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Impulse induced wave propagation in quartz marine sands

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Abstract: This investigation studied the spectrum of oscillations and velocity of wave propagation that are created by different mechanical actions upon dense saturated marine quartz sand -by impact upon a free surface, by a contact explosion, by impact upon sand under water, ultrasonic sounding in situ. Spectrum of ultra sounding impulse and velocity of its propagation Vp are investigated in laboratory during testing marine sand samples in three axial testing device. Role of acoustic emission in experiments is discussed.

1 Intraduction

The acoustic properties of non consolidated granular matearals as are pure marine sands are not detailed investigated and understood. The strong stress sensitivity of sand packings and multiple fluid and gas phases conspire to make the present understanding of this class of materials incomplete. Sands experimental researches leave to works of Bagnold (1) and theoretical – to Biot (2). Experimental works of Paterson (3), theoretical researches Nikolaevskii (4), experiments Plona (5) follow

Since sand is a specific continuous media possessing internal structure grains that are in contact and are interconnected by pores, it must demonstrate specific properties such as internal resonance effect, for example, according [6]. The first experiments in which internal resonant effects of sand are mentioned, is (7) The work follows of theorists and experimenters [8,9,10,11,12,13], in laboratory and in a field. To the end of 90 years of the last century interest to Earth materials and to their nonlinear properties becomes more active in laboratories all over the world that is well reflected in the review [14, 16]

Research reported herein has been carried out with the goal to develop and establish an understanding of shock and ultrasound impact-induced wave propagation. Transitional liquefaction and wave generation are two stages in saturated soils response. In saturated sandy soils, the phenomena in the following sequence are examined: dense sandy soil impact loading - its dilatancy - filtration - liquefaction – sedimentation and underwater consolidation - filtration - dense soil. The velocity of propagation of dilatancy wave was studied alongside with the duration of existence of local instability in the sandy soil depending on the value of dynamic or quasi-static impact loading. Experiments were carried out in pure dense saturated marine sands in situ at the seaside and in laboratory(the same sand) in three axial testing camera.

2 Sea sand in situ

The experiment was conducted *in situ* in the beach quartz sand with its maximum density. The possibility of transforming the massif into maximally dense, undisturbed condition during a few minutes after its destruction is a very convenient feature of working with sand massifs. Which strong medium, completely destroyed earlier, can be restored during a short period of time? At that, the maximum density is restored, the sand particles deposit underwater by themselves, and the massif becomes stronger due to the filtering of water

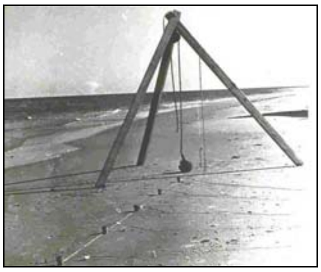

Figure 1: Experiment site and set-up

Sand originated from the destruction of fine-grained, medium-grained and coarse-grained granite, producing, correspondingly, fine-grained, medium-grained and coarse-grained sand. The only source of quartz sand is the cracked crystal of quartz. In the state of the maximum density in situ, that sand rather resembles “soft crystals”, fractured into approximately similar in size domains of a crystalline substance, which comprises a whole massif due to cohesion.

The experiments were carried out in situ: the fine-grained quartz marine sands formed a 2-m layer, with underlying dolomite. Solid phase density is 2.64 – 2.65

gr/sm^3, frame density 1.36 gr/sm^3, heterogeneity coefficient (K 60/10) was 3, prevailing fraction 0.25 – 0.1 mm, its content 68%, fraction 0.5 – 0. 25 content - 30%.

The sand massif was described in such detail because the experiments cannot be repeated in other sand types. The homogeneity of the grains strengthens resonance effects, which produce the main results.

3 Experimental procedure

The water-saturated dense sand massif was excited by the impact of a falling weight [8] from the height from 2 m to 2.5 cm. The smallest height was tested during careful lowering of the weight to the sand surface, rather than by impact, with the purpose to discover the static loading regime. Sensors were located along the radius from the loading point to the distance (sensors distanced 1 m) of up to 14 m, see Fig.1 Regretfully, even the most careful and slowest lowering of the weight caused clear dynamic response in the frequency range 38-40 Hz even in the most remote sensors, with the duration of oscillations of up to 0.2 sec. (Fig . 2).

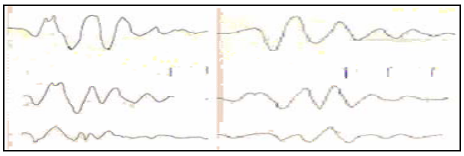

Figure 2: Oscillations and instability in full-saturated sandy soils excited by dry-up wave propagation from carefully lowering weight at the loading point. Three component sensor 'Tcherepaha', distance between sensor and loading point is 3 m (left), 4 m (right).

Carefully slowly placed weight means quasi-static loading and observed dry- up surface wave propagating from loading point is deformation wave. Remember: in dense sands shear deformation goes with dislodge - it means that pore space enlarges, filtration conditions improve. It may be seen how the dry-up waves propagate from carefully lowering weight to the landing point: after the dry-up wave propagation, surface drying follows from the loading point, reaching full saturation stage. Propagation velocity of drying (visual) is little than velocity of saturation. Nearby, the static loading point at the distance of 1, 2 and 3 m sensors are placed. The appearance of dynamic response is fixed by sensors (Fig.2).

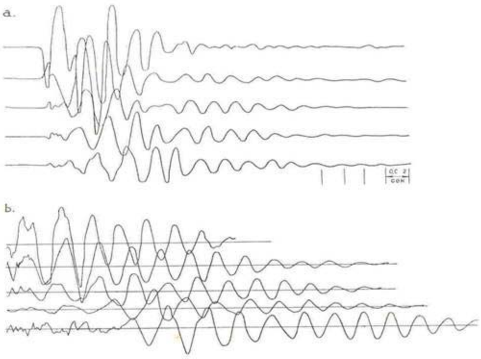

Figure 3: Oscillations excited by shock at sand surface (a), and a micro explosion (b), at the site of experiment,

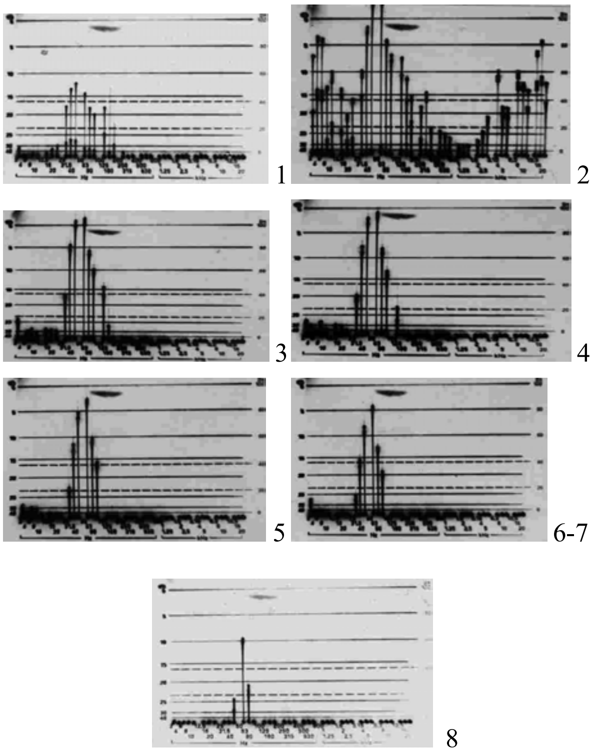

Figure 4: Real time oscillation spectra recorded from real time spectrometer FSP-80 (frequency band 1Hz-20 kHz) for shock-induced oscillations in dense saturated sand H=1.5m, L=1.5m ; max amplitudes spectra (2), 0.1 sec. before max (1) and koda-frequances (3).The spectrum of a so-called harbinger - the oscillations before the first entry is seen on fig.4(1). The harbinger contains frequencies in a near field up to 100 Hz, where the first introduction fig. 4(2) contains high-frequency components, till 20 kHz .

3.1. Experiment: dilatancy wave of humidity on the surface of saturated dense marine sand.

The process of the impact of concentrated load by the dense saturated sand with the thin film of water on surface visually looks like the propagation of the halo of drying from load point. After its appearance, this dry halo begins saturation during fractions of one minute, also from load point, and the lusterless surface of drying was changed into the bright surface of the irrigation. The velocity of process drying-irrigation and induced oscillations are recorded from 2 sensors distanced at 20 cm from loading point.

The duration of the process of the propagation of halo drying-irrigation filtering and the formation of the tightly packed sand continues during fractions of one minute, afterwards, also during fractions of one minute, there is a diluted state, which is extended in space as far as the halo of drying is extended.

The degree of dilution decreases along a radius from the load point, also as with the reduction of loading at the applied point. The skeleton of sand perceives all loading and if it appears to exceed the strength, there begins shear with according volume change - dilatancy of sand.

All process of drying - saturation around the loading point is accompanied by instability for a short time. It produces the dynamic signal, which has been recorded from seismic vertical sensor SV-10, located in the field of drying - saturation at the distance of 20 cm from each other.

Time of instability existence, velocity of instability propagation depend on filtration and size of action load.

Table 1: Time of instability existence and velocity of filtration propagation

No.	Density, t/m^3	Load, kPa	W,% water content	Signal freq., Hz	Instability existence time, sec.	V filter., m/sec
1	1.80	30	28%	25-50	0.3-0.5	5
2	1.80	30	28%	8-60	0.3-0.4	4
3	1.82	30	24%	8-12	0.4-0.6	4
4	1.82	30	24%	12.5-25	0.4	3
5	1.85	30	20%	14-50	0.16	4.3
6	1.85	30	20%	33	0.14	5

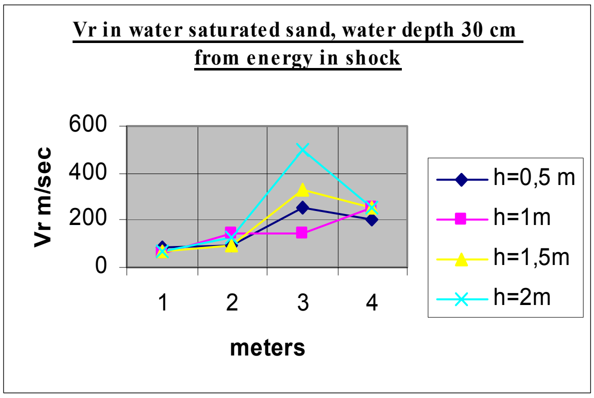

Figure 5: Surface wave propagation velocity Vr in dense sandy bottom, depending on shock energy and distance to impact point. Shock in water (30 cm deep) at dense sand bottom

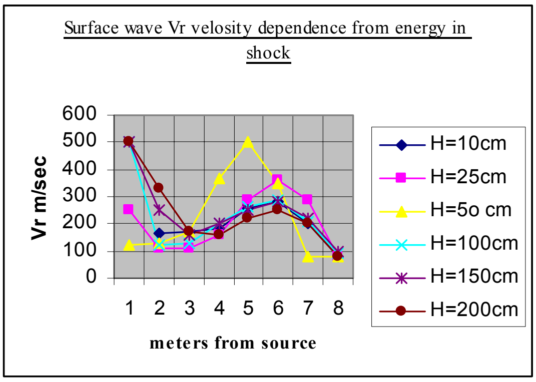

Figure 6: Surface wave propagation velocity Vr in dense water saturated sandy soil versus distance to impulse. Shock on dense water saturated sand (see Fig.1). Propagation velocity of shock-induced oscillations in far field comes nearer to speed of a shear elastic wave.

3.2. Ultrasonic sounding in situ

This work deals with the results of investigations of stress waves with different frequencies in natural dense marine quartz sand in situ with different moisture content [7]. The DUC-20 equipment was used for the emission and reception of ultrasound oscillations in the pulse mode, with its original stress cells 0_x; the following frequencies were used: 25; 60 and 150 kHz. The period of the pulse propagation was determined using the delay scale of the device. In order to single out the frequency components of the oscillations, which have come through the sand, the FSP-80 spectrum analyzer was used, see figure 7, 8, 9.

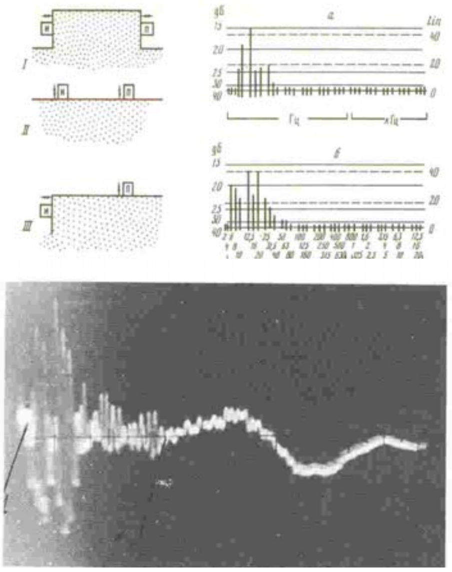

Figure 7: The image of the sounding signal 25 kHz., which has come through the sand, and its spectrum were filmed.. The emitter and the receiver were located, in relation to one another, based on the configurations I, II, III.

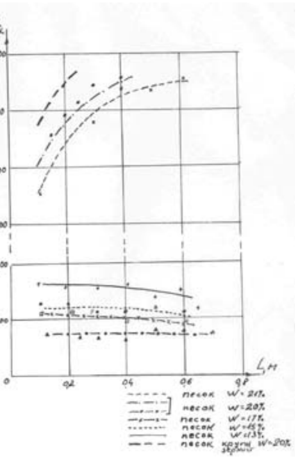

Figure 8: Vp distribution in marine dense sand massif in situ depending on humidity (W%) on various bases (L) from ultrasound (25 kHz) sounding. For sand (W~=20%) exist two velocity of propagation: high-frequency high-velocity (1200-1500 m/sec) and low-frequency low velocity (≤200m/sec) simultaneously. The low-frequency wave exists on bases till L=0,7m., the high-frequency wave exists on bases only till L= 0,45 m. The increase in velocity of propagation high-frequency waves with increase in basis speaks about existence of a zone of destruction around of a point of emission the ultrasonic frequency filled pulse. Influence of length of basis on velocity of propagation a slow waves is much less.

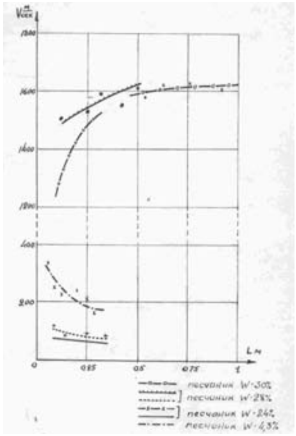

Figure 9: Vp distribution in red sandstone(marine sand + red clay) massif in situ depending on humidity (W%) on various bases (L) from ultrasound (25kHz) sounding. For sandstone (W=24-28 %) exist two velocity of propagation: high-frequency high-velocity (1250-1650 m/sec) and low-frequency low velocity (≤100 m/sec) simultaneously. The low-frequency wave exists on bases till L=0, 3 m., the high-frequency wave exists on bases till L= 0, 5 m.

3.3. Transitional instability from laboratory experiments

The mechanism of transit instability of impact loading is studied in the laboratory, using tri axial testing devices. They are computer controlled by Geotechnical Digital System (GDS) with acoustic control (non published), and LIIZT tri axial testing system with acoustic control [9]. Experiments with constant axial deformation velocity (device GDS, Fig.9, 10) show measured instability in wave propagation velocity. Tri axial tests with step by step loading [9] (device LIIZT) show instability of sounding impulse quality and, if measurements are done after sounding signal stabilization (for sands, stabilization lasts no more than 5 minutes), the Vp curve is close to the stress curve till the moment of destruction [9].

Time of the existence of instability in the laboratory (~ 5 min.) is much longer than in situ experiments. This influence the conditions of a filtration

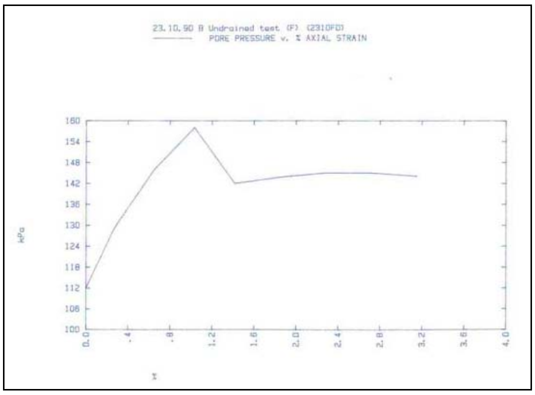

Figure 10: Pore pressure versus axial strain, saturated marine sand. Cell pressure 200 kPa, back pressure100 kPa, rate of axial deformation 40.00 mm/hour, undrained experiment, Triaxial Testing by Geotechnical Digital System (GDS). Moment of falling pore pressure indicates approach of dilatancy.

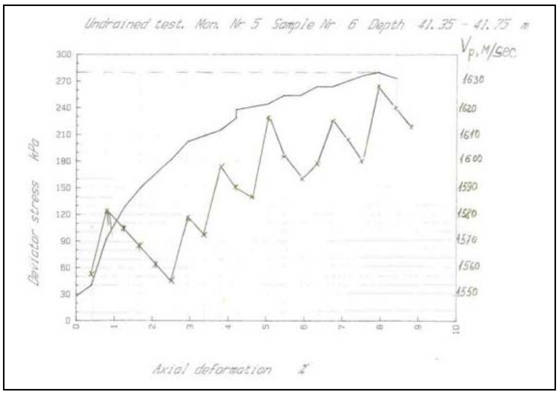

Figure 11: Pore pressure versus axial strain, saturated marine sand. Cell pressure 200 kPa, back pressure100 kPa, rate of axial deformation 40.00 mm/hour, Triaxial Testing System GDS [20], ultrasound transducers(54 kHz) are mounted in testing camera. Vp- ultrasound impulse propagation velocity. The moments of sharp falling velocity of propagation Vp specifie approach of dilatancy.

4 Conclusions

1. Since the sand is water-saturated, hydrodynamic forces play a role in the emission of low-frequency oscillations by the sand under loading. According to the computer simulation results [17], nonlinear dynamic response of grains in a liquid-saturated soil produces oscillations in the frequency range 1-100 Hz. Experimental results (Fig. 2,3,4) indicate 20-80 Hz. Simulation results are in good agreement with the results of in situ measurements.
2. Impact induced wave propagation velocity is dependente from distance to loading point (Fig..5 ,6 ,8). Low propagation velocity domain existence (Fig. 5, 6) is in good agreement with results [18] of shock wave propagation in a two-dimensional granular flow. In soft soils what are sea sand, shock and ultrasonic pulses causes changes in the near fields of emitters. Its role decreases with increase in basis. The near field effect depend of the impact energy.
3. In situ (Fig. 2) and laboratory (Fig. 10, 11) experiments show the dominant role of dilatancy in short-term instability produced by load. Patterns that are visible in experiments [19] are a good evidence of possible dilatancy pattern forming: there may exist shear strain on the traces of maximum loaded grains.
4. The emission of the slow wave occurs at one of the sand resonant frequencies using the energy transferred to soil by the high-frequency pulse. Pumping of ultrasonic energy into sand leads to the emission of sound by it (see also [1, 7]).
5. Dilatancy in dense sand is accompanied by acoustic emission (AE). Quasi static and slow dynamic loading is source of low-frequency (20-40 Hz) signals. Strong motion causes high frequency (0,8-20 kHz) signals of AE, they characterize destruction of sand massif (not of sand grains).
6. It is necessary to discuss about informatively of high velocity propagated harbinger spectra.

References

[1] Bagnold, R. A. (1936). The movement of desert sand. *Proc. R. Soc. London, Ser. A 157*,594–620,Bagnold, R. A. (1937). The size–grading of sand by wind. *Proc. R. Soc. London163*(Ser. A), 250–264.Bagnold, R. A. (1941). The physics of blown sand and desert dunes. London: Methuen. Bagnold, R. A. (1973). The nature of saltation and bed–load transport in water. *Proc.R. Soc. London 332*(Ser. A), 473–504. Proc. Roy. Soc., A, vol. 295, No. 1442, pp.219-233,(1966).

[2] Biot M.A.)Theory of propagation of elastic waves in a fluid – saturated porous solid."*JASA,*"

V.28, pp 168-191,(1956*), J. Acoust. Soc. Amer., , vol. 34, No. 9, pp. 1254-1264.(1962)*

[3] Paterson N.R. Seismic wave propagation in porous granular media. *Geophysics,VXXI,N 3, pp.691-714, (1955)*

[4] Nikolayevskiy. V. N., K. S. Basniev, A. T. Gorbunov and C. A. Zotov. *Mechanic nasyshchennykh poristykh sred (Mechanics of a Saturated Medium).* Moscow, Nedra,(1970).

[5] Plona T.J. Observation of a second bulk compressional wave in a porous medium at ultrasonic frequencies*. Appl. Phys.Lett.,* 36,(4).pp.259-261,(1980)

[6] Haikin S.E. *Physical basis of mechanics*. Moscow: Nauka Publ.,(1971) (in Russian).

[7] Vilchinskaja N.A. Stress waves in sand and acoustic emission. *Dokladi Acad. Nauk SSSR*, vol.262, N3, pp.568-572,(1982)

[8] Vilchinskaja N. A. and V. N. Nikolajevskiy The Acoustical Emission and Spectrum of Seismic Signals Izvestiya, *Earth Physics* pp.393 - 400 Vol. 20, No. 5, (1984)

[9] Vilchinska, N.A. Kulvinova, J.B., Shehter, E.Y. Triaxial tests with acoustic control*. Academy of Sciences USSR., Engineering Geology No. 2,* Moscow, pp. 110-113 (in Russian) (1984).

[10] Vilchinska N.,Nikolajevskiy V, V.Lisin Slowly waves and natural oscillations in sandy marine soils*. Izvestiya Acad. Nauk SSSR, Oceanology* Nr. 4 (Russian)(1985)

[11] Nikolajevskii V.Vjazkouprugost s vnutrennimi oscilatorami kak vozmoznaja model seismoaktivnoi spedi. *Dokladi Acad. Nauk SSSR,*V283,N6,pp1321-1324(1985)

[12] Vilchinska N. Low frequency shear modules and structure resonance phenomenain saturated soils in situ. “*Problems of non-linear seismology”,* edit. Nikolaev A., .Moskow, Nauka, pp.227-231.(Russian)(1987)

[13] Vilchinska N. Effective relaxacation and dynamic viscosity for slight non-linear stress waves in sand “*Problems of non-linear seismology”,* edit. Nikolaev A., .Moskow, Nauka, pp.227-231.(Russian)(1987)

[14] Vilchinska N., Dzilna I. Resonance frequencies in sands. Proseedings of” *Field Measurements in Geotechnics*”, edited by Geraldine Sörum, A.A. Balkema, Rotterdam, ISBN9054100257, pp. 927-935.(1991)

[15] Ostrovsky L A., Johnson P.A. Dynamic nonlinear elasticity in geomaterials. *La Rivista del Nuovo Cimento*,V24, serie 4, N 7 della Societa Italiana di Fisica ,Bologna, 46 p (2001)

[16] Liu Z.&RectorJ.W.,Nihei K.T.,L.Tomutsa, L.R.Myer&S.Nakagawa Extensional wave attenuation and velocity in partialy-saturated sand in the sonic frequancy range(2002?) *pre print* (http://appliedgeophysics.berkeley.edu:7057/geoengineering/appliedgeophysics/papers/velocity_sands.pdf)

[17] Hedberg ,C.M. Nonlinear dynamics of grains in liquid-saturated soil. *16th ISNA, Nonlinear acoustics at the beginning of the 21st Century,* Moscow, 2002, pp. 735-738

[18] S. Hörlück and P. Dimon. Statistics of shock waves in a two-dimensional granular flow. *Physical Review*, July 1999, Vol. 60, No. 1.

[19] Daniels K E, Coppock J E, Behringer R P Dynamics of meteor impacts. *Chaos: An Interdisciplinary Journal of Nonlinear Science* -- December 2004 -- Volume 14, Issue 4, p. S4

[20] Donaghe,R.T, Ronaldc Chaney, Marshall L.Silver,Eds., *Advanced Tri axial Testing of Soil and Rock*, ASTM STP 977 American Society for Testing and Materials, Philadelphia,pp.82-94,(1988)