

SETTLEMENT CONTROL OF SIMULATED BALLAST LAYER WITH  
GEOGRID REINFORCEMENT

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## ABSTRACT

Railway track is an important part of the transportation infrastructure of a country and playing a significant role in sustaining a healthy economic. It provides a quick and safe public and freight transportation system. Rail track needs to be maintained to make sure it is in a good condition in order to provide an optimum performance. Unfortunately, in railway system most attention has been given to the track superstructure that serves the railway, and less attention has been given to substructure that supports the foundation of the track. The most important requirement in railway system is that, the track geometry must be maintained during operation. Poor track geometry can lead to settlement of the track that caused by the degradation of the ballast i.e. ballast breakage. Many researchers have done investigations to understand how the track structure components work and the inclusion of geogrid in ballast layer to reduce the settlement. The present study recreates the composite foundation in a lab-scale static test with geogrid placed at various heights in the ballast layer. The steel model box measured 180 mm x 180 mm x 180 mm. There was no apparent yielding of the ballast layer, with or without geogrid inclusion, indicative of a strain-hardening behaviour of the material under load. The inclusion of the geogrid in the simulated ballast layer show a significant effect on the resulting reduced settlement. This can be shown for sample  $D_g = 50$  mm that had experience less settlement than the other. A graphical analytical method was next adopted to identify the Ballast Breakage Index ( $B_g$ ) in relation to the overall settlement reduction. Overall particle breakage was not found to be expediently mitigated by geogrid installation in the ballast layer. The settlement reduction though was very much attributed to lateral spread control by the geogrid reinforcement. The geogrid deformation shows a significant with the stress that been applied to the sample. Surface tear is the highest deformation for the geogrid. This is because when the stress applied, ballast in the sample being pushed through the aperture instead of interlocking with the geogrid.

## ABSTRAK

Landasan kereta api adalah satu bahagian penting dalam infrastruktur pengangkutan negara dan memainkan peranan penting dalam mengekalkan ekonomi. Ia menyediakan pengangkutan awam yang cepat dan selamat. Untuk memberikan prestasi yang optimum landasan keretapi perlu berada dalam keadaan yang baik. Malangnya, dalam sistem kereta api perhatian yang lebih diberikan kepada struktur trek yang berkhidmat untuk kereta api dan kurang perhatian diberikan kepada substruktur yang menyokong asas trek. Bahan yang paling penting di landasan keretapi adalah lapisan balast yang menyokong struktur trek dan memindahkan beban kepada subgred. Keadaan geometri trak yang tidak baik disebabkan oleh kemerosotan balast. Ramai penyelidik telah melakukan siasatan untuk memahami bagaimana komponen struktur trek dan kemasukan geogrid dalam lapisan balast untuk mengurangkan kemerosotan trak geometri. Kajian ini mencipta asas komposit dalam ujian statik berskala makmal dengan geogrid diletakkan di pelbagai tahap dalam lapisan balast. Kotak model keluli diukur 180 mm x 180 mm x 180 mm. Tiada berhasil jelas lapisan balast, dengan atau tanpa kemasukan geogrid, menunjukkan tingkah laku pengerasan terikan bahan di bawah beban. Kemasukan geogrid di dalam lapisan balast simulasi menunjukkan kesan yang besar ke atas sampel yang menyebabkan penurunan sampel dapat dikurangkan. Ini boleh ditunjukkan dengan sampel  $D_g = 50$  mm yang mempunyai pengalaman penurunan kurang daripada yang lain. Kaedah analisis grafik telah dipakai untuk mengenal pasti Indeks Pecah Balast ( $B_g$ ) berhubung dengan pengurangan penyelesaian keseluruhan. Keseluruhan pecahnya zarah tidak didapati dikurangkan dengan pemasangan geogrid dalam lapisan balast. Pengurangan penurunan banyak dikaitkan dengan kawalan penyebaran sisi oleh tetulang geogrid itu. Ubah geogrid menunjukkan yang signifikan dengan tekanan yang telah digunakan untuk sampel. Kerosakan permukaan adalah ubah bentuk permukaan yang paling tinggi untuk geogrid itu. Ini adalah kerana apabila tekanan yang dikenakan ke atas sampel menyebabkan balast dalam sampel ditolak melalui bukaan geogrid.

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**LIST OF SYMBOL AND ABBREVIATIONS**

Cu	Coefficient of uniformity
Cc	Coefficient of curvature
D <sub>10</sub>	Particle diameter corresponding to 10 % finer by dry mass on the grain size distribution curve (mm)
D <sub>30</sub>	Particle diameter corresponding to 30 % finer by dry mass on the grain size distribution curve (mm)
D <sub>60</sub>	Particle diameter corresponding to 60 % finer by dry mass on the grain size distribution curve (mm)
LAA	Los Angeles Abrasion
AIV	Aggregate impact value
AAV	Aggregate abrasion value
BBI	Ballast breakage index
PSD	Particle size distribution
D <sub>g</sub>	Depth of geogrid from surface
D	Dry sample
W	Wet sample
m <sub>1</sub>	molarity of concentrated HCl
m <sub>2</sub>	molarity of dilution
v <sub>1</sub>	volume of concentrated HCl

$v_2$	volume of distilled water used (depends on volumetric flask)
HCL	Hydrochloric acid
$A_i$	Area initial
$A_f$	Area final

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Background of study**

Railway track is an important part of the transportation infrastructure of a country and playing a significant role in sustaining a healthy economic. Many countries had planned and constructed the railway project, even though huge amounts of annual budget need to be spent. In United Kingdom for example, the annual budget for maintaining the track system can reach up to 5 billion pounds per year with 3 billion pounds committed to tracking renewal work (Ching, 2006).

Wee (2004) noted that, in railway system the most attention has been given to the track superstructure and less attention to the substructure. This is ironic as substructure components often form the major part of the cost of track maintenance. According to Said, Xie & Liu (2012) the lack of attention given to the substructure can cause the difficulties in defining many variables of the substructure compared to those of the superstructure.

The most important requirement of the railway track system is that, track geometry must be maintained during operation. Many superstructure defects, such as rail breaks, are directly or indirectly caused by poor track geometry. Settlement or uneven track deterioration is the main cause of poor track geometry. Ching (2006), also mentioned that, settlement is the main cause of poor track geometry and irregular track which is often highly depend on site condition i.e. type of subgrade, ballast etc.

Ballast is the main contributor to track settlement compared to subballast and subgrade. According to Anursudkij (2007), the conventional method to restore the settlement is tamping. However, tamping can destroy the ballast in addition to the damage from traffic loading. Due to traffic loading, the ballast will be subjected to

higher stress, which are sufficient to cause the ballast resulting in breakage. Ultimately, this leads to track settlement and uneven deterioration that leads to poor track geometry.

Since the introduction of the Tensar geogrid in early 1980s, the application of reinforcing geogrid has been proved that, it can reduce the settlement in the ballast layer. However, less effort has been expended to understand the characteristic of grid/aggregate interaction and current practice involve geogrid reinforcement is still limited (Chen, 2013). Geogrid reinforcement that include in railway ballast has a potential to allow longer maintenance cycles that can lead to cost savings.

Therefore, this research has been designed to determine the settlement reduction of stimulate ballast layer with inclusion of geogrid reinforcement at different depths. Deformation of the geogrid under load and ballast such as ballast breakage were also examined. Sieve analysis also was conducted to determine the ballast breakage.

## **1.2 Problem statement**

The ballast layer is an important part in transmitting and distributing the wheel load from sleepers to subballast and subgrade at an acceptable stress level (Selig and Waters 1994). Because of its good mechanical properties that can bear the load from the track and train, ballast need to be maintained during operation to make sure the track is in good condition. Ballast normally composed of strong, medium to coarse granular sized particles from 10 to 63 mm that have a high load bearing capacity with a large of pore space and a permeable to assist structure in rapid drainage (Indraratna and Salim, 2005).

During operation, ballast deteriorates due to breakage of sharp edges, repeated grinding, wearing aggregates, and crushing of weak particles under heavy cyclic loading may cause the track settlement and unevenness of the surface. As a result, adopting innovative and effective methods to improve the serviceability and effectiveness of the track was the inclusion of geogrid in ballast layer. According to Chen (2013), the development of geogrid in railway ballast is still limited to experience gathered on the site based on ad hoc work. Ching (2006) stated that, the

use of geogrid reinforcement in rail track layer ballast has the potential to reduce rate of ballast deformation.

Thus, in this study, the potential of geogrid in reducing settlement was being investigated. In order to investigate, a compression test was conducted to determine the effectiveness of the geogrid in simulated ballast layer. Besides, the particle breakage was also being investigated to identify the degradation of the ballast.

### **1.3 Research objectives**

The objectives of this study are:

- (i) To determine the settlement of a simulated track ballast layer with geogrid reinforcement.
- (ii) To determine the ballast degradation i.e. ballast breakage after the compression test.
- (iii) To identify the deformation and damage of geogrid reinforcement in a simulated track ballast layer.

### **1.4 Research scope**

The scopes of this study are as below:

- (i) A compression test was being conducted by using a standard compression test to quantify the settlement, ballast breakage and deformation of the geogrid.
- (ii) The test was being conducted in two condition i.e. dry and wet.
- (iii) The tensile strengths of the geogrid used in this study were provided by the company and laid at 3 different depths from surface, i.e. 50 mm, 90 mm, and 130 mm.
- (iv) The mould used in this study was a steel mould with the dimension of 200 mm x 200 mm x 200 mm and a weight of 21 kg.
- (v) Sieve analysis was conducted to determine the degradation of ballast after the compression test.

## **1.5 Significance of research**

Ballast is one of the important parts of railway track that need to be maintained all the time. Ballast under repeated traffic loading will cause deterioration of the track and poor geometry. Therefore, this research can identify the benefit of using geogrid reinforcement. It can also determine the effectiveness of geogrid to reduce the settlement rate and make the ballast cycle life longer.



## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

Rail track form the largest worldwide network need to provide quick and safe public and freight transportation. To achieve optimum performance of the rail tracks, it is important to understand how the track structure components work. The structure can be divide into superstructure (rail, fastening system and sleeper or tie) and substructure (ballast, sub ballast and subgrade). Figure 2.1 shows the cross sectional view of rail track.

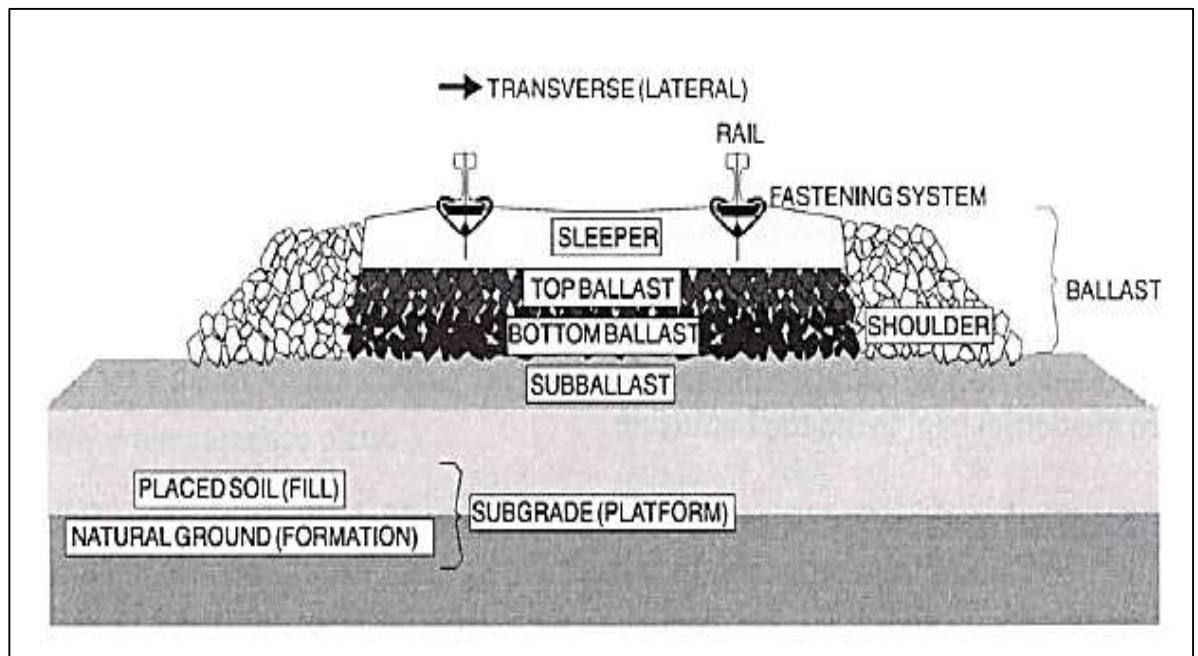


Figure 2.1: Cross sectional view of a rail track (Ching, 2006)

According to Indraratna (2006), ballast is the largest component in the rail track substructure. It is the most important part in rail track as it is functioning to support the rail and sleepers so that it can give the optimum performance. In that case, the material of ballast should have a good properties to ensure the track always in a good condition.

However, ballast will deform and degrades under rapidly cyclic loading from train and caused the settlement of the track. Figure 2.2 shows a typical profile of the relative contributions of substructure components to track settlement based on a good subgrade foundation. From the figures it shows that, the most contribution to track settlement is ballast compared with subballast and subgrade.

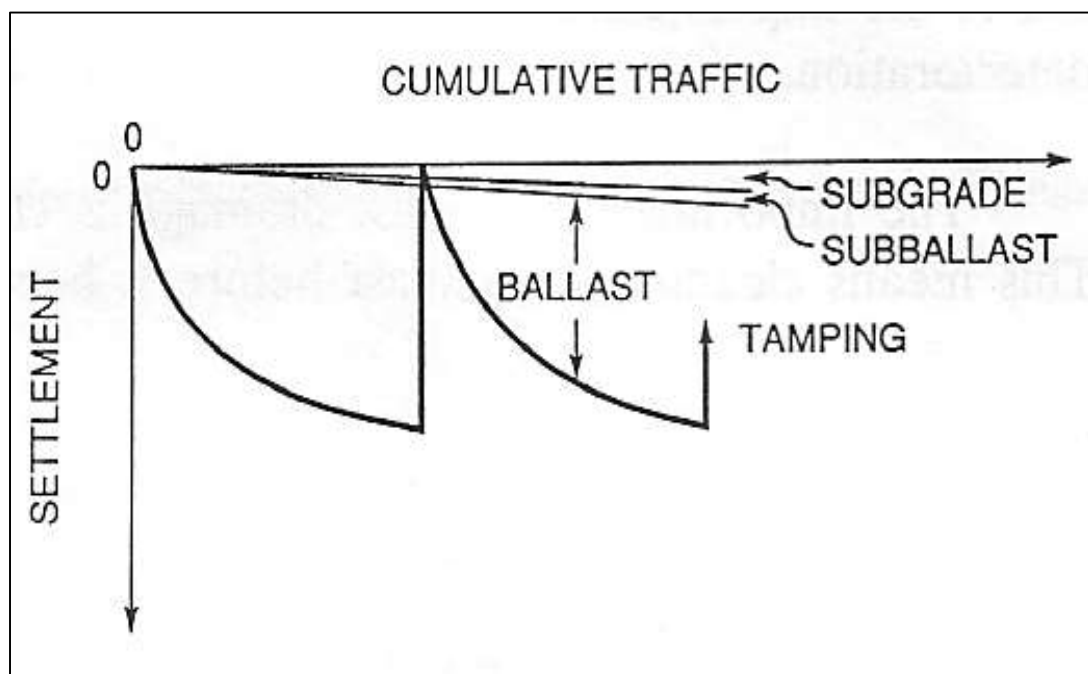


Figure 2.2: Substructure contributions to settlement (Aursudkij, 2007)

## 2.2 Railway track

The role of a modern railway is to provide economical and relatively speedy transportation. To achieve this, the railway track structure has to provide a safe and stable platform under stringent vertical and horizontal alignment constraints. It is therefore important to identify the specific roles that each different component plays and how they combine and perform as an entity. In the recent 200 years, the railway

tracks have become more advanced. According to Said (2012), several aspects of the modern railway track included:

- i. Safety and accuracy
- ii. Increasing the load capacity
- iii. Avoiding physical degradation to get the system more stable.

Esvald (2001) state that, the track must be constructed in such a way that trains running on it do not cause excessive environmental pollution in the form of noise and vibration. While the cost of the total service life and maintenance of the track must be as low as possible. Track are assets which will last for some years so that it is important to choose the suitable track system that can be used for 20 – 50 years.

### **2.2.1 Rail track component**

In the previous study by Ching (2006), ballasted rail track is divided by 2 main divisions of components: the superstructure and the substructure. The superstructure component include the rails, fastening system and the sleepers while the substructure covers the ballast, the sub-ballast and the subgrade.

The main purpose of the rails is to guide train wheels. The rails are part of the track component that comes into direct contact with the train. Rail pads must have sufficient stiffness to transfer the wheel loads onto the sleepers with minimum deflection between sleeper supports. Therefore, the material of the rails should be strength, fatigue endurance, wear and resistance in corrosion (Bonnett, 2005). If there is defect detected in the profile or an entity, it can caused large dynamic loads which can compromise the track substructure.

The fastening system function as a means to retain the rails against the sleepers. The general functions of the fastenings are to absorb rail loads elastically and transfer them to the sleeper. Besides that, it also must be able to help the rails resist any vertical, lateral, longitudinal and overturning movements (Wee, 2004). It also can help to damp traffic vibrations, prevent or reduce rail or sleeper attrition as well as providing electrical insulation for track signals

Sleepers is a part of structure that act to receive the rail loads and distribute them over the ballast. The sleepers also act as a restraint against any lateral, longitudinal and vertical rail movement through anchorage of the superstructure into

the ballast (Bonnett, 2005). The sleeper must also be resistant to mechanical wear and weathering. The two most common types of sleepers are wood and concrete sleepers.

Ballast is the crushed granular material which is placed in the top layer of the substructure. It is used to support and confine the sleepers, and to minimize any vertical and lateral movement transferred to the sleepers. Ballast material also reduces sleeper pressures and distributes it to the underlying materials, e.g. sub-ballast and subgrade.

Sub-ballast sits between the ballast and the subgrade material and is often referred to as the blanket layer. The role of these structures is very similar to the ballast. The function of the sub-ballast is to reduce the traffic induced stress and distribute it to the subgrade. Sub-ballast also allows should have a good drainage of water and prevent mixing of the subgrade and ballast.

According to Bhanitiz (2007), subgrade provides the platform on which the track is constructed. Usually, the main function of the subgrade is to provide a stable foundation for the track substructure. The lack of such quality is often the cause of many track defects.

### **2.3 Track settlement**

According to Dahlberg (2003), when track is loaded by the passing train, the track will superimpose to that and high-frequency load variations of the ballast and sub ground may undergo a non-elastic deformations. When unloaded, the track will not return exactly to its original position, but to a position very close to the original one. After the track experienced thousands of train passages, all these small non-elastic deformation will increase that contribute into deformation of the track. This phenomenon is called differential track settlement. The track alignment and the track level will change with time depend on the sub ground condition.

The settlement of the track is a result of permanent deformation in the ballast and the underlying soil. It caused by the repeated traffic loading and it also depends on the quality and behaviour of ballast, sub ballast and subgrade. The track settlement occurs in two major phases that are:

- i. First phase
  - a. Directly after tamping, when the track position has been adjusted to a straight level, the settlement become more fast until the gaps between the ballast particles reduced and the ballast is consolidated
  - b. Settlement with time is an approximate linear relationship.
- ii. Second phase – caused by several basic mechanisms of ballast and subgrade behaviour:
  - a. Continued from the first phase, densification of the ballast and sub ground that caused by particle rearrangement produced by repeated train operation.
  - b. Subballast or subgrade penetration into the ballast voids. This causes the ballast to sink and the track level will change.
  - c. Volume reduction by particle breakdown from train loading or environmental factors. For example the ballast particles may divided into two or more due to loading.
  - d. Volume reduction caused by abrasive wear such as originally corned stones becomes rounded thus it make less space.
  - e. Inelastic recovery on unloading. This means that all deformation will not be recovery upon loading the track
  - f. Movement of ballast and subgrade particles away from under sleepers that can caused the sleeper to sink into the ballast layer and subgrade.

The train also may have opposite effect that caused by particle rearrangement due to repeated train loading. The train will lift the rail and sleepers in front and behind the loading point due to the elastic foundation. Dynamic high frequency train track interaction forces can caused a waves that normally propagate from the wheel-rail contact patches either through the ballast and subgrade or through the track structure. These waves normally propagate faster than the train and give vibrations in the unloaded ballast. Thus it may cause the rearrangement of the ballast particles so that the density decreases.

## **2.4 Ballast**

Ballast is a layer that consisted of broken stoned, gravel or any other granular material placed and packed below the sleepers from distributing load from sleepers to the formation. Anderson (1999) state that, ballast is the crushed granular material which is placed in the top layer of the substructure and it is packed between, below, and around the ties. It is used to bear the load from the railroad ties, to facilitate drainage of water, and also to keep down vegetation that might interfere with the track structure.

These coarse grained materials are used to support and confine the sleepers, and to minimize any vertical and lateral movement transferred to the sleepers, and hence retain track position. The ballast material also reduces sleeper pressures and distributes it to the underlying materials, e.g. sub-ballast and subgrade. Ballast also provides a certain amount of resilience as well as energy absorption for the rail track.

According to Indraratna et al. (2006), ballast is a free-draining granular material used as a load bearing material and it is composed of medium to coarse gravel sized aggregates (10-60 mm). The optimum thickness of the ballast is usually 250-300 mm from the subgrade. The ballast should be clean and graded crushed with hard, dense, angular particle and cubical fragments to provide proper drainage and interlocking qualities.

### **2.4.1 Ballast material**

In Gehringer and Read (2012) study, state that there are differences in the mineral composition of the various aggregate materials used for ballast applications and the respective in track performance of those materials. It also many have variations exist in the mineral properties of aggregate materials within the same general name of the aggregates known as granites, trap rocks, quartzite, dolomites, and limestone. One particular aggregate material may possess most of the desirable characteristics for a good ballast material while a deposit of apparently similar material located in the same general geographical area will not meet the applicable specification requirements for ballast.

A mixture of materials may be processed into railroad ballast. Table 2.1 shows list the of ballast material:

Table 2.1: Types of ballast material

<b>Material</b>	<b>Definition</b>
<b>Granite</b>	A plutonic rock having an even texture and consisting mainly of feldspar and quartz. Plutonic rock is rock formed at considerable depth by chemical modification. It is characteristically medium to course grained, or granite texture.
<b>Trap rock</b>	Any dark-coloured, fine grained non-granitic hypabyssal or extrusive rock. Hypabyssal rock pertains to igneous intrusion or to the rock of that intrusion whose depth is intermediate between that of plutonic and the surface.
<b>Quartzite</b>	A metamorphic rock consisting mainly of quartz and formed by crystallization of sandstone or chert by either regional or thermal metamorphism. Quartzite may also be a very hard, but metamorphosed sandstone, consisting chiefly of quartz grains with secondary silica that the rock breaks across or through the grains rather than around them.
<b>Chert</b>	Hard, dense cryptocrystalline sedimentary rock consisting dominantly of interlocking crystals of quartz.
<b>Carbonate</b>	Sedimentary rock consisting primarily of carbonate materials such as limestone and dolomite.

### **2.4.2 Ballast function**

The function of ballast have been well documented by many research (Chandra and Agarwal 2013, Indraratna et al 2011, Indraratna and Salim 2005) and it serves the following function in a railway track:

- i. It provide a level and hard bed for the sleepers to rest on.
- ii. It holed the sleepers in position during operation of trains.
- iii. It transfer and distributes the loading from the sleepers to a large area of the formation.
- iv. It provide the necessary resistance to the track for longitudinal and lateral stability.
- v. It provide effective drainage to the track.
- vi. It provide an effectiveness means maintaining the level and alignment of the track.
- vii. Absorb noise and provide sufficient electrical resistance.
- viii. Prevent weed growth.

### **2.4.3 Ballast gradation**

Alemu (2011) research state that, a method set to categorize the different size of the aggregates is by use a series of graduated sieve and applying mechanical sieving by agitator on it according. Mechanical sieving is the method that been used for categories the aggregates sizes accordingly to the standard. The process that's been done in this method are washing, drying the particles and agitating the sieve series by mechanical shaker. Figure 2.3 shows the graphical definition and the gradation can be classified in aggregate mix as and:

- i. Well graded (dense or broad graded)
- ii. Uniformly graded (open)
- iii. Gap graded



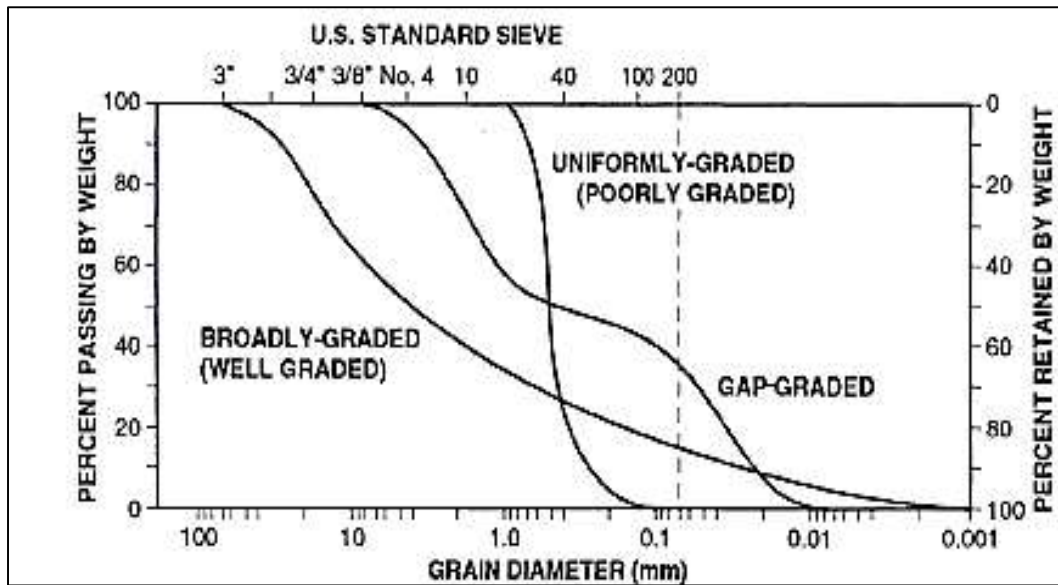


Figure 2.3: Graphical definitions of grain size distribution (Selig, 1994)

There is a major problem in using ballast in railroad as it can cause the degradation and permanent deformation to the track. However, ballast is the most important material in railroad track as its purpose is for drainage. But when the ballast experience a higher load in rapid time it will produce more fines and it is the main reason for ballast contamination.

Naturally ballast that crushed, angular and rock material is good for ballast construction. Angular stones are better shape than rounded. Figure 2.4 shows the angular shape of aggregates that good material as ballast. This is because the angular shape has a better particle interlocking and resistance to dynamic loading in the transverse and longitudinal direction. However, when the particles that used in ballast is bigger than the maximum size, it will only make some of the particles beneath the tie or slipper which will distribute the loading insufficiently to the subgrade.



Figure 2.4: Angular shape of aggregates

When particles used bigger than the maximum size of the particle, there will be only some particles beneath the tie or slipper which will distribute the load insufficiently to the subgrade. But when there is too much smaller size particles used than the minimum, the void between the bigger sizes will be filled with these particles and caused the structure for further drainage problem. (Bonnett, 2005).

In Bonnet (2005) further research state that, ballast particle degradation will cause either traffic or operation during maintenance. In these processes, the particle may experience from the loss of edge, become rounded that will minimize the interlocking of the particle and crush due to repeated loading. Rail joints, which most of the time gets an impact loading will cause ‘wet spots’, furthermore, it will give bad riding comfort and will be cause for rapid failure of the structure.

Essentially there are two gradation curve shape factors used in unified soil classification systems (USCS), these are  $C_u$  (coefficient of uniformity which sometimes called coefficient of “non-uniformity”) and  $C_c$  (coefficient of curvature). These shape factors are defined as,

$$C_u = \frac{D_{60}}{D_{10}} \quad (2.1)$$

$$C_c = \frac{(D_{30})^2}{D_{10}D_{60}} \quad (2.2)$$

$D_{10}$ ,  $D_{30}$  and  $D_{60}$  are particle diameters that are 10%, 30% are weight finer than each sieve size. According to USCS the value of  $C_u$  is for uniformly graded material. The material that used for ballast should have a value of  $C_u < 4$  and when it is not gap graded. On the other hand, when  $C_u > 4$  and  $1 < C_c < 3$ , the gradation classification can be considered as well graded or broadly graded material (Das, 2010). According to Brecciaroli and Kolisoja (2006) research, state that the compacted well graded aggregates have a better tendency to resist under the repeating load test than uniformly graded aggregates.

#### **2.4.4 Ballast specifications**

Ballast particles used for rail track should have a good properties such as hardness, durable, have good angularity, chemical resistance and be free from dust. According to (Chandra and Agarwal, 2013) the ballast material should have the following properties:

- i. Tough and wear resistant.
- ii. Hard so that it does not get crushed under the moving loads.
- iii. Generally cubical with sharp edges.
- iv. Non-porous and should not absorb water.
- v. Resist both attrition and abrasion.
- vi. Durable and should not get pulverized or disintegrated under adverse weather conditions.
- vii. Good for drainage
- viii. Cheap and economical.

Besides that, the ballast also need to fulfil certain specification especially on the size, shape, hardness, gradation, angularity, surface roughness, bulk density, strength, durability and resistance to weather (Kwan, 2006). To meet the requirement, railroad organisation had introduce several specification and standard for the ballast.

Based on the past researchers, physical and chemical properties of ballast has been obtained which insures better overall performance of the track which requires minimum cost of maintenance. To get the ballast that has good yield performance are obtained by conducting series laboratory, field test and evaluating the performance of different material of ballast under existing condition under the track.

In this research, ballast specification and testing is referring BS EN 13450 (2012) to make sure the aggregates were able to stimulate the ballast layer. This specification required the uniformity of the ballast grading, where the sieve analysis is conducted. This specification comprises five properties process for ballast properties as the ballast track specification which are Sieve analysis, Los Angeles Abrasion (LAA), Aggregate Impact Value (AIV), Flakiness index and Elongation index. The particle size distribution for ballast is shown in Table 2.3

Table 2.2: BS EN 13450 (2012)

European standard (13450, 2002) [11]						
Sieve Size (mm)	Railway Ballast Size 31.5 to 50 mm			Railway Ballast Size 31.5 to 63 mm		
	Percentage passing by mass					
	Grading category					
	A	B	C	D	E	F
80	100	100	100	100	100	100
63	100	97 to 100	95 to 100	97 to 99	95 to 99	93 to 99
50	70 to 99	70 to 99	70 to 99	65 to 99	55 to 99	45 to 70
40	30 to 65	30 to 70	25 to 75	30 to 65	25 to 75	15 to 40
31.5	1 to 25	1 to 25	1 to 25	1 to 25	1 to 25	0 to 7
22.4	0 to 3	0 to 3	0 to 3	0 to 3	0 to 3	0 to 7
31.5 to 50	≥ 50	≥ 50	≥ 50	-	-	-
31.5 to 63	-	-	-	≥ 50	≥ 50	≥ 85
<p><b>Note 1</b> The requirement for passing the 22.4 mm sieve applies to railway ballast sampled at the place of production.</p> <p><b>Note 2</b> In certain circumstances a 25 mm sieve may be used as an alternative to the 22.4 mm sieve when a tolerance of 0 to 5 would apply ( 0 to 7 for category F)</p>						

The LAA test measures a material toughness or tendency to break. It also measures the particle resistance to fragmentation with provision of a Los Angeles Abrasion (LAA) coefficient. The LAA coefficient is the percentage of material passing through the 1.6mm sieve upon completion test. According to BS EN 13450 (2013), the limits of LAA value is 20. High LAA value signifies a brittle material (Lim, 2004).

The AIV test can determine the aggregates properties that subjected to the mechanical degradation such as toughness and resistance to dynamic or impact loading. It can be test in either dry or soaked condition. The aggregate impact value that greater than 30% should be reported with caution as it can't stand the dynamic or impact loading (Alemu, 2011).

The flakiness index test is specified in BS EN13450 (2013). Definition of flaky particle is having one thickness which is the smallest dimension of less than 0.5 times the larger sieve size fraction. It is consist of two sieving operations which is, the first one involves using test sieves to separates ballast samples into various particle size of fraction and second is to sieve each size fraction using bar sieves. The bar sieves have parallel slots of width 0.5 times the larger sieve size. Flakiness index is expressed as the percentage by weight of ballast particles passing the bar sieve and shall not exceed 30%.

#### **2.4.5 Ballast fouling**

The life and performance of the railway track is depend on the ballast layer. The ballast layer is subjected to deformation and degradation during traffic loading. Various sources of ballast fouling have been identified and in Selig and Water's (1994), they have listed the 5 main sources of ballast fouling:

- i. Ballast Breakdown
- ii. Infiltration from ballast surface
- iii. Sleeper wear
- iv. Infiltration from underlying granular layers
- v. Subgrade infiltration

It has been widely agreed that ballast breakdown is the major source of ballast fouling. This is quantified in Figure 2.5 based on a study by the University of Massachusetts. The report from the University of Massachusetts is based on a variety of mainline track conditions across North America.

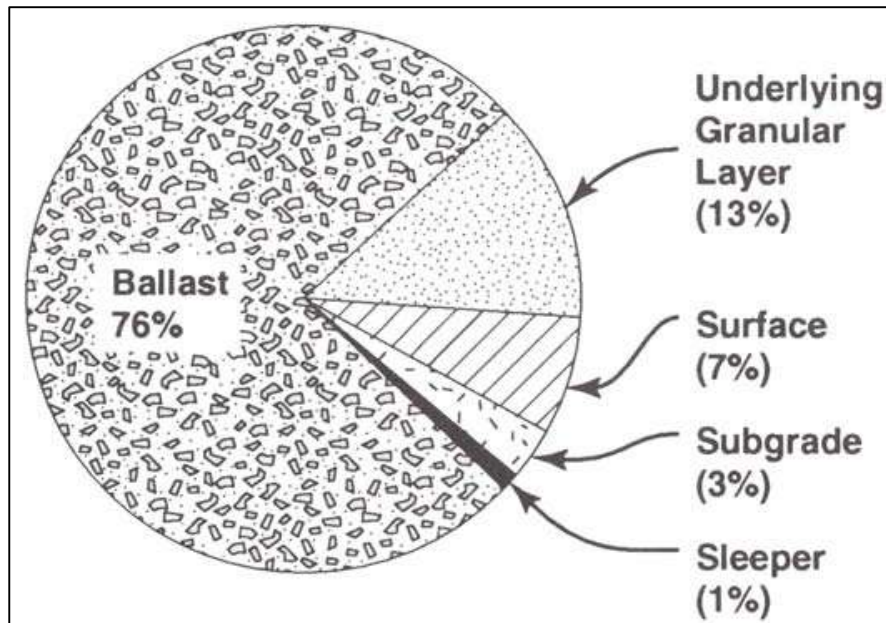


Figure 2.5: Major source of ballast fouling (Selig and Waters, 1994)

During transportation and construction work are the initial stage of ballast breakage. Selig and Waters (1994) expected 1 to 2% of the weight of fouling material to accumulate when new ballast is placed. Fouling materials are deemed as particles of less than 6mm diameter.

Ionescu (2004), investigated the mechanical degradation of a rail track. He accounted that the volume of voids in a newly built track was around 45%. When the rail track settles under cyclic train loading, the ballast grains rearrange into a denser reducing the volume of voids. At this stage, ballast crushing at contact points of the coarser grains, resulting in loss of corners and sharp edges which will be collected as fines in the voids. This grain rearrangement will carry on with additional ballast crushing with further traffic loads.

#### **2.4.6 Ballast degradation**

Indraratna, Shahin & Rujikiatkamjorn (2006) mentioned that, excessive cyclic loading and vibration, temperature and moisture fluctuation as well as impact load on ballast may cause ballast degradation. Since ballast particles are primary angular, most of the breakage is from the corner degradation and attrition. The particle degradation can occur in three ways (Raymond & Diyaljee, 1979):

- a. The angular projections breakage which influences the initial settlement
- b. The breakage of particles into equal parts, which influences the long term stability and safety of rail tracks
- c. The grinding off small scale asperities where the presence of fines can adversely affect the drainage conditions.

#### **2.4.7 Factors affecting ballast degradation**

According to Indraratna, Shahin & Rujikiatkamjorn (2006), the factors governing particle degradation are particle size distribution and effect of confining pressure. The gradation of ballast significantly controls ballasted track performance thus it should provide adequate shear strength and necessary porosity to allow proper run-off groundwater. Indraratna et al. (2003) conducted a large scale cyclic triaxial test to assess the effect of particle size distribution on deformation and degradation behaviour of ballast. The cyclic test results indicate that even a modest change in uniformity coefficient significantly affects the deformation and breakage behaviour of ballast. The test results suggest that a distribution similar to the moderate grading would give improved track performance. The gradation and void ratio characteristic of the test specimens are shown in Figure 2.6.

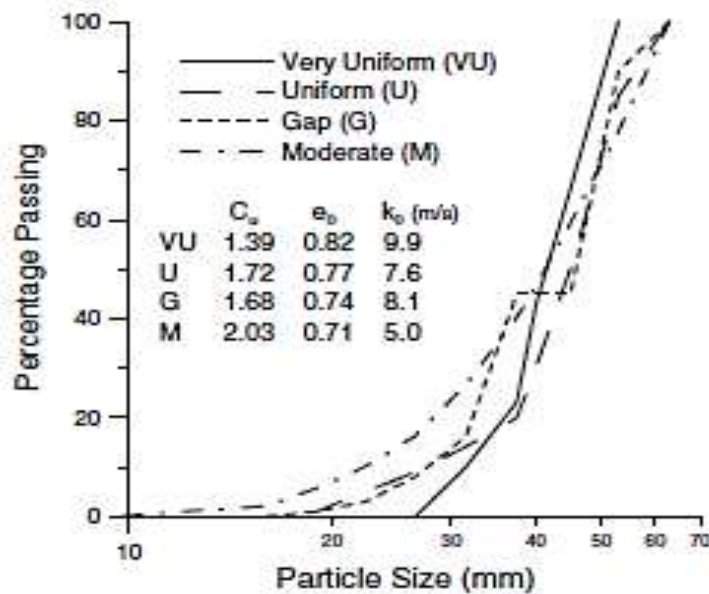


Figure 2.6: Particles size distribution used in cyclic triaxial test (Indraratna et al., 2003)

The confining pressure acting on ballast layer has not often been considered as a significant actor. This is because the confining pressure applied on tracks by the shoulder ballast and sleepers is small comparison with the relatively high vertical stress. . The role of confining pressure on ballast performance under cyclic loading has been investigated by Indraratna et al. (2004; 2005a) to evaluate whether there is an optimum confining pressure in the track to reduce the amount of ballast breakage.

#### 2.4.8 Ballast particle breakage

Several researcher had investigate how to quantify the particle breakage upon loading. Some of them had proposed their own techniques for computation to quantify the particle breakage while others focused on the probability of particle fracture. Indraratna et al. (2011) had summarized the most widely usage breakage indicates comparison.

Marsal (1967), Lee & Farhoomad (1967) were the first who developed independent techniques and index for quantifying particle breakage. According to Marshal (1967), noticed a significant amount of particle breakage during the large scale triaxial on rock fill material and purposed an index of particle breakage,  $B_g$ . Marshal's method involved the evaluation of change in overall grain-size distribution



of aggregates after breakage, where the specimens before and after each test were sieved. The difference in percentage retained on each size were computed. Marshal defined the breakage index  $B_g$ , as the sum of positive value of difference in percentage retained on each size. This method suggest that  $B_g$ , can used a different set of sieves.

Lee & Farhoomad (1967) measured the particle breakage while investigating earth dam filter. They proposed a breakage indicator expressing the change in a single particle size ( $D_{15}$ ) which is the key parameter in filter design. Miura & O-hara (1979), noticed that the changes in grain size area can indicate as particle breakage. Their concept was based on the idea that new surfaces could be generated as the particle breakage. The sieving data before and after test along with specific area are used to calculate the change in surface area. While Hardin (1985), defined that two difference quantities as the breakage potential and total breakage based on change in size gradation and introduced the relative breakage index.

After considering various method of particle breakage quantification, Indraratna et al. (2011) had introduced a new Ballast Breakage Index (BBI) for railway ballast to quantify the degradation. The evaluation of the BBI is the change in the particle size distribution before and after test. Figure 2.7 shows the BBI. By adopting a linear particle size axis, BBI can be determined from Equation 2.1.

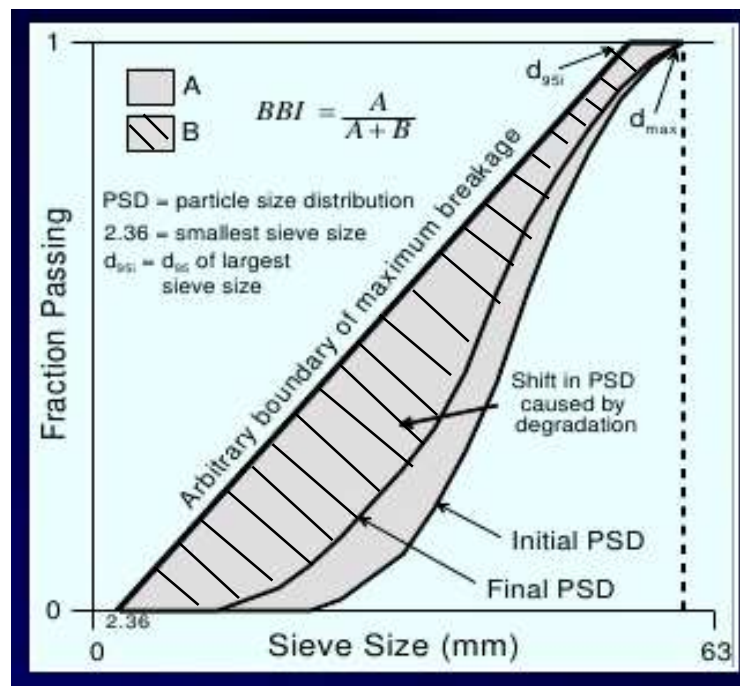


Figure 2.7: Ballast breakage index (Indraratna et al. 2011)

$$BBI = \frac{A}{A+B} \quad (2.1)$$

A = Initial particle size distribution

B = Final particle size distribution

## 2.5 Geogrid reinforcement

Geogrid is defined as a polymeric (i.e., geosynthetic) material consisting of connected parallel sets of tensile ribs with apertures of sufficient size to allow strike-through of surrounding soil, stone, or other geotechnical material. Their primary functions are reinforcement and separation. Reinforcement refers to the mechanism(s) by which the engineering properties of the composite soil/aggregate are mechanically improved. Separation refers to the physical isolation of dissimilar materials (Das, 2011).

Tensar (2009) mentioned that, geogrid have been successfully used for the reinforcement of railway track over the past decades. A geogrid can be placed within the ballast layer to reduce ballast deformation and extend the maintenance cycle by a factor of about 3.0, or at the top of the subgrade to increase the bearing capacity of the track foundation. In his research was used the conventional biaxial and triaxial geogrid, as shown in Figure 2.8.

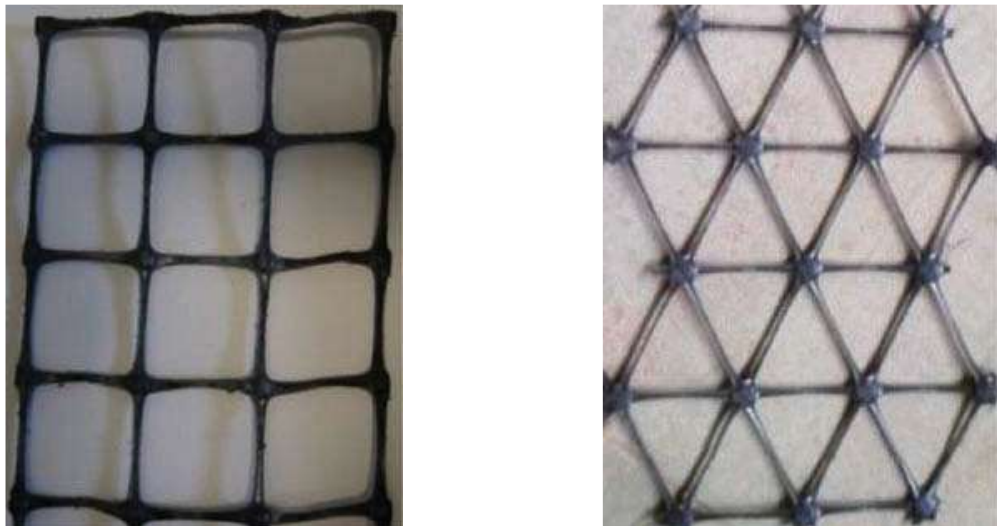


Figure 2.8: Biaxial and triaxial geogrid. (C. Chen et al. 2013)

The conventional biaxial geogrid are produced with high stiffness in longitudinal and transverse directions with square apertures to suit the ballast grading. The triaxial geogrid has evolved which involves a change in grid aperture shape from rectangular to a triangular one which is a more stable geometric shape for structural efficiency (Tensar 2010).

### 2.5.1 Reinforcing Principle

Usually a geosynthetic placed strategically at the position of maximum tensile plastic strain to make sure it is able to reduce such strain by carrying tensile stress in itself. Thus it makes good transfer of stress from the soil to the geosynthetic. In the case of geogrid, this requires good interlock. Figure 2.9 shows reinforcement in a railway track where the geosynthetic resists granular extension strains with confinement provided by the tensile strength of the polymer geogrid.

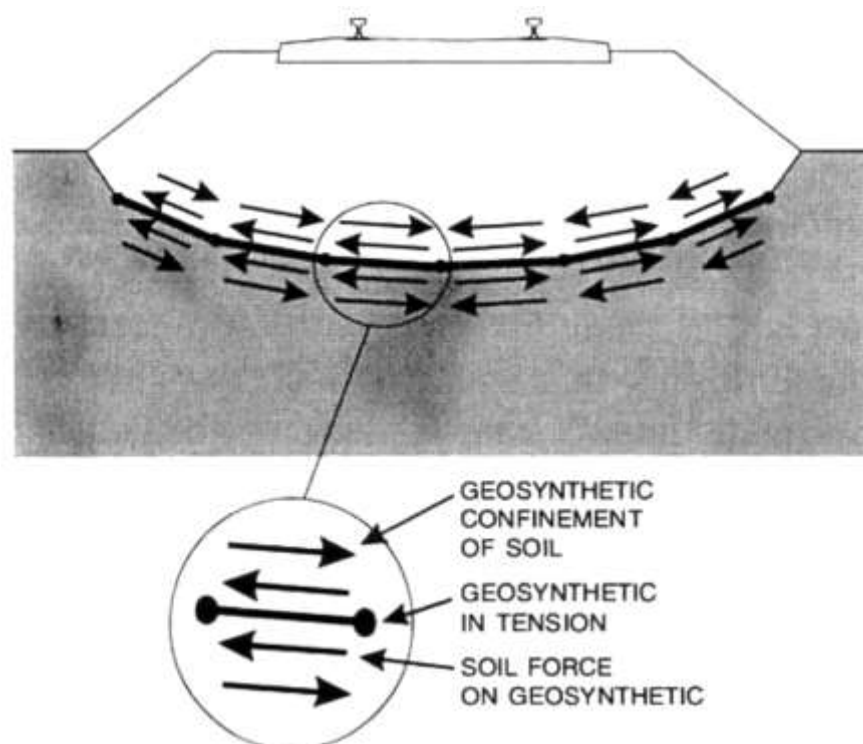


Figure 2.9: Reinforcing effect of polymer geogrid (Kwan, 2006)

According to Brown (1996), it is widely agreed that to achieved the reinforcing potential of a polymer geogrid, an appropriate stiffness and an ability to interlock effectively with the host material is vital. The interlocking effect of geogrid with soil

particles which penetrates and locked into position between the strands will increase the bearing capacity of the soil. Figure 2.10 shows the interlocking mechanism of a typical polymer geogrid.

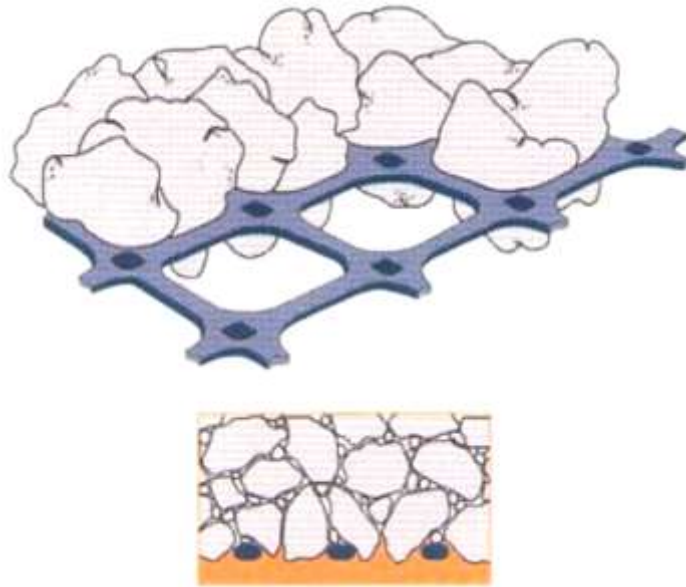


Figure 2.10: Interlock mechanism of polymer geogrid (Kwan, 2006)

### 2.5.2 Experimental measurement on geogrid reinforcement

Brown et al. (2006), conducted a full scale test to identify the key parameters that influence geogrid reinforcement of railway ballast as shown in Figure 2.11. Repeated load of 20 kN at 2 Hz were applied for 30 000 cycles to the ballast through a loading platen. Extruded biaxial geogrid were used for the test with square aperture and various tensile strength. From the test, it give that the tensile strength may not necessary to the parameter alone which control the settlement.

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