Relationship between Porosity, the Maximum Dry Density and the Mechanical Behavior of Stabilized Dune Sands

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Abstract

In this paper, the stabilization of studied dune sands was made by compaction and addition of stabilization agents; cement and fillered sand. The cement percentage ranges from 2 to 10

Index terms— dune sands; stabilization; relationship; porosity accessible to water; maximum dry density; mechanical behavior.

1 Introduction

his is the second paper in a series reporting on the results an investigation into the physical and mechanical properties of stabilized dune sands of the Djelfa region (Algeria). The first paper [1,2] reported on the utilization of stabilized dune sand in road foundation layers. The aim of the work presented in the first paper is the valorization of dune sand, which is abundant in Djelfa. This study consists of valorizing a local material in road construction. The results obtained show that the formulations selected have sufficient performances to be used in road foundation layers. The studied dune sands of the region of Djelfa belong to the D1 class according to the classification of the technical guideline on embankment and capping layer construction (GTR). They are poorly graded and contain a high proportion of fine elements (high porosity); their stabilization requires the addition of a granular corrector. The maximum dry density increased with cement addiition, owing to the higher absolute density of the cement. However, the optimal water content decreases. The increase in the maximum dry density with sand FS addition is attributed to the increase in the compactness of the mixtures. The addition of sand FS takes part in a very positive way to correct the grading of the studied sands, by improvement of the compactness of the mixtures and consequently the mechanical performance, particularly the compressive and tensile strength. The effect of the origin of sand on the physical characteristics and mechanical is very significant. This is attributable to the relative distinction of grading for each of sand. The use of sand FS improves the mechanical performances tested (tensile and compressive strength and elasticity modulus).They develop satisfactory mechanical performances to consider their valorization in road foundation layers. This second paper investigates the relationship between porosity accessible to water, the maximum dry density and the mechanical behaviour (MB) and presents empirical models that have been developed to describe this relationship. Stabilized dune sand is a porous material. In other words, it contains pores or voids. These pores are crucial to affect the mechanical behavior and durability of cement-based materials [3]. Indeed, a low porosity is the best defence against any aggressive agents. Porosity is a natural consequence of the quantity of water added more than is necessary to cement hydration, and of the voids present in the aggregate [4,5]. The inconvenience of this porosity is marked at two levels: on the strength and durability of cement-based materials. The compressive strength, the splitting tensile strength and elasticity modulus of cement-based materials are important design parameters in civil engineering. The splitting tensile test has been reported as indirect measure of the tensile strength of cement-based materials [6,7]. It has been used widely in practice due to its testing ease, simplicity of specimen preparation, and possible field applications, particularly in road engineering. In our study, the stabilization of studied sands (three dune sands of the Djelfa region) is made by compaction and the addition of a cement and a granular corrector; the cement percentage ranges from 2 to 10% with a step of 2%, and that of the granular corrector from 0 to 30% with a step of 10%, Sixty mixtures have been prepared. For each mixture, the optimal normal Proctor, the porosity accessible to water, the compressive strength, the splitting tensile strength and elasticity modulus were determined. The main objective of this paper was to study the effects of the addition of stabilization agents on the porosity accessible to water and its relationship with the maximum dry density and the mechanical behavior (compressive strength, the splitting tensile strength and elasticity modulus).

2 II.

3 Experimental Program a) Materials i. Cement

The cement used is of composite cement (CEM II/A) class 42.5 MPa with 20% to limestone fillers. The clinker is from the cement factory of M'sila. Specific density = 3.06 g/cm 3 and fineness = 3.918 cm 2 /g. The mineralogical composition of clinker is presented in Table 1. The potential mineralogical composition of the clinker is calculated according to the empirical formula of Bogue [8]. ii. Fillered Sand (FS)

This sand comes from the centre of crushing Ben Labiad (municipality of Zakkar) located at approximately 40 Km in the south-east of the Djelfa centre (Fig. 1). The addition of this sand consists to improve the grading of studied sands (porosity about 45%) in order to reduce these voids. This increase in the compactness permits to develop better mechanical performances [1,2]. The fillered sand, is of calcareous nature consisting mainly of calcite (95.23%), specific density = 2.64 g/cm 3 . The grading curve of sand is given in Fig. **??**. The chemical analysis shows that this sand contains almost no harmful elements (0.23% of chlorides and 0.01% of sulphates).

iii. Studied Sands Fig. 1 shows the locations of the studied sands. This work has been undertaken on three types of dune sand in the Djelfa region (Algeria); sand of El-Masrane (SM) (municipality of Hassi Bahbah located about 35 Km north of the Djelfa centre), sand of Zaafrane (SZ) (municipality of Zaafrane located about 57 Km northwest of the Djelfa centre) and sand of El-Amra (SA) (municipality of Ain El-Ibil located approximately 40 Km southwest of the Djelfa centre). The different results of the physical characteristics of the studied sands are summarized in Table 2. Fig. **??** shows the grading curves of the studied sands. It can clearly be seen that 90% of the elements are lower than 0.5 mm. These sands can be classified from a granular viewpoint as fine sands [9]. The grading is very tight; nearly 90% of the grains have a dimension ranging between 0.1 mm and 0.5 mm. the sand alone could not have a sufficiently large compactness, and thus non adequate mechanical performances (compressive and the splitting tensile strength). It should be noted that the considered sands, need therefore to be granularly corrected. The chemical composition (Table 3) shows that the studied sands are principally made up of silica. The contents of the essential harmful substances (sulphates and chlorides) lie within the tolerable limits recommended by standard NF P 18-011 (this standard gives the definition and classification of chemically aggressive environments). This allows us to use a Portland cement as a binder or as an agent of stabilization. The choice of a cement of class CEM I (ordinary Portland cement) or CEM II (composite cement) is very suitable [1]. The mixtures are compacted by using normal Proctor energy according to ASTM D1557-09 Standard [10]. The test was carried out just after mixing operation and therefore could not take into account the effect of the hydration of cement. The values obtained of the optimal normal Proctor (maximum dry density and optimal water content) are required for the preparation of specimens that will be tested in this study (the specimens are made up at the optimal normal Proctor).

ii. Mechanical strengths and elasticity modulus test The compression strength test was carried out according to EN 13286-41 standard [11]. Three specimens were tested at 28 days for each mix proportions. The splitting tensile test was run at 90 days according to EN 13286-42 standard [12]. Similar to the compressive test, the splitting tensile test was carried out on triplicate specimens and average the splitting tensile strength values were obtained. The elasticity modulus test was effectuated according to ASTM C469 standard [13]. The specimens were removed from their conservation and tested in simple compression on a universal press with a capacity of 300 KN. It is equipped with a force sensor and a displacement sensor connected to a data acquisition program (Fig. **??**). The force sensor is connected to the upper cross member of the press. The velocity of displacement of the plate was fixed at 0.2 mm/min. This test was conducted in laboratory of the building materials -University of Djelfa.

Figure **??** : Universal testing machine used

The precision of the force sensor is 0.01 KN, and that of the displacement sensor is 0.002 mm. The elasticity modulus is determined in the linear elastic range of the material and in the relative value of the axial strain versus axial deformation.

4 iii. Water Porosimetry Test

The most method used for characterization is undoubtedly the measurement of porosity accessible to water. It provides a total result (total porosity), indicator of the material quality. From the volume of the specimen, we can calculate its porosity representing the ratio of the pore volume to its total volume [3]. On an experimental basis, either by hydrostatic weighing of a saturated specimen, it then determines the total volume of the specimen (fraction porous and solid) and calculates its porosity, P (%) from the following relation:(P (%) = ((M SSD -M D) / (M SSD -M HYD)) × 100%).

Where: P: porosity determined experimentally by hydrostatic weighing, excluding the volume of trapped air and/or trained (%); M SSD : mass of saturated surface dry specimen, weighing air (g); M D : dry mass of specimen (g); M HYD : hydrostatic mass of saturated surface dry specimen, weighing in water (g).

This method has been used to measure the porosity of the cement-based materials successfully [14][15][16][17]. The water porosimetry is determined by method of hydrostatic weighing (Fig. 5) which is based on the Archimedes' principle on a sample saturated and submerged in a wetting fluid (water). The procedure for evolution the porosity is as follows: The specimens are dried in an oven at 105 °C until constant mass (M D). Then, the specimens are saturated by imbibitions in a cell during 24 h by complete immersion. Then a hydrostatic weighing of the saturated specimens immersed in water (M HYD) and a weighing in air of the saturated specimens wiped with a wet rag (M SSD). The method used in this test is that established by ASTM designation C 624 [3]. This test was conducted in laboratory of the building materials -University of Djelfa. ? Physical stabilization: correction of the grading of studied sands by addition of a granular corrector (sand FS).

? Chemical stabilization: obtaining mechanical strength by addition of a hydraulic binder (cement). The cement percentage ranges from 2 to 10% with a step of 2%, and that of the fillered sand from 0 to 30% with a step of 10% (the percentages based on the weight of dry mixture). Sixty (60) mixtures are to be studied in this investigation. The mixtures are denoted by SX-PS-PC-PFS; where X represents the sand source, PS the sand percentage, PC the cement percentage, and PFS the percentage of fillered sand, respectively. Details of the mixtures proportions are given in Table 4. For each mixture, the optimal normal Proctor (ONP), the porosity accessible to water, the compressive strength, the splitting tensile strength and elasticity modulus were determined. The specimen's preparation was made by static compression according to EN 13286-53 standard **??**18], this operation allows obtaining ends of the specimens perfectly perpendicular with the cylinder axis (not taking into account the effect of the ends on compressive strength). The moulds used allow obtaining a cylindrical specimen of 80 mm in diameter and 80 mm in height. The specimens were preserved in tight bags with a temperature of 20 ± 2 °C until the time of test. Test Results and Discussion a) Evolution of the porosity accessible to water

The results shown in Fig. **??** proves that for a constant sand FS proportioning, the increase in the quantity of cement added to the mixture, influences negatively and in a very significant way the porosity. This indicates that the addition of cement participates in the improvement of the mixtures compactness. The same remark can be made concerning the influence of sand FS proportioning on the porosity; which explains the effectiveness of the granular corrector used to improve the mixtures compactness (Fig. **??**). The added cement in the presence of water tends to lubricate the sand particles thereby resulting in a denser packing during the compaction process; which explains the decrease of the porosity. Moreover, the cement and the FS particles tend to occupy, the voids between the dune sands particles, hence, resulting in a denser sand matrix [1,19] (the cement and the sand FS participate in improving the mixtures compactness). For 2% cement and 0% sand FS, the porosity varied from 26.87%, 26% and 26.22% respectively for the sands SM, SZ and SA, , and increased with the cement and the sand FS content to a maximum value of about 16.78%, 17.70% and 18.31% respectively for 10% cement and 30% sand FS addition. Fig. 8 shows the relationship between porosity and the maximum dry density of the stabilized dune sands; the regression coefficient (R 2) is presented. We can notice that for different dune sands origins and different stabilization agent percentages the porosity accessible to water is significantly linked to the maximum dry density. A coefficient of more than (0.80) indicates a good relationship between porosity and the maximum dry density [20]. This relationship is of decreasing order and follows a linear function. It can be represented by the equation: (P = -36.12 × ?d + 87.33); regression coefficient (R 2 = 0.81). These results show that it is possible to estimate the porosity of the stabilized dune sands when the maximum dry density is known. Where: P: porosity accessible to water (%); ? d : maximum dry density (g/cm 3). Fig. 9 indicates that the mechanical behavior (MB) of stabilized dune sands ((1) compressive strength, (2) the splitting tensile strength and (3) elasticity modulus) decrease with an increase in the porosity. The experimental data, depicted in Fig. 9, were utilized to develop a relationship equation between porosity and the mechanical behavior of the stabilized dune sands. The relationship between the fitted parameters is of decreasing order and follows an exponential function as: (MB = a × e (-b × P)). Where: MB: are the mechanical behavior (compressive strength, the splitting tensile strength and elasticity modulus); P: is the porosity accessible to water; (a) and (b): are the empirical constants. The constants (a) and (b) were obtained through the regression analysis of the experimental data. The best-fit values of constants (a), (b) and the regression coefficient are summarized in Table **??**. A regression coefficient of more than (0.85) indicates an excellent relationship between the fitted parameters [20]. Therefore, the data in Table **??** indicate a significant relationship between porosity and the mechanical behavior of the stabilized dune sands (compressive strength, the splitting tensile strength and elasticity modulus). It is to be noted that the relationship equation relating porosity accessible to water and mechanical behavior of the stabilized dune sands, developed in the present work, would help to estimate the compressive strength, the splitting tensile strength and elasticity modulus of these materials, irrespective of the dune sand origin and the stabilization agent content. It should be noted that the relationships reported in this paper were developed for the dune sands of the Djelfa region (Algeria), which have been stabilized by compaction and by addition of composite cement and the sand FS, as such similar relationships may need to be developed for other types of dune sands and agents of stabilization.

(3)

5 Conclusion

The main objective of this paper was to study the effects of the addition of stabilization agents on the porosity and its relationship with the maximum dry density and the mechanical behavior (compressive strength, the splitting tensile strength and elasticity modulus). Based on the results of this experimental study, the following conclusions could be drawn:

? The increase in the quantity of stabilization agent added to the mixture, influences negatively and in a very significant way the porosity. This indicates that the addition of cement and sand FS participates in the improvement of the mixtures compactness.

? For different dune sands origins and different stabilization agent percentages the porosity accessible to water is significantly linked to the maximum dry density. A regression coefficient of more than (0.80). Indicates a good relationship between porosity and the maximum dry density. This relationship shows that it is possible to estimate the porosity of stabilized dune sands when the maximum dry density is known.

? The mechanical behavior data of stabilized studied sands were related to the porosity accessible to water through a single equation noted below: (MB = a $\times$ e (-b $\times$ P)). Where: MB: are the mechanical behavior (compressive strength, the splitting tensile strength and elasticity modulus); P: is the porosity accessible to water; (a) and (b): are the empirical constants. An excellent relationship was noted between mechanical behavior and the porosity accessible to water, expressed in terms of the above expression. The relationships developed in the present work are related to the dune sands of Djelfa region, the composite cement and the sand FS. They could be utilized to estimate the compressive strength, the splitting tensile strength and elasticity modulus of other stabilized sands knowing the porosity accessible to water, of course, with a certain error degree. [1] [2]

1

Figure 1: Figure 1 :

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Figure 2: Figure 2 :Figure 3 :

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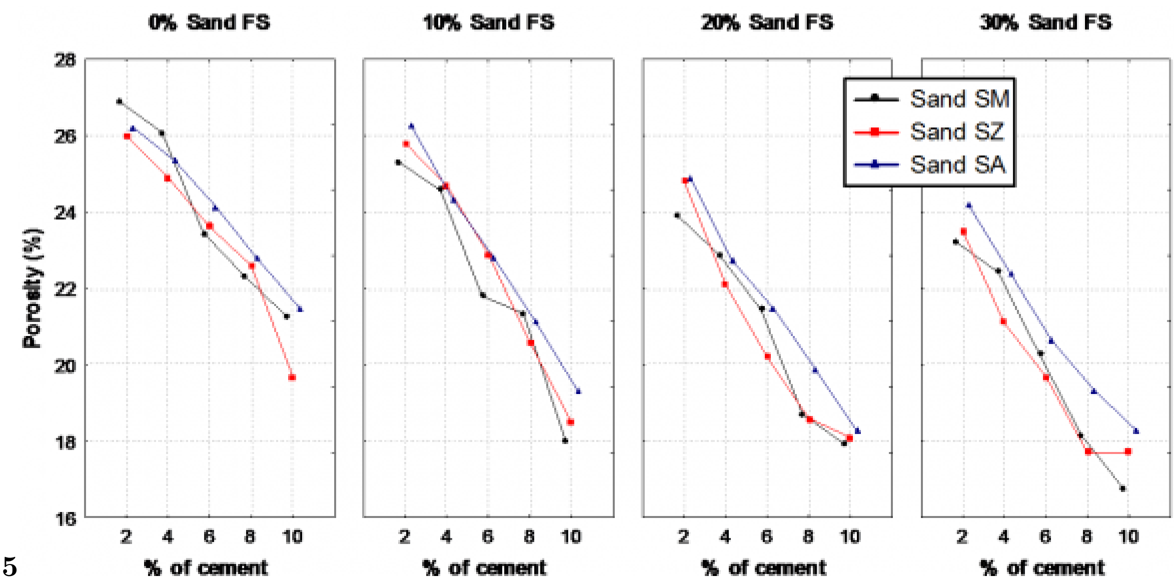

Figure 3: Figure 5 :

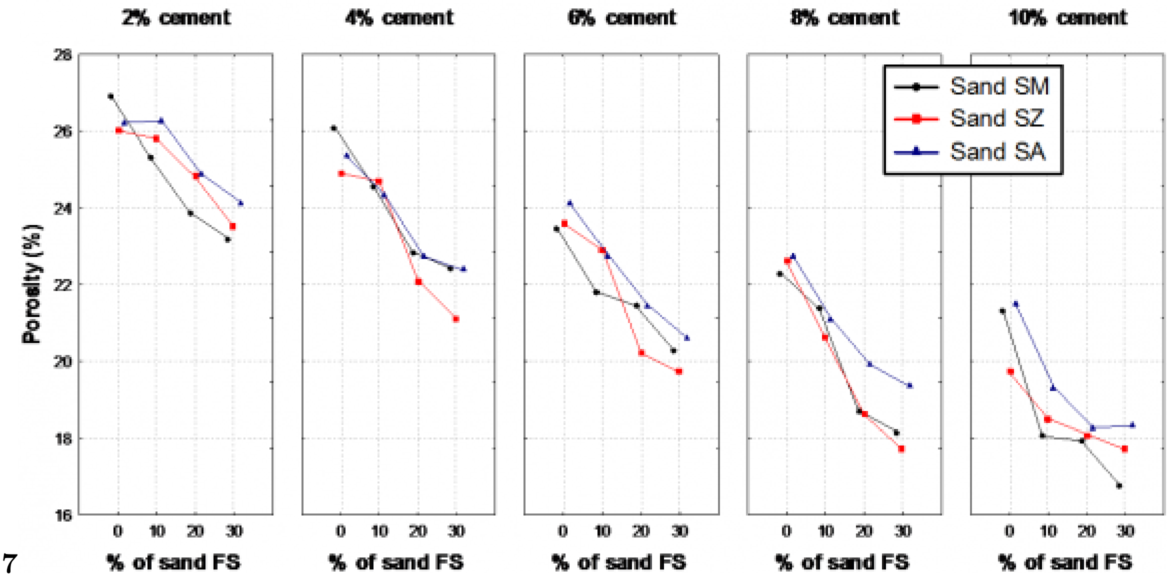

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Figure 4: Figure 6 :Figure 7 :

1

C 3 S	C 2 S	C 3 A	C 4 AF
81.18	2.79	6.85	9.18

Figure 5: Table 1 :

2

Physical characteristics	Sands SM	SZ	SA
Apparent density (g/cm 3)	1.40	1.44	1.42
Specific density (g/cm 3)	2.58	2.56	2.60
Porosity (%)	46.00	44.00	45.00
Compactness (%)	54.00	56.00	55.00

Figure 6: Table 2 :

3

Chemical composition (%)	Sands SM	SZ	SA
Silica	97.63	97.43	97.14

Figure 7: Table 3 :

Sulfates	Traces	Traces	Traces
Chlorides	0.85	0.82	0.78
Organic matter	1.17	0.93	0.76

b) Tests Conducted

i. Proctor Compaction Test

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Figure 8: Grain size (mm) % of passing Sand SM Sand SZ Sand SA

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Mixtures SM series	SZ series	SA series	% of dune sand	% of cement	% o s F
SM 98-02-00	SZ 98-02-00	SA 98-02-00	98	2	
SM 96-04-00	SZ 96-04-00	SA 96-04-00	96	4	
SM 94-06-00	SZ 94-06-00	SA 94-06-00	94	6	0
SM 92-08-00	SZ 92-08-00	SA 92-08-00	92	8	
SM 90-10-00	SZ 90-10-00	SA 90-10-00	90	10	
SM 88-02-10	SZ 88-02-10	SA 88-02-10	88	2	
SM 86-04-10	SZ 86-04-10	SA 86-04-10	86	4	
SM 84-06-10	SZ 84-06-10	SA 84-06-10	84	6	1
SM 82-08-10	SZ 82-08-10	SA 82-08-10	82	8	
SM 80-10-10	SZ 80-10-10	SA 80-10-10	80	10	
SM 78-02-20	SZ 78-02-20	SA 78-02-20	78	2	
SM 76-04-20	SZ 76-04-20	SA 76-04-20	76	4	
SM 74-06-20	SZ 74-06-20	SA 74-06-20	74	6	2
SM 72-08-20	SZ 72-08-20	SA 72-08-20	72	8	
SM 70-10-20	SZ 70-10-20	SA 70-10-20	70	10	
SM 68-02-30	SZ 68-02-30	SA 68-02-30	68	2	
SM 66-04-30	SZ 66-04-30	SA 66-04-30	66	4	
SM 64-06-30	SZ 64-06-30	SA 64-06-30	64	6	3
SM 62-08-30	SZ 62-08-30	SA 62-08-30	62	8	
SM 60-10-30	SZ 60-10-30	SA 60-10-30	60	10	

Figure 9: Table 4 :

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Constants (a) and (b) and regressions coefficients (R 2)			
Mechanical behaviours (MB)	a	b	R 2
Compressive strength	6201.2	0.38	0.88
Splitting tensile strength	797.1	0.39	0.85
Modulus of elasticity	6200.2	0.43	0.86

IV.

Figure 10: Table 6 :

[Toulouse ()] , France Toulouse . 1997. p. 283.

[Torrent ()] 'A general relation between tensile strength and specimen geometry for concrete-like materials'. R J Torrent . *Mater Struct* 1977. 10 (4) p. .

[Gbb -Groupement ()] *Belge du Béton. Concrete technology*, Gbb -Groupement . 2006. Bruxelles.

[Bogue ()] *Chemistry of Portland cement. 2 nd ed*, R H Bogue . 1955. New York: Reinhold Publishing Corp. p. 790.

[Ployaert ()] *Durability of concrete by mastering water absorption. Fédération de l'Industrie Cimentière Belge (FEBELCEM). Technologie, Bruxelles, Novembre*, C Ployaert . 2009. p. 16.

[Afpc-Afrem] 'Durability of concretes, recommended methods for measurement of quantities associated with the durability'. Afpc-Afrem . *Compte rendu des Journées Techniques AFPC-AFREM*,

[Xudong et al. ()] 'Influence of porosity on compressive and tensile strength of cement mortar'. C Xudong , W Shengxing , Z Jikai . *Constr Build Mater* 2013. 40 (3) p. .

[Montgomery and Peck ()] *Introduction to linear regression analysis*, D C Montgomery , E A Peck . 1982. New York: Wiley.

[Mixtures treated and not treated with hydraulically bound mixtures -Part 41: test method for the determination of the compress *Mixtures treated and not treated with hydraulically bound mixtures -Part 41: test method for the determination of the compressive strength of the mixtures treated with hydraulic binders*, AFNOR (NF EN 13286-41. 2003.

[Mixtures treated and not treated with hydraulically bound mixtures -Part 42: test method for the determination of the indirect *Mixtures treated and not treated with hydraulically bound mixtures -Part 42: test method for the determination of the indirect tensile strength of treated with hydraulic binders mixtures*, AFNOR (NF EN 13286-42. 2003.

[Mitiche-Kettab et al. ()] *Physicochemical soil stabilization: the case of sand dunes and tuffs gypsum and limestone gypsum. 1 er séminaire international de génie civil CIGCB*, R Mitiche-Kettab , A Ghrieb , M Serikma . 2013. Mars. p. . Université de Bechar, Algérie

[Chindaprasirt and Strength ()] 'porosity and corrosion resistance of ternary blend Portland cement, rice husk ash and fly ash mortar'. P Chindaprasirt , Rukzon S Strength . *Constr Build Mater* 2008. 22 (8) p. .

[Matusinovic et al. ()] 'Porosity-strength relation in calcium aluminate cement pastes'. T Matusinovic , J Sipusic , N Vrbos . *Cem Concr Res* 2003. 33 (11) p. .

[Chauvin ()] *Sands: technical guide road-use. ISTED, France*, J J Chauvin . 1987. p. 76.

[Ghrieb et al. ()] 'Stabilization and utilization of dune sand in road engineering'. A Ghrieb , R Mitiche-Kettab , A Bali . *Arab J Sci Eng* 2014. 39 (3) p. .

[Al-Amoudi and Khan ()] 'Stabilization of a Saudi calcareous marl soil'. O Al-Amoudi , K Khan , Al-Kahtani , N . *Constr Build Mater* 2010. 24 (10) p. .

[Astm C469 ()] *Standard test method for static modulus of elasticity and Poisson's ratio of concrete in compression. Annual Book of ASTM Standard 04*, Astm C469 . 2002.

[Standard test methods for laboratory compaction characteristics of soil ()] *Standard test methods for laboratory compaction characteristics of soil*, ASTM D1557-09. 2009.

[Papayianni and Stefanidou ()] 'Strength-porosity relationships in lime-pozzolan mortars'. I Papayianni , M Stefanidou . *Constr Build Mater* 2006. 20 (9) p. .

[Raphel ()] 'Tensile strength of concrete'. J M Raphel . *J Am Concr Inst* 1984. 81 (2) p. .