NATURE OF NONLINEAR-INELASTIC PHENOMENA IN NANO-SIZED MEDIUM UNDER INTENSIVE IMPACTS

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SUMMARY:
At strong seismic impacts strength of soft soils strongly falls; their structural connections became weaker and shear wave velocities decreases. This is again caused by medium properties on molecular and atomic level.
Results of analysis of ground vibrations caused by powerful natural and artificial sources are presented. Features of other radiation objects and their parameters are given.
Correlation of nonlinear medium properties with acceleration level is considered. During intensive loadings inelastic deformations are accompanies by HF (high-frequency) radiation with amplitude of vibrations higher than original ones but due to strong absorption are commonly not registered. Vibrations amplitude is directly proportional to medium temperature increases with impact level.

Keywords: nonlinearity, soils, nanosized effects

1. INTRODUCTION

It is known that virtually everything is exposed to destruction. The main damage dynamics is the fracture behavior, the rate of proliferation and branching in the medium. Despite the apparent simplicity of this phenomenon, its theoretical understanding is still in its infancy.

Let's consider the features of the soils behavior of different densities under intense external impacts, including seismic. Since the ground depending on the type and physical condition is subject to some degree of plastic deformation that can absorb elastic energy during an earthquake, then the question of its nature at the microscopic level is interesting.

Plastic deformation is effected by specific defects - dislocations - line defects in the crystal structure. Dislocations initially exist in any material and applied loads change its properties. Dislocations affect almost all of the macroscopic material properties – strength, electrical resistivity, magnetic quality. If there were no these defects, then the deformation of the material would need to apply a load equal to the theoretical strength. As soon as the actual strain deformations are negligible, then there must be some kind of hub, focusing the applied load in a small part of the material.

The process of plastic deformation preceding fracture can be represented as a single layer of atoms sliding over another, just as the shifting pile of sheets of blank paper. Because this process occurs simultaneously throughout the plane of the sheet, then the interatomic bonds between all atoms on both sides of the slip plane are forced to break at once. Attracting forces between layers of paper are negligible. But between the layers of atoms, they are great. Therefore, the attempt to move two atomic layers - one over the other - though possible, but require a very large effort. This is the so-called theoretical strength of the material. Ya.I. Frenkel recounted this effort for the usual stress and found that the strength in this case reaches very high values exceeding normal in 1000 times. If the dislocation is fixed, then the deformation cannot be plastic. When many dislocations are braided, they obstruct each other to move, making the material to resist plastic deformation i.e. more durable. Consequently, the abundance of dislocations leads to the suppression of plasticity. Dimensions of dislocations – the length of several millimeters (centimeters), and the thickness of one atom (one hundred millionth of a centimeter).

Internal residual stresses that are “kept” by medium, are often the source of cracks and, consequently, sudden unexpected destruction. At this stage of destruction plastic deformation dominates, this process accompanies by high-frequency vibrations and further development of the crack.

Waves in rocks are subject to the principle of superposition and force the crack to subordinate this principle as well. Nonlinear properties appear in loose soils, and the waves of different nature interact with each other. It is difficult to predict the trajectory of the crack, and hence the self-destruction.

2. NONLINEAR PHENOMENA DURING SEISMIC LOADINGS

Any destruction is accompanied by acoustic radiation. Among the objects of inanimate nature, capable of sound radiation, a crack has perhaps the most high-frequency sound. This is due to the fact that destruction is a process in which simultaneously occurs elastic and plastic deformation. A complex combination of them accompanies all stages of phenomena development during the crack initiation, progression and after the rupture. Naturally, all stages are accompanied by a complex interaction of wave processes. It is impossible to hear the crack, because the basic tone sound of crack lies in an ultrasonic field.

The behavior of soft soils (clay artificial mound of 40m capacity, a new component of the ring road in Tbilisi) for large dynamic loads was investigated in 1987. Sensors were located at a depth of 1.0 m and 5.0 m. The pulse impact was applied on the strata surface by the moving part of the scraper. On the seismogram (Fig. 1) is clearly visible the predominant peak of high frequency (HF), which attenuates rapidly with depth.

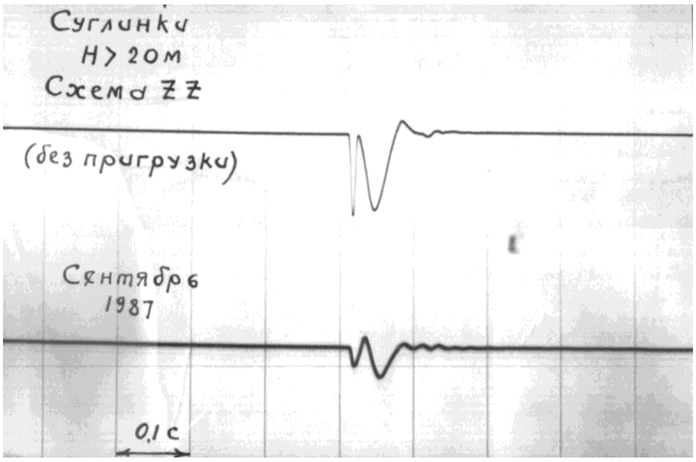

Figure 1. Nonlinear phenomena in soft soils under intense seismic loads

The Huygens Spacecraft of European Space Agency landed on the surface of Saturn's moon Titan in 2005. Accelerometer and penetrometer data allowed to determine the nature of the surface on which the spacecraft landed. It appeared to be not hard nor too soft. It is not ice, but not a thick layer of deposited aerosol. According to mechanical properties the surface resembles soft clay, lightly rammed snow or sand.

Despite the huge differences in temperature and other climatic conditions Titanium is more like Earth than any other planet in the solar system. Methane and ethane perform the role of water in the hydrological cycle on Titan - they fall as rain and snow.

Acoustic data obtained during the last 90 meters of flight, have shown that the underlying surface is relatively plane, but not absolutely smooth. After landing, the spacecraft has registered signs of methane vaporization. This suggests that the soil could be saturated with methane. For example, it could be a methane sea coast or a river bank. However, the data is not contradicting with the possibility that the surface is composed of very fine, but dry sand. The final choice between these options cannot be made so far because analysis of liquid presence in the soil is not complete yet.

Analysis of the corresponding seismogram (Fig. 3) shows that here we have the high-frequency component at the beginning of the process as well. This suggests that, by analogy with the previous seismogram (Fig. 2) soil of site is undoubtedly very fragile and must be formed by bulk soils or substantially fluid-saturated soils.

Analysis of the measurement results performed on Titan's surface (presumably the soft clay, slightly rammed snow or sand) shows that here, with intense impacts there is a high-frequency radiation as well (Fig. 2).

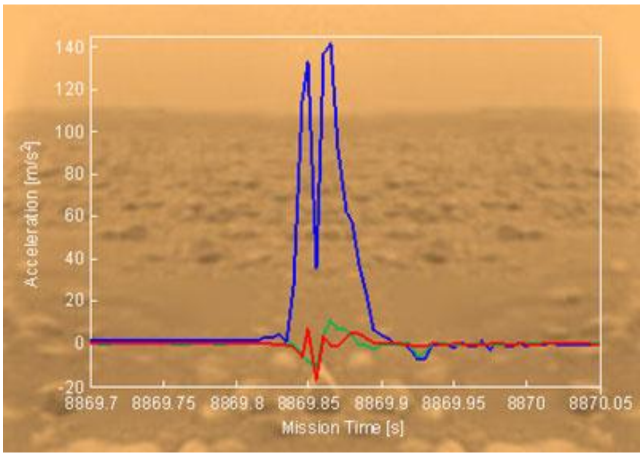

Figure 2. Data of “Huygens Spacecraft” accelerometer while landing on Titan's surface
The landing speed was equal to 4.6 m/sec [site www.esa.int].

Under pulsed impact on the surface of sands stratum (Voronezh) in the near field of a powerful source of GSK-6M appeared HF region, decaying rapidly with distance (Fig. 3).

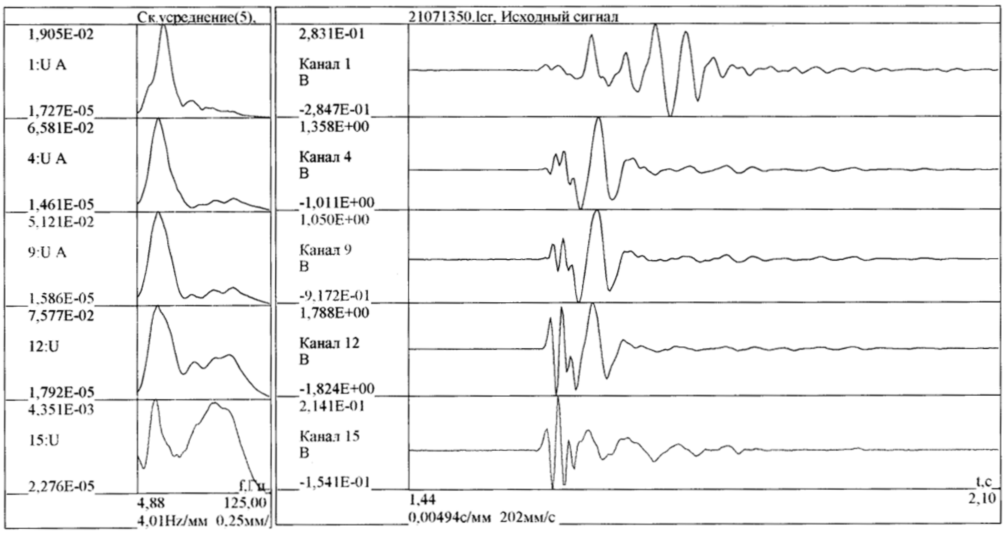

Fig. 3. Occurrence of a significant HF component in the near field of a powerful non-explosive pulsed source of GSK-6M

Undoubtedly effects occurring at least at the molecular level are the reason of HF radiation. Under intense impact the medium goes into the stress-strain state. This state is not only the external appearance of the substance (medium) reaction but also the integral result of molecular vibrations about the equilibrium position. In this case, the amplitude of the vibrations is directly proportional to medium temperature, which will grow with increasing impact levels.

Thermal motion causes the ions in the lattice vibrate around their equilibrium positions. Forces of chemical bonding are restraining forces. All of the elastic properties, compressibility and propagation of seismic waves are determined by these properties. Moreover, these properties are usually described within the continuum theory, which does not take into account the atomic structure. Continuum approximation corresponds to the phonon spectrum, taken at a wave vector $K \to 0$ ($\lambda \to \infty$), also called “long-wave approximation”. Consideration of processes on a more detailed level should provide answers to many questions and, in particular, the increase in absorption of seismic energy with increasing intensity of impact that constitutes nothing more than a transfer of energy in the “thermal field”.

The area of the real spectrum of vibrations is an important indicator of nonlinear behavior of soil at different impact levels. It is a reliable indicator of the physical state of the medium and characterizes its deformability or the degree of deviation from the behavior of linear-elastic Hooke's law.

According to the investigation results of large earthquakes records of the system SMART1 (Taiwan) significant non-linearity in the graphs appears, starting with the acceleration a = 0.1 g (Fig. 4). Due to the fact that a significant non-linearity occurs for values of the accelerations of the order of 0.1 g, exactly for these levels of impact the HF radiation which decays rapidly with distance from the source and, therefore, was not recorded during strong earthquakes.

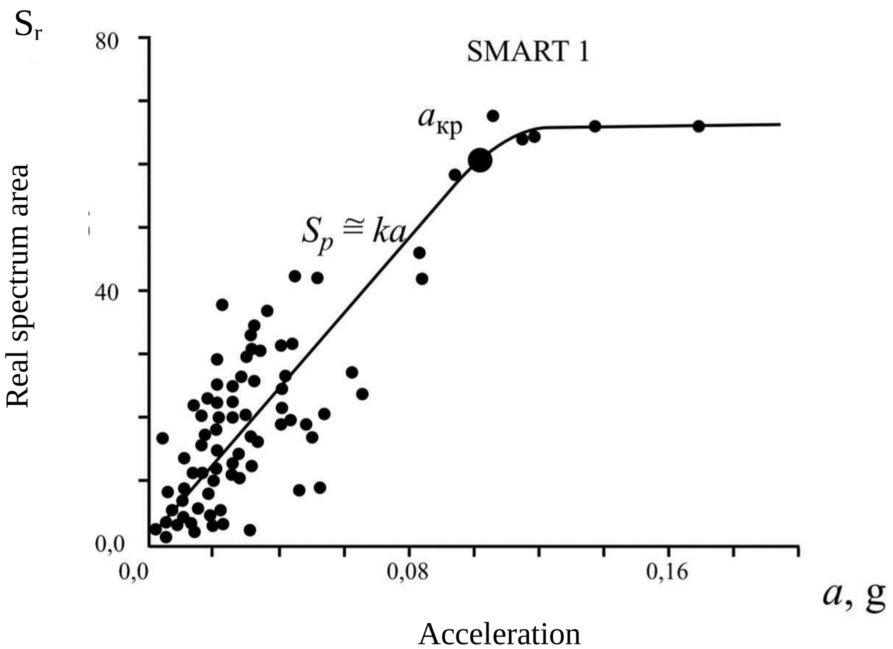

Figure. 4. The dependence of the real spectrum area from acceleration (Taiwan)

The same “break” of the curve of the area of the real spectrum at a = 0.1g is obtained for station Zemobari (Fig.5b) located on loose soil (SMACH, Georgia). On the rocky soil this phenomenon is absent (Fig.5a). The absorption at low-level impact increases linearly up to the acceleration a = 0.08 – 0.1 g then rapidly decreases, and at the acceleration of a > 0.2 g absorption begins to increase again, thus describing the transition of a physical system to a new hard -deformed state.

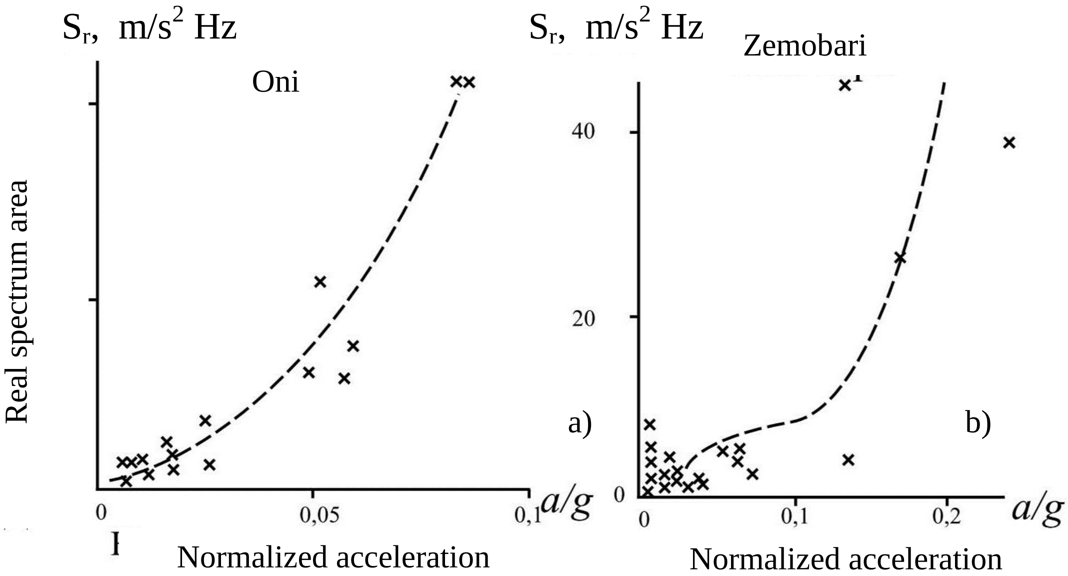

Figure5. The dependence of the real spectrum area of vibrations from acceleration SMACH (Georgia, 1991)

3. MOLECULAR AND ATOMIC LEVEL

Thermal motion causes the ions in the lattice to vibrate around their equilibrium positions. Forces of chemical bonding are restraining forces. All of the elastic properties, compressibility and propagation of seismic waves are determined by these properties.

For simplicity, let’s consider the Lennard Jones’ potential (Fig. 6), usually used to describe the simplest molecular crystals [Ashcroft, Merlin, 1979]:

$$\phi(r) = -\frac{A}{r^6} + \frac{B}{r^{12}}, \qquad (1)$$

where A and B – positive coefficients, r – distance between the atoms.

Thus at large distances the potential is “attractive”, but at short distances “strongly repulsive” (the exponent is chosen equal to 12 for convenience of calculations, and the requirement that this number was greater than 6).

Features of interaction potential of atoms and molecules in medium also explain the well-known phenomenon of “bimodule”, i.e. different types depending on the stresses and deformations under compression and tension [Zaalishvili, 2009]. It must be noted that the angle of the surface rocky soils is not actually depended on the intensity of the impact on the rocks (Fig. 7. b).

Generally speaking, the whole theory of vibrations, based on Hooke's law, is approximate because it is based on the decomposition of the elastic energy in series of the strain tensor, and retained terms up to second order [Landau and Lifshitz, 1987]. Accordingly, the components of the strain tensor and the equations of motion are linear. For the following approximations the linear properties disappear, and occur anharmonic effects of geometric nonlinearity. The effects of these approximations are small, but in some cases can play the main role. Effects of anharmonicity of third order lead to the fact that on the set of basic monochromatic waves with frequencies of ω_1 and ω_2 are superimposed some "waves" of weak intensity with combination frequencies $\omega_1 \pm \omega_2$. Another type is the physical nonlinearity that is expressed in the nonlinear relation "stress-strain".

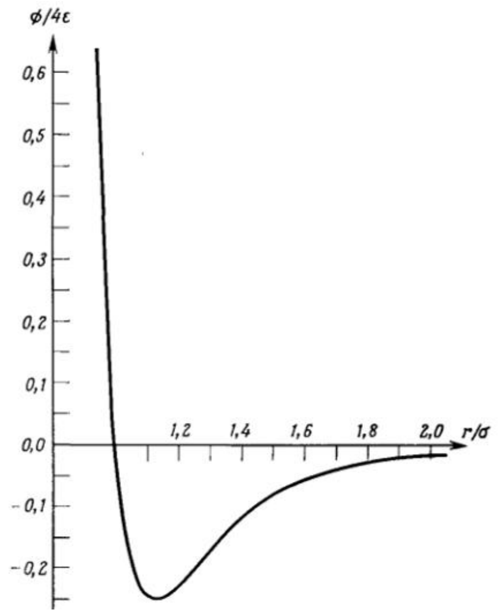

Figure 6. Lennard-Jones' potential [Ashcroft, Merlin, 1976].

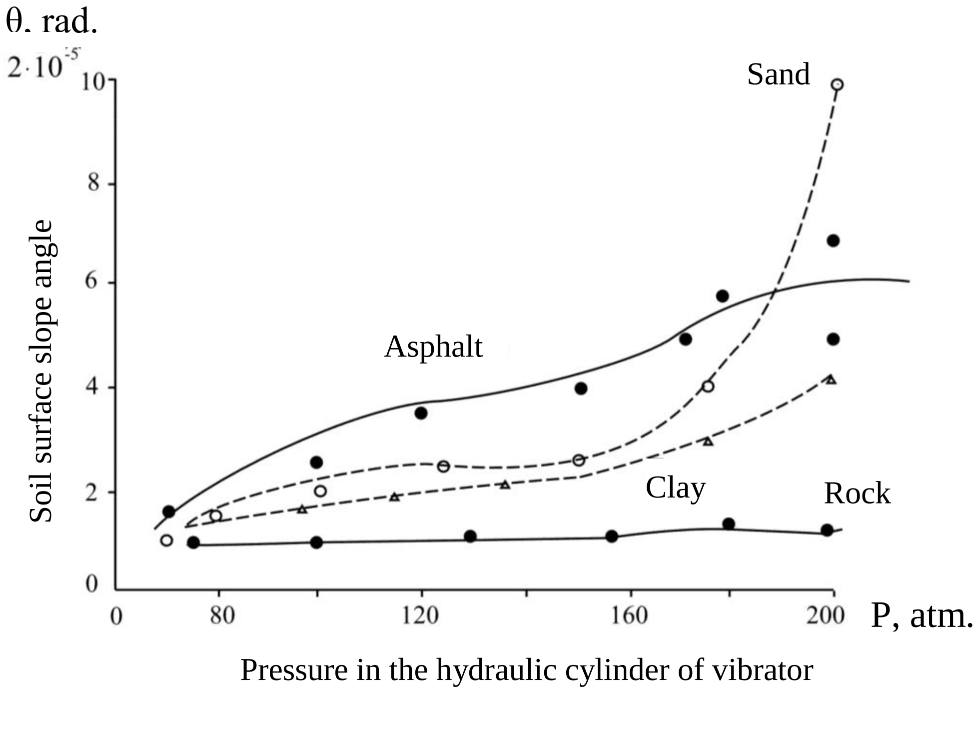

Figure 7. The effect of pressure in the hydraulic cylinder of the vibrator on seismic radiating effect of soil slope from the distance to the source (P. Uznozh, Belarus, 1992; city Dedoplistskaro, Georgia, 1992)

In addition, under intense loads, when there is an increase in absorption of seismic energy, these processes can no longer be assumed to be isothermal. Assuming processes to be adiabatic (i.e., without heat exchange with other parts of the medium) then the elastic “constants” become dependent on the temperature [Landau and Lifshitz, 1987].

The velocities of elastic waves depend on the properties of the medium at the molecular and atomic level, what is stipulated by the energy of the crystal-chemical relationships. It was first noted in 1959. by M. Born and H. Kun and later by O. Anderson and R. Liberman (1970), Krueger (1984) [Krieger, Kozhevnikov, Mindel, 1994].

Dispersibility indicates that the soil is composed of separate particles of different size, unrelated or related to each other, but with bonding strength much less than the strength of soil particles. There are pores between the particles that can be filled with either gas or liquid. As the results of experimental investigations show the structured water has a significant effect on various properties of building materials [Rodionov, 2006]. The structure of water and its properties are determined by the relationships and form of clusters that are united in atoms of water under the influence of external activating effects. The size of the atom (0.3 nm) and water clusters (a few nm) technology of using structured water should be classified as nanotechnology.

Dispersed rocks are a specific medium for propagation of seismic waves. This fact is taken into account by modern seismology insufficiently. Meanwhile, the practical importance of this issue is great, because dispersed rocks are mostly foundations of buildings and structures [Krieger, Kozhevnikov, Mindel, 1994].

Physical-chemical and seismoacoustic processes interact in disperse rocks. Elastic waves can cause physical and chemical processes. Therefore, the seismic characteristics of the dispersed rocks and the intensity of the seismic effects are largely dependent not only on the composition of the rocks, but also changing thermodynamic conditions.

The crystal lattice of hard soil particles is formed by chemical elements - ions carrying any given electric charge. Inside the crystal lattice the charges of ions of different signs are balanced, and on the surface of a solid particle ions are balanced only partly. Thus, such a particle is not neutral and behaves as a charged body. Theoretically, the charge should cover the entire surface of the particle equally, however, as the S.S. Vyalov [1978] notes the basal planes of the clay particles are negatively charged, and the edges (ends) - positively.

Typically, at grains diameter of > 0.1 mm, the influence of the structure of dispersed rocks on their seismic properties is weakly expressed [Krieger, Kozhevnikov, Mindel, 1994], this size corresponds to the fine sands. Pulverescent particles (pulverescent sands) have a particle size of 0.05-0.005 mm [Abukhanov, 2006] and according to characteristics take intermediate position between sand and clay particles. According to size the clay particles are particles with sizes <5·10-6 m, i.e. in fact, the investigated processes considered at the nanoscale (particle sizes ranging from 1 to 1000 nanometer, commonly referred to as nanoparticles). Many researchers noted that the properties of the clay particles significantly differ from the sand. Clay particles have the form of scales, needles, plates or irregular angular shape, with thickness of 10-50 and even 100 times less than the maximum size. As a result, the clay particles have a greater surface area than sand.

It is known, that one of the most important issues facing nanotechnology – is to make the molecules group in a certain way, self-organize in order to eventually obtain new materials with new properties. At the same time these examples show that under intense seismic loads the structure of soils is changing. These phenomena in soils are also of interest for supramolecular chemistry, investigating more complex chemical systems involved in a whole through the intermolecular (noncovalent) interactions than the molecules.

Thus under intense impacts behavior of the stress-deformed medium is determined by the integral result of molecular vibrations about the equilibrium position. The amplitude of the vibrations is directly proportional to medium temperature, which will grow with increasing impact levels.
Under strong seismic impacts abruptly decreases the strength of loose soils and their structural bonds weaken, and shear wave velocities are reduced. This is again due to the properties of the medium at the molecular and atomic level. The velocities of elastic waves depend on the properties of the medium at the molecular and atomic level, what is stipulated by energy of the crystal-chemical relationships. It was first noted in 1959. By M. Born and H.Kun and later O.Anderson and R.Liberman (1970), Krueger (1984) [Krieger, Kozhevnikov, Mindel, 1994].
Investigations of the mechanisms of energy absorption of seismic vibrations at the nanoscale will explain the phenomena observed during intense seismic loads in mediums with different properties.

CONCLUSIONS

With intense impacts in weak mediums occur plastic deformations. Plastic deformation is accompanied by HF (high frequency) radiation, the value of which exceeds even though the so-called major vibrations, but decays rapidly with distance due to the strong absorption and generally is not recorded.
Under intense impacts behavior of the stress-deformed medium is determined by the integral result of molecular vibrations about the equilibrium position. The amplitude of the vibrations is directly proportional to medium temperature, which will grow with increasing impact levels.
Under strong seismic impacts the strength of loose soils abruptly decreases, and their structural bonds weaken, and shear waves' velocities are reduced. This is again due to the properties of the medium at the molecular and atomic level.
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