# THE EFFECTIVENESS OF USING A MECHANICALLY STABILISED LAYER FOR UNPAVED ROADS IN VIETNAM: SOME CASE STUDIES

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**Abstract** - The construction of onshore wind powers requires an access road network, whose pavement design is challenging due to the complexity of ground conditions subjected to heavy vehicles. A thick pavement structure, therefore, is often required following the conventional design method, leading to uneconomic designs and solutions. The use of multi-axial stabilisation geogrids to form a Mechanical Stabilised Layer (MSL) was considered to optimise the pavement structures as well as to reduce material costs, construction time, and carbon footprint of construction activities while maintaining the technical requirements. This paper presents experimental tests conducted in wind power projects in Vietnam to evaluate the pavement performance with and without MSL. A comparison between stabilised and conventional sections is analysed in terms of the modulus of elasticity, rutting depth, and carbon emission reduction. The study results can be applied to pavement design procedures for residential roads, industrial roads, and highway projects.

**Key words** - Mechanical Stabilised Layer; multi-axial stabilisation geogrids; pavement structure; heavy load; experimental test.

## 1. Introduction

With a coastline of over 3000km, shallow water depths, and high consistent wind speeds at an average of over 20 km/h, Vietnam has emerged as one of the strongest adopters of wind energy among the ASEAN countries in recent years. ASEAN Centre for Energy reported that an approximately 4 GW wind energy was installed by the end of 2021. Onshore and offshore wind power energy are still a potential and promising market for the construction industry in the near future.

In Vietnam, onshore wind farm projects are commonly located in highland or coastal areas. In both regions, the optimisation and construction of wind farms deal with different challenges and restrictions. The access road network connected to the wind turbine, which is estimated at approximately 3% of the total investment cost, is often required to provide temporary access into and through the construction site, as well as permanent for ongoing maintenance activities in a wind farm project [1, 2]. Because of the complexity of the ground condition, which is subjected to heavy construction vehicles in the construction stage, it is challenging for engineers to design and optimize the unpaved road structure. It is noted that the conventional design methods for unpaved roads are usually developed based on field testing with imprecise input parameters. As a result, a thick pavement structure is often required by the conventional design method, leading to uneconomic designs and solutions.

Geosynthetics, particularly geogrids, have been used successfully for subgrade stabilisation to construct unpaved roads in recent years [3, 4]. It is important to distinguish two geogrid mechanisms: the stabilisation and reinforcement mechanisms. Reinforcement mechanism is mainly dependent on the tensioned membrane effect. Under the traffic road, the reinforcement geogrid is deformed and under tension resulting in deep rutting of the pavement structure. [5] mentioned that for a typical rut depth, the tensioned membrane effect is negligible, and works only with channelised traffic. However, the traffic is not channelised in the case of unpaved roads. In contrast, the performance of multi-axial geogrid is based on the concept of mechanical stabilisation, which is defined by the International Standards Organization in ISO 10318 standard. When aggregate particles are compacted over the multi-axial geogrids, they interlock into the aperture of the geogrid, restraining the aggregates' lateral movement. This effect can result in a confinement effect that forms a Mechanically Stabilised Layer (MSL) [6], as illustrated in Figure 1.

***Figure 1.*** *Interlocking mechanism of geogrid with aggregate [6]*

The lateral restraint provided by geogrid contributes to the stiffness of the aggregated layer and hence, the induced strain is reduced under traffic loading [7, 8, 9]. The confinement effect is investigated by [10] by conducting a multi-level shear box. The results of shear box testing show that the confinement effect can be divided into fully confined, transition, and unconfined zones, as shown in Figure 2. It is found that the influence of geogrid on the stiffness of a granular layer decreases in relation to the distance from the geogrid.

The MSL layer also allows loading to spread more effectively than a traditional section, which can increase the bearing capacity of a platform. Multi-axial stabilisation geogrids are considered an effective solution to reduce pavement thickness while maintaining trafficking performance, reducing surface rutting and deformation to minimize maintenance costs.

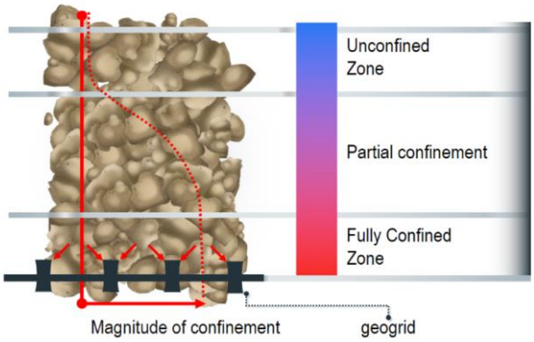


***Figure 2.*** *Confinement zones in MSL structure [10]*

This study discusses the effectiveness of using multi-axial stabilisation geogrid to optimize the unpaved road structure is discussed based on the trials carried out in the B&T Quang Binh Windfarm project and Hacom Hoa Binh 5 windfarm project. The performance of the MSL structure is analysed and compared with the traditional design structure in terms of Modulus Elasticity, the rut depth under the traffic loading, and the carbon footprint. The outcomes of this research confirmed the effectiveness of using MSL structure for unpaved roads. It can be considered for integration into pavement design procedures as a practical approach for any highway projects or traffic areas of industrial and residential projects.

## 2. Design method for unpaved road

The ability of unpaved roads has been investigated by analysing the provision of a stable platform that will not rut excessively under the loading of construction traffic. One of the most common guidelines used in this region is LR1132, which provides good and simple practice guidance for unpaved road design without using stabilisation geogrid based on the deformations criteria of the sub-base layer. For the rut depth of the sub-base layer, which is lower than 75mm, the required aggregate layer thickness can be determined as below [11].

$$h = \frac{190 \times LogN}{CBR^{0.63}} \quad (1)$$

in which: N is the number of standard 80 kN axles; CBR: California Bearing Ratio of Subgrade material.

[12,13] conducted several pilot-scale trials in the UK. The results show greater resistance to rutting of good quality aggregate layer compared to the predicted one using the above equation. Therefore, the equation is adapted with the smaller deformation, which is limited to 40 mm, as below:

$$h = \frac{190 \times (LogN + 0.24)}{CBR^{0.63}} \quad (2)$$

The design procedure for unpaved road structures using stabilisation geogrid is similar to that of conventional pavement design without geogrid. However, it is considered the effect of stabilisation geogrid by using a structural number $f_{SN}$, as below:

$$h = \frac{190 \times (LogN + 0.24)}{f_{SN} \times CBR^{0.63}} \quad (3)$$

The structural number $f_{SN}$ in the pavement design using stabilisation geogrid has been evaluated and validated using large-scale laboratory testing and accelerate pavement testing carried out at US Army Corp.

## 3. Case studies

### *3.1. B&T Quang Binh Windfarm case study*

The B&T Quang Binh wind farm project is located in Quang Ninh and Le Thuy District, the central province of Quang Binh with a capacity of 252 MW, as shown in Figure 3. As one of the largest wind farms projects in Vietnam to complete commercial electricity generation, the cluster comprises Quang Ninh district with 26 turbines, and BT2 wind farm with 24 turbines in the first stage and 10 turbines in the second stage.


***Figure 3.*** *B&T Quang Binh wind farm project location*

In this project, based on the function of the access road and the number of trucks passing through the project site, the access road structure was classified into three entrances: wind farm pavement, trunk road pavement, and branch road pavement. The original section was designed with 310mm thick aggregate sub-base type 2 and 150mm aggregate base type 1. The subgrade was backfilled with 300 mm of mixed stone with a minimum compaction density of 95% and filling sand layer. The typical cross-section of unpaved roads is shown in Figure 4.

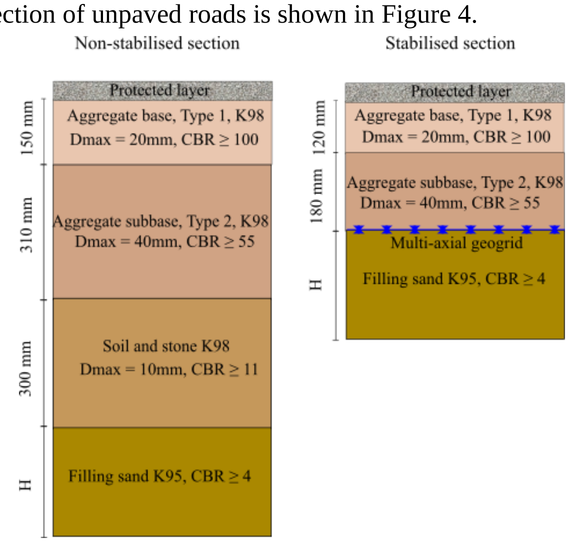


***Figure 4.*** *Non-stabilised and stabilised structure for the unpaved road*

The original section was optimised by incorporating multi-axial geogrid at the bottom of the sub-base layer to reduce the overall thickness. The alternative geogrid-stabilised aggregate base layer design resulted in 180mm of geogrid-stabilised aggregate sub-base type 2 layer, 120 mm of aggregate base type 1 layer and the backfilled sand layer with minimum compaction density of 95% on top of the natural subgrade. In this project, multi-axial geogrid was a triaxial structural geogrid manufactured from a punched and drawn polypropylene sheet. The geogrid has a hexagonal structure forming a series of triangular apertures. The base and sub-base material is made of crushed stone and complies with the requirements following Vietnamese standards.

A trial was conducted on both non-stabilised and stabilised unpaved road sections to validate the performance of MSL. The plan view of trial construction for the access road is shown in Figure 5. The total length of the trial section is 84.0m, divided into two main sections for original structure and stabilised structure. The dimension of each section is 25m in length and 4.5m in width. The remaining areas on both sides of the sections are the preparation and buffer zones.

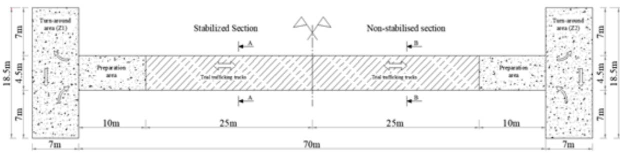


***Figure 5.*** *Detail plan view of trial construction for access road*


***Figure 6.*** *Construction process of trial test in Quang Binh B&T windfarm project*

The construction of the trial section requires several stages, such as subgrade preparation, installation of geogrid for stabilised section, construction and compaction of the sub-base and base layer, as shown in Figure 6. For subgrade preparation, the subgrade of the selected site-won sand shall be levelled, and tight controls placed on the elevation. Both non-stabilised and stabilised sections had the same conditions, with a minimum compaction density of 95% and a minimum California Bearing Ratio (CBR) of 4%. For the stabilised section, a layer of multi-axial geogrid was then placed on the subgrade, which is parallel to the center line of the road. Since the width of the trial section is wider than the typical width of the geogrid, the overlapping of the geogrid was required with a minimum of 0.3 m, and it was connected by using a U-shape staple to secure the geogrid to the ground without wrinkles, prior to placement of base and sub-base layer. The construction aggregate base and subbase were carried out after the installation of the geogrid. The aggregate base and subbase layer were required to be compacted to reach the minimum compaction density of 98%, as required by the project specification. The picture documenting the construction operations is provided in Figure. 6.

Field testing was carried out to investigate the performance of structures with and without geogrid for comparison. The detailed construction of trial and field testing are discussed in the following section.

### *3.2. Hacom Hoa Binh 5 case study*

The Hacom Hoa Binh 5 wind farm project is the largest onshore wind power project in Bac Lieu Province, in the south of Vietnam. This project consists of 26 wind turbines with a total capacity of 80MW in a project area of 32 hectares. The existing soil consists of a 20 m thickness of soft soil layer, with an undrained shear strength of 12 kPa at the ground surface, increasing with depth. Due to the presence of soft ground and high-water level conditions, building the unpaved road network for approaching the construction site is essential. The general layout plan of the access road network is shown in Figure 7.


***Figure 7.*** *The general layout of the access roads in Hacom Hoa Binh 5 Project*

In this project, the unpaved road is designed to achieve a surface elastic modulus (Eyc) of 90 MPa. Based on technical requirements in this project, a stabilised structure using multi-axial geogrid for the unpaved road was proposed to the client. The stabilised section consists of 250mm thick aggregate base type 2 with a layer of multi-axial geogrid at the bottom and 400mm of filling sand layer with a minimum compaction density of 95%. The subgrade layer was backfilled by pumped sand layer to reach the design elevation of the unpaved road structure in this project. The typical cross-section of stabilised section is presented in Figure 8.

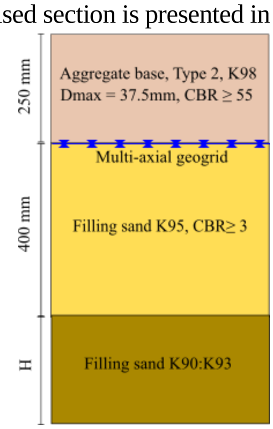


***Figure 8.*** *Stabilised structure for the unpaved road in Hacom Hoa Binh 5 windfarm project*

To investigate the performance and evaluate the feasibility of the MSL, a trial test of the access road was required to carry out on site. The dimensions of the trial section are 50.0 m in length and 5.5m in width. The detailed plan view of trial construction is shown in Figure 9.

The method statement of the trial for the Hacom Hoa Binh 5 windfarm project is similar to the Quang Binh B&T windfarm project. Figure 10 shows the setting up of the trial area in Hacom Hoa Binh 5 Project.

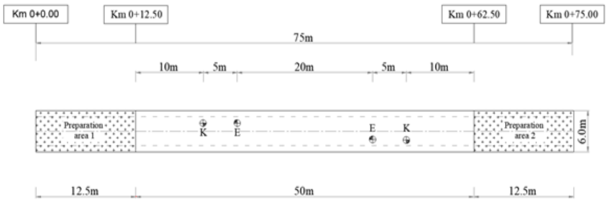


***Figure 9.*** *Plan view of trial construction in Hacom Hoa Binh 5 windfarm project*


***Figure 10.*** *The setting up of trial at Hoa Binh 5 windfarm project*

### *3.3. In-situ testing*

Several local standards and regulations were referred to conduct the site testing and quality control to investigate the stabilised and non-stabilised pavement. Three different kinds of test and test methods were used after completing the base and sub-base course layers.

An experimental procedure called 22 TCN 346-06, which was issued by Ministry of Transport of Vietnam, was applied to control the compaction quality of the aggregate layers. The compaction ratio (K values) is determined by the sand hopper equipment.

For unpaved road structures of onshore wind projects, strain modulus at the second load cycle (Ev2) following DIN 18134:2012-04 [14] is typically referred to for turbine transportation. However, the local practice adopted the elastic modulus at the second cycle of the static plate load test (E2) instead. The testing equipment and procedure adhere to the TCVN 8861:2011 – Flexible Pavement – Determination of Elastic Modulus of Soils and Pavement Components Using Static Plate Load Method Standard.

Trafficking test is uncommon types of tests in Vietnam. However, it is the most effective method to evaluate the performance of the unpaved road section. The test has a similar approach to the US Army Corp of Engineers [15], and AASHTO design guidelines (1993) [16]. Fully loaded dump trucks with a single-axial dual wheel gear were loaded and moved bi-directionally on the different sections of the unpaved road. The tyre position is maneuvered in the buffer zone outside the test area to minimize the effect from the side of the load. The trucks are moving at approximately 5km/h through the test area.

Surface rut and deformation were measured after applying a set number of load cycles. The rutting measurement consists of incremented and accumulated permanent surface deformation in the wheel path. Rut depths were recorded using a straight wooden bar and ruler at the cross-section in each test section.

## 4. Results and discussion

### *4.1. Density test results*

The density test results of the trial construction for the Quang B&T windfarm project and the Hacom Hoa Binh 5 windfarm project are shown in Figure 11. In both cases, the requirement of compaction density for subgrade and base/ subbase layers following the project's technical specification is 95% and 98%, respectively. The result shows that the non-stabilised and stabilised section achieved the required subgrade density and base/sub-base layer density in the Quang Binh B&T windfarm and Hacom Hoa Binh 5 windfarm project. For Quang Binh B&T windfarm, the compaction density of the subgrade and base layer for the non-stabilised section was slightly higher than that of stabilised section. It can be observed that the non-stabilised section required more compaction effort to achieve the required compaction density of 98%. Additional compaction work has been carried out on the non-stabilised section, resulting in a compaction density of 103%.

On the other hand, the compaction density of stabilised section for the subgrade and base layer in Hacom Hoa Binh 5 project achieved 95.6% and 98.8%, respectively. The presence of multi-axial geogrid has significantly reduced the section's compaction effort due to the interlocking mechanism of aggregate material with a geogrid aperture.

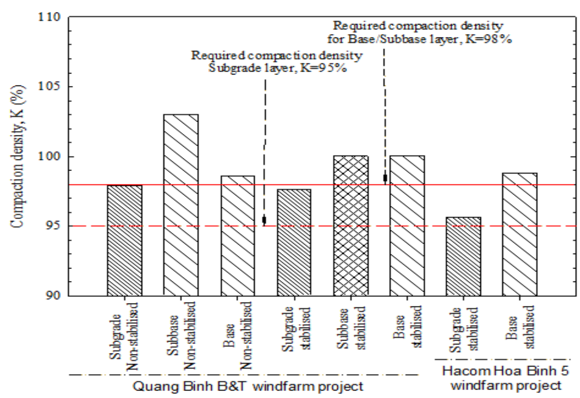


***Figure 11.*** *Compaction density results of trial section in Quang Binh B&T windfarm and Hacom Hoa Binh 5 Projects*

### *4.2. Plate load test results*

Figure 12 compares measured elastic modulus values from non-stabilised and stabilised sections at difference-tested locations for Quang Binh B&T windfarm projects. The increase in elastic modulus values in the stabilised section is evident from the static plate load tests done at various locations. This can be seen in both cycles of loading. In the first loading cycle, the maximum elastic modulus for the stabilised section was 260.4 MPa, about 74% higher than the non-stabilised section. On the other hand, the E value of stabilised section was 94.1% higher than the non-stabilised section at the second loading cycle.

In addition, the modulus of elasticity of the stabilised section is consistent at various points during both loading cycles. The graph also reveals that the elastic modulus obtained in the first cycle was much lower than in the second cycle for both non-stabilised and stabilised sections. The higher elastic modulus values in the stabilised section in the second cycle demonstrate the effect of interlocking. This shows that the MSL can increase the elastic modulus value of the pavement layers.

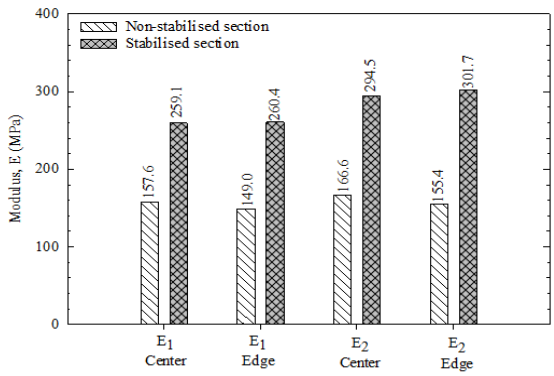


***Figure 12.*** *Elastic Modulus of Non-stabilised section with stabilised section at difference tested location in Quang Binh B&T windfarm project*

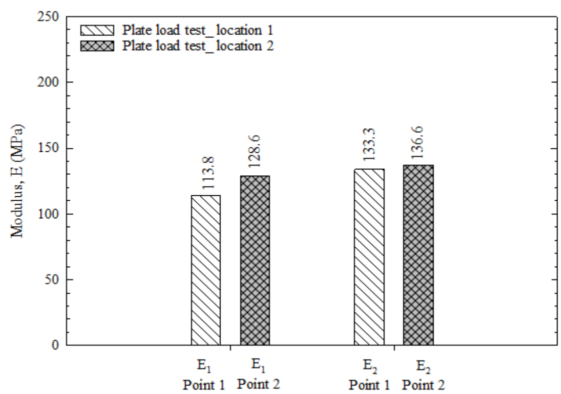


***Figure 13.*** *Elastic Modulus of stabilised section at different tested location in Hacom Hoa Binh 5 windfarm project*

The elastic modulus achieved from the plate load test at different locations for Hacom Hoa Binh 5 windfarm project is shown in Figure 13. The results show that the pavement structure using multi-axial geogrid satisfied the technical requirement of the project specification. The achieved elastic modulus was much higher than the 90 MPa for unpaved road structure design in this project. The maximum elastic modulus value in the first loading cycle ($E_1$) was 128.6 MPa, 42% higher than the required value. Similar behaviour of elastic modulus value in the first cycle loading ($E_1$) and second loading cycle ($E_2$) was found in Hacom Hoa Binh 5 wind farm project. The elastic modulus value in the second loading cycle was much higher in the first loading cycle due to the effectiveness of interlocking mechanism. It is worth mentioning that the ground condition in Hacom Hoa Binh 5 Project was very soft soil with an undrained shear strength of 12 kPa. However, the multi-axial geogrid can achieve the elastic modulus well. The multi-axial geogrid can be used to enhance the elastic modulus of the soil at different soil conditions.

### *4.3. Trafficking test results*

The relationship between rut depth versus the number of visits from the trafficking test for the non-stabilised and stabilised sections is shown in Figure 14. It is noted that the trafficking test was only conducted in the trial section of Quang Binh B&T windfarm project. The results show that the trafficking test result of the control and stabilised pavement structure met the requirements of the allowable rutting depth for the operation of trucks on site, which was a maximum of 75mm. In the first 50 passes, the road surface damage in both structural sections were found to be almost the same. A marked difference has appeared from the 100th passes of the trucks. At the end of the test at the 1200th pass, the rut depth in the control section was much higher than that induced in the stabilised section. The rutting depth of the control structure was about 29mm, which was higher than the value of 22mm in the proposed structure pavement stabilised by multi-axial geogrid. This indicates that using multi-axial geogrid significantly reduces the ruting depth for pavement section.

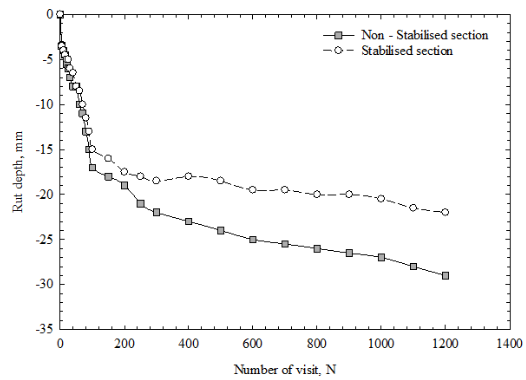


***Figure 14.*** *Trafficking test results for non-stabilised and stabilised section in Quang Binh B&T windfarm project*

### *4.4. Carbon calculator*

The construction activities for an access road such as natural quarrying aggregates, transportation, and delivery from the quarry field to the construction site and backfilling and compaction of aggregate, can be considered as main factors affecting carbon emissions. If any geosynthetic material is used, the other factors related to the manufacturing process, transportation, and installation of material should be taken into account to evaluate the carbon footprint. In this section, the construction of the access road for Quang Binh B&T wind farm project is considered an example for determining the carbon footprint, and the comparison of carbon footprint in the non-stabilised and stabilised section can be assessed. The multi-axial geogrid used in the Quang Binh B&T wind farm project has been certified by international testing organisations and complies with ISO 14025 – Environmental labels and declarations and EN 15804 – Environmental Product Declaration.

The details and assumptions of carbon footprint evaluation are summarised in Table 1. The analysis involves the manufacturing, transportation of geogrid from the factory to the site, land and sea freight, extraction, transportation, and installation of aggregate for an access road.

***Table 1.*** *Details Carbon footprint evaluation*

| **Descriptions** | **Values** |
|---|---|
| Project area, A | 10.000 $m^2$ |
| Thickness of stabilised section, $H_{stab}$ | 300 mm |
| Thickness of control section, $H_{non\text{-}stab}$ | 450 mm |
| Unit weight of granular material, ρ | 2.2 $t/m^3$ |
| Weight of geogrid in $m^2$, $w_g$ | 0.22 $kg/m^2$ |
| Distance from quarry to site, $D_q$ | 21.8 km |
| Distance over land from factory to site, $D_l$ | 267 km |
| Distance over sea from factory to site, $D_s$ | 2136 km |
| Carbon footprint of extracted aggregate, $c_{qr}$ | 0.00438 $kgCO_2e$ /kg |
| Carbon footprint of compaction, $c_{cp}$ | 5.35 $kgCO_2e$ /$m^3$ |
| Carbon footprint of land transport per tonne-km, $c_{tr,l}$ | 0.062 $kgCO_2e$ /T-km |
| Carbon footprint of sea transport per tonne-km, $c_{tr,s}$ | 0.0166 $kgCO_2e$ /T-km |
| Estimated carbon footprint of manufactured geogrid, $c_{gg}$ | 0.8 $kgCO_2e$ /$m^2$ |

The comparison of Carbon footprint emission of stabilised and non-stabilised sections of windfarm access roads is summarized and presented in Table 2.

***Table 2.*** *The calculated carbon footprint for non-stabilised and stabilised sections of access road structure for Quang Binh B&T windfarm projects*

| Material | Activities | Stabilised | Non-stabilised |
|---|---|---|---|
| Aggregate | Source | 28908.00 | 43362.00 |
| | Delivery | 8920.56 | 13380.84 |
| | Compaction | 24075.00 | 35130.00 |
| Multi-axial geogrid | Source | 8000.00 | |
| | Delivery | 114.25 | |
| **Total** ($kgCO_2e$) | | **70017.81** | **91872.84** |
| **Savings** ($kgCO_2e$) | | **23.7%** | |

All measurement in $kgCO_2e$

The result shows that the total carbon emission for the stabilised section is 70017.81 $kgCO_2e$, which is approximately a 23.7% reduction compared to the non-stabilised section. It can be explained that the decrease in aggregate material contributes to the reduction of carbon footprint. The carbon footprint of transportation activity on land is four times higher than transportation in the sea. This disparity leads to a low carbon emission from the delivery of geogrids, despite the transportation distance being the furthest.

## 5. Conclusions

A series of trials were carried out in both wind farm projects to assess the performance of MSL in the unpaved road structure, as discussed in this paper. The following conclusions can be drawn:

- The compaction density of the section stabilised by multi-axial geogrid can achieve well-required compaction density following the technical specification of the project. It can be done quickly with conventional construction methods and equipment. The multi-axial geogrid significantly affects the reduction of compaction time for base and sub-base aggregate because of the interlocking mechanisms of the geogrid.

- The plate load test results proved that multi-axial geogrid significantly increases aggregate material's elastic modulus. The elastic modulus for the stabilised section was 74% and 94.1% higher than that of the non-stabilised section in the plate load test's first and loading cycle, respectively. The increase of elastic modulus of stabilised structure can be considered for integration into pavement design procedures by using the modulus improvement factor, which is considered the effect of multi-axial geogrid in aggregate layer.

- The multi-axial geogrid profoundly affects the reduction of rutting depth for pavement sections. At the same number of passes, the rutting depth of stabilised section was much lower than that of the non-stabilised section. At the same rut depth value, the performance of stabilised section is much higher than that of the non-stabilised section.

- Using multi-axial geogrid has significantly reduced the volume of aggregate materials, carbon footprint and resulted in more sustainable development.

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