Geogrid reinforcement has become a specialized field nowadays, thanks to the rapid advancements in technology. The stability of foundation under an embankment or superstructure soil mass is governed mostly by the shearing resistance provided by the foundation soil. Therefore based on imposed contact pressure, the founding layer poses a problem of bearing capacity. This is where Geogrid reinforcement comes into picture. Geogrid reinforcement thus, may be placed at the interface to prevent a shear failure for both in embankment fill as well as in foundation soil, wherein reduction of settlement comes as next consideration.

The aspect of permeability plays the most important role during loading i.e., during the period of construction. The gain in shearing resistance during the process of consolidation adds to the process of stability. Geogrid reinforcement is used in the foundation substructure to enhance the resistance of the founding layer to avoid failure through excessive deformation or shear in founding layers. Basal reinforcement stabilises an embankment over soft ground by preventing lateral spreading of the contained fill, extrusion of founding layers of soil beneath and overall rotational and local shear failure. Stabilisation is achieved by generating resistive force in Geogrid reinforcement by shear stresses transmitted from foundation fill, through integrally jointed junction of the Geogrid, which places the reinforcement in tension.

Both 'Ultimate' and 'Serviceability' limit states being considered during design. The following aspects are considered in ultimate limit state design:

- Local stability of the embankment fill.
- Rotational stability of the embankment fill.
- Lateral stability of the embankment.
- Foundation extrusion stability.
- Overall stability.

The serviceability limit state considers the following:

- Excessive strain in reinforcement.
- Settlement of foundation.

The other aspect that Geogrid reinforcement caters to in the construction of embankment is the role of a tensioned membrane effect over soft soil cavities, or voids, where subsidence and settlement is taken care off by the effect of reinforcement.

In such cases maximum reinforcement strain is determined to be limited, restricting the surface deformation of the embankment to 1% for principle roads. Reinforcement tensile properties are checked allowing a partial load factor of safety.

Ground improvement is required where imposed contact pressure from super structure is in excess of available safe bearing capacity. A few typical cases are discussed in this paper, wherein such treatment is required using geosynthetic structures, such as:

- Under Road embankments.
- Under access roads or loaded area over soft soil.
- Reinforced soil retaining walls.

Illustration of failure mechanism of road embankments under dynamic loading

In the case of highway infrastructure, construction of highways through
various terrains, such as, through soft compressible strata e.g. marshy land or through backwaters is a common practice. Construction of highways on such strata by conventional methods results in huge dumping of expensive granular fill sinking progressively till a working platform emerges. Even after the process it gives rise to unacceptable settlements leading to damages to the road surface resulting in poor riding quality and requires frequent maintenance. Use of methods such as stone columns, sand a drain etc, are time consuming and uneconomical. Methods of stabilization of soil by addition of stabilizers are usually not adopted due to its inherent uncertainty to control moisture and difficulty in designing them. Normally unbound aggregate layers sink rapidly with application of wheel load, since the sub-grade accepts the load distribution without being able to provide sub-grade reaction. The result is sinking and mixing of sub-grade inducing heavy surface deformation and rutting.

The main reason for the cracking and large settlement in pavements, particularly over soft soil foundation, is high stress concentration below the wheel load as shown in the figure above. Differential settlement caused by pavement failure is caused by the action of wheel load and creates an oscillatory pulse of sway at the bottom of pavement inducing tensile forces and tension cracks. High transient cyclic stress develops below the wheel load, which forces the particles in bottom layers move away from each other. This lateral sway allows pumping of fines from the compressible clayey sub-grade upward, and loose aggregates slowly sink into the void created by the migration of fines. The pavement thickness reduces slowly and deformation increases heterogeneously depending on sub-grade strength and loading conditions. Consequently, ruts and potholes appear on surface apart from cracks etc.

The solution in such a situation is to provide a tensile inclusion of an integrally jointed HDPE Biaxial Geogrid placed as reinforcement cum separator. Inclusion of Geogrid reinforcement distributes the load uniformly over a larger area resulting in development of low stress at sub grade level hence induces far less settlement. Additionally, the Geogrid acts as a separator and prevents sinking of pavement by interlocking the particles within its aperture. With enhanced stiffness the Geogrid provides effective confinement to the pavement particle sway, which has direct influence reducing vertical permanent strain. This happens since the Geogrid is able to confine the aggregate surrounding it in interlocking.

Relevance of Essential Requirements of Geogrid to Function as Soil Reinforcement

In order to perform the function of soil reinforcement Geogrid must have integral joint, stiffness and dimensional stability. A Geogrid is a planar structure formed by a regular network of tensile elements with apertures of sufficient size to allow interlocking with surrounding soil, rock earth. They are also characterized by high dimensional stability, high strength and high tensile modulus at very low elongation (achieved by patented processes of orientation of polymer molecules). They are of two varieties, viz., uni-axially oriented and bi-axially oriented with enhanced strength in one or both the directions. They are primarily used for soil
reinforcement. Biaxial Geogrids are used under pavement as stresses are biaxial in nature in Bousine type load distribution.

The Ministry of Road Transport & Highways (MoRTH), in India, specification for Geosynthetics in CI:701.2.2 (4th Edition), defines Geogrid properties as:

“Geogrid shall be made from integrally jointed mono or bi-directionally orientated or stretched mesh made from Polyethylene or Polypropylene or Polyester or similar polymer, with high secant modulus, is square, rectangular, hexagonal or oval mesh form. Their junction strength shall be high with high creep resistance, and dimensional stability. Their open structure shall permit effective interlocking with soil, aggregates, rock etc., they shall be used as a tensile member or reinforcement”

Therefore just any other grid shaped look alike product is unlikely to function as “Geogrid”, (such as geonets, coated or uncoated woven or knitted fibrillated mesh/fabrics/textiles, fused tape-form mesh elements etc), unless they have these three essential characteristics mentioned above. Use of such look alikes can lead to serious consequences since they don’t conform to soil Geogrid interaction requirements defined in BS 8006-1995. These are disqualified for use as Geogrid, as they lack integral joint, and have poor junction strength to ensure interlocking of the soil, which provides confinement to soil particles leading to load transfer from soil to Geogrids.

HDPE/PP Geogrids which made their appearance first in the early 70’s have a long development history. Current technology is extremely advanced with decades of research and evaluation, building user confidence. They are used as long term soil reinforcement in innumerable structures for last 40 years and standardized all over the world, including ASTM, BS 8006-1995 & FHWA. HDPE/PP extruded punched sheet, integrally jointed Geogrids conform to the true definition of Geogrids, providing ideal junction strength, dimensional stability, oval aperture for optimum interlocking, connection strength for Geogrid continuity and load transfer from soil to grid, long term design strength and service life of 120 yrs. The design of reinforced soil walls for highways require to meet MoRTH specification in India, meeting provisions of BS 8006:1995 and FHWA, with seismic load considerations.

**Ground Improvement using Integrally jointed Geogrids**

The soil stratum comes under high bearing pressure when construction of highways takes place over poor soil. Such construction requires improvement of foundation soil strata and bearing capacity. Improvement of soil strata using Geosynthetics is done by use of layers of Bi-oriented Geogrids. Use of polymer Geosynthetics for ground stabilization provides long term and durable solution. The oriented Geogrids are inert to chemical and biological agents. Their use allows for both economy and rapid construction.

The volume of earth to be filled in these cases is directly dependent on the strength of sub-grade. Enormous volume of earth fill is required if the usual marshy terrain needs to be developed as a working platform for a proposed expressway. The typical conventional increase in requirement of aggregate sub-layer due to changing CBR is shown below. It may be noted that for CBR approximating below 0.25, the requirement can be limitless (very high), depending upon available boundary condition of fill. The foundation soil is improved by using layers of Bi-oriented Geogrid to the required depth and compacting soil over it in layers. This result in additional confinement of the base soil while taking shear stresses developed in the soil, thereby increasing the bearing capacity. Use of Geogrid reduces requirement of sub-base thickness by 40-50% and is a proven and accepted practice in highway construction worldwide.

Integrally jointed biaxial oriented Geogrids are high strength planar polymer materials which impart strength to soil mass with its interlocking action with the soil particles. Installation of layers of Geogrids within the bearing soil mass or Geocell mattress improves soil load bearing capacity. The treatment can even be used to improve the bearing capacity of soft compressible soils such as marshy land or soft compressible clay (Black Cotton soils).

The soil interlocking mechanism is demonstrated in integrally jointed oriented Geogrid due to 95% junction strength, providing unique pseudo-cohesive confinement of soil composite, allowing full load transfer.

Integrally jointed bi-axially oriented Geogrids when laid in the layers is proven to improve the performance of the of foundation soil through three mechanisms:

- Interlocking & Confinement of soil composite (imparts pseudo-cohesive load transfer)
- Wider load distribution through reinforced aggregate basal layer
- Tensioned Membrane Effect (which absorbs tensile stresses)

The phenomenon of interlocking of the soil particles into the apertures of

![MODEL OF SOIL CONFINEMENT](https://www.masterbuilder.co.in/article_images/61_Ground-Improvement-using-Integrally-jointed-Geogrids.png)
the Geogrid also reduces degradation of the mechanical properties of the aggregate and prevents lateral displacement of the soil particles, thereby increasing the overall stiffness of the foundation layer. When a proposed embankment is to be built over soft soil (say, CBR<5), which passes through marshy waterlogged terrain, swamps mudflats or overlying compressible substratum with poor ground conditions, for construction of access roads, highways or hardstand for large loading area, the following problems are encountered:

1. Marshy soft ground condition, accumulation of water-logging causes difficulty in initiation of construction of embankment and access road. Unavailability of initial sub-grade strength initiates rapid deterioration of embankment bed materials, large scale deformation and sinking of valuable fill materials transported from far away sources.

2. Embankment fails due to flexural deformation of base and tension crack on embankment formation, sinking and loss of bed materials

3. To ensure adequate stiffness, conventional embankment needs higher embankment thickness to ensure adequate modulus for controlled overlying pavement deformation, which is counterproductive since higher the overburden, the embankment becomes more unstable. The deformation increases with time.


The key here lies in the property of interlocking. Though other forms of knitted or woven mesh form provide frictional interaction between soil and reinforcement, lack of interlocking (due to poor junction strength) does not enable these materials to impart soil confinement condition. In the light of above it is easily explained why knitted mesh without junction strength cannot provide lateral confinement of soil and therefore does not perform as biaxial soil reinforcement.

The property of interlocking is the key to eminent load transfer of soil directly to lateral strands, leading to soil confinement. Though other forms of knitted or woven mesh form provide frictional interaction between soil and reinforcement, lack of interlocking (due to poor junction strength) does not enable these materials to impart soil confinement at k0 condition. In the light of above it easily explains why knitted mesh without junction strength cannot provide lateral confinement of soil and therefore does not perform as biaxial soil reinforcement.

Stabilization over soft soil involves creating a stable platform

There are some effective methods available to improve the bearing capacity of soft soil. One of the early methods consists of reinforcing the soil through lateral confinement of the soil particles and improved resistance to tensile stresses. Traditionally these effects were obtained by using basal support using soling of stones. Present day Geosynthetic technology, instead, uses engineered plastics to obtain the same effects of lateral confinement and tensile resistance using bi-oriented Geogrid and Gecell. Laying a layer of Geogrids quite literally allows walking on marsh.

Another method involves providing a separation medium between the soft soil and the structure placed on it, and to provide a positive drainage medium to avoid stagnation of water and pore pressure buildup. Modern Geotextiles are used for separation to prevent migration of fines (mud-pumping) and Geonets for drainage, or Geocomposites for fulfilling both functions. An engineered structure such as a road, a bridge, or a railway, needs a design life well in excess of 100 years.

Natural materials used in the process may have limitations. Geosynthetics: like Geogrids, Geocells, Geotextiles and drainage Geonets are produced with constant factory controlled characteristics which allow incorporating their properties into an engineering design. Moreover their expected lifetime is far
in excess of 120 years, if properly handled and installed.

Geogrids are usually placed within a layer of granular material, thus producing a reinforced soil mattress to support the overburden embankment weight. Geogrids are also used to form a cellular soil mattress called Geocells. Such system also acts as a drainage medium, thereby protecting the embankment soil from saturation and facilitates the dissipation of pore water pressures from beneath the embankment, allowing the consolidation, increasing the shear strength of the foundation, and an increase in the factor of safety against bearing capacity failure.

The bearing capacity of shallow foundations can be increased by placing one or several layers of bi-oriented Geogrids in the foundation soil. With the installation of bi-oriented Geogrids in the subsoil, the shallow foundations become more stable, and the factor of safety against bearing capacity failure is increased. The Geogrids also allow an even settlement of the foundation, thus minimizing the risk of differential settlement.

**Basal foundation mattress for ground improvement in soft soil**

A Geogrid reinforced granular soil filled foundation mattress is a very stiff foundation platform designed to support an imposed loading either due to live loads (highways & railways, stockyards for stacking, cargo berths, large loaded area etc.) on to embankments on very soft ground. It is generally installed at existing soft virgin ground level with a geotextile added separation layer to arrest mud pumping.

Geogrid reinforced soil mattress is formed from high strength Geogrid to form a layered or cellular construction. The Geogrid foundation mattress is found to rotate/alter the direction of initiation of normal slip circle failure plane by forcing it to pass vertically through the mattress. This in turn deepens the failure surface and takes it into the stiff underlying base. Before the base material shears, the plastic failure is assumed to occur in the soft layer beneath the loaded area. The plastic condition is considered for the design. Conventional low cost ground improvement technique uses replacement of foundation soil with better quality granular compacted backfill. However the question of unregulated settlement still remain unless the granular soil is deep enough (say 5-6m), which is expensive and difficult to implement due to presence of high ground water table, availability of suitable soil etc.

**Cellular Geocell Mattress for Basal platform under embankment**

Geocells are stone filled cellular mattresses formed using extruded and oriented Geogrids. They are used extensively to reduce differential settlement for high embankment, where underlying soft compressible stratum is deficient in strength and plastic extrusion of sub-grade soil is major construction impediment.

For higher height retaining wall over soft deep compressible sub-grade Geocell foundation mattresses are provided for improvement of foundation bearing capacity. Geocell mattress can be made using both uniaxial and Biaxial Geogrid. Generally 1-2 meter depth Geocell are made with Bi-oriented Geogrid as derived from detail design. The Geocraft system/Geocell Mattress is designed to allow the building of structures with rigid foundations on very soft and yielding soils.

This is accomplished by using bi-axial- Geogrid placed at the base, and a uniaxial- Geogrid capable of giving high tensile strength, which are laid vertically and joined to each other by a proprietary loop joint. Different configurations such as a chevron or box shaped structure, can also be achieved. This confined system is then filled in with granular material.

The design procedure follows the 15 flow-net diagram for plastic failure analysis of a soft compressible material between two rough, rigid, parallel platens, when the platen width exceeds (more than four times) the soft material thickness. The Geocell foundation mattress provided over weak foundation soil alters the direction of normal slip circle failure planes by forcing it to pass vertically through the mattress. This in turn deepens the failure surfaces and takes them into the stiff underlying base layer. Before the base material shears, the plastic failure condition is assumed to occur in the soft soil sandwiched between Geocell mattress.
and stiff under layer. In the process of such plastic failure mechanism, a rigid block of soil extruded at both the ends of the mattress and the stiff underlying strata and two regions of plastic material between them develops, separated by two ostensibly rigid blocks effectively adhere to the platens and do not slide or shear outward relative to them. For design purposes plastic failure condition is considered. These properties enable the Geocell mattress to influence the deformation of the soft foundation and hence mobilize its maximum shear strength and bearing capacity.

The design principle follows the plastic failure of material between two rough, rigid, parallel platens, when the platen width exceeds the material thickness. The method of analysis relies on the following characteristics of the foundation mattress:

a) A high tensile stiffness of the mattress to ensure that the full shear strength of the soft soil is mobilised on the base.

b) Rigidity of the mattress to ensure an even distribution of the load onto the foundation material. This is achieved by providing high tensile strength oriented Geogrids and adoption of cellular construction filled with suitable graded granular fill.

c) High friction on the base of the mattress. The geogrid base of the mattress allows the granular infill material to partially penetrate through the apertures, creating a rough underside to the mattress.

**Layered Geocell mattress**

Layered Geocell mattress is commonly used under RE wall foundation, where ground improvement is required within finite boundary constraints. Generally granular soil is compacted with layers of biaxial - Geogrids, with a toe extended beyond the RE wall face.

Geogrid foundation mattress is a three dimensional honeycombed structure formed from a series interlocking cells of orientated Geogrids. The mattress provides a very stiff foundation platform designed to support an imposed loading due to live loads on to embankments on very soft ground. It is generally installed at existing ground level with graded granular in-fill material, e.g., crusher run stone, rubble etc. The mattress is formed from high strength orientated Geogrids to form a stiff cellular construction.

\[
h = \frac{0.868 + (0.661 - 1.006J^2) \left( \frac{r}{h} \right)^{1.5} \log N}{1 + 0.204[R_E - 1]}
\]
Foundation under unpaved road

Cyclic load on pavement induces lateral movement of aggregates at the interface of base layer and a saturated sub-grade, inducing pumping of soil fines (mud pumping) within the crevices of moved particle. Sinking of base aggregates follows in pockets with pumped fines of poor sub-soil, leading to settlement and loss of base materials sinking into the sub grade. Formation of rut on pavement demonstrates failure and rapid deterioration of pavement, which may be arrested by providing (i) interlocking reinforcement layer of Geogrid to prevent lateral movement and sinking of base layer and (ii) separator layer of NW Geotextile fabric to stop mud pumping.

A foundation structure generally needs to be thicker initially to take on major dynamic stresses transmitted from the structure above. This phenomenon occurs, for example, when a car passes quickly over them. The foundation structure, under the stresses of dynamic loads for short periods, is subject to ruptures until it collapses.

Bi-oriented Geogrids without or with Geotextile (when mud pumping is anticipated) used in combination for the construction of paved and unpaved roads, is used where the soil is soft or loose and waterlogged and the base needs to be separated and confronted for improvement of foundation shear strength.

The design of unpaved road for reduced pavement thickness (h) can be seen from following expressions derived from presentation by Jiroud & Han, modified later by several researchers.

Bi-oriented Geogrids helps in saving time and money in highway construction projects. The method also provides for much needed access platform over cross country alignment on weak soil.

The effective way to resist deformation is to ensure sufficiency in:
- spread of load over wider area
- improving the tensile resistance in the pavement.

In case of unbound granular base material reinforcement, the mechanism of confinement of Geogrids can be divided into three distinct modes (refer Jewell, et al. 1984):

i) Shearing over plane grid areas.
ii) Bearing over grid bearing surfaces.
iii) Shearing of inter-locked material layer with adjoining surfaces.

Geogrid with integral joints provide effective confinement and tensile inclusion to address all the three phenomenon

Conclusion

Construction of embankment over soft compressible soil depends on the depth of effective removal of soft stratum, wherever possible, using stone columns or pile foundations or by using pre-consolidation techniques with wick drains made with sand filled natural fabric wicks. Wherever the compressible strata exceed a depth of 2m, generally removal becomes expensive. Use of integrally jointed Geogrids, along with use of debris, Fly ash, etc, provides an ideal low cost solution to effectively provide ground improvement by distribution of imposed load over an increased area. While using this method, the ground is mostly untreated, but the overlying structure is suspended due to increased load incidence angle. The integral junction strength of HDPE/PP Geogrid plays the most important part in this process.

The use of biaxial integrally jointed Geogrid helps in saving time and money in highway construction projects. The method also provides for much needed access platform over cross country alignment on weak soil.