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The local sand as heavy pavement construction material, the experience and tests done into genova port

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Abstract

The paper presents the performance achieved for the sand material when it is confined inside a 3D cellular confinement mattress. The test area was located inside the Genova Port in order to validate the potential improvement of the 3D dredged sand confinement solution. It was decided to create a demo area and test its performance versus the conventional pavement. In particular, the target was to use the available dredged sand confined as an alternative layer of the expensive well graded crushed rock aggregate, usually used on the traditional Port pavement substructure.

The testing involved static plate loading (deformation modulus and bearing capacity) and simultaneous measuring of pressure cells which were installed on the subgrade surface in order to assess the vertical stress.

The static plate load test is a standard test method performed according to CNR UNI n.146 (deformation modulus), ASTM D 1194-93 (modulus).

Using the dredged sand confinement, the stress transfer from the test plate to the pressure cell on the subgrade surface was reduced by 33% to 40% than the traditional good quality aggregate layer; the modulus reached from ASTM D 1194-93 improved factor 3 than traditional layer; the deformation modulus reached from CNR UNI n.146 improved on factor +1,6 (between 0,5kg/cm2 – 1,5kg/cm2), +2,6 (1,5kg/cm2 – 2,5kg/cm2) +4,1 (2,5kg/cm2-3,5kg/cm2). It is very important to state that a failure was noticed at the local subgrade soil in the traditional layer section at only 3,5kg/cm2, where at the sand confinement section, the loading easily reached 7,0kg/cm2 without any sign of failure

Keywords: Pavement materials, Pavement Surface Properties, Recycling, Design Methods, Case studies.

Introduction

The performance of pavements is governed by the strength and stiffness of the pavement layers. The cost and duration of construction are dependent on the availability of aggregate materials for construction. It is essential to look at alternatives to achieve improved quality of pavements using new materials and reduced usage of natural materials. Several types of ground improvement techniques involving stabilizing or reinforcing the soil are used for construction [1-2]. Among the various techniques available for ground improvement, soil reinforcing has been emphasized by many researches as an effective method [3-5]. The 3D

Cellular Confinement (3DCC) system is the latest development in the field of geosynthetics and its benefits have been highlighted by several researchers [6-11]. Research and development of 3DCC system began with the U.S. Army Corps of Engineers in September 1975 to test the feasibility of constructing tactical bridge approach roads over soft ground (Webster, 1979) [11]. Engineers discovered that sand cellular confinement systems performed better than conventional crushed stone. In terms of the effectiveness of confinement, the cellular confinement system has more attractive features due to its 3D structure than any other planar geosynthetic reinforcement. Hence 3DCC system can provide better lateral confinement to infill soil [4]. The reinforced composite formed by 3D and the infill soil has a higher stiffness and shear strength than the unreinforced soil. These cellular shape, completely encase weak material such as: uncohesive local soil, gravel, sand (all kinds), RAP (Reclaimed Hot Asphalt), fly ash, bottom ash etc. They provide all round confinement due to its three-dimensional structure thus preventing the lateral spreading of the material due to a much stiffer mat forming a structure distributing the overcoming load to a much wider area. Extensive research of the reinforcement mechanisms in 3DCC system shows that the stiffness of the material is the most important confinement parameter [6-11]. This significantly increases the strength of confined infill as well as the pavement layer elastic modulus. The three-Dimensional confinement prevents movement and shearing of the layer under cyclic loading, while reducing aggregate abrasion. The confinement also maintains compaction to retain the long-term structural reinforcement.

Application of 3D Cellular Confinement system (3DCC system)

Pavement and road construction

Thakur et al. [7] have studied the effect of 3D reinforced recycled asphalt pavement (RAP) bases over weak subgrade under cyclic plate loading and found that it has improved the performance of RAP bases over weak subgrade as compared with the unreinforced base section and has significantly increased the percentage of resilient deformation of the RAP base. The 3D reinforcement reduced the vertical stress transferred to the subgrade by distributing the load over a wider area. Emersleben et al [8] have studied about the bearing capacity improvement of gravel bases layers in road constructions using 3D system and concluded that the layer placed within the gravel base layer of an asphalt paved construction reduced the vertical stresses on subgrade during vehicle crossing about 30% and increased the layer modulus of the gravel base layers compared to an unreinforced layer. As a result, the measured deflections on the asphalt surface were also reduced.

Foundation

Sireesh et al. [9] have performed experiments on circular footing on 3D sand mattress overlying clay bed with void to study the increase the bearing capacity of circular footing. A series of model load tests have been conducted to evaluate the potential benefits. The test results clearly demonstrate that 3D mattress can substantially increase the bearing capacity and reduce settlement of the clay subgrade with void. Dash et al. (2003) conducted experiments on circular footing supported on 3D reinforced sand underlain by soft clay and concluded that provision of 3D reinforcement in the overlying sand layer improves the load carrying capacity and reduces the surface heaving of the foundation bed substantially [4]

Railway

Leshchinsky et al. (2012)[10] studied about the numerical modelling of behaviour of railway ballasted structure with 3DCC system. At the end of this he concluded that the confinement of the ballast using 3DCC system was quite effective in reducing vertical deformations, especially when low quality material was used. Higher shear strength of the ballast reduces the need for reinforcement, reducing the need for substructure improvement.

In situ 3D Cellular Confinement reinforcement test

The Port Authority has been creating a new container yard by infilling the area between two existing wharfs. The first phases include the dredging and infill operations with local marine sand. The wet marine sand needs to be consolidated for a long period and during this waiting period the Port Authority and the contractor choose to examine the impact of the 3DCC system. The goal was to examine the impact of the 3DCC system of the sub base layer of a heavy duty pavement by installing subsurface measurement device to monitoring the vertical stresses developed immediately underneath the reinforcement and comparing them to those vertical stresses developed at the same elevated location in a control section, built with a traditional granular sub base. The conventional heavy duty pavements are based on thick pavement layers (1,5m) and strong materials: well graded crushed aggregate as sub base, cement stabilized as base and quality asphalt concrete as binder and wearing course. The Genoa Port Authorities and the contractor choose to test the 3D mattress reinforcement as structural pavement reinforcement to:

1. Reduce the total pavement thickness;
2. Replace the traditional granular sub base layer with locally dredged sand.

Materials

Subgrade and infill soil for 3D Cellular Confinement system

The sub grade consists of A3 AASHTO class, its dredged sand having a maximum grain size of 2mm. The other parameters are: internal friction angle 24°C, compressibility c_v= 2x10^{-7}m/s, permeability k=5x10^{-10}m/s, water optimum w_{opt}=10,3%, unit weight y=15,6kN/m^3, CBR=17,62%, CBR$_{imb}$=6,43% (soaked) - see tab.1 for other details-.

Table 1.

Sieve dimensions (UNI)	Passing (%weight)
2mm	98
0,425mm	85,9
0,075mm	7,8

Sub base – granular material from original prescription

The original technical performances requested to the granular materials were: quality well graded crushed aggregate, Los Angeles <30%, CBR (AASHO Modified) >70%, Liquid Limit<25, Plastic Limit <6, deformation modulus (test method CNR UNI n.164 and test method SNV 10317) >100MPa between 150-250kPa. The well graded crushed aggregate has a maximum grain size 71mm (see tab.2 for other details)

Table 2.

Sieve dimensions (UNI)	Passing (%weight)
71mm	100
40mm	75-100
25mm	60-87
10mm	35-67
5mm	25-55
2mm	15-40
0,4mm	7-22
0,075mm	2-8

3D Cellular Confinement system (3DCC)

The technical performances, of 3DCC system material, are the following:

Table 3.

Properties	Value	Test Method
Polymer	NPA Novel Polymer Alloy	
Coefficient of soil cell friction	0,95	ASTM D5321
Cell dimensional Stability by CTE Coefficient of Thermal Expansion	135×10^{-6} °C^{-1}	ASTM E831
Long Term plastic deformation at 51°C	< 0,6%	ASTM D6992 (SIM)
Flexural Storage Modulus at 45°C	> 700MPa	ASTM E2254(DMA)
Single Cellular Dimension	245x210mm	

Field test demo

In order to validate the effectiveness of the 3DCC system for the storage yard, it was decided to create a demo and test its performance vs a conventional pavement. Two demo sections, measuring 2,5m wide x 4,0m long 37cm high at 2,00m distance each other, were constructed. The first had dredged sand reinforced with 3DCC system and the second had the conventional well aggregate infill material. The 3DCC system is comprised of: 10cm of granular material for buffer zone above subgrade for pressure cell protection; 17cm dredged sand confined 3DCC system; 10cm of granular material above the 3DCC system to prevent the plate from sinking into the layer.

The test involved static plate loading and simultaneous measuring of sub grade stress, using the pressure cells, which were installed on the subgrade surface in order to assess the vertical stress.

Plate Load test

To determine the deformability and the load bearing capacity of sub base reinforced and unreinforced sections two load tests were carried out in middle distance sections, in accordance with the Italian CNR UNI N.146 and the American ASTM D 1194-93. In these tests the soil is charged and discharged by circular footing with a diameter 30cm and a max force of 200kN. The device had Certificate of Calibration No.724/2010 – Politecnico di Milano. A load settlement curve can be designed from the average values of the applied stress and measured settlement of load plate. From the load settlement curve Md and E values are calculated. They give information on the bearing capacity of the different sub base layers.

Stress measurements Earth Pressure Cells

The objective of the examination is the determination of the influence of 3DCC system below a sub base on the magnitude and the distribution of the stresses in the sub grade. To measure the stresses the pressure cells produced by Sisgeo, model CRD-400, were used, vibrating wire, having a maximum load capacity at 700kPa, the calibration has been made according to UNI EN ISO 9001:2008-IST10/01. The two pressure cells were installed: one in the middle of 3D reinforced section and the second in the middle of unreinforced section, at the same depth and under the plate load axle. After installation, the pressure cell, as protection layer in reinforced section, was placed in 10cm thick gravel layer and then compacted.

Plate Load test results

The tests result as measured by the laboratory was calculated according to the following formulas (first load cycle):

$M_d = (\Delta P/\Delta s)\phi$ (1)

Md = deformation modulus[kPa] ; ΔP = variation pressure[kPa]; Δs = settlement[cm]; ϕ = plate diameter[cm]

$E = 0{,}791(1-\mu^2)(\Delta P/\Delta s)D$ (2)

E = modulus[kPa]; 0,79 = plate constant[/]; D = plate diameter[cm]; P = loading pressure[kPa]; s = settlement[cm]; μ=Poisson's ratio[/]

Unreinforced Section

Table 4. unreinforced section M_d, measurements after compaction

Pressure [kg/cm^2]	Stabilization time [min.]	Settlements Average value [mm]	Pressure cell [kPa]	Pressure [kPa]	Stabilization time [min.]	Settlements Average value [mm]	Pressure cell [kPa]
1st cycle load				2nd cycle load			
0,20	1	0,00	5	20	1	10,21	21
0,50	4	0,46	10	100	2	10,33	35
1,00	9	1,58	20	200	2	10,75	55
1,50	8	2,83	30	300	3	11,30	77
2,00	9	4,41	41	350	infinite	11,95	90
2,50	11	6,31	55				
3,00	13	8,61	72				
3,50	infinite	11,35	88				

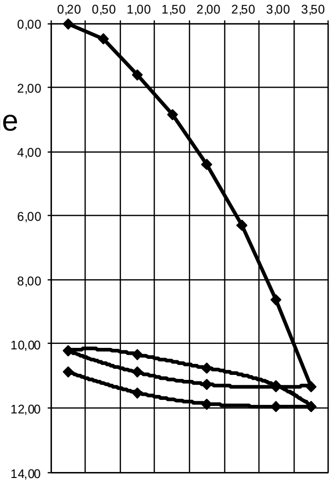
M_d = 12.700kPa between 50-150kPa; **M_d = 8.600kPa** between 150-250kPa;

Table 5. unreinforced section E modulus

Pressure [kPa]	Stabilization time [min.]	Settlements Average value [mm]
150	8	2,83
300	13	8,61

E = 5.600kPa

In this section a failure was noticed at the local subgrade soil at 350kPa during the loading of the static plate load test at the first cycle. The stress transfer from the test plate to the pressure cell on the subgrade surface of the unreinforced section was 20-27%. The following graph shows the pressure-displacement curves under static loading for the unreinforced section as measured by settlement vs stress.



3DCC system reinforced section

Table 6. reinforced layers deformation modulus, measurements after compaction

Pressure [kPa]	Stabilization time [min.]	Settlements Average value [mm]	Pressure cells [kPa]	Pressure [kPa]	Stabilization time [min.]	Settlements Average value [mm]	Pressure cells [kg/cm^2]
1st cycle load				2nd cycle load			
20	1	0,00	3	20	1	4,81	12
50	2	0,42	6	100	2	4,88	22
100	5	1,24	13	200	2	5,21	37
150	5	1,93	22	300	2	5,57	54
200	5	2,62	30	400	2	5,96	72
250	5	3,24	39	500	5	6,57	92
300	5	3,85	49	550	4	6,95	103
350	6	4,47	59	600	6	7,52	116
400	5	5,05	69	650	7	8,15	129
450	5	5,64	80	700	7	8,70	142
500	8	6,29	91				

M_d = 19.900kPa between 50-150kPa; **M_d = 22.900kPa** between 150-250kPa; **M_d = 24.300kPa** between 250kPa-350kPa

Table 7. reinforced section modulus, measurements after compaction

Pressure [kPa]	Stabilization time [min.]	Settlements Average value [mm]
150	5	2,83
300	5	8,61

E = 17.160kg/cm² (+3,05 times unreinforced section with good quality aggregate)

In this section the loading easily reached **700kPa without any sign of failure**. The stress transfer from the test plate to the pressure cell on the subgrade surface with 3DCC system was only 12-18%. This is evident at a stress of 350kPa where the pressure cell measurement is only 59kPa (as opposed to 88kPa in the unreinforced section). The 3DCC section significantly reduced stresses to the subgrade by **33** to **40%**. The following graph shows the pressure – displacement curves under static loading for the 3DCC reinforced section as measured by settlement vs stress

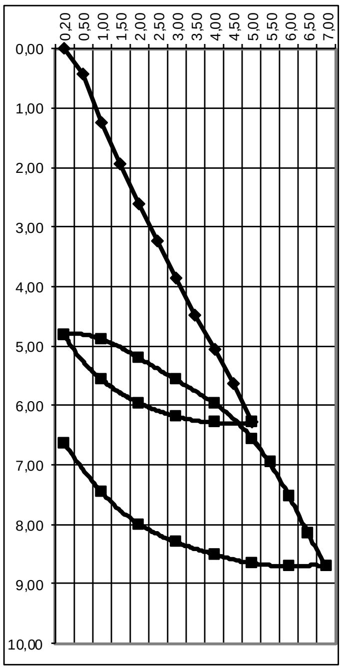


Table 5. settlements comparison

Settlements difference = (Reinforced – Unreinforced)				Settlements difference = (Reinforced – Unreinforced)	
Pressure [kPa]	[mm]	[%]	Pressure [kPa]	[mm]	[%]
1st cycle load			2nd cycle load		
150	-0,90	-31,8	20	-5,40	-52,9
200	-1,59	-36,1	100	-5,45	-52,8
250	-3,07	-48,7	200	-5,54	-51,5
300	-4,76	-55,3	300	-5,73	-50,7

Conclusion

In situ field testing of the *3DCC system* demonstrated that it reduced sub grade vertical stress of the dredged reinforced sand by 33% to 40% vs the good quality crushed gravel. The Plate static load test showed that the bearing capacity of the sub base reinforced layer increased by +1,6 times, as deformation modulus between 50-150kPa, by +2,7 times, as deformation modulus between 150-250kPa. In terms of weighted modulus (ASTM D 1194-93) the bearing capacity of the sub base reinforced layer increased by +3,05 times.

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