World Journal of Engineering and Technology, 2024, 12, 552-574
https://www.scirp.org/journal/wjet
ISSN Online: 2331-4249
ISSN Print: 2331-4222

Use of Geosynthetic Access Mats in Construction

Waseem A. Khatri[1], Abdullah Al Gazlan[1], Nawaf Alubaidi[1], Abiola Ojo[1], Waleed Al Safarji[2]

[1]Consulting Services Department, Saudi Arabian Oil Company, Dhahran, Kingdom of Saudi Arabia
[2]Industrial Projects Department, Saudi Arabian Oil Company, Dhahran, Kingdom of Saudi Arabia
Email: waseem.khatri@aramco.com

How to cite this paper: Khatri, W.A., Al Gazlan, A., Alubaidi, N., Ojo, A. and Al Safarji, W. (2024) Use of Geosynthetic Access Mats in Construction. *World Journal of Engineering and Technology*, **12**, 552-574.
https://doi.org/10.4236/wjet.2024.123036

Received: May 16, 2024
Accepted: July 23, 2024
Published: July 26, 2024

Abstract

A stable surface to move manpower and equipment is a key for the construction operations. To create a stable road surface, the road construction techniques are time-consuming and expensive for a traditional construction which requires compaction of soil, aggregate base, sub-base and asphaltic layers. A Geosynthetic Access Mat (GAM) system can serve as an alternative to other traditional construction techniques to accommodate temporary construction. Due to its rigidity, the mat system can provide substantial vertical resistance to the applied load under a large deflection subject to soil conditions. This paper provides details of GAM specifications, soil conditions, applications, installation procedure, comparison with other soil stabilization methods and Aramco experience for deployments of these mats.

Keywords

Geosynthetic Access Mats (GAM), Bearing Capacity, Ground Water Level (GWL), Soil Testing, Construction, Installation

1. Introduction

In pavement and/or geotechnical engineering applications, weak subgrade is usually pretreated by mechanical or chemical stabilization techniques to form a working platform or temporary roadway for access of traffics and construction equipment, such as cars, trucks and cranes. Weak subgrade usually needs to be stabilized on construction sites for access of traffics and construction equipment. The options for stabilizing the weak subgrade include chemical stabilization (e.g., cement or lime stabilization) and mechanical stabilization (e.g., placement of an aggregate base over weak subgrade). Chemical stabilization and aggregate placement require a large amount of materials as well as heavy machinery work in the process of mixing and compaction. For permanent roadway construction, both chemical stabilization and aggregate placement can be good choices. For temporary roadways, however, these techniques are expensive, unsustainable, and difficult for restoration if needed.

Under this situation, a reusable geosynthetic mat system would be a better solution. Geosynthetics, including geotextile, geogrid, geocell, etc., have been used in different applications in civil engineering in the recent past years, including base course reinforcement, weak subgrade stabilization, crack mitigation in flexible pavements, erosion control, earth retention structures etc.

Geosynthetics can provide lateral restraint through friction or interlocking between geosynthetics and soils The geosynthetics can also provide vertical support through tensioned membrane effect (such as geogrid or geotextile) or bending resistance of the geosynthetic-soil composite layer with flexural rigidity (such as geocell). Furthermore, the inclusion of a geosynthetic layer can also improve the bearing capacity of a weak subgrade. Many researchers have investigated the performance of geosynthetic-stabilized roads using laboratory/field tests and theoretical analysis It is shown that the inclusion of a geosynthetic layer could widen the area of the vertical stress distribution in soil layers caused by a vertical load. Correspondingly, the vertical stress underneath the geosynthetic is reduced so that the weak subgrade can be protected from bearing failure. The permanent deformation of the subgrade would accumulate more slowly due to the reduction of the vertical stress The inclusion of a geosynthetic would increase the radial stress in a stabilized base layer under a vertical load Researchers also investigated the performance of geosynthetics in mitigating rutting, fatigue cracking, and/or reflective cracking in an asphalt layer or asphalt overlay The cracking propagation of a glass-fiber geogrid-stabilized asphalt overlay was investigated by model tests The rutting performance of geosynthetic-stabilized asphalt overlays was investigated by through laboratory accelerated loading.

Besides the traditional geosynthetic products, such as geotextile, geogrid, and geocell, a Geosynthetic Access Mat (GAM) system has been used for temporary support for vehicles, airplanes, and construction equipment over weak ground. Temporary road is a term including many types of solutions for accessing construction sites. Steel, aluminum, wood and plastic are just a few of the materials that are being used around the world. Temporary roads are used in many industries such as; oil and gas, building construction and the forest industry to get access to rural areas.

GAM system usually consists of inter-lockable manufactured polymer panels and anchorages. To avoid warping of the mat system under a traffic load, soil anchors are installed in a certain pattern to fasten the mat layer on the weak subgrade. It can be assembled on site and eventually form a large access mat over a weak subgrade.

GAM system bears a vertical load due to its flexural rigidity under large deflections. Accordingly, the contact pressure at the interface is reduced substantially so that the subgrade can be protected from bearing failure. Due to the resilience of the GAM system, it can be reused and therefore is a cost-effective and sustainable solution for weak subgrade stabilization. Limited studies have been conducted to investigate the performance of the mat system. Applied 39,100 passes of 5-ton tandem-axle load on a steel landing mat over 1%-CBR subgrade and observed a 50 to 87.5 mm subgrade deformation. Compared the performance of five different mat systems by field tests investigated the application of mat systems over extreme soft soil with 0.1% - 0.7% CBR and sand with 2.9% - 4.3% CBR respectively using the same loading truck as [1]. Conducted tests on a mat system over subgrade with different CBR and suggested that the performance of the mat system is largely attributed to the subgrade CBR and the connection between panels.

For the analytical research of these geosynthetic products, there are a few existing. Researchers developed mechanistic-empirical models for geosynthetic-stabilized roadways based on finite element analysis. Some other researchers also put efforts into developing theoretical solutions for geosynthetic-stabilized layered systems as an alternative to the finite element analysis. For instance, considering the geosynthetic as a thin plate with flexural rigidity, derived the solution for a geosynthetic-stabilized layered elastic system, developed an analytical model to quantify the effect of a geosynthetic in a triaxial condition, developed the solutions for both unpaved and paved geogrid-stabilized roadways according to the layered elastic theory [2].

Use and Advantages

For temp road normally gravel or asphalt concrete is used, the material used for gravel roads needs to have requirements in terms of bearing capacity and moisture retention properties. A gravel road is constructed in several layers; subgrade, sub-base and unbounded base layer as shown in **Figure 1**.

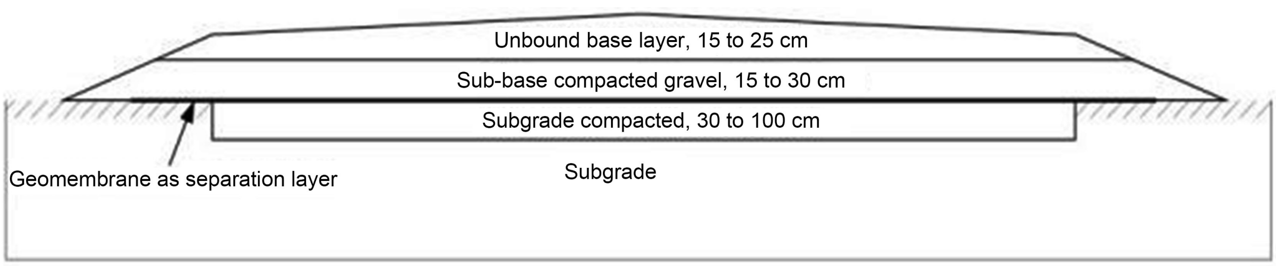

Figure 1. Cross section of a gravel road (Based on [3]).

The road is constructed with a crowned driving surface to prevent water to accumulate on the road surface. The subgrade consists of the underlying soil and if necessary fill material transported to the site. The subgrade is acting as a foundation for the road and therefore a geotechnical investigation is required before constructing the road to determine the bearing capacity of the soil. The sub-base layer distributes the load and is operating as a separation layer between the subgrade and the base. It is also common to use a geomembrane under the sub-base as a separation layer to avoid material erosion. The sub-base is usually constructed with natural gravel and works as a platform during the construction of the upper layers. The unbounded base layer is where the main load spreading occurs

In comparison to traditional gravel or AC road, GAM have various uses in supporting soil for different applications, such as construction, civil engineering, manufacturing, material processing, energy, and transportation. One of the most common uses of GAM is to support soil for cranes and heavy machinery operations. GAM offer several advantages in terms of performance, cost, time, and environment when compared to other methods of soil support, such as compaction, stabilization, or reinforcement.

Some of the advantages of GAM are:

1) Performance:

GAM provides a high level of performance in supporting soil for cranes and heavy machinery. GAM can withstand loads of up to 200 tons or more, depending on the substrate and the type of plate [4]. GAM are more durable, corrosion-resistant, wear-resistant, and easy to handle than metal or wood [5]. GAM also have a low thermal conductivity, which means they do not transfer heat or cold to the ground surface. This reduces the risk of frost heave or thermal expansion that may affect the stability of the soil [6].

2) Cost:

GAM are cost-effective in supporting soil for cranes and heavy machinery. GAM have a lower initial cost than metal or wood, as they are made from recycled materials and require less processing and fabrication [5]. GAM also have a lower maintenance cost, as they do not need any painting, coating, or treatment to prevent rust or decay [7]. GAM also have a longer lifespan than metal or wood, as they do not degrade or deteriorate over time [8]. GAM can be reused multiple times for different projects, which reduces the waste disposal and replacement costs [9].

3) Time:

GAM save time in supporting soil for cranes and heavy machinery. GAM can be installed and removed quickly and easily without requiring any excavation or preparation of the ground surface [10]. GAM can also be transported and stored conveniently, as they are lightweight and stackable [11]. GAM can be used in any weather condition and season, as they are not affected by rain, snow, or temperature changes [12]. GAM can also be used in any location and terrain, as they can adapt to uneven or sloped ground surfaces [13].

4) Environment:

GAM are environmentally friendly in supporting soil for cranes and heavy machinery. GAM can be made from recycled materials, which reduces the consumption of natural resources and energy [14]. GAM also reduce the emission of greenhouse gases and pollutants, as they do not require any burning or combustion during production or use [15]. GAM also prevent any damage or contamination to the ground surface, as they do not leach any chemicals or substances into the soil or water [16]. GAM also promote the growth of vegetation and wildlife, as they allow air and water to pass through their gaps [17].

The Key features of geosynthetic access mats include following:

• Stability: They offer a stable and load-bearing surface over challenging terrains like mud, sand, or wetlands.

• Versatility: Geosynthetic mats are versatile and can be used in various industries, including construction, oil and gas, utilities, and environmental projects.

• Temporary Access: These mats provide temporary access roads, work platforms, or staging areas in areas where conventional access might be difficult.

• Environmental Protection: They minimize environmental impact by preventing soil erosion, protecting vegetation, and reducing the risk of soil contamination.

• Reusable: Many geosynthetic mats are designed to be reusable, making them a cost-effective solution for multiple projects.

• Easy Installation and Removal: Geosynthetic mats are relatively easy to install and remove, allowing for quick deployment and demobilization. Common applications include creating construction site access roads, supporting heavy equipment during infrastructure projects, enabling work in environmentally sensitive areas, and facilitating temporary access for events or emergencies. When considering the use of geosynthetic access mats, it's essential to assess the specific requirements of the project, including load-bearing capacity, environmental considerations, and the nature of the terrain. Proper installation and adherence to manufacturer guidelines are crucial for ensuring the effectiveness and safety of these mats.

2. Design and Standards

For civil engineering works, such as roads and buildings, it is important to determine the ground conditions beneath the structure. This is important because the soil needs to support the expected loads from the structure above to avoid collapse, settlements and other failures. The part of the structure that transmits the load directly to the underlying soil is called a foundation, thus a road could be defined as a foundation.

The process where the applied load on foundations transfers to the ground is called soil-structure interaction. The soil together with the foundation seen as one rigid body is called geo-structure. Different design codes are developed to ensure that the design of the structure is made in the correct manner. The structure is often designed to meet two principal performance requirements, called Ultimate limit states (ULS) and Serviceability limit states (SLS).

ULS ensure that the foundations capacity or resistance is sufficient to support the loads applied and SLS to avoid excessive deformation, which might lead to function loss or damaging of the structure. In Sweden, the Swedish Standard Institute, SIS, has developed a standard for geotechnical design called SS-EN1997 Eurocode 7. This code mentions several types of failures that one need to consider when designing structures on ground.

The Ultimate limit states (ULS) in Eurocode 7 are the following [18]:

• Overall equilibrium in the geo-structure (EQU).

• Internal failure or excessive deformation of the structure (STR).

• Failure or excessive deformation of the ground (GEO).

• Loss of equilibrium of the geo-structure due to uplift by water pressure (UPL).

• Hydraulic heave or internal erosion caused by hydraulic gradients (HYD) Eurocode 7 is also recommending safety factors for soil parameters and bearing capacity.

Bearing capacity: The bearing capacity of the soil is calculated using the general bearing capacity equation. Soils have different properties to support loads and one common measure to describe this is to determine their bearing capacity (q_f), which is defined as the pressure that causes shear failure under, and adjacent to a foundation [19]. The general bearing capacity equations is an Ultimate Limit State calculation and could be used for example, foundations and plates.

3. Bearing Capacity of Soil and Impact of Water

The bearing capacity of a soil could be estimated with the general bearing capacity equation described by Terzaghi. To be able to calculate the bearing capacity one must know the angle of shearing resistance for the soil (ϕ), the soil average unit weight (γ) and the cohesion (c). These parameters could be determined by in-situ tests or in laboratories. The equation depends on three different terms each contributing to the total bearing capacity [20].

$$q_f = q_c + q_q + q_\gamma q_f$$

The first term (1) depends on the cohesion and friction of a weightless material carrying no surcharge load.

$$q_c = cN_c \tag{1}$$

The second term (2) depends on the friction of a weightless material with a surcharge load (σ) on the ground surface. The load (σ) could also be described as the weight of the soil (γ) and the depth (D_f) above the footing. If the footing is placed on the ground surface with no surcharge load, this term can be neglected.

$$q_q = \gamma D_f N = \sigma_q N_q \tag{2}$$

The third term (3) describes the friction of a material with a weight and carrying no surcharge. The variable B depends on the width of the footing and with this form it is assumed that the footing is continues.

$$q_\gamma = \frac{1}{2}\gamma B N_\gamma N \tag{3}$$

These terms together describe the general bearing capacity of a soil, which can be expressed as following:

$$q_f = cN_c + \sigma_q N_q \frac{1}{2}\gamma B N_\gamma N$$

where:

N_q = Bearing capacity factor depending on surcharge load.

N_c = Bearing capacity factor depending on the cohesion.

N_γ = Bbearing capacity factor depending on weight of the soil under the footing.

To determine which parameters that are the most sensitive to the result a parametric analysis is performed (results are presented in **Figures 2-4**). The groundwater level determines the effective weight of the soil hence, three cases for the groundwater are evaluated; one for groundwater at ground level, one for groundwater level at 1 m under the foundation and one for the groundwater level at great depth under the foundation (not having an effect on soil unit weight). In each figure, the maximum plate pressure of 153 kPa is presented as a horizontal dotted line. When the bearing capacity exceeds this line, the soil is able to bear the load. The angle of shearing resistance for the sandy till and the sand is varied between the values presented in below **Table 1**.

Table 1. Values varied in the parametric analysis.

Soil	Angle of shearing resistance φ [˚]	Undrained shear strength, cu [kPa]	GWL
Sandy Till	42 - 45		Ground Level—1 meter below—Grate depth
Sand	28 - 35		
Clay		5 - 300	

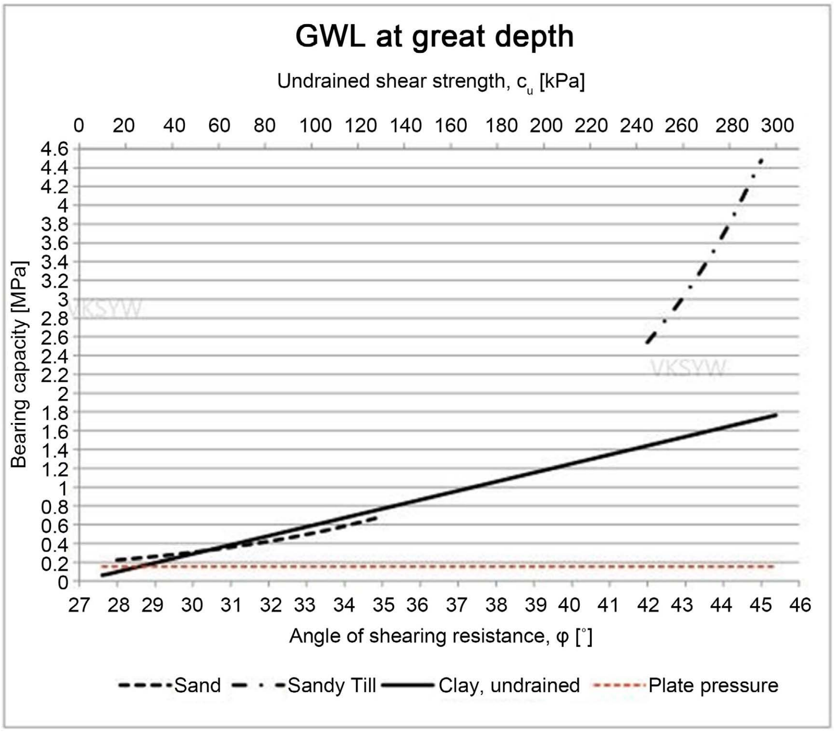

Figure 2. Parametric analyses of the bearing capacity for different soil parameters (GWL at great depth).

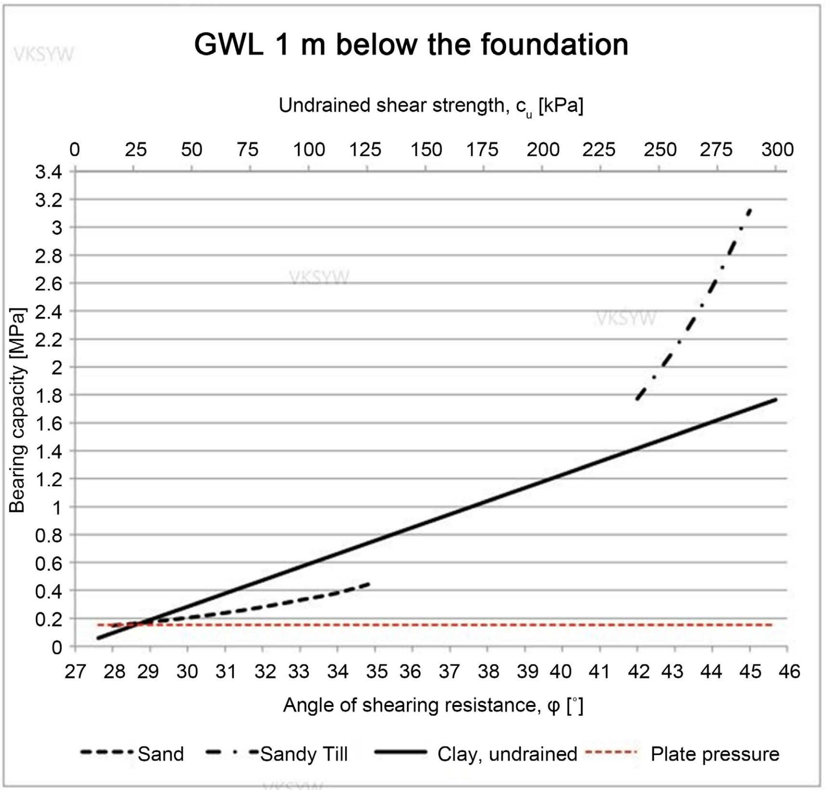

Figure 3. Parametric analyses of the bearing capacity for different soil parameters.

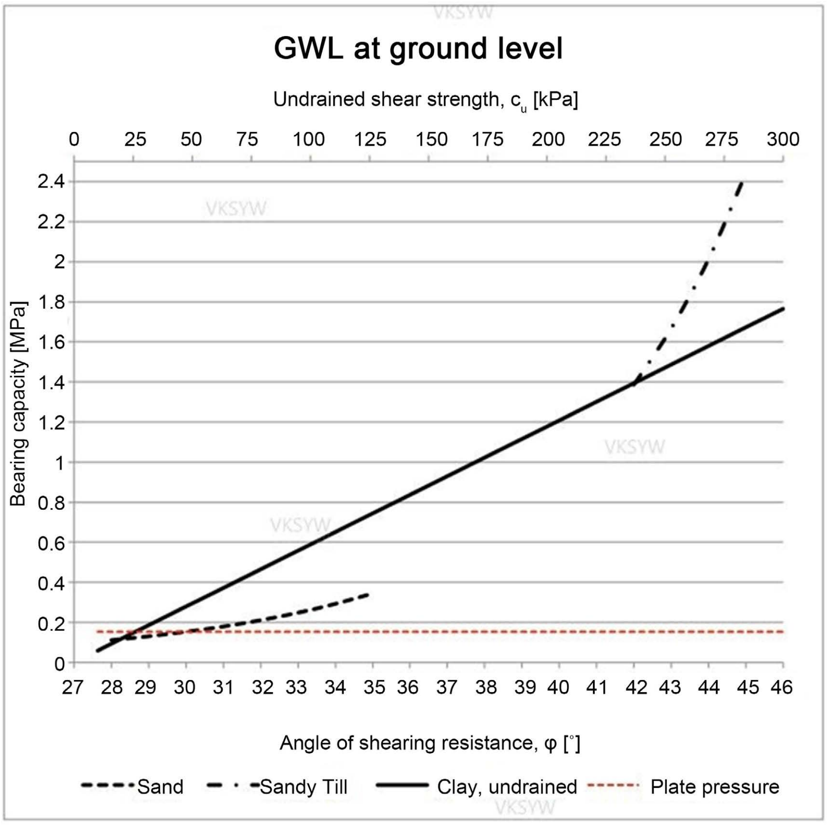

Figure 4. Parametric analyses of the bearing capacity for different soil parameters.

Figure 2 shows the bearing capacity for the three soils is presented. The bearing capacity is calculated for groundwater at a great depth below the foundation. The most critical soils are clay and sand where the bearing capacity for some of the investigated parameters lays under the pressure from the plate. When the angle of shearing resistance is 28˚ for the sand it corresponds to a bearing capacity of 222 kPa. This means that with an angle of 28˚ the sand should be able to handle the load. The undrained shear strength of the clay needs to exceed 25 kPa to handle the considered load. Otherwise the bearing capacity will be too low compared to the maximum plate pressure and a failure will occur. The bearing capacity for the sandy till case is much greater than the pressure of the plate and it is fairly safe to conclude that it should be able to handle the load.

The impact of the GWL is examined in Figure 3. The GWL is assumed to be one meter below the foundation, which affects the effective weight of the soil. The results show that the GWL does not impact the bearing capacity of the clay. This is due to the fact that the bearing capacity of the undrained clay is only dependent on the undrained shear strength cu. In the cases of the sandy till and the sand the GWL has an impact of the bearing capacity. The bearing capacity for sand with an angle of shearing resistance of 28˚ drops from 222 kPa to 148 kPa when the GWL is one meter under the foundation instead of as previously at great depth. This means that with this GWL the soil's bearing capacity is too low to handle the maximum pressure from the plate. To be able to resist the plate pressure the angle of shearing resistance needs to be at least 29˚ which corresponds to a bearing capacity of 173 kPa. For the case of the sandy till the bearing capacity drops with the influence of the ground water but it is still much greater than the plate pressure. For an angle of shearing resistance of 42˚ the bearing capacity is 1771 kPa.

In the last parametric analysis shown in Figure 3, GWL is set to the ground level. As mentioned above the groundwater level affects the effective weight of the soil. In Figure 4, the bearing capacity for the different cases is presented. The bearing capacity for the clay is not affected by the GWL thus the results are the same as in previous cases. To be able to handle the maximum pressure from the plate the sand needs to have at least an angle of shearing resistance of 31˚. This angle corresponds to a bearing capacity of 179 kPa, which is relatively close to the plate pressure of 153 kPa. The result for the case of sandy till shows that with an angle of shearing resistance of 42˚ the bearing capacity is 1386 kPa. According to the calculations above the bearing capacity for the sandy till should be able to withstand the pressure from plate in every case.

According to the results presented in Figure 4, it seems that the mat system for most cases is able to handle the load from the transportation. However, there are some uncertainties about the mats behavior that need to be addressed before claiming that they are suitable for wind turbine transportation. To be able to perform the calculations for a real case, it is required to investigate the soil properties at site. Shear strength parameters, groundwater level and thickness of the topsoil are all parameters that can be determined by geotechnical investigation. The cases in this study are soil with homogenous layers, which may not reflect how the soil is structured in the field. However, when the soil's strength varies in the soil stratum, averages values for the soil parameters can be used for the calculations, and the results from the parametric analysis show bearing capacity and deformations for a range of values.

The effective area is one of the most sensitive parameters that determine if the mat is able to function as an access road. When applying load close to the edge and corner the effective area supporting the load will be relatively small. For this reason, it is necessary to consider a connection system between the mats that has the ability to distribute the load over a larger area. Specific connection system is a critical part when considering the use of GAM as access roads, and needs to be further analyzed.

The analysis is performed with a maximum load on one dual tire. However, trailers carrying wind turbine components often have several axles to distribute the load. Hence two or three pairs of duals could be on one mat at the same time. The reasons for only analyzing one tire load are to investigate critical positions on the mat and due to limitations of the models used. Nevertheless, the effective area distributing the load sets the limit rather than the load itself.

It is also unknown how sensitive the transports are to uneven surfaces. If the lateral gradient of the road is too great there may be a risk for the truck to turn over. This depends on the transport's center of gravity and the overall balance. The requirement from Vestas is that the lateral gradient should be a maximum of 2 degrees. However, only flat surfaces have been considered in this section due to limitations in the models. Whether an inclined or uneven surface affect the bearing capacity or the stability of the transports needs to be investigated.

The maximum allowable deflection is related to the sensitivity of the transports. The sensitivity has not been studied, but to not exceed the requirement of the later gradient of 2 degrees, the maximum difference in deflection on an axle is calculated to be 70 mm. Therefore, if the GAM deform equally under an axle, the stability of transport may not be an issue. Nevertheless, the maximum allowable settlement and deflection should be further studied to not risk the safety of the transport nor the road [2].

Geosynthetic access mats are portable, temporary ground reinforcement systems used to provide stable surfaces over soft or uneven ground. These mats are typically made from materials such as high-density polyethylene (HDPE), polypropylene, or other geosynthetic materials. They are designed to distribute the load of heavy equipment, vehicles, and pedestrians, reducing ground pressure and preventing damage to the underlying soil.

4. GAM Specifications

GAM is made of high-density polyethylene (HDPE), which is a type of thermoplastic polymer that has high strength-to-density ratio. HDPE is resistant to many solvents and has excellent impact resistance. HDPE can also resist up to

450 tons per square meter of compressive load [21].

The thickness of the GAM varies from 12 mm (light duty) to 120 mm (heavy duty), depending on the type and series of the plate. The thicker the mat, the higher the load capacity and durability. The thickness also affects the weight and handling of the plate.

GAM are environmentally stable, meaning they do not absorb any liquid, are chemically inert, and are easy to clean. They also have a fire rating of UL 94 HB, which means they are classified as slow burning materials that have a burning rate less than 76 mm per minute [22].

GAM can be used as a replacement for conventional materials like aggregate base and sub-base course for temporary roadways or bases for cranes and heavy machinery. This reduces the need for excavation, compaction, stabilization, or reinforcement of the soil. It also reduces the environmental impact and cost of using natural resources.

The following **Table 2** summarizes some of the typical dimensions, physical and chemical properties of GAM:

Table 2. Minimum technical requirement of GAM.

Property	Heavy	Medium	Light
Typical Dimensions (mm)	4000 × 2000 × 94	3000 × 2500 × 40	2400 × 1200 × 12
Material	>500	300 to 450	>250
Weight (kg)	HDPE with EPM (Expanded polyetehlene Foam)	HDPE solid composite	HDPE solid composite
Thickness (mm)	50 to 120	10 - 30	
Poison Ratio (Min)	0.30	0.30	0.30
Load capacity (tons/m^2)	415 (max 730)	200 (max 400)	80 (max 120)
Typical Tensile strength (MPa)	30	25	23
Thermal conductivity (W/mK)	0.49	0.40 - 0.47	0.38
Vicat softening temperature (˚C)	132	112 - 130	110

The tensile strength of HDPE depends on the molecular weight, degree of crystallinity, and orientation of the polymer chains. The higher the molecular weight, the higher the tensile strength. The higher the degree of crystallinity, the higher the tensile strength. The higher the orientation, the higher the tensile strength.

The design and use of geosynthetic access mats are guided by industry standards and guidelines to ensure their effectiveness and safety. While specific standards can vary by region and application, some commonly GAM referenced standards:

1) ASTM D6465—Standard Guide for Selecting Materials for Geosynthetic Reinforcement in Subsurface Drainage Applications. This ASTM (American So-

ciety for Testing and Materials) standard provides guidance on selecting materials, including geosynthetics, for use in subsurface drainage applications, which may include aspects relevant to access mats.

2) ASTM D7005—Standard Test Method for Determining the Bond Strength (Ply Adhesion) of Geo Composites. ASTM D7005 outlines a test method for determining the bond strength of geocomposites, which may be applicable to certain types of geosynthetic materials used in access mats.

3) ISO 13438:2017—Geotextiles and geosynthetics—Screening test method for determining the resistance to hydrolysis in water. This ISO (International Organization for Standardization) standard addresses the resistance of geosynthetics to hydrolysis in water, which is relevant for assessing the durability of materials used in access mats.

5. Soil Testing Methods

This section describes some of the soil testing methods that can be performed before using the GAM for soil support. These methods are used to determine the properties and suitability of the soil for supporting cranes and heavy machinery.

Some of the tests that are commonly used to determine the properties and suitability of the soil are:

5.1. Plate Load Test

This test is used to measure the ultimate bearing capacity and settlement of the soil under a given load. A steel plate is placed on the soil surface and loaded gradually until failure or a predetermined settlement is reached. The load-settlement curve is plotted and analyzed to obtain the soil parameters. This test is performed according to ASTM D1194 or BS 1377.

5.2. Standard Penetration Test (SPT)

This test is used to estimate the relative density and shear strength of the soil. A standard split spoon sampler is driven into the soil by a hammer at a constant rate and the number of blows required to penetrate a certain depth is recorded. The SPT value or N-value is calculated as the number of blows per 300 mm of penetration after an initial seating of 150 mm. This test is performed according to ASTM D1586 or BS EN ISO 22476-3.

5.3. Atterberg Limits Test

This test is used to classify the soil based on its consistency and plasticity. The liquid limit, plastic limit, and shrinkage limit of the soil are determined by various methods and apparatus. The liquid limit is the moisture content at which the soil changes from a plastic to a liquid state. The plastic limit is the moisture content at which the soil changes from a semi-solid to a plastic state. The shrinkage limit is the moisture content at which further loss of moisture does not cause any volume change in the soil. This test is performed according to ASTM D4318 or BS 1377.

5.4. Sieve Analysis Test

This test is used to determine the particle size distribution and gradation of the soil. A representative sample of soil is passed through a series of sieves with different openings and the mass retained on each sieve is weighed. The percentage of soil passing each sieve is calculated and plotted on a semi-logarithmic graph. The particle size distribution curve can be used to classify the soil based on its texture and uniformity coefficient. This test is performed according to ASTM D6913 or BS EN ISO 17892-4.

The following **Table 3** summarizes the tests, their purposes, and their standards:

Table 3. Geotechnical tests for soil assessment.

Test	Purpose	Standard
Plate load test	To measure the ultimate bearing capacity and settlement of the soil under a given load	ASTM D1194 or BS 1377
Standard penetration test (SPT)	To estimate the relative density and shear strength of the soil	ASTM D1586 or BS EN ISO 22476-3
Atterberg limits test	To classify the soil based on its consistency and plasticity	ASTM D4318 or BS 1377
Sieve analysis test	To determine the particle size distribution and gradation of the soil	ASTM D6913 or BS EN ISO 17892-4

These are some of the tests that can be conducted before using the GAM for soil support. However, depending on the site conditions and project requirements, other tests may also be necessary, such as compaction test, permeability test, consolidation test, shear test, etc. These tests should be performed by qualified engineers or technicians following the relevant standards and procedures. Once these tests are conducted CSD-Civil group to be contacted for concurrence of the calculations and intended application.

6. Comparison of GAM with Another Subgrade Stabilization

There are other methods which can be used and following is the comparison **Table 4**:

Table 4. GAM vs soil stabilization methods.

Stabilization Method	Ease of Installation/processing	Schedule Impact	Ease of Dismantling and operation	Recycling
GAM	-Easy	Low	Easy to remove and re-assemble	-Can be recycled at end of service life
Mechanical stabilization	-Labor intensive -Expensive	High	Not applicable	-Possible but will be difficult to process
Chemical stabilization: cement and lime	-comprehensive soil testing is required to prepare design mix -Mixing is critical to achieve desired results	High	Not applicable	-Possible but will be difficult to process
Polymer Stabilization	-Environmental assessment required -Can be complicated process and mixing is key	High	Not applicable	-Possible but will be difficult to process

Continued

Stabilization Using Geo web	-Expensive -Labor intensive -Time consuming	Medium	Not applicable	-Geo web possible can be recycled but will require
Aggregate base course or Reclaimed Asphalt concrete	-Compaction in layers	High	Possible	-Possible but will be difficult to process

7. Application

GAM are particularly useful when the schedule impact is important to speed up the project delivery. GAM also allows ease of installation and moving them to different locations as and when required.

7.1. Access Roadways: Temporary or Permanent

Using GAM, can be used for temp or permanent roadways as shown in Figure 5. By using these it can prevent rutting, delays, protect soft substrates and keep the job on time and in budget. Provide reliable access to vehicles, equipment, and workers to the jobsite. Create a staging area to park vehicles and equipment and keep grass and lawns protected.

Figure 5. Temporary access road [23].

7.2. Lay-Down Access and Temporary Parking

GAM have been used on outdoor storage areas or lay-down yards to provide easy access for equipment and vehicles. GAM lock together to provide any shape needed for the size of the lay-down yard entrance.

Product or equipment can be stored on top of the ground protections mats to be kept away from soil or water. Using the ground protection mats can help to create a safe storage area for products and materials and provide additional protection from the elements. The non-porous ground protection mats are easy to keep clean and dry.

The mats have both a flat pedestrian traction pattern and a vehicle traction pattern which can be used for various tire types. The pedestrian side traction may be better suited some vehicles, specifically vehicles that use solid tires.

(a) (b)

Figure 6. Site lay-down areas and access road [24].

Parking or storing material on dirt or another soft substrate is a muddy problem waiting to happen. A critical part of site preparation is safely staging equipment, supplies, and vehicles on a stable substrate as shown in **Figure 6**. When working on loose soil and undeveloped land, creating a stabilized parking and staging pad can prevent vehicles from getting stuck in the mud and require towing or causing costly delays. To avoid getting vehicles and equipment stuck in the mud or rutting the staging area, construction mats can be used to create a large parking or staging pad where the crew can store vehicles and material without fear of inclement weather.

Ground Protection Mats interlock to form any shape or size of staging area needed. Using secure bolts the corners of the parking mats together, the system can be formed into one large staging mat or parking mat. The area can then be safely used for storage, parking or operating equipment and vehicles (**Figure 7(a)**, **Figure 7(b)**).

(a) (b)

Figure 7. Temporary parking [25].

7.3. Construction Mat

GAM is often used for providing access to residential construction projects where equipment is used. Having stable site access in muddy conditions allows work to continue without delays. In addition, to provide site access, the GAM can allow vehicles to enter the work site to deliver materials, and exit without ever driving on the muddy substrate. In addition, GAM can be used to protect grass or other soft substrates without requiring aggregate to be introduced to the job site.

GAM are easy to move by hand, and weight only 87 lb. As they are made of HDPE, they do not rot or degrade in wet conditions. The mats are built tough to last through multiple projects, and have an expected lifespan of 10 years. When building track houses, the 4' × 8' GAM can protect the substrate, prevent rutting, and save the time and money wasted on maintaining plywood access. GAM provides a durable, quickly deployed system which enables contractors to provide stable surface for various applications like access ways and aviation facilities (**Figure 8(a)**, **Figure 8(b)**).

(a) (b)

Figure 8. Construction areas [26].

7.4. Remote Areas Access

Working in remote areas typically means dealing with poor vehicle access roads or even no existing roadways. Contractors who are building energy infrastructure, power lines, or pipelines often need to build a temporary roadway to deliver supplies and heavy equipment to the job site. Contractors build access ways using temporary road for vehicles as they cross soft soil, grass and other sensitive substrates.

GAM can also be used to create construction pads or staging areas on location. Cranes and excavator mats stabilize the ground beneath the legs of the equipment to avoid sinking while carrying loads. Wet weather conditions pose an additional threat to equipment that can slide and create a dangerous situation for workers and equipment. Having a stable network of mats below the equipment can help to spread out the weight and stabilize against sinking or slipping (**Figure 9(a)**, **Figure 9(b)**).

(a) (b)

Figure 9. Temporary access road in poor/water logged soil [27].

7.5. Equipment Access

Skid steers and bobcats are used on projects of all sizes and commonly are used to move dirt, supplies and materials into areas that are difficult to access with a full-size vehicle. When loading supplies across an unstable, sandy or wet substrate, tires and tracks can slip and the equipment can slide to the sides of the access way. Construction mats can be used to protect the equipment as well as the substrate below. Using GAM as skid steer mats can help make the access way more stable and prevent track slipping, rutting, spilling of materials, or even property damage. GAM also provides a layer of protection for curbs and sidewalks against direct impact from vehicles and equipment. While plywood and steel plates can also be used to provide access and stabilize the substrate, there is a tradeoff between durability and portability. GAM strikes a balance between these and provides contractors a durable, water proof solution that is easy to relocate and transport to the next job (**Figure 10**).

Figure 10. Ground protection mats [28].

8. Installation

GAM is designed to be easy to use and install for soil support. They can be laid on any type of ground surface without requiring any excavation or preparation provided that the surface is leveled, stable and the ground is not water logged. These can be used in water logged areas but requires some preparation. They can also be removed and reused after use without leaving any trace or damage on the ground. The following steps describe how to use or install GAM for soil support:

- **Step 1:** Determine the size and quantity of GAM needed for the project. This depends on factors such as the type and size of crane, the load weight and distribution, the soil condition and bearing capacity, and the desired safety factor. The manufacturer or supplier of GAM can provide guidance and calculation tools to help with this step. A geotechnical engineer shall be consulted together with experienced geotechnical investigation company.

- **Step 2:** Transport the GAM to the site using a truck or a trailer. The GAM is lightweight and stackable, which makes them easy to transport and store.
- **Step 3:** Unload the GAM from the truck or trailer using a forklift or a crane. The GAM has handles or holes that allow them to be lifted and moved easily with machines.
- **Step 4:** Lay the GAM on the ground surface where the crane will operate. The GAM can be laid in any direction or pattern depending on the site layout and requirements. The GAM has interlocking edges that allow them to be connected securely with each other (**Figure 11**).

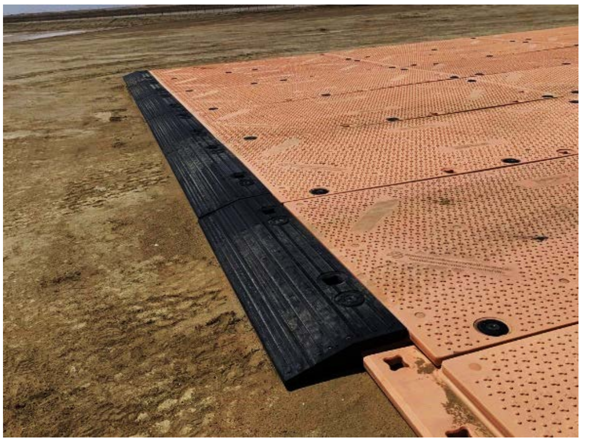

Figure 11. GAM laid on ground and supplied with a ramp [29].

- **Step 5:** Check that the GAM is level and stable on the ground surface. If necessary, use shims or wedges to adjust the height or alignment of the GAM to make them leveled.
- **Step 6:** Drive or position the crane on top of the GAM. The GAM will distribute the load evenly over a large area and prevent any damage or deformation to the ground surface (**Figure 12**).

Figure 12. Positioned crane on top of the laid GAM [29].

- **Step 7:** Perform the lifting or moving operation with the crane as normal (**Figure 13**).

Figure 13. A crane performing the lifting supported by the GAM [29].

- **Step 8:** Remove the crane from the GAM when finished (**Figure 14**).

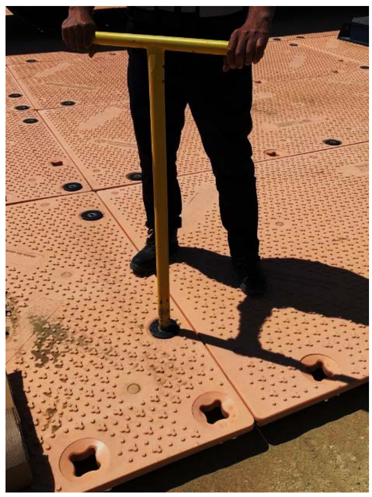

Figure 14. Unlocking the GAM in place [29].

- **Step 9:** Disconnect and lift up the GAM from the ground surface using a forklift or a crane.
- **Step 10:** Load the GAM back to the truck or trailer and transport them to the next site or storage location.

9. Saudi Arabian Oil Company Experience and Pilot

Aramco proposed GAM to be used for access road and site preparation works at Dry Port -King Salman Energy Park (SPARK). This project was selected as these were heavy duty applications to move large amount of sand and required constant moving of GAM to meet project schedule.

These mats did not require specific sub grade preparations and can be laid directly on the leveled unprepared ground. Mats are connected using bolts and allow the movement of light vehicles, trucks and heavy construction machineries. Two types of mats were used in the pilot to support loads up to 80 tons (for light vehicles) and 600 tons (heavy trucks and machineries) vehicle loads. These Mats allowed easy fit, unscrewed, transported and moved to other locations to suit site operations which is not possible in traditional pavement or marl construction. GAMS were successfully used at site for 6 months (**Figure 15**).

Figure 15. Mat application at SPARK construction site [29].

Aramco also successfully deployed the use of GAM to support the replace of flare tip at location F 605. The use of GAM helped to speed up the mounting of cranes and provided a safer working platform to support the crane outriggers. Pavement construction using materials like marl or asphalt layers were possible to avoid. GAM do not require specific sub grade preparations and were laid directly on the leveled ground. GAM are fixed to each other using connectors and allow the movement of cranes (**Figure 16**).

Figure 16. Deployment of plastic plates [29].

10. Conclusions

GAM is a rapid and effective solution to support soils for various applications like construction activities, access roads, parking, crane, heavy machinery transport operation and provide a working platform. GAM provides a stable and level base to operate safely and efficiently without causing any harm to the ground surface or the environment. GAM have many advantages over other methods of soil support in terms of performance, cost, time, and environment. GAM is easy to use and install for soil support and can be reused for different projects. The initial cost of purchase of GAM can be a constraint but these can be justified after number of use and also these mats can be hired instead of purchase which may prove economical for the project.

To determine if the GAM can be used, a geotechnical investigation is required. The parameters that need to be investigated for non-cohesive soils (e.g. sand & sandy till) is the angle of shearing resistance and for undrained soils (silt and clay), the undrained shear strength. These parameters combined with the groundwater level and the unit weight of the soil can be used to determine the bearing capacity. According to the results from the hand-calculations and the calculations in using appropriate models to mimic the load and scenarios be analyzed and designed to meet the project requirements.

If the mats are connected the calculations for the edge and especially the corner load are valid to show the importance of not driving too near the edges. It is important that the connections between the mats distribute the loads between each other especially if they should be used in soft soils. The deflection and stress distribution of the mat are highly dependent on the soil condition considered. The stress distribution for the special case of soft soil on a dry crust shows that the top soil deforms while the greatest stress is mobilized in the dry crust. Research has shown that, it is possible to use the GAM as long as the thickness of the top layer is not too great and that the soil beneath has a dry crust with enough strength. By using temporary GAM, instead of gravel or other traditional construction materials, project schedule and the environmental impact of the construction can be optimized. Groundwork may be necessary to meet the leveling requirements but if a lot of groundwork is needed to be leveled or requires soil improvement, the positive aspects of using GAM to be carefully assessed for economics, project schedule and practicality. Further research is required as how the GAM can be standardized that will reduce the costs and optimize the production and further scale up GAM use in construction.

Acknowledgements

Note that 29% of this paper comes from "Evaluation of plastic mats as access roads to wind farms," a Master of Science Thesis in the Master's Programme Industrial Ecology, VICTOR GILLHOLM & ISAC ROSANDER, CHALMERS UNIVERSITY OF TECHNOLOGY, Göteborg, Sweden, 2014.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Tingle, J.S., Santoni, R.L. and Webster, S.L. (2002) Full-Scale Field Tests of Discrete Fiber-Reinforced Sand. *Journal of Transportation Engineering*, **128**, 9-16. https://doi.org/10.1061/(ASCE)0733-947X(2002)128:1(9)

[2] Sun, X., Guo, J., Han, J. and Guo, K. (2021) Stress Analysis of Geosynthetic Access Mat Systems over Weak Subgrade. *Computers and Geotechnics*, **134**, Article 104071. https://doi.org/10.1016/j.compgeo.2021.104071

[3] Robinson, R. and Thagesen, B. (2004) Road Engineering for Development. Spon Press.

[4] Gillholm, V. and Rosander, I. (2014) Evaluation of Plastic Mats as Access Roads to Wind Farms. Chalmers University of Technology.

[5] Chu, J., Guo, W. and Yan, S.W. (2011) Geosynthetic Tubes and Geosynthetic Mats: Analyses and Applications. *Geotechnical Engineering*, **42**, 56-65.

[6] Bowles, J.E. (1992) Engineering Properties of Soils and Their Measurement. 4th Edition, McGraw-Hill.

[7] Isokon. Isotrack X—Extreme Heavy Duty Road Mat. https://www.isotrack.eu/ground-protection-mats/isotrack-x-series/

[8] European Bioplastics e.V. Bioplastics—Facts and Figures. https://www.docs.european-bioplastics.org/2016/publications/EUBP_facts_and_figures.pdf

[9] Lamancusa, J.A. (2001) Thermal Expansion of Solids and Liquids. Pennsylvania State University.

[10] Auras, R., Harte, B. and Selke, S. (2004) An Overview of Polylactides as Packaging Materials. *Macromolecular Bioscience*, **4**, 835-864. https://doi.org/10.1002/mabi.200400043

[11] Kunioka, M. (1994) Biodegradation and Carbon Recycling of Bioplastics. In: Chiellini, E. and Solaro, R. *Biodegradable Plastics and Polymers*, Elsevier, 245-264.

[12] Malmendal, A., *et al.* (2005) Environmental Benefits from Reusing Clothes. *Resources*, *Conservation and Recycling*, **44**, 317-336.

[13] Isokon. Isotrack H—Heavy Duty Solid Composite Mat. https://www.isotrack.eu/ground-protection-mats/isotrack-h-series/

[14] Isokon. Isotrack L—Lightweight Man-Handable Mat. https://www.isotrack.eu/

[15] Isokon. Isotrack—The Ultimate Ground Protection Solution. http://groundtrax.com/downloads/pdf/IsoTrack%20X%20-%20Product%20Sheet%20Rev%202.0.pdf

[16] Slope Stability Analysis. https://abg-geosynthetics.com/technical/slope-stability-design/slope-stability-design/

[17] Geyer, R., Jambeck, J.R. and Law, K.L. (2017) Production, Use, and Fate of All Plastics Ever Made. *Science Advances*, **3**, e1700782. https://doi.org/10.1126/sciadv.1700782

[18] Swedish Standard Institute (SIS) (2008) Eurocode 7—Geotechnical Design—Part 1: General Rules, Swedish Edition SS-EN1997-1, Swedish Standards Institute, Stockholm.

[19] Craig, R. and Knappett, J. (2012) Craig's Soil Mechanics. 8th Edition, Spon Press.

[20] Terzaghi, K. (1967) Soil Mechanics in Engineering Practice. 2nd Edition, Wiley.

[21] Hopewell, J., Dvorak, R. and Kosior, E. (2009) Plastics Recycling: Challenges and Opportunities. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **364**, 2115-2126. https://doi.org/10.1098/rstb.2008.0311

[22] Muthu, S., *et al.* (2014) Environmental Impacts of Plastic Bags. In: Muthu, S.S., Ed., *Assessment of Carbon Footprint in Different Industrial Sectors*, *Volume* 1, Springer, 69-93. https://doi.org/10.1007/978-981-4560-41-2

[23] Ground Guards (2024) Temporary Roadway. https://www.ground-guards.co.uk/

[24] Construction Mats. Geo Solutions. https://www.geosolutionsinc.com/

[25] Ground Mats, Ground Protection, Load-Bearing Ground and Surface Protection. https://groundprotection.ie/products/ground-mats/

[26] Application: Heavy Duty Equipment Mats, HDPE Composites. https://www.xtremematting.com/hdpe-plastic-composite-mats/

[27] Composite Mats. https://eps.net/en/products/drivable-event-flooring/pisteco/

[28] Track Mats, Ground Protection Mats. https://www.balloohire.com/product/equipment-hire/track-mats

[29] Aramco Project Site Activities Photos Covering Construction and Flare Tip Installations.