Geobags, Geocomposites, Geosynthetic Clay liners (GCLs) etc. Their application remains sustainable if they avoid side effects that can damage the environment to the maximum extent possible.

II. LITERATURE SURVEY

A. Embodied Energy

Embodied energy is the sum of all the energy required to produce any goods or services, considered as if that energy was incorporated or 'embodied' in the product itself. The concept can be useful in determining the effectiveness of energy-producing or energy-saving devices, or the "real" replacement cost of a building, and, because energy-inputs usually entail greenhouse gas emissions, in deciding whether a product contributes to or mitigates global warming. Embodied energy analysis is interested in what energy goes to supporting a consumer, and so all energy depreciation is assigned to the final demand of consumer.

B. Carbon dioxide emission

Carbon dioxide (CO_2) is the primary greenhouse gas emitted through human activities. Typical embodied energy units used are MJ/kg (mega joules of energy needed to make a kilogram of product), tCO_2 (tons of carbon dioxide created by the energy needed to make a kilogram of product). Converting MJ to tCO_2 is not straightforward because different types of energy (oil, wind, solar, nuclear and so on) emit different amounts of carbon dioxide, so the actual amount of carbon dioxide emitted when a product is made will be dependent on the type of energy used in the manufacturing process. Out of many references listed frequently used values are assumed to be standard as per following table.

Table-1: Embodied energy, CO_2 emitted per kg manufacture along with densities of materials used in analysis

S.No	Material	Energy MJ per kg	CO_2 per kg	Density kg/m^3
1	Concrete (1:1.5:3)	1.11	0.159	2400
2	Bricks (common)	3	0.24	1700
3	Concrete block(medium density)	0.67	0.073	1450
4	Limestone Block	0.85	0.53	2180
5	Steel (general av recycled content)	20.1	1.37	7800
6	PVC (general)	77.2	2.41	1380
7	Cement mortar (1:3)	1.33	0.208	2162
8	HDPE	103.97	6	970
9	LDPE	103.91	6	925
10	Polypropylene	95.4	6	946
11	Sand	0.04	0.8	1700
12	Virgin rock	0.02	0.0048	2650

III. METHODOLOGY

For calculation of Embodied Energy the formula used is **Embodied Energy of Material (MJ) = Weight of Material in kg X Value of Embodied Energy in MJ/kg**

. CO_2 emitted in kg = Weight of Material in kg X Value of CO_2 emitted in kg/kg of material.

IV. CASE WISE ANALYSIS

For various applications like retaining structures, slope protection, coastal protection, landfill; a particular site is selected based on real time plans made for implementation and its replacement with other means is considered with other available methods by proper calculations. The amount of different types of materials used is calculated and values are predicted as per formulae mentioned above.

A. RETAINING STRUCTURES

Retaining structures are designed and constructed to resist the lateral pressure of soil when there is a desired change in ground elevation that exceeds the angle of repose of the soil. Retaining structures can be constructed using different types of materials. Widely used varieties are described below.

i) Concrete gravity retaining wall:

Gravity walls depend on their mass (concrete) to resist pressure from behind and may have a 'batter' setback to improve stability by leaning back toward the retained soil. The details of the design considered for calculation of embodied energy and CO_2 emissions is given in table 2 and the cross-section of seawall is shown in fig 1.

Table 2: Design details of concrete gravity retaining wall

Length of the wall	10 m
Area of the section	7.083 m^2
Volume of concrete used	70.83 m^3
Density of concrete	2400 Kg/m^3
Weight of concrete used	169992 Kg

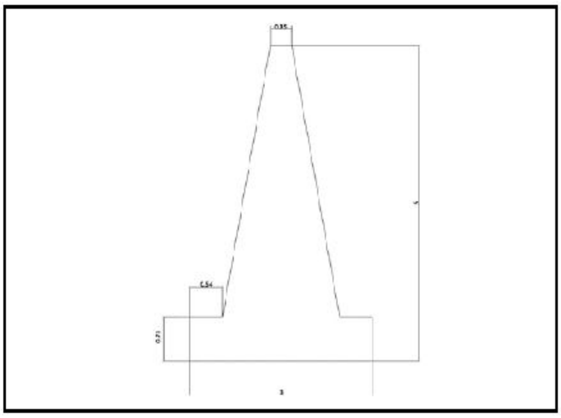

Fig.1 Cross-section of gravity retaining wall

Embodied energy of concrete is 1.11 MJ/kg and CO_2 emission while manufacturing per kg of concrete is 0.159 kg.

Total embodied energy of concrete gravity retaining wall for the above design is **188691.12 MJ** and CO_2 emitted is **27028.728 kg.**

ii) Gabion gravity retaining wall:

A gabion is a cage, cylinder, or box filled with rocks, concrete, etc. Gabion walls are usually battered (angled back towards the slope), or stepped back with the slope, rather than stacked vertically. Steel wire is used as mesh in gabion. The details of the design considered for calculation of embodied energy and CO_2 emissions is given in table 3.

Table 3: Design details of rock gabion gravity retaining wall

Length of the wall	10 m
Height of the wall	5 m
Base width	3 m
Area of section Gabion density	9.5 m^2 1700kg/m^3
Length of the mesh width of mesh	100 mm 80 mm
diameter of steel wire density of steel	2.7 mm 7800kg/m^3
Mesh opening area	8000mm^2
No. of mesh openings in 1m*1m*1m gabion box	750
Total no. of mesh openings in wall	71250
volume of steel	0.147m^3
Mass of aggregates needed	161500 kg
Mass of steel needed	1145.5 kg

Embodied energy of aggregates is 0.083 MJ/kg and CO2 emission while manufacturing per kg of aggregates is 0.0048kg. Similarly, Embodied energy of steel is 20.1MJ/kg and CO2 emission per kg production of steel is 1.37 kg.

Total embodied energy of gabion gravity retaining wall for the above design is **36429 MJ** and CO2 emitted is **2345 kg**.

iii) Steel reinforced cantilever retaining wall:

Cantilevered retaining walls are made from an internal stem of steel-reinforced, cast-in-place concrete or mortared masonry (often in the shape of an inverted T). These walls transfer cantilever loads (like a beam) to large structural footings, converting horizontal pressures from behind the wall to vertical pressures on the ground below. The details of the design considered for calculation of embodied energy and CO_2 emissions is given in table 4 and the cross-section of seawall is shown in fig 2.

Table 4 : Design details of steel reinforced retaining walls

Volume of concrete	39.65 m^3
Area of cross-section of vertical bars	0.000314 m^2
Area of cross-section of transverse bars	0.000112 m^2
Volume of steel	0.35m^3
Density of concrete	2400Kg/m^3
Density of steel	7800Kg/m^3

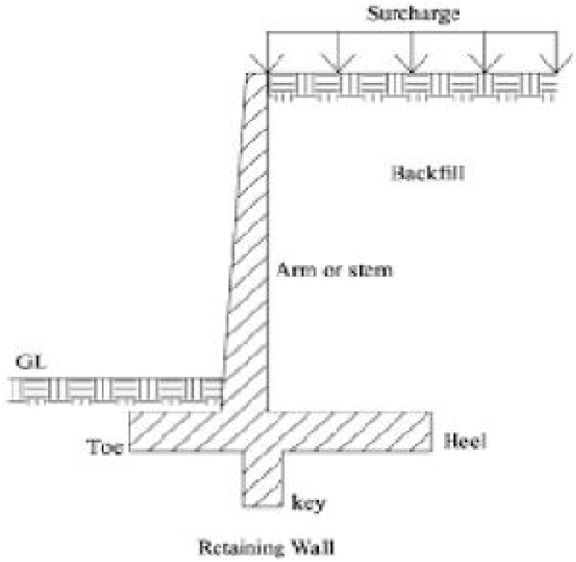

Fig.2 Design details of reinforced retaining wall

Embodied energy of concrete is 1.11 MJ/kg and CO2 emission while manufacturing per kg of concrete is 0.159 kg. Similarly, Embodied energy of steel is 20.1MJ/kg and CO2 emission per kg production of steel is 1.37 kg.

Total embodied energy of gabion gravity retaining wall for the above design is **160527 MJ** and CO2 emitted is **18872 kg**.

B. COASTAL PROTECTION

Coastal erosion and accretion are natural processes. However, in some places erosion is more dominant which result in encroachment of sea towards land. This wearing away of land and the removal of beach is mainly because of wave action and tidal currents. There are many ways to protect sea shore from erosion. One of the methods is by constructing a sea wall. Sea wall can be constructed using different types of materials. Some of them are described below

i) Geotextile tube sea wall:

Geotextile tubes are filled with filling material (like sand, stone etc.) are stacked up and placed along the coast. These tubes are protected generally by rock armor. This combination of tubes and rock armor takes the load from wave action and prevents erosion of sand along the length of seawall. The material used to make Geotextile is considered as polypropylene. The details of the design considered for calculation of embodied energy and CO_2 emissions is given in table 5 and the cross-section of seawall is shown in fig 3

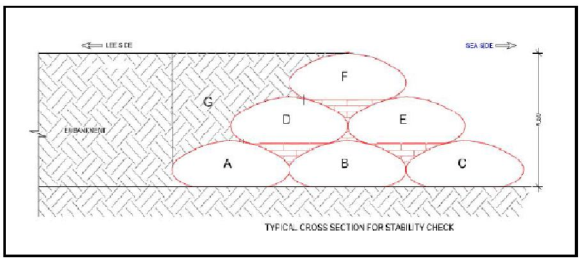

Fig 3: Cross section of Geotextile tube sea wall

Table 5: Design details of Geotextile tube seawall

Length of tube	20 m
Diameter of tube	3 m
Actual Cross-section area	7.065 m^2
Fill cross section area	5.85 m^2
Cross section area of polymer	1.215 m^2
Number of tubes used	6
Total area of polymer	7.29 m^2
Volume of polymer used	145.8 m^3
Density of Polypropylene	946 k/m^3
Weight of Polypropylene used	137927 kg
Volume of sand used to fill	702 m^3
Unit weight of sand	1700 Kg/m^3
Weight of sand used	1193400Kg

Embodied energy of polypropylene is 94 MJ/kg and CO_2 emission while manufacturing per kg of polypropylene is 6 kg. Similarly, Embodied energy of sand is 0.04 MJ/kg and CO2 emission per kg production of sand is 0.8 kg.

Total embodied energy of geotextile tube seawall for the above design is **13205972 MJ** and CO_2 emitted is **1782282 kg.**

ii) Using Concrete tetrapods:

A tetrapod is a tetrahedral concrete structure used as armor unit on breakwaters. A tetrapod's shape is designed to dissipate the force of incoming waves by allowing water to flow around rather than against it, and to reduce displacement by allowing a random distribution of tetrapods to interlock.

To compare the embodied energy of different structures, similar design conditions are considered for different type of structures. Length of seawall considered is 20m. Area of cross-section is same as the above design which is 7.065 m^2. The details of the design considered for calculation of embodied energy and CO_2 emissions is given in table 6;

Table 6: Design details of tetra pods for coastal protection

Length of tube	20 m
Diameter of tube	3 m
Equivalent Cross-section area	7.065 m^2
Volume of concrete used	310.5 m^3
Density of concrete used	1450kg/m^3
Weight of concrete used	450225 kg

Embodied energy of concrete is 0.67 MJ/kg and CO_2 emission while manufacturing per kg of concrete is 0.073 kg.

Total embodied energy of tetra pods seawall for the above design is **301651 MJ** and CO_2 emitted is **32866 kg.**

iii) Using virgin rocks for coastal protection:

To compare the embodied energy of different structures, similar design conditions are considered for different type of structures. The details of the design considered for calculation of embodied energy and CO_2 emissions is given in table 7;

Embodied energy of rock is 0.02 MJ/kg and CO_2 emission while manufacturing per kg of rock is 0.0048 kg.
Total embodied energy of virgin rock seawall for the above design is **16457 MJ** and CO_2 emitted is **3950 kg.**

Table 7: Design details of virgin rocks for coastal protection

Volume of rocks used	310.5m^3
Density of rock	2650Kg/m^3
Weight of rock used	822825Kg

C. SLOPE PROTECTION

Slope protection refers to construction and other man-made activities on slopes with the goal of lessening the effect of landslides. Slope protection can be done using many methods. Some of them are described below :

i) Rock apron for slope protection:

Natural rocks are used as apron to protect the slope. The details of the design considered for calculation of embodied energy and CO2 emissions is given in table 8;

Table 8: Design details of rock aprons for slope protection

Thickness of layer	0.1m
Volume of stone required	7.5m^3
Density of virgin rock	2650 Kg/m^3
Weight of rock used	19875Kg

Embodied energy of natural rock is 0.02 MJ/kg and CO2 emission while manufacturing per kg of concrete is 0.0048 kg.
Total embodied energy of natural rock apron slope protection structure for the above design is**397.5 MJ** and CO_2 emitted is **95.4 kg.**

ii) Cement mortar (1:3) for slope protection:

Cement mortar (1:3) layer is used as apron to protect the slope. The details of the design considered for calculation of embodied energy and CO2 emissions is given in table 9;

Table 9: Design details of using cement mortar for slope protection

Thickness of cement mortar layer Area to be covered	0.05 m 75 m^2
Volume of cement mortar concrete used	3.75 m^3
Density of cement mortar	2162 kg/m^3
Weight of cement mortar used	8107.5 kg

Embodied energy of cement mortar is 1.33 MJ/kg and CO2 emission while manufacturing per kg of concrete is 0.208 kg.
Total embodied energy of cement mortar slope protection structure for the above design is**10783 MJ** and CO_2 emitted is **1686 kg.**

iii) Gabion mattress for slope protection:

Gabion mattress is used to protect slope. Gabion is a box made up of steel mesh. Aggregates are used as gabion material. The details of the design considered for calculation of embodied energy and CO2 emissions is given in table 10;

Table 10: Design details of using gabion mattress for slope protection

Thickness of gabion mattress	0.5m
Length of slope	5m
Spread of slope	15m
Area of slope	75m^2
Gabion density	1700kg/m^3
Length of the mesh	100mm
Width of mesh	80mm
Diameter of steel wire	2.7mm
Density of steel	7800kg/m^3
Mesh opening area	8000mm^2
No. of mesh openings in 0.5m*1m*1m gabion mattress	500
Total no. of mesh openings in mattress	37500
Volume of steel	0.077m^3
Mass of aggregates needed	63750kg
Mass of steel needed	602.9kg

Embodied energy of aggregates is 0.0083 MJ/kg and CO2 emission while manufacturing per kg of aggregates is 0.0048 kg. Similarly, Embodied energy of steel is 20.1MJ/kg and CO2 emission per kg production of steel is 1.37 kg.

Total embodied energy of Gabion mattress slope protection for the above design is **17410 MJ** and CO2 emitted is **1132kg**.

iV) Garmat for slope protection:

Garmat is a composite geomat comprising a layer of bio-degradable mulching material sandwiched between and mechanically bonded to two layers of polymer netting. The product combines the moisture retention and soil enrichment characteristics of the mulch with the tensile strength and durability of the polymer netting. The details of the design considered for calculation of embodied energy and CO2 emissions is given in table 10;

Table 10: Design details of using Garmat for slope protection

Area of slope covering	75 m^2
Mass per unit area of garmat	0.25 kg/m^2
Weight of garmat used	18.75 kg
Weight of HDPE used in garmat	0.07 kg/m^2 (Around 25% of total weight of garmat)
Weight of coir used	0.18 kg/m^2

Embodied energy of HDPE is 103.97MJ/kg and CO_2 emission while manufacturing per kg of HDPE is6 kg.
Total embodied energy of Garmat slope protection structure for the above design is**545.8 MJ** and CO_2 emitted is **31.5 kg.**

iv) Brick tile as apron for slope protection:
Bricks are used as apron to protect the slope. The details of the design considered for calculation of embodied energy and CO2 emissions is given in table 11;

Table 11: Design details of brick tiles as aprons for slope protection

Length of slope	5 m
Spread of slope	15 m
Thickness of brick	0.05 m
Area of cover	75 m^2
Volume of bricks used	3.75 m^3
Density of brick	1700 kg/m^3
Weight of bricks used	6375 kg

Embodied energy of brick (common) is 3 MJ/kg and CO2 emission while manufacturing per kg of brick is 0.24 kg.
Total embodied energy of brick (common) apron slope protection structure for the above design is **19125 MJ** and CO2 emitted is **1530 kg**.

IV. RESULTS

All the results obtained by calculations are presented in relative percentages with respect to highest values of embodied energies and CO_2 emissions in the table below (although the values obtained above are accurate for a particular plan with values as considered, they are explicitly expressed in relative percentages as follows). It is noteworthy that embodied energy and CO2 emission values involved in transportation are not taken into consideration in these calculations.

Table 12: Results obtained in relative percentages

Materials used	Embodied energy w.r.t maximum embodied energy for specific use in percentage %	CO_2 emission w.r.t maximum CO_2 emitted for specific use in percentage %
Coastal Protection		
Geo textile tube , sand	100	100
Concrete tetrapods	2.28	1.84
Virgin rocks	0.125	0.22
Retaining structures		
Concrete gravity wall	100	100
Concrete and steel for Reinforced retaining wall	85.07	69.82
Steel, rocks for gabion wall	19.33	8.55
Slope Protection		
Bricks as apron for slope to prevent erosion	100	90.73
Gabion Mattress	91.03	67.12
GarMat	2.85	1.87
Rock as apron	2.1	5.66
Cement mortar (1:3)	56.38	100

V. INFERENCE

In this paper analysis is done for three major areas of Geosynthetics applications - Coastal Protection, Retaining structures, Slope Protection. It is clearly evident from the table above that

- In coastal protection virgin rock usage had remained eco friendly
- In retaining structures Gabion wall remained eco friendly
- In slope protection Garmat usage is eco friendly

Although this is the scenario observed, preferred usage will be different as there are issues of cost and availability of material. At the same time environmental impact needs to be taken into consideration before choosing a material. In order to evoke its importance the published results can be used as reference.

CONCLUSION

Geosynthetics have replaced many traditional construction practices. If we look at their application in terms of eco-friendliness, some are causing harm to environment whereas some provide a real sustainable solution for effective usage. All the calculations are done with design courtesy from 'GARWARE WALL ROPES Pvt Ltd'. The product data like specifications, material etc were also obtained based on their real time project applications. In order to maintain any system sustainable its adverse effects are also needed to be taken into consideration. In case of applications in coastal protection, slope protection and retaining structures due care needs to be taken in choosing appropriate solution for the problem which should remain eco friendly.

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