# Inchon International Airport: subgrade reinforcement with geogrids

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Keywords: Airports, Case study, Geogrids, Installation Damage, Numerical modelling

ABSTRACT: This paper describes the technical solutions that were adopted for the reinforcement of the airport runways of the new international Airport of Inchon, South Korea. The reinforcement is provided by bioriented Polipropylene geogrids. Since many concrete box culverts had to be built below the surface, the possibility of tension cracking of the pavement was considered. A Finite Element Method analysis was performed in order to assess the capacity of the geogrids to reinforce the base and reduce cracking around the culverts. Tensile strength tests were performed on the geogrids in order to evaluate the chemical resistance of the geogrids when in contact with the cement treated sub-base. Since both the sub-base layer and the lean concrete layer were spread by the finisher, also the possibility of installation damage to the geogrids was considered.

## 1 INTRODUCTION

The new Inchon International Airport is being built at Yongjong Island, 52 km west of Seoul (Fig. 1). Airport construction began in November 1992 with the target date for initial opening in the beginning of 2001. The airport project will continue until 2020. It is estimated that the first phase of construction will cost 6557.2 billion Korean won (5.90 billion USD). In addition to this cost, another 1734 billion Korean won (1.56 billion USD) will be spent for the airport access facilities.

The new airport is being developed on 5610 hectares of reclaimed tidal land which was created by connecting two existing islands, Yongjong and Yongyu, using a 17.3 km dike (Fig. 1, Fig. 2). This reclaimed tidal land has an average depth of 5 meters of normally or slightly overconsolidated soft soil.

At end of 1999, site preparation work was almost completed except for the second runway. First runway pavement, underground tunnel and outer circulation roads are at the height of construction.

Since many box culverts had to be constructed under the runways in the airfield, the possibility of occurring differential settlements in the adjacency of box culverts or underground structures had to be considered.



Figure 1. Aerial view of the airport site (October 1993).



Figure 2. Aerial view of the airport site (May 1997).

In fact the high stiffness of the underground box, compared to the remarkably lower stiffness of the fill soil, brought to the necessity of providing a positive reinforcement and a more uniform distribution of the settlements.

As it is well known, plain concrete pavements are particularly vulnerable to tension cracking. Moreover since high levels of fill compaction were required, the difficulties related to the filling and compaction of the area around the concrete box culverts had to be taken into account: for this reason more soil compressibility had to be expected for the laterals belts adjacent to both the vertical sides of the culverts.

#### 2 THE PROPOSED SOLUTION

When designing foundation structures that will have to sustain large loading concentrated on small areas, like airport runways or taxiways, the common engineering practice should always suggest the insertion of tensile resistant elements, like reinforcing geogrids, in order to achieve a more effective spreading of the surcharge loads.

As it is widely reported in scientific literature, Geogrids can remarkably improve foundation structures behavior (Cancelli et al., 1996; Cancelli and Montanelli, 1999; Cancelli et al. 2000) by means of their confining effect and, at the same time, of the tensioned membrane effect (Giroud et al., 1984; Koerner, 1986); thus reducing shear and tension actions on stiff foundation structures. For this reason it has been decided to insert bioriented Geogrids into the subgrade stabilized layer.

Two different conditions were analyzed, namely the Embankment and the Base Course (being the first one reinforced with two Geogrids layers and the second one with a single Geogrid layer as reported in Fig. 3). Basically it could be summarized that under a concrete slab (plain concrete layer on a lean concrete base) a cement treated sub-base and two stabilized soil layers (namely 100% and 95% compaction) had to be placed (the thickness was about 0.6 + 0.5 + 0.7 m = 1.80 m for the Embankment and 0.6 + 0.5 + 0.5 m = 1.60 m for the Base Course).

The used geosynthetics were bioriented extruded polypropylene geogrids; the particular production process of the proposed geogrid, yields a monolithic structure with an uniform distribution of rectangular apertures, with oriented longitudinal and transversal ribs which keep the integrity of the molecular polymer chains for the whole length, even through the junctions. Thanks to this production process, the geogrids were expected to maintain their mechanical properties even after the heavy compaction that was required in the present project (see installation stages in Fig 4 and 5).

A reinforcing geosynthetic could be subjected, during the design life of the work, to a chemically or biologically aggressive environment. The geogrid is produced from Polypropylene (PP), which is considered as one of the most chemically and biologically inert polymers.

Another important point in the choice of the geogrid to be used was its flexural rigidity (particularly important in this case where the geogrid should spread a load over areas with totally different stiffness); this requirement brought to the choice of an extruded geogrid. In Tab. 1 are resumed the main properties of the used geogrid.

Tab. 1: technical characteristics of the used geogrid (Tenax LBO 440 SAMP)				
TECHNICAL	TEST METHOD	UNIT	MD	TD
CHARACTERISTICS				
Mass per unit area	ISO 9864	g/m²	650	
Tensile strength at 2% strain	GRI-GG1	kN/m	14.0	15.0
Tensile strength at 5% strain	GRI-GG1	kN/m	28.0	30.0
Peak tensile strength	GRI-GG1	kN/m	40.0	40.0
Yield point elongation	GRI-GG1	%	11.0	11.0

Tab. 1: technical characteristics of the used geogrid (Tenax LBO 440 SAMP)





Figure 3. Basic layout for Embankment and Base course (the lower part is identical).



Figure 4. Installation of Geogrids.



Figure 5. Stabilized layer compaction.

## **3 GEOGRIDS TESTING**

One of the most relevant feature, when designing with geogrids, is the assessment of their residual physical properties due to the possibility of both mechanical and chemical damaging.

Since soil is commonly directly spread on geogrids and successively heavily compacted, geogrids may suffer damage due to local punctures and abrasions by the aggregate. Moreover in this particular problem, the cement treated sub-base layer was spread by the finisher: for this reason specific installation damage tests were performed at the Inchon University in order to determine the loss of tensile strength. The tests showed an expected tensile strength reduction ranging from 1.16% to 1.90% (Shin et al. 1999), thus confirming that the residual tensile strength was still complying the specification required (Fig. 6).

These results were compared to other literature tests performed on similar geogrids of the same manufacturer. Extensive independent test have been performed in UK (Wright and Greenwood 1993, Watts and Brady 1994) for evaluating the residual tensile strength of different geosynthetics after a full scale compaction damage trial according to the procedure set by Watts and Brady (1990). The damaging tests, performed with crushed limestone, showed a tensile strength loss ranging about 1.5%.



Figure 6. Installation damage test on a 30kN class Geogrid.

Slightly larger amounts of tensile strength (less than 2.5%) were obtained during laboratory tests performed according to ENV ISO 10722-1 damaging procedure (Cancelli 1999). In this case the difference seems due to the characteristics of the used aggregate (a sintered aluminum oxide: Corindon 5-10 mm as prescribed): sharpness, grain size, hardness.



Figure 7. Chemical damage test on a 40kN class Geogrid.

Where aggressive conditions (e.g. pH outside the range of 2 to 10) are found to exist, it is suggested that advice shall be sought from the geosynthetic manufacturers and, if necessary, polymer scientists and industrial chemists working in the geotechnical field. Polypropylene geosynthetics are reported to be resistant to Acid conditions with 2 < pH < 7 and for all Alkaline conditions (pH>7).

It can be concluded that extruded polypropylene geogrids can be used without problems for soils having pH $\geq$ 2. Nevertheless, a series of test have been conducted at Inchon University to compare the tensile strength of the proposed geogrid after exposure to a chemically aggressive environment (cement, in this case).

The results are shown in fig. 7; although the sample exposed to cement has an apparent slight reduction in its tensile properties, it is worth noticing how the residual value is superior to the specified value (see tab. 1).

This is due to the fact that, obviously, it is not possible to test exactly the same specimen in both conditions. The "undisturbed "specimen had a slightly higher tensile strength respect to the standard (42 kN/m rather than 40 kN/m).

A number of studies, both in the geosynthetics industry but especially in the plastic industry and in the water and gas piping industry, have shown that the synthetic polymers used for the manufacturing of the geogrids used in this project are resistant to attack by micro-organisms (i.e. aerobic and anaerobic growth of bacteria, fungi and algae) and macro-organism such as rodents and termites.

Moreover, for soil reinforced structures the biological activity is typically low due to the depth at which geogrids are typically buried and to the fact that the fill soil is biologically inert since it is mainly composed of granular soil with no traces of organic soil or products coming from decomposition.

Finally the junction strength had to be taken into account; typical junction strength tests performed on the used geogrids show that the junction strength  $T_{JCT}$  measured in MD is at least 90.0% of the nominal peak value.

The partial factor that can be found from these tests can be applied to the peak (ultimate) tensile strength in order to define the long term design strength for the geogrid, according to GRI GG4 Standard (1991).

$$T_{\text{allow}} = T_{\text{ult}} / (FS_{\text{creep}} * FS_{\text{ID}} * FS_{\text{CD}} * FS_{\text{BD}} * FS_{\text{JCT}})$$
(1)

where  $FS_{creep}$  = partial factor of safety for creep (typically = 3.50 for polypropylene geogrids)

 $FS_{ID}$  = partial factor of safety for installation damage (from tests, 1.02)

 $FS_{CD}$  = partial factor of safety for chemical degradation (from tests, 1.00)

 $FS_{BD}$  = partial factor of safety for biological degradation (from bibliography, 1.00)

 $FS_{JCT}$  = partial factor of safety for junction strength (from tests, 1.10 in MD)

These partial factors give the final design load, equal to 10.00 kN/m.

### **4** FINITE ELEMENTS ANALYSIS

The complexity of a Finite Elements Analysis requires a noticeable number of hypothesis to be done in order to completely characterize the problem: in this paragraph some of the most important ones are summarized.

As in common engineering practice, in order to evaluate the stability conditions of long strip structures, a plane-strain analysis is performed. This means that, for the problem we are studying, a calculation of the conditions of one half of the single typical cross section could be considered fully representative of the real situation.

According to the options available with the software used in the analysis (PLAXIS, Holland -Brinkgreve and Vermeer, 1998), every soil element has been described with quadratic 6-node triangular elements (the same type of elements were used for the stabilized base layers and the pavement).

In representing geogrid elements, 3-node tension elements were used. Since it's also necessary to model the interaction between soil and geogrid, special interface 3-node elements were adopted (Van Langen and Vermeer, 1991).

As it's common practice in computational structural engineering, reduced values of interface strength and deformability parameters should therefore be assigned to these elements.

The interface reduction coefficient could be assessed on the basis of previous experimental researches (Cancelli et al., 1992) that included full scale direct shear and pull-out tests on geogrids of the same kind.

In order to represent the stabilized soil behavior, the Mohr Coulomb elastic plastic constitutive law was used. Furthermore the mechanical behavior of the concrete pavement layer was described with a simple linear elastic model.

Since the difficulties connected to the fill soil compaction in the area close to the box culverts were highlighted as a relevant problem, reduced deformability parameters (about 35% reduction) had to be expected for the laterals belts (0.5 m width) adjacent to both the vertical sides of the culverts.

As previously reported the calculations were performed for the conditions of the Embankment reinforcement and the Base Course reinforcement; in both cases only one half of the typical section, under a load of a four cycle landing gear (70 tons), was studied.

Being the determination of differential settlements the main objective of the analysis, the soil area under the base level of the concrete structures and the concrete structure themselves were considered fixed.

The actual objective of the calculations was, of course, the weak soil area beneath the concrete structures: for this reason the loading position was chosen in the most critical condition.

## 5 RESULTS

Some of the most interesting results are reported in the following figures and briefly commented.

The expected deformed mesh has been represented in Figure 8 and 9 for both the Embankment and Base course conditions. In order to allow an easier interpretation, the displacements were amplified by a factor of 100.

In both cases maximum displacements were expected to be less than 3 mm. Nevertheless the shape of the deformed geogrids shows a significant concentration of the calculated deformations in proximity of the concrete culverts.

The shaded contours distribution of the relative shear stresses for the Base course condition is reported in Fig. 10. It's worth to remember that the relative shear stress is defined as the ratio between the mobilized shear stress and the plastic limit shear stress.

The drawing is clearly referred to a magnified particular of the whole structure: more precisely the aim was to highlight the distribution of the shear plasticised area.

As it was clearly predictable an intense shear plasticisation ( $\tau_{rel} \cong 1$ ) is affecting the concrete culvert in proximity of the corner, with an orientation approximately inclined toward the bottom of the excavation.

The total displacements of the reinforcing geogrid have been plotted in Fig. 11 (for the Base course condition) in order to notice the abrupt difference of settlements at the culvert's corner. Moreover the total displacements at the ground level have been plotted in Fig. 12 (on a different scale). The uniformity of the calculated settlements was fully compliant with the specifications required.



Figure 8. Embankment deformed mesh (displacements amplified x 100).



Figure 9. Base course deformed mesh (displacements amplified x 100).



Figure 10. Base course Relative shear shaded contours (magnified particular).



Figure 11. Base course geogrids displacements (not to scale).



Figure 12. Base course surface displacements (not to scale).

#### 6 CONCLUSIONS

The experience made during this case study, both during design and installation, allows the authors to state the following conclusions:

- in the choice of the type of geosynthetic, lot of features should be considered; main topics should include not only the type (in this case geogrids), but also the polymer and the structure.
- the determination of the design strength of a geosynthetic should be done after considering all the aspect that can reduce its strength.
- in particular cases, specific tests can be done to give the designer instruments to find out an accurate and safe design strength.
- extruded PP geogrids have demonstrated to be particularly suitable for the use in environmentally aggressive soils (such as cement treated backfill), and to be resistant also to very high compaction.
- through finite element analysis it is possible to have a very good idea of the behaviour of a reinforced structure, particularly when settlements represent a major problem under working conditions.

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