NUMERICAL TESTS FOR SOIL EROSION REDUCTION SOLUTIONS UNDER THE ACTION OF THE WIND

Bogdan-Iulian DOROFTEI[1], Mircea DEGERATU[2], Georgeta BANDOC[3]

Rezumat. *Obiectul acestui studiu este de a realiza un model numeric al mișcării aerului deasupra unui teren nisipos prevăzut cu ecrane de protecție. La baza acestui model au stat o serie de teste fizice asupra curgerii aerului într-un tunel aerodinamic cu discontinuitate pentru care s-au obținut profile de viteză în diferite secțiuni aval de intrarea aerului. În urma simulării numerice a curgerii aerului în aceleași condiții ca cele din testele fizice s-au obținut profile de viteză în aceleași secțiuni aproape identice. Acest lucru a permis validarea modelului numeric și adaptarea acestuia pentru a simula mișcarea aerului din zona stratului limită atmosferic deasupra unui teren nisipos prevăzut cu un număr de ecrane permeabile de protecție având ca scop diminuarea vitezei vântului.*

Abstract. *The purpose of this study is to make a numerical model of air movement over a sandy terrain provided with protective screens. This model was based on a series of physical tests on air flow in a wind tunnel with discontinuity, for which velocity profiles were obtained in different sections downstream of the air inlet. Following the numerical simulation of the air flow under the same conditions as those of the physical tests, almost identical velocity profiles were obtained in the same sections. This allowed the validation of the numerical model and its adaptation to simulate the movement of air in the atmospheric boundary layer zone above a sandy terrain provided with a number of permeable protective screens with the aim of reducing the wind speed.*

Keywords: soil erosion by wind, permeable protection screen, numerical modelling, ANSYS Fluent LES, COMSOL k-ε turbulent model

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1. Introduction

One of the ways to reduce the phenomenon of erosion is by using permeable protective screens placed in the direction of wind flow, in areas strongly affected by wind erosion of soils, to reduce the air speed, which drives fine sand particles.

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The permeable screens not only prevent soil erosion, but also fix sandy soils to the ground, they protect against mechanical damage of crops (by deflation) and regulate soil moisture by retaining snow in the winter [1-5].

Currently, the method used to determine the geometric characteristics of such protection screens and the protected area associated with them, as well as the penetrability characteristics of permeable screens, is an empirical one based on measurements and observations at natural scale, carried out over long periods of time, of the order of decades, only for a limited number of characteristics regarding the dimensions and degrees of permeability of the screens, the granulometry of the sand, and the wind speeds.

By doing this present study we hope to get a much more closer understanding of the wind speed reduction phenomenon caused by permeable screens, and therefore have a numerical model to help in determining the characteristics of permeable screens.

2. Validating the numerical model

The aim is to compare the numerical model with a real situation in order to be able to modify different parameters of the system, such as the introduction of obstacles in the simulated experimental vein, in order to monitor their effects on the air flow [6-7].

As part of the physical tests, a series of speed profiles obtained through experimental tests carried out in the wind tunnel with discontinuity (TAD) were made. The measurements were performed with the Pitot-Prandtl probe, connected to a piezoelectric differential pressure transducer.

Using the finite element modeling program ANSYS Fluent, a numerical simulation of the physical experiment realized in the wind tunnel with discontinuity was carried out. The results obtained from the numerical simulation were compared with those obtained from the physical experiment for validating the model.

Similar to the previously mentioned model, through the numerical modeling program COMSOL Multiphysics, a numerical simulation of the physical experiment in the wind tunnel with discontinuity was carried out also. The results obtained from this numerical simulation were compared with the results from the physical experiment for fitting the model, then compared with the results obtained in the simulation using the LES method.

The results can be seen in the next graphs, where it is clear that all the models, either numerical or physical are almost the same for the specific sections of measurement downstream of the inlet.

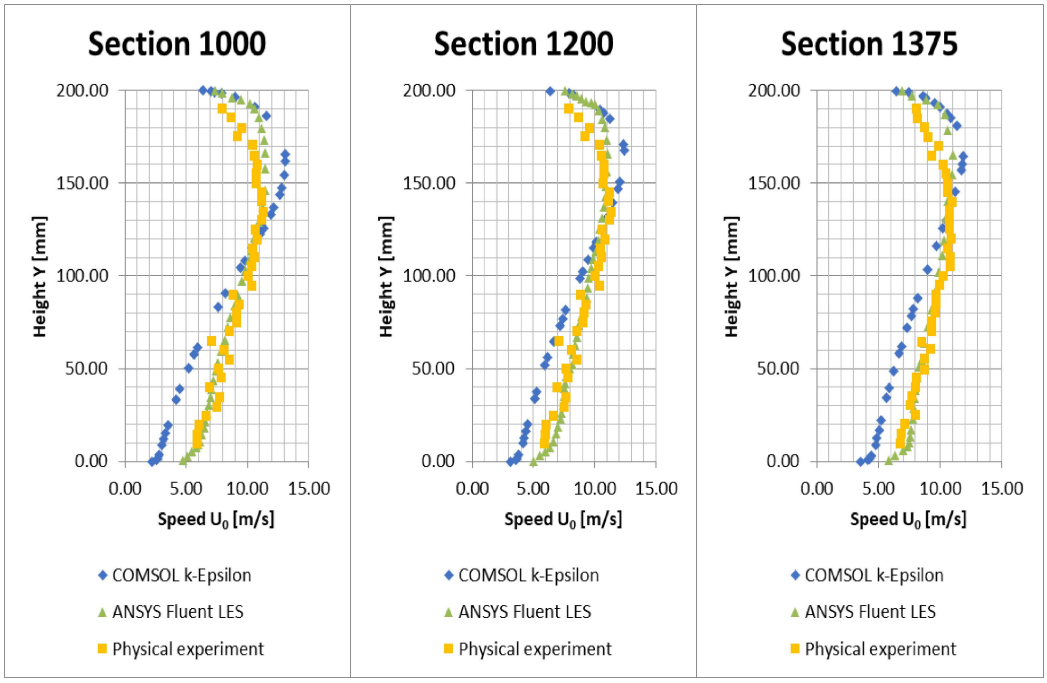

Fig. 3. Comparison between Comsol, Ansys and physical tests results for wind speed in sections 1000 mm, 1200mm and 1375 mm downstream of inlet

The COMSOL numerical simulations led to very close results, in terms of velocity profiles, with the experimental tests, thus considering the numerical model as experimentally validated.

Due to this fact, it was considered that the numerical treatment of the studied problems, and therefore the related numerical tests, can be solved, with a very good approximation, by using the COMSOL Multiphysics finite element modeling method.

3. Using the validated numerical model to simulate air movement over sandy soil provided with permeable screens

Numerical aerodynamic tests were performed for different categories of reference wind speeds ($U(10)$ = 8 m/s, 12 m/s, 16 m/s) and for different protection groups characterized by the number of protection screens (n = 1,2,3,4 screens).

The numerical tests performed followed the way in which these permeable protection screens achieve the reduction of the wind speed downstream of the last row of the set of screens, compared to the incident wind speed upstream of the first row of the set of protection screens.

The numerical models were developed for 3 reference wind speeds upstream of the protection screens, i.e. for the speeds measured at a height of 10 m from the ground, as the speed is measured at the weather stations near the study area. These speeds are $U(10)$ = 8 m/s, $U(10)$ = 12 m/s, $U(10)$ = 16 m/s. The 3 reference speeds (8 m/s, 12 m/s and 16 m/s) used in the numerical calculations were chosen taking into account the specific intensity classes for wind erosion, namely the moderate class ($U(10)$ = 8 m/s) and strong class ($U(10)$ > 11 m/s).

Numerical tests were also performed for 3 wind speed profiles of the incident wind in the section located 20 m upstream of the group of protection screens, all speed profiles being of the power law type with Davenport's exponent corresponding to a sandy terrain, i.e. $\alpha = 0.16$ [8].

At the same time, the numerical tests were performed for 4 situations regarding the number of protection screens, i.e. with 1 protection screen, with 2 protection screens, with 3 protection screens and 4 protection screens. The protection screens have a height of H = 10 m and have a permeability characteristic of 40%. The distance between the rows of screens is 4 m.

The representation of the speed profiles downstream of the set of protection screens were made for the distances $d_{av} = 2H$, $4H$, $6H$ and $8H$ from the last row of screens.

The calculation range, as part of the range of air movement in the atmospheric boundary layer, has a length between 100 m and 112 m for the case with 1 protection screen and respectively for the case with 4 protection screens.

The air velocities were observed, both upstream and downstream of the set of protection screens, at heights important for the studied phenomenon, i.e. at z_1 = 0.20 m, z_2 = 1 m and at z_3 = 2 m. The first two heights refers to the phenomenon of triggering the process of wind erosion and the process of wind transport, respectively. The third height was taken into account due to the fact that, above this height, the influence of the land on wind transport becomes practically negligible.

3.1. Ordering and coding of numerical tests

A total of 48 tests, were performed for 3 reference wind speeds, for 4 types of protection screens assemblies and for 4 downstream sections of the screens.

The 48 numerical tests (48TN) in this research are ordered as follows:

- 16 numerical tests grouped in 3 categories of numerical tests CTi, i = 1,2,3 (CT1, CT2, CT3), each of these categories corresponding to a reference speed of the upstream incident wind, $U(10)$ ($U(10)$=8 m/s, $U(10)$=12 m/s, $U(10)$=16 m/s);

- each category of numerical CTi tests comprises 4 groups of tests GTi,j (GT1,1...GT3,4); each test group corresponds to the number of protection screens (n=1, 2, 3, 4);

- each group of tests GTi, j comprises 4 numerical tests TNi, j, k, corresponding to the 4 sections located at the distances d_{av} from the last row of protection screens (d_{av}=2H, d_{av}=4H, d_{av}=6H, d_{av}=8H).

Table 1 shows, schematically, the way in which the numerical tests were ordered by reference speeds, by the number of protection screens and by the position of the downstream sections..

Table 1. Numerical tests ordering

CT- Category Tests	1CT=4GT=16TN	3CT i (i=1…3)	CT1…CT3	3CT=12GT=48 TN
GT- Group Tests	1GT=4TN	12GT i,j (i=1…3, j=1…4)	GT1,1…GT3,4	12GT=48TN
TN- Numerical tests	1TN=1TN	48TN i,j,k (i=1…3, j=1…4, k=1…4)	TN1,1,1…TN3,4,4	48TN=48TN

Table 2 shows the distribution of numerical TN tests related to downstream d_{av} distances, by groups of GT tests corresponding to the number of protection screens n and by categories of CT tests related to reference speeds U(10).

Table 2. Distribution of TN numerical tests by groups of GT tests and by categories of CT tests

CT1 U(10)=8 m/s				**CT2** U(10)=12 m/s				**CT3** U(10)=16 m/s			
GT1,1 n=1	**GT1,2** n=2	**GT1,3** n=3	**GT1,4** n=4	**GT2,1** n=1	**GT2,2** n=2	**GT2,3** n=3	**GT2,4** n=4	**GT3,1** n=1	**GT3,2** n=2	**GT3,3** n=3	**GT3,4** n=4
TN1,1,1 d_{av}=2H	TN1,2,1 d_{av}=2H	TN1,3,1 d_{av}=2H	TN1,4,1 d_{av}=2H	TN2,1,1 d_{av}=2H	TN2,2,1 d_{av}=2H	TN2,3,1 d_{av}=2H	TN2,4,1 d_{av}=2H	TN3,1,1 d_{av}=2H	TN3,2,1 d_{av}=2H	TN3,3,1 d_{av}=2H	TN3,4,1 d_{av}=2H
TN1,1,2 d_{av}=4H	TN1,2,2 d_{av}=4H	TN1,3,2 d_{av}=4H	TN1,4,2 d_{av}=4H	TN2,1,2 d_{av}=4H	TN2,2,2 d_{av}=4H	TN2,3,2 d_{av}=4H	TN2,4,2 d_{av}=4H	TN3,1,2 d_{av}=4H	TN3,2,2 d_{av}=4H	TN3,3,2 d_{av}=4H	TN3,4,2 d_{av}=4H
TN1,1,3 d_{av}=6H	TN1,2,3 d_{av}=6H	TN1,3,3 d_{av}=6H	TN1,4,3 d_{av}=6H	TN2,1,3 d_{av}=6H	TN2,2,3 d_{av}=6H	TN2,3,3 d_{av}=6H	TN2,4,3 d_{av}=6H	TN3,1,3 d_{av}=6H	TN3,2,3 d_{av}=6H	TN3,3,3 d_{av}=6H	TN3,4,3 d_{av}=6H
TN1,1,4 d_{av}=8H	TN1,2,4 d_{av}=8H	TN1,3,4 d_{av}=8H	TN1,4,4 d_{av}=8H	TN2,1,4 d_{av}=8H	TN2,2,4 d_{av}=8H	TN2,3,4 d_{av}=8H	TN2,4,4 d_{av}=8H	TN3,1,4 d_{av}=8H	TN3,2,4 d_{av}=8H	TN3,3,4 d_{av}=8H	TN3,4,4 d_{av}=8H

The numerical tests were performed for 3 reference speeds of the incident wind are presented (U(10)=8 m/s, U(10)=12 m/s, U(10)=16 m/s), for 4 types of protection screens (n=1, 2, 3, 4 screens) and for 4 downstream sections of the screens (d_{av}=2H, d_{av}=4H, d_{av}=6H,d_{av}=8H).

3.2. Numerical test example and it's results

These numerical tests were performed for the situations included in the group of numerical tests GT1,1 which refer to the movement of air over a sandy soil provided with 1 row of permeable protective screens. (n=1), group belonging to the category of numerical tests CT1 relating to a reference speed upstream of the protection screen (U(10)=8 m/s).

The calculation range corresponding to the GT1,1 numerical test group has a length of 100 m (10H) and a height of 20 m. At a distance of 2H = 20 m from the section entering the calculation range there is a protection screen with permeability of 40% and with height H = 10 m.

Figure 2 shows the speed field in the computational domain for the reference speed ***U*(10)=8 m/s** and number of protection screens n=1 (CT1,GT1,1, **CB:40-10-4-2H**).

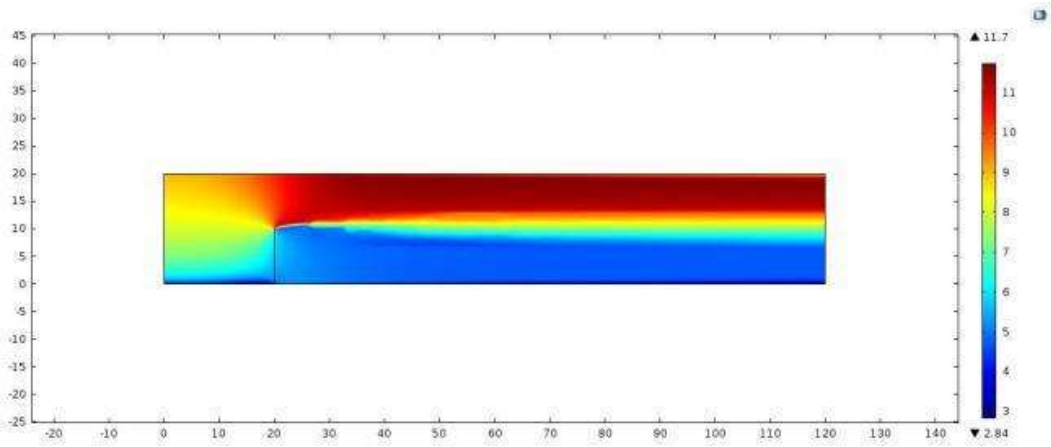

Fig. 4. Speed field in the computational domain for the reference speed U(10)=8 m/s and number of protection screens n=1 (CT1, GT1,1, CB:40-10-4-2H)

From the speed field corresponding to the test group GT1,1, from the category of tests CT1, the speed profiles from 4 sections located at the downstream distances from the protection screens were extracted, d_{av} = 2H, d_{av} = 4H, d_{av} = 6H, d_{av} = 8H. These speed profiles were represented up to the height z = 10 m, because, for the present research, only the speeds at heights z_1 = 0.20 m, z_2 = 1.00 m and z_3 = 2.00 m are concerned, heights at which the phenomenon of sand entrainment produces.

The speed profiles in the 4 sections downstream of the protection screen ((d_{av} = 2H, d_{av} = 4H, d_{av} = 6H, d_{av} = 8H), resulting from the reduction of the incident wind speed, were compared with the power law type speed profile in upstream of the protection screens, i.e. at heights z_1 = 0.20 m, z_2 = 1.00 m and z_3 = 2.00 m.

Figure 3 shows the speed profiles ***U*(z)** downstream of the screen, for the reference speed ***U*(10)=8 m/s** and number of protection screens ***n***=1, at distances d_{av} = **2*H*** (CT1, GT1,1, TN1,1,1, **CB: 40-10-4-2H**, **CT: 8-1-2H**), d_{av} = **4*H*** (CT1, GT1,1 , TN1,1,2, **CB:40-10-4-2H, CT:8-1-4H**), d_{av} = **6*H*** (CT1, GT1,1, TN1,1,3, **CB:40-10-4-2H, CT: 8-1-6H**), d_{av} = **8*H*** (CT1, GT1,1, TN1,1,4, **CB:40-10-4-2H, CT:8-1-8H**), compared to the speed profile of the incident wind.

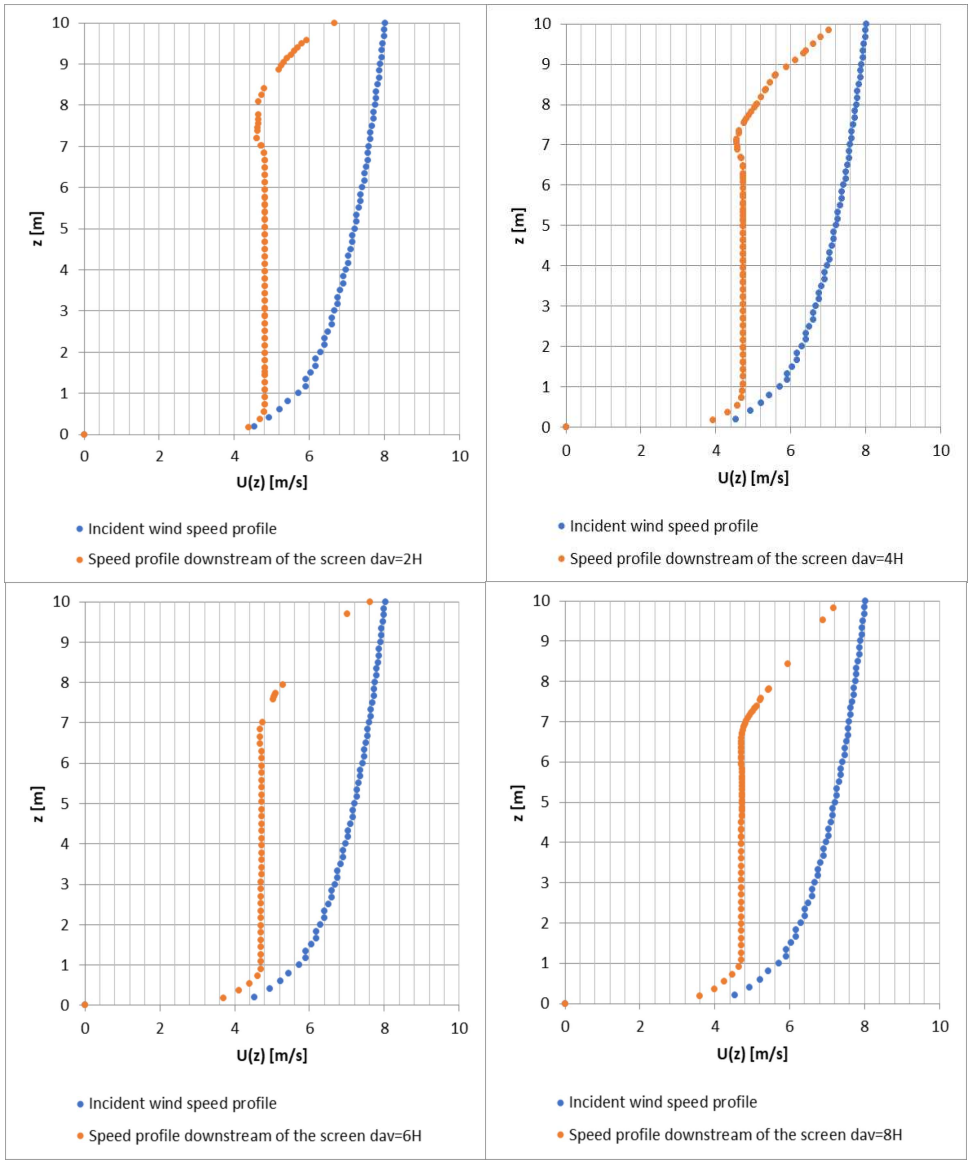

Fig. 5. Comparison of the speed profiles downstream of the screen and the incident wind speed profile

Next, wind speeds were determined at heights z_1=0,20 m, z_2=1,00 m și z_3=2,00 m from the speed profiles corresponding to the downstream sections of the protection screens located at distances $d_{av}=2H$, $d_{av}=4H$, $d_{av}=6H$, $d_{av}=8H$.

Figure 4 shows the variation of ***U*(*z*)** speeds at heights z_1=0,20 m, z_2=1 m și z_3=2,00 m, depending on the downstream distance $\boldsymbol{d_{av}}$ for the reference speed ***U*(10)=8 m/s** and number of protection screens ***n***=1 (CT1, GT1.1, **CB:40-10-4-2H**).

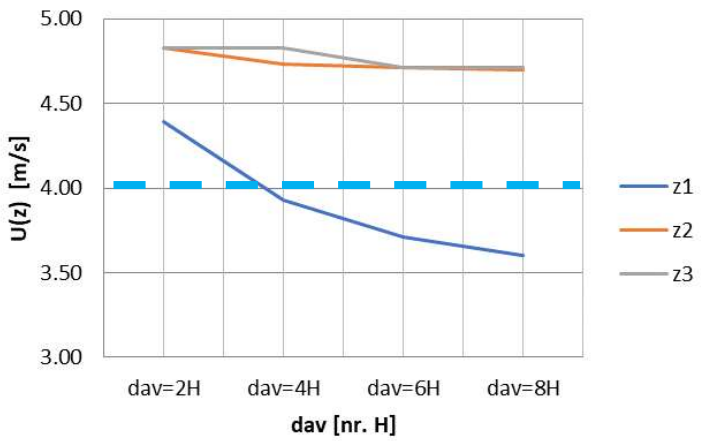

Fig. 6. Variation of *U*(*z*) speeds at heights z_1=0,20m, z_2=1m și z_3=2m, depending on the downstream distance dav for the reference speed *U*(10)=8 m/s and number of protection screens *n*=1 (CT1, GT1.1, CB:40-10-4-2H)

4. Conclusions regarding numerical testing

In view of the results of the numerical simulations that were done in the study, a number of conclusions can be drawn as follows.

From the graphs presented in Chapter 3, it is noted that, in terms of ground speed, denoted by $U(z_1)$, it decreases with increasing distance downstream of the protective screens, denoted by d_{av}.

Considering the minimum sand entrainment speed at ground level, $U(z_1)_{minantr}$, as 4 m/s, depending on this speed two tables were made, namely table 3 showing the effect of wind at ground level depending on the number of screens, of the reference speed and the downstream distance for $U(z_1) < 4$ m/s and table 4 showing the effect of wind at ground level according to the number of screens, the reference speed and the downstream distance for $U(z_1) > 4$ m/s.

This minimum sand entrainment speed at ground level, $U(z_1)_{minantr}$, was established based on Molinkov's study, presented in the work of Moțoc M. from 1963 [9]. In this study it is shown that at speeds between 0.5 m/s and 4 m/s the

wind at ground level does not lift the sand granules, at speeds between 4 m/s and 7 m/s it drives sand granules with a diameter below 0.5 mm, at speeds between 7 m/s and 11 m/s entrain sand granules with a diameter between 0,5 mm and 1 mm, at speeds between 11 m/s and 17 m/s entrain sand granules with a diameter between 1 mm and 2 mm, and at speeds between 17 m/s and 28 m/s drive sand granules with a diameter between 2 mm and 5 mm.

Table 3. Effect of wind at ground level depending on the number of screens, the reference speed and the downstream distance for $U(z_1) < 4$ m/s

Number of screens - *n*	**Reference speed – *U*(10) [m/s]**	**Downstream distance - d_{av} [nr. *H*]**	**The effect of wind at the ground level – at z_1**
$n = 1$ screen	$U(10) = 8$ m/s	$d_{av} = 4H - 8H$	Does not entrain sand- $U(z_1) <$ 4 m/s
$n = 2$ screens	$U(10) = 8$ m/s	$d_{av} = 0H - 8H$	Does not entrain sand - $U(z_1) <$ 4 m/s
$n = 3$ screens	$U(10) = 8$ m/s $U(10) = 12$ m/s	$d_{av} = 0H - 8H$ $d_{av} = 0H - 8H$	Does not entrain sand - $U(z_1) <$ 4 m/s Nu antreneazănisip- $U(z_1) < 4$ m/s
$n = 4$ screens	$U(10) = 8$ m/s $U(10) = 12$ m/s	$d_{av} = 0H - 8H$ $d_{av} = 0H - 8H$	Does not entrain sand - $U(z_1) <$ 4 m/s Does not entrain sand - $U(z_1) <$ 4 m/s

Table 4. Effect of wind at ground level depending on the number of screens, the reference speed and the downstream distance for $U(z_1) > 4$ m/s

Number of screens - *n*	**Reference speed – *U*(10) [m/s]**	**Downstream distance d_{av} [nr. *H*]**	**The effect of wind at the ground level – at z_1**
$n = 1$ screen	$U(10) = 8$ m/s $U(10) = 12$ m/s $U(10) = 16$ m/s	$d_{av} = 0H - 4H$ $d_{av} = 0H - 8H$ $d_{av} = 0H - 8H$	Entrains sand under 0,5 mm - $U(z_1) > 4$ m/s Entrains sand under 0,5 mm - $U(z_1) > 4$ m/s Entrains sand under 0,5 mm - $U(z_1) > 4$ m/s
$n = 2$ screens	$U(10) = 12$ m/s $U(10) = 16$ m/s	$d_{av} = 0H - 8H$ $d_{av} = 0H - 8H$	Entrains sand under 0,5 mm - $U(z_1) > 4$ m/s Entrains sand under 0,5 mm - $U(z_1) > 4$ m/s
$n = 3$ screens	$U(10) = 16$ m/s	$d_{av} = 0H - 8H$	Entrains sand under 0,5 mm - $U(z_1) > 4$ m/s
$n = 4$ screens	$U(10) = 16$ m/s	$d_{av} = 0H - 8H$	Entrains sand under 0,5 mm - $U(z_1) > 4$ m/s

Numerical tests have shown that protection against sand entrainment, through screens, at different speeds of the incident wind, takes place in the following situations:

1. For $U(10) = 8$ m/s :

- $n = 1$ screen, protection is provided at downstream distances $d_{av} = 4H - 8H$,
- $n = 2$ screens, protection is provided at downstream distances $d_{av} = 0H - 8H$,
- $n = 3$ screens, protection is provided at downstream distances $d_{av} = 0H - 8H$,
- $n = 4$ screens, protection is provided at downstream distances $d_{av} = 0H - 8H$.

2. For $U(10) = 12$ m/s :

- $n = 3$ screens, protection is provided at downstream distances $d_{av} = 0H - 8H$,
- $n = 4$ screens, protection is provided at downstream distances $d_{av} = 0H - 8H$.

3. For $U(10) = 16$ m/s :

No group of screens $n = 1, 2, 3, 4$ provides protection against sand entrainment.

Therefore, for $n = 1$ screen and $n = 2$ screens, at wind speeds $U(10) = 12$ m/s and $U(10) = 16$ m/s, the wind at ground level ($U(z_1) > 4$ m/s) entrain sand below 0.5 mm, and for $n = 3$ screens and $n = 4$ screens, at wind speeds, $U(10) = 16$ m/s, wind at ground level ($U(z_1) > 4$ m/s) entrain sand below 0.5 mm.

To reduce the speed at ground level in the cases of sand entrainment presented above, action can be taken by increasing the number of permeable protective screens or by decreasing the permeability of the protective screens, whether natural or artificial [10].

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