Reduction of Greenhouse Gas Emissions Through Utilization of Turf and Root Reinforcement Mat (TRM) Technology in Green Armouring of Civil Structures as Compared to Traditional Rock Armouring

Ian Corne, CPESC, M.Land.Arch., B.E.S.
Application Specialist, Erosion and Sediment Control
Nilex Civil Environmental Group

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Abstract

Carbon footprint impact and the reduction of greenhouse gas emissions is beginning to pervade modern civil construction and operational practices. Designers, owners, communities and nations are struggling to incrementally reduce greenhouse gas emissions. Green armourning of civil structures, historically hard armoured in rock, holds promise for significant reduction of the carbon footprint of construction.

This paper explores the reduction of greenhouse gas emissions by utilizing Turf and Root Reinforcement Mat (TRM) technology in armouring civil structures as compared to traditional rock armouring.
The paper outlines the generally accepted use of geosynthetics in civil structure construction, and surveys the current greenhouse gas reduction strategies in construction.

A case study of the Assiniboine River Diversion Failsafe in Manitoba, Canada outlines successes in the armouring of a civil structure against erosion utilizing TRM technology. A comparative analysis explores the carbon footprint of constructing with this green technology as compared to hard armouring with conventional construction methods such as rock riprap and rock armouring.

Highlighted is the significant carbon footprint efficiency of this Turf and Root Reinforcement Mat green armourning technique.

Introduction

Environmental degradation and greenhouse gas emissions are growing societal concerns. Construction activities represent a large source of environmental pollution of water, air and atmosphere. Much advancement has been made in minimizing water pollution through erosion and sediment control measures. Geosynthetic materials developed to protect structures from erosion have evolved technically to also serve as robust permanent armouring materials to be employed with vegetation as bio-technical systems in lieu of rock riprap. Turf and Root Reinforcement Mats (TRMs) have been utilized for almost twenty years and are now becoming more widely accepted as viable alternatives to rock riprap, especially in regions where armour rock availability is limited. and/or costly.

Originally developed to reduce construction costs of conveyance structures, these green armouring techniques have proven valuable also in pollution mitigation. The United States Environmental Protection Agency 'Stormwater Technology Fact Sheet; Vegetated Swales' outlines the performance characteristics of vegetated swales; including the ability of a vegetated swale to mitigate for pollution as compared to hard-lined swales. The Fact Sheet states; "a conservative estimate would say that a properly designed vegetated swale may achieve a 25 to 50 percent reduction in particulate pollutants, including sediment and sediment-attached phosphorus, metals, and bacteria." (1) Despite the potential of this benefit, there exist no regulations around this form of pollution reduction.

Further, the employment of TRM armouring techniques are now being considered from the perspective of greenhouse gas reduction. This paper will explore, through case study, a comparative reduction of greenhouse gas of a TRM armoured flood control structure as compared to traditional rock armouring and will outline the general acceptance of geosynthetics in design and construction. Current Greenhouse Gas reduction strategies in construction will also be surveyed.

While not examined herein, the reality of increasing aggregate scarcity is an inter-related issue that requires mention. Municipalities are having to transport construction aggregate from quarries of greater and greater distance from infrastructure projects. Further complicating demand is the increasing difficulty in procuring environmental permits to open new quarries. The resulting aggregate scarcity is causing proponents to explore construction methods outside of traditional hard armouring techniques.

Acceptance of Geosynthetics

Robert M Koerner wrote in the Introduction of 'Designing with Geosynthetics', Sixth Edition (2)
"Since 1977, the time of the first geosynthetics conference in Paris, geosynthetics have emerged as exciting engineering materials in a wide array of civil engineering applications, e.g., transportation, geotechnical, geoenvironmental, hydraulics, and private development. The rapidity at which the related products have been and continue to be developed is nothing short of amazing. At no time in the author's experience has a new engineering material come on so strong. The reasons for this explosion of geosynthetic materials onto the civil engineering market are numerous and include the following:

- They are quality-control manufactured in a factory environment.
- They can be installed rapidly.
- They generally replace raw material resources.
- They generally replace difficult designs using soil or other construction materials.
- Their use is required by regulations in many cases.
- They have made heretofore impossible design and applications possible.
- They are being actively marketed and are widely available.
- Their technical database (both design and testing) is nicely established.

- They are being integrated into the profession via generic specifications.
- They are invariably cost competitive against soils or other construction materials.
- Their carbon footprint is very much lower than traditional solutions."

Turf and Root Reinforcement Mat (TRM) Performance

This paper presumes the acceptance of Turf and Root Reinforcement Mats as an equal performance alternative to rock riprap structure armouring. Many different styles of TRMs combined with varying levels of vegetative establishment will address nearly any permissible shear performance benchmark. This paper is predicated on the ability of a partially vegetated TRM to perform to the same permissible shear as 300mm riprap and beyond.

The United States Army Corps of Engineers have defined the permissible shear of 300mm d_{50} as 245 Pascal, 450mm d_{50} as 365 Pascal and 600mm d_{50} as 485 Pascal. (3) By comparison, TRMs perform, per manufacturers' specifications, in the range of 145 Pascal in the unvegetated state to over 700 Pascal in the fully vegetated state.

Product manufacturer specifications are supported through independent testing performed by the American Association of State Highway and Transportation Officials (AASHTO) National Transportation Product Evaluation Program (NTPEP).(4) Originally providing only bench-scale testing, as of 2011 product manufactures now have the option of full-scale testing under the NTPEP program.

In considering TRM as a viable design alternative, it is best to always consider design alternatives as unvegetated. A number of velocity reduction and energy dissipation strategies can be employed to meet permissible shear values up to approximately 400 Pascal in the unvegetated state.

The case study presented herein details an overtopping failsafe armoured in TRM since 1997. There exist many examples of successful TRM armourings where rock riprap would otherwise have been employed.

Greenhouse Gas Reduction Strategies.

Government agencies and private industry are working diligently to find solutions for greenhouse gas emission reduction. Much has been examined on the topics of construction operational efficiency, building design and construction for increased energy efficiency and the creative accounting concept of carbon tax and carbon offsets. This paper presents the relatively simple concept of aggregate reduction in construction. The concept is focused on the elimination of rock riprap in infrastructure armouring through the use of geosynthetic reinforced green armouring.

Operational efficiency has been one strategy for greenhouse gas emission reduction. In 2011 the British Columbia Ministry of Infrastructure and Transportation published 'Reducing Greenhouse Gas Emissions in the B.C. Road Building and Maintenance Industry'. This document outlines the largely operational efficiencies to be gained in practices such as right-sizing on-road fleets, modernizing fleets and equipment, alternate fuels, maintaining trucks and equipment, idle reduction equipment, driver behaviour, solar and grid-based power and road and weather information systems. (5)

Building design and construction for increased energy efficiency has been another strategy for greenhouse gas emission reduction. The city of Edmonton Greenhouse Gas Management Plan aims to achieve a 50 per cent reduction in greenhouse gas emissions from City operations by 2020 (from 2008 levels), an 80 per cent reduction by 2050 with carbon neutrality as the eventual long-term outcome. Investments in street lighting upgrades, higher energy efficiency standard for retrofit buildings, higher energy efficiency standard for the City's Compost Facility, higher energy efficiency standard for new building construction and the purchase of green power have all been deemed cost-effective strategies.(6)

The creative accounting concept of carbon tax and carbon offsets is another widely accepted method of accounting for / offsetting carbon production in construction.
As explained by Christopher Pollon in BC Business Online, "If a polluter releases greenhouse gases into the atmosphere, it can 'offset' those emission by paying to guarantee that an equal amount of carbon remains stored safely somewhere else" (5)

In all, the above strategies employ tactics to increase, by relatively small increments, operational efficiencies and thereby reduce greenhouse gas emissions. Significant reductions appear difficult to achieve.

As will be outlined, the use of green armour technology in civil engineering structures can realize significant savings of carbon emissions when compared to traditional rock armouring. The production, transportation and placement of rock armouring produces large amounts of carbon emissions. The production, transportation and placement of green armour TRMs yield significantly less carbon emissions; usually in the range of ninety-five percent reduction, as will be quantified.

Case Study

The following case study overview is an excerpt from a peer-reviewed project case study prepared for the 2012 International Erosion Control Association Annual Conference. The full case study is available through the IECA. 'Assiniboine River Diversion Failsafe; Fourteen Years' Experience Armouring of a Critical Flood Control Structure Utilizing TRM Technology' outlines the successes as well as the failures of green armouring at this structure. (8)

The Assiniboine River Diversion is a historic structure built in Manitoba, Canada during the 1960s. The diversion stretches north from the Assiniboine River at Portage la Prairie to the south basin of Lake Manitoba. It diverts flood water from the Assiniboine River watershed into Lake Manitoba before flooding can reach lower elevations of the heavily populated city of Winnipeg and environs. The diversion is one of three critical flood control structures in the province of Manitoba. The approximately 330m wide structure was originally designed to carry 708m^3/sec and in May, 2011 portions of the structure received an emergent upgrade to carry 963 m^3/sec.

To safeguard against overland flooding in the event of a major structure breach, the diversion was designed to fail over an 800m stretch of the west levee into a marsh immediately south of Lake Manitoba. Subsequent to numerous breaches and detrimental heavy sediment loading of the marsh, it was decided the unreinforced grass levee was to be armoured to perform as an overtopping failsafe with the intent to stop the levee breaches.

The failsafe was originally armoured in 1997 with a turf and root reinforcement mat. Since then the failsafe has overtopped six times; always with ice and debris in the overtopping water. The failsafe was re-armoured in 2005 and 2009 following significant flooding events. (10)
(Please refer to full case study for complete description of performance successes as well as failures and mechanisms of same.)

Spring 2011 saw significant 1-in-360-year flooding throughout the Assiniboine River watershed and again, the TRM armoured failsafe performed well. It is important to qualify the 2011 performance by illustrating this performance was achieved with only one year of vegetation establishment. 2009 reconstruction was completed in November as winter set in. There had been only one growing season before the flood began in the spring of 2011.

TRM High Performance in Lieu of Rock Riprap
The 2005 reconstruction and re-armouring included a test section approximately 30m long which was armoured with 300mm angular limestone rock armour over woven geotextile. In the 2009 overtopping, the angular armour rock was conveyed off the 5:1 backslope and deposited in the marsh beyond the toe. The adjacent vegetated turf and root reinforcement mat performed well.

Spring, 2009
300mm rock armour conveyed in overtopping, adjacent TRM in the foreground performed

Carbon Calculation
Further to the advantages of geosynthetic use described by Koerner at the opening of this paper, geosynthetics have been commercially sold based on the economic benefits of geotextile in construction as strongly supported by the technical design benefits. This paper begins to explore the benefit of carbon reduction through the use of TRM green armouring technology.

The values presented below were prepared following carbon calculation industry conventions and parameters (9) citing input from authored papers by Allen & Sprague (10), Hammond & Jones (11), Stevens (12), Heerten (13), Alcorn (14) as well as commercial information from Caterpillar (15), industry information from the International Society of Arboriculture (16) and Wikipedia (17).

The comparative evaluations consider a thorough investigation of design and construction input parameters as well as carbon produced in riprap and TRM production, transport and placement. A complete structure armouring will be compared utilizing general engineering 'budget' costs for placement rates and machine charges.

Two comparisons will be given:
'Armouring on Grade' compares a TRM with d_{50} 300mm riprap placed 300mm thick over geotextile directly onto the grade as was trialed in the 2005 re-armouring.
'Subcut and Spoil' compares a TRM with more traditional riprap armour methodology of rock placed at $1.5d_{50}$. This comparison considers d_{50} 300mm riprap placed respecting the general riprap rule of 1.5 depth, or 450mm deep. Further, this comparison considers the carbon utilized in sub-cutting the grade by 450mm. For the calculations in this example, haul distance of subcut material considers only on-site spoiling. Off-site spoiling increases the carbon footprint of earth-moving.

Both examples consider a project size of approximately 18,000 m^2. This example is accentuated by the 200km round-trip riprap haul distance. It is important to note that shorter riprap haul distances also yield high percentages of carbon savings.

	Armouring	Transportation tCO_2	Material tCO_2	Installation tCO_2	Total tCO_2	Carbon Saving
Armour on Grade	300mm rock armour	62.23	494.02	13.80	570.05	
	TRM	5.49	23.33	2.21	31.03	95%
Subcut and Spoil	450mm rock riprap	91.82	735.09	51.75	878.66	
	TRM	5.49	23.33	2.21	31.03	96%

Economic Evaluation
While this paper focuses on the carbon reduction of TRM armouring, it is important to note that an economic evaluation of these two examples illustrates a $170,000 supply and install savings in the 'Armour on Grade' example and a $380,000 savings in the 'Subcut and Spoil' example when comparing TRM with rock armour.

To further explore the economic evaluation, the following examines the concept of 'Carbon Offset'. Considering the City of Edmonton's 'City Operation Greenhouse Gas Management Plan' discussed earlier "[the city] acknowledges a social cost of carbon of at least $40.00 / t CO_2", (18) then the 'Armouring on Grade' realizes an additional $20,600 in carbon offset and the 'Subcut and Spoil' realizes an additional $31,400 in carbon offset .

Conclusion

The greenhouse gas reduction benefit of TRM use as compared to traditional rock armouring is clear.

Widespread acceptance of Turf and Root Reinforcement Mat technology would yield significant greenhouse gas emission reduction where infrastructure construction practitioners are currently struggling to quantify incremental, and relatively small efficiencies.

Moving forward with the lessons learned herein, all geosynthetic construction practices should be evaluated to attribute value to the reduction of all types of construction aggregate.

Aggregate reduction in construction needs to be further examined as a method to significantly reduce greenhouse gas emission in infrastructure construction and life cycle costing.
Further exploration should include:

- Roadbase aggregate reduction through the use of biaxial and triaxial georgids.
- Engineered fill reduction or elimination by utilizing common fill through the use of uniaxial geogrids.
- The reduction or elimination of drain-rock through the use of geosynthetic drainage composites.

The continued development of geosynthetics focusing on the reduction of construction aggregates will serve well in supporting the reduction of greenhouse gas emissions.

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Notes

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8. Corne, Ian D. & Pack, Jill. (2012). Assiniboine River Diversion Failsafe; Fourteen Years' Experience Armouring of a Critical Flood Control Structure Utilizing TRM Techology. pp. 2 - 9

9. Carbon emission reduction evaluations were prepared by Nicole Socha, EIT, Nilex Civil Environmental Group. These calculations are not published as they are the output of an internal company resource

utilized to illustrate the carbon footprint reduction gained through geosynthetic use as compared to traditional construction methods. The calculations behind the evaluation presented have been independently reviewed by The Delphi Group, a Canadian strategic consultancy and solution provider specializing in the area of climate change. Calculation notes as follows (notations embodied within to follow)

Materials

- Embodied carbon for all products (including geosynthetics and aggregates) are based on the University of Bath Inventory of Carbon and Energy (ICE) Report, Version 1.6a.
- 6oz Geotextile was the base to calculate the total carbon emissions for both Riprap and ArmorFlex.

Transportation

- Carbon emissions from material transportation calculated using conversion factors for diesel fuel (Canadian Fuel Consumption Guide, 2012).
- Fuel consumption for haul trucks based on Class 8 vehicles, as defined by the US Department of Energy
- Carbon emissions for quarried aggregates calculated using the distance from quarry to site (specified by User).
- Carbon emissions for Nilex products were calculated based on distance from Manufacturer to Nilex warehouse, then Nilex warehouse to site (specified by User).

Construction

- Carbon emissions for construction machines calculated, based on fuel consumption and production rates from the Caterpillar Performance Handbook, Edition 42 (2012).
- Total hours for construction and placement cost calculations are based on one crew, using one machine.

Carbon

- Carbon absorption statistic of 2.6 tonnes of CO2/yr/acre of trees sourced through the US Environmental Protection Agency

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