Formation of ripples on sand surface as result of nonlinear interaction of sound waves and wind drift particles

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The phenomenon speaks within the limits of nonlinear acoustics, considering it as amplification of surface acoustic waves (SAWs) by drift of carriers.
Interaction and amplification of SAWs, borne from falling sand particles on dry sand surface and drift sand particles under wind action is responsible for first ripple forming on dry sand flat surface. SAWs interact with drift sand particles in the moment, when the velocity of drift is equal to velocity of a sound propagation. The sound wave acts on drifting particles so, that sand grains, a little bit advancing wave, will be braked, and lagging behind-be accelerated. Particles will gather in a phase of a wave - take place grouping of particles and ripple forming. The distance between groups is a ripples wave length λ.
Experimental in-situ are measured weak sound field on frequencies 25 Hz in just forming sand massif, and near surface velocity of sand drug under wind action. Measured ripples wave lengths λ are in good agreement with measured diapason of wind velocity. Measurements were carrying out on sand beach Gulf of Riga, Latvia.
Theoretically the phenomenon speaks within the limits of nonlinear acoustics or within the limits of nonlinear mechanic.

1 Introduction

A large number of works aimed at studying the transport of sand under the action of a wind or water stream is known. Comprehensive reviews on this subject were published [1, 2, 3, 4, 5]. Ripples are the most widespread form of the bottom of the coastal zone of a sea, dry beach or desert sand. Ripples are observed also on the surface loose snow and in clouds. Ripples are visible on Mars (in basalt sand) and on the surface of the satellite of Saturn - Titan. Empirical dependences of the ripple step from the ripple height h, diameter d of sand grains and velocity of the stream V were obtained. The formation of ripples on a smooth horizontal surface were investigated [3, 5]

2 State of art

At present, initial ripples forming according to the basic theory, that of turbulence [2, 3, 5] has been explained based on the following precondition: roughness of a sandy surface and zero speed of a stream on a surface or, according to the theory of Kaneko A. and Honji H. [6], a pair of particles connected by the stream of particles tends to position perpendicular to the stream. The turbulent theory is criticized [2]. Experiments in situ have not proven that the 0 velocity of wind exists on a smooth surface of loose dry sand with the typical porosity $\varepsilon = V_{Pore} / V_{Solid}$ varying within the limits of $0.6 < \varepsilon < 0.75$., where V_{Pore} and V_{Solid} is volume of pore and volume of solid in sand sample.

The physics of wavelength λ and physics of the process which is the cause of the initial ripple forming on a smooth surface has not been explained by any of the authors.

2.1 The research theoretically and experimentally basis

This work is based theoretically on the studies of particles grouping under the impact of vibrations [7] and on the theory of sound intensification by the drift of carriers developed during the 1960s [8, 9, 10], which was applied at very low sound propagation velocities ($V_{sound} \sim 1$m/s) in loose sand in the low-frequency range (15-50 Hz) and on resonance frequency research in soil [11].

Experimentally, work is based on resonant (dominant) frequencies in pure marine sandy soils known from 1980s [12, 13, 14, 15, 17]. Any influence - impact, explosion, an ultrasonic impulse and wind generates an acoustic field of resonant frequencies at a distance from the place of impact.

In this work the phenomenon of the ripple formation and length of its step λ is explained for the first time by nonlinear interaction of a sound wave of the resonant frequency resulting from the wind action in sand with drifting sand grains This interaction well explains the physics of the ripple occurrence on a flat surface, the length of the ripple wave depending on diameter of grains of sand, increase and blow-off of ripples at an increased wind velocity.

2.2 The location of the experiments

Observations and experiments were carried out at the Roja test site, at the coast of the Gulf of Riga, Latvia. Pure fine-grained quartz sand occurs on the beach and in the sea there, with the prevailing fraction 0.2-0.1 mm, the content varies from 56 % up to 68 %. The water level in the gulf varies depending on the wind direction, therefore the ripples are formed in the same sand, and both dry on the beach and saturated in sea. The location is ideal for the studies of the ripple formation under the wind and water stream action.

3 The physics of the initial ripple forming

3.1 Physics of occurrence of sound waves of resonance frequencies

As a result of wind filtering into sand, sound surface waves appear. The velocity of propagation of that wave is low; it is equal to the velocity of air filtration through sand and, certainly, depends on the wind velocity. The direction of the propagation of a sound wave coincides with the wind direction. The falling particles impacting the ground are yet another source of surface waves of resonant frequencies, their harmonics and sub harmonics.

The resonance frequency depends [12, 13] on the grain size of sand - the larger the sand particles, the lower the resonant frequency is, and on the uniformity of sand – the higher the uniformity, the better the resonant frequency is singled out and traced. Marine sand, sorted by wind and wave action, is the ideal environment for studying resonant frequencies of this granular material. For fine dry sand, the resonant frequency of 25 Hz was observed at the test site on the coast of gulf of Riga [15]

Studies of bottom sandy soil in situ have demonstrated that there exists the resonance frequency of the order of 40-50 Hz [14]. Occurrences of dominant frequencies are observed also during the simulation of filtration of water through sand [16].

3.2 Interaction of drifting particles with sound waves

If *V drift* = *V sound*, the sound wave acts on drifting particles so that the sand grains, that are somewhat ahead of a wave, are decelerated, and those lagging behind are accelerated. The particles gather in a phase of a wave, and grouping of particles occurs. The distance between the groups is the ripple step λ.

If *V drift* > *V sound*, the drifting particles transfer energy to a sound wave, i.e. the accumulation of particles (ripple) takes energy of drifting particles, thus the amplitude of its oscillations increases as well as its size.

The resulting ripples exist until those are able to absorb the energy of drifting particles, and, finally, the wind energy. When the amplitude of fluctuations reaches some critical value, the ripples are blown off. In experiments on a vibrating table, all that process is well traced: the sand activation on horizontal surface, gathering of all sand grains on a surface at an angle, the growth of the angle to maximal and alignment of the surface that corresponds to the amplitude of vibratory acceleration at which the angle of a slope is levelled into a horizontal plane, see below.

If the *V drift* <*V sound*, the accumulation of particles (ripple), spends a long time in an accelerating half-cycle of a sound wave, i.e. the ripple absorbs energy of the sound wave. The drifting particles are accelerated by a sound wave, causing an increase in the attenuation of a sound.

In the forming of ripples, an important role is played by the quantity of sand transported by wind. Depending on the wind velocity and quantity of loose dry sand, waves of resonant frequency appear, their harmonics and sub-harmonics In the nonlinear mechanics, the possibility of excitation of low-frequency oscillations by high-frequency ones [7] at impact is known.

4 Observations

Observations have demonstrated that, at wind velocity 2.8 m/s the fine sand starts moving.

At wind velocity 3 m/s active ripple forming from fine-grained sand begins. The formation of stable ripple forms occurs for 20 minuets: parallel lines with the step of 3.5 cm, perpendicular to the wind direction. If the wind velocity does not vary, this form of ripples exists stably for a long time. The amount of grains that roll down from the top of one ripple, settles on the other barrier.

At increase in the wind velocity to 3.5 m/s ($V_{sound} =$ 1m/s) all fine sand accumulated in a ripple, rises in the air - ripples of that formation are blown off completely. At the wind velocity 4 m/s., the sand forming ripples with the size 7-10 cm, which exist until the wind velocity reaches 4.5 m/s At the stage of active ripple forming, observations were carried out until the wind velocity reached 18 m/s. Wind speed is varying with height, measurements are made on height ~ 1 m . With a gradual variation of the wind velocity from 3 m/s. to 18 m/s., a discrete ripple in dry sand with λ =3,5-4, 7-8, 14 -17, 28-32, 56-64 and 112-128 cm was observed.

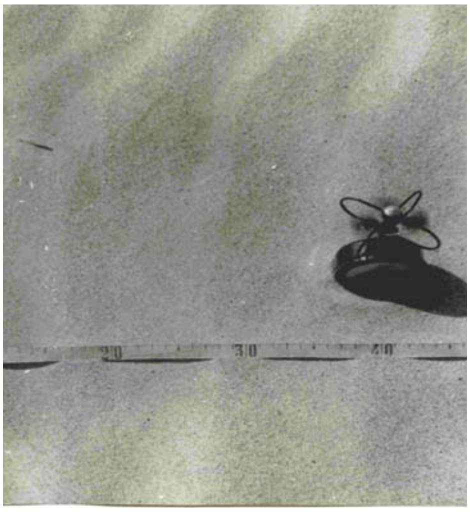

Fig.1 Active ripple forming and nearer surface wind velocity measurement

Fig.2 Active ripples forming, λ=7-8 cm, near surface wind velocity=2m/s

Fig.3 Active ripples forming, , λ=28-32 cm, near surface wind velocity = 8 m/s,

4.1 Experiment in situ

When the experiment was continued at an area of $1m^2$, the formed ripple surface was completely levelled.

The near-surface wind velocity 3m/s was such that the fine sand flew above the surface; at the same time, some sand begins the flight from the allocated square, another part of sand ends its flight there, falling on the surface. just levelled sand on the surface. The influence of sand grains, falling and coming off the surface, results in lack of dynamically equilibrium condition. During the initial moments - 2-3 minutes, a part of the kinetic wind energy is absorbed by the porous granular environment of the surface.

The kinetic energy, transferred to the environment by falling and coming off particles, is sufficient for the creation of the excited condition of the surface of sand. It reminds of a high-frequency field or boiling, as a result of which a fine mobile honeycomb is formed on the sandy surface, which moves and enlarges. At the initial stages, the kinetic energy absorbed by the surface of sand is quite sufficient for the excitation of high-frequency oscillation modes in the surface layer of sand. The absorbed energy increases in time and already some 10 minutes later, the surface pattern enlarges considerably.

If, in the beginning of observations, the size of the honeycomb was 5 mm, then 10 mm, by the 10th minute, the size of the already formed honeycomb became 15-17 mm, thus the pattern can be clearly seen, but it is short-lived. The process of ripple forming continues and, by the end of the 15th minute, barriers of the final ripples with the step of 3.5 cm, which are completely restored by the 20th minute from start, can be traced. Here it is necessary to note that the whole area of the levelled dry sand under wind action simultaneously reaches the excited condition, the honeycombs are formed simultaneously on all the surface area and line-barriers of the final ripples are singled out on all the surface simultaneously.

Thus, in the air, dry fine sand (diameter of (0,06- 0.2) mm)at the wind velocity 3 m/s, the formation of stable ripple forms occurs during 20 minutes, at that, the wave pattern varies from the high-frequency unstable one to low-frequency stable one. If the wind velocity does not vary, that ripple form produces parallel lines with the step of 3.5 cm; they exist stably for a long time: the amount of grains that roll down from the top of one ripple, settles on the other barrier body.

4.2 Laboratory studies of beach sand on vibrating table

Laboratory studies of beach sand on vibrating table have demonstrated that all that process is well traced: the sand activation on horizontal surface, gathering of all sand grains on a surface at an angle, the growth of the angle to maximal and alignment of the surface that corresponds to the amplitude of vibratory acceleration at which the angle of a slope is levelled into a horizontal plane. As result of these experiments were checking out frequencies [Hz] and acceleration [m/s^2], at which the maximal angles of a slope is formed and at which the angle disappear. See Table 1. The sizes measured experimentally allow to calculate vibration velocity [m/s] which defines a range of speeds of the drifting particles cooperating with a propagating sound wave by ripple forming, growth of the angle to maximal and alignment of the surface.

Predicted from vibrating table experiments and measured in-situ near surface and filtration velocities are in good agreement of ripple forming, growth of the angle to maximal and alignment of the surface.

Hz	$m/s.^2$	m/s.	Response (<angle, patterns)
15	2,5	0,16	<25
	6	0,4	<18, ripples move from a bottom
	7	0,45	<9, ripples 12 mm
	10	0,66	Horizontal surface,
20	5	0,25	<30, ripples absent
	12	0,6	<10, ripples 13 mm on slope of angle
	20	1	<5, cells on surface
25	12	0,47	<20, ripples absent
	23	0,92	<5, ripples 15 mm
	30	1,2	horizontal
30	12	0,4	<30
	23	0,76	<6, ripples 15 mm
	30	1	horizontal, cells

Table1. Results of laboratory studies of fine beach sand on vibrating table

Fig.3.Laboratory experiments had been carried out on vibro table for research VEDS-10A Under research is beach sand, Roja all that process is well traced: the sand activation on horizontal surface, gathering of all sand grains on a surface at an angle, the growth of the angle to maximal and alignment of the surface that corresponds to the amplitude of vibratory acceleration

at which the angle of a slope is levelled into a horizontal plane.

5 Conclusions

1. Ripples are sounds produced by wind and recorded by wind in dry beach sand.

2. Ripples on beaches represent the memory of sand of wind impacts. The greatest ripple is the memory of sand of the strongest winds existing there once. Only a stronger wind can destroy it, which had erased that and will create a new and larger one.

3. An estimation of the ripple wave length λ, from the velocity of wind filtration V_{filtr} and resonant frequency f of the investigated sand give a good agreement with the ripple step λ , measured in situ.

4. Ripples are an example of self-organizing in the inanimate nature, thus they bear the information on the energy level of their formation processes.

5. Sand is the environment with memory and possesses the property of self-organizing for self-defence from wind actions.

6. May be, the mechanism of the formation and existence of ripples is the key for understanding the history of dynamics of sandy waves and large dunes during the previous geological periods of the Earth and today. It becomes especially important during global warming.

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