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Blast Charge Technique as a Method of Soil Improving to Locate the New Supporting Runways

Eligiusz Mieloszyk[1], Anita Milewska[1], Mariusz Wyroslak[2]

[1]Gdansk University of Technology, Faculty of Civil and Environmental Engineering, Department of Rail Transportation and Bridges, ul. Narutowicza 11/12, 80-180 Gdansk, Poland

[2]Gdansk University of Technology, Faculty of Civil and Environmental Engineering, Department of Geotechnics, Geology and Marine Civil Engineering, ul. Narutowicza 11/12, 80-180 Gdansk, Poland

mariusz.wyroslak@pg.edu.pl

Abstract. A quick and effective method of reinforcing the ground base designed for the construction of engineering structures used for performing various types of air operations was presented. It allows to use wastelands, wetlands, swamps, etc. for these purposes, thus creating a dispersed network of landing sites, increasing the access of large social groups to air transport and increasing their mobility.

1. Introduction

The location of aerodromes or their elements (including the creation of landing areas, runways, spare runways, etc., temporary - in crisis conditions), especially in cases of higher necessity, can be less and less often adapted to the proper / desirable conditions of the foundation.

The above conditions force decision-makers to place these objects also on soils considered to be difficult from the point of view of their suitability for broadly understood transport and communication activities. This concerns swamps, organic land, dump grounds, industrial waste, rubbish dumps.

It should also be remembered that airport infrastructure may be destroyed, for example as a result of unexpected circumstances (failure, catastrophe, natural disaster, terrorist attack). The reconstruction of this infrastructure in the aforementioned crisis situations should make it possible to restore it in the shortest possible time.

From a practical point of view, a good solution is the ongoing creation of a dispersed network of airports in difficult engineering and hard-to-reach areas. Here, methods to strengthen the ground surface are helpful in the struggle against time [1]. However, from the point of view of the limited time needed to prepare the subsoil for designed aerodrome objects, an important and effective method of using explosives for reinforcing the subsoil for these aerodromes and access roads, including railways or railway sidings, should be considered.

The use of the possibility of creating airports with the limited certification under different conditions of the ground subsoil allows for the creation of innovative solutions. It will increase the communication accessibility of the citizens. It will also be an impulse for an action for local government units, transport, forwarding, logistics, tourism, medical, rehabilitation, free time industry, etc.

2. Subsoil improvement

Organic soils (e.g. peat) subjected to stress are characterized by high compressibility. During consolidation their internal parameters change [2], [3]. The organic soils are characterized by low initial strength, high deformability and a wide variety of properties depending on the type and content of minerals and organic components. It follows that this type of land can not be directly used as a foundation for the engineering structures necessary for performing aerial operations. Generally, it can be concluded that low-bearing soils without their modification can not be used to implement the aforementioned ventures.

Modification of the soil substrate to improve its geotechnical properties can be implemented in many ways. Geotechnical parameters of the soil substrate can be changed or their consolidation can be accelerated by reinforcing or improving the soil properties with various methods to the extent that they meet the requirements of engineering structures for the implementation of air operations, including runways, engineering facilities and various types of access roads.

From the point of view of the problems discussed here, two groups of ground improvement can be distinguished: soil improvement methods and soil reinforcement methods for engineering objects related to the implementation of aviation operations.

The first group are the methods in which the soil is modified by using various types of injections in order to obtain a more compacted or tight substrate. This modification consists in strengthening the contact between the ground grains, which simultaneously reduces its porosity, creating a useful base for taking up large dynamic loads from landing aircraft.

The second group are the methods consisting in introducing a structural element to the ground in order to increase its mechanical strength or mechanical violation of the internal structure of the soil thus improving the soil strength parameters.

Detailed methods for strengthening or improving the ground surface include: low pressure injections, high pressure injections, vibroflotations, chemical injections, dynamic replacement, dynamic consolidations, deep dynamic compaction, vibrating methods, vertical drains, compacted columns from granular soils, soil mixing with additives, deep soil mixing, soil reinforcement, static overloading, etc.

One more method should be added here - the method that uses blasting charges. This is the method important from the point of view of the subject considered here, which has some common features as to the principle / idea with dynamic exchange or dynamic consolidation.

The dynamic replacement method is a combination of methods used for compaction of the soil, and especially impact methods with the method of land exchange, the concept of which consists in increasing the load-bearing capacity of the ground by introducing stone, gravel or sand columns in it. It works best when strengthening organic soils, irrigated cohesive soils and anthropogenic soils. This technology consists in the dynamic formation of load-bearing gravel columns or columns made of aggregate (e.g. crushed structural concrete, blast furnace slag, stone breakage) by means of rammers (most often weighing from 8 to 15 Mg) dropped by gravity most often from a height of 15 to 30 m.

Such compacting causes the overpressure of water in the pores of the ground, which dissipates causing the outflow of filtration water to the column performing the drainage function. Detailed selection of the appropriate type of method is possible after thorough assessment of the parameters of the soil to be improved, as well as the depth of deposition and stratification of the low-bearing substrate. In the process of soil reinforcement, the distribution of impact points is important (Figure 1), as well as the selection of other technological parameters, including the frequency of impact. After this operation, the ground surface is prepared for carrying out, for example, runways on it.

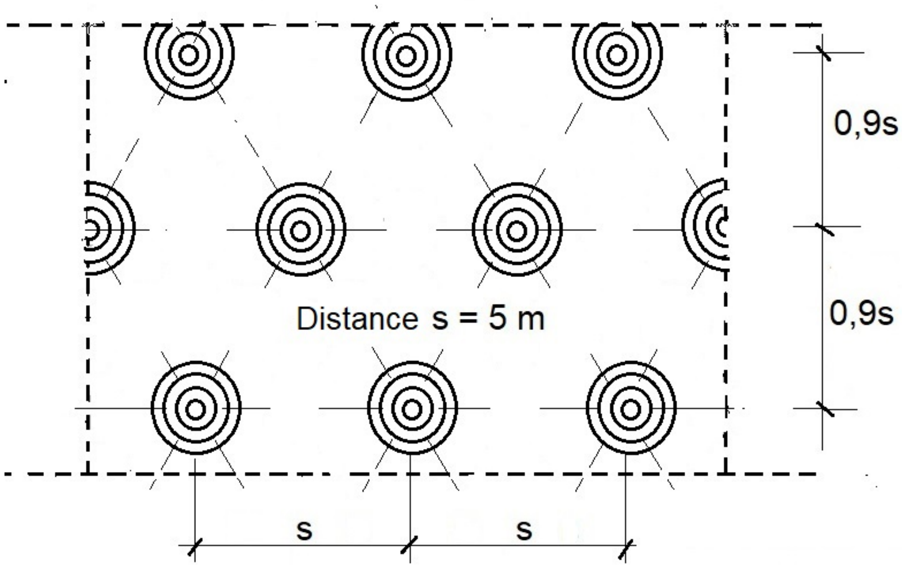

Figure 1. The net of hit points in the dynamic replacement method

Similar equipment is used to perform dynamic consolidation of the ground, as in the case of dynamic exchange. This technology consists in repeatedly dropping (generally from 10 to 40 m) a heavy rammer (generally with a mass of 10 to 50 Mg) at a frequency of about 1 to 3 beats per minute. As a result of this operation, in a weak ground a solid of reinforced soil is formed below the crater. Gravitational rammer (Figure 2) causes the formation of overpressure of water in the pores and the formation of volume waves: transverse and longitudinal waves and surface waves [4].

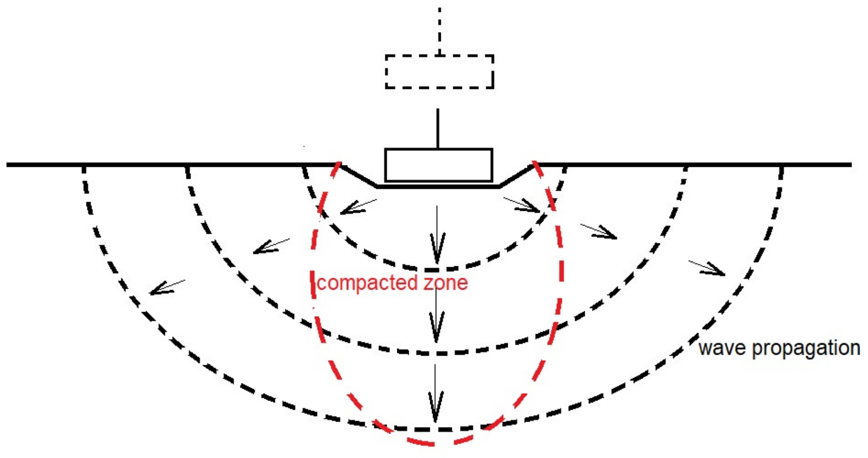

Figure 2. Dynamic compaction. Propagation of vibrations (waves) in the ground

The propagation of elastic waves consists in inducing the particles of the medium more and more distant from the source of the waves. However, the most important feature that distinguishes elastic waves from any other ordered movement of the medium particles is that in the case of small disturbances, the propagation of elastic waves is not related to the transfer of substances. In the case of very short durations and large amplitudes, shockwaves are created.

From our point of view, the elastic waves created in this process (Figure 3) can be divided into volume waves propagating in the ground and air (noise) and surface waves propagating along the surface separating the media with different properties, including waves propagating on the surface of the ground.

Longitudinal volumetric waves P reach the vibration recorder first. These waves cause a vibration deviation in a direction parallel to the direction of wave propagation. They cause squeezing and stretching of the medium, and their speed is marked by c_L. Transverse volumetric waves S reach from the source into the vibration recorder after wave P. Their speed is marked by c_S. The speed of the P and S waves depends on the magnitude of the elastic parameters of the medium and together with the change of these parameters, these speeds may vary considerably, and in particular these changes may be related to, for example, an increase in depth in the ground.

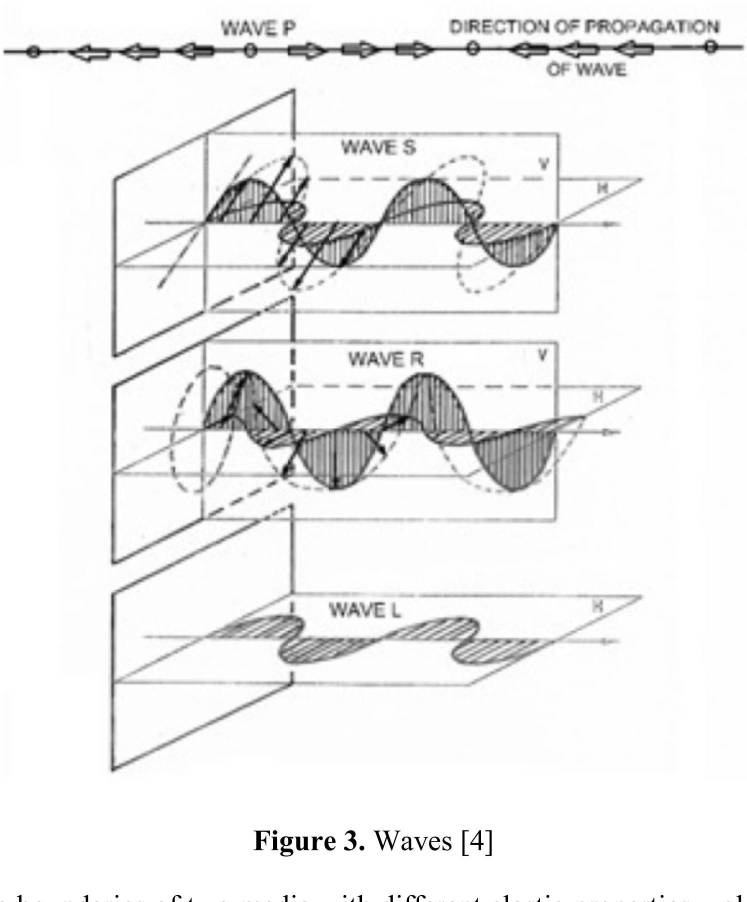

Figure 3. Waves [4]

When crossing the boundaries of two media with different elastic properties, volumetric waves are reflected and refracted. The refraction and reflection of these waves is accompanied by the formation of both types of waves [4].

Surface waves: Rayleigh and Love waves (also called R-waves and L-waves) have long periods and variable amplitudes, with the amplitude of their vibrations decreasing exponentially with increasing depth.

Rayleigh surface waves propagate horizontally and cause both vertical and horizontal but not often lateral movements of the ground surface (Figure 3), with vertical and horizontal components being opposite in phase, so that the movement of particles is elliptical - takes place along a vertically oriented ellipse and which is perpendicular to the direction of the wave.

A Love wave is also a surface wave having a horizontal motion that is transverse (or perpendicular) to the direction the wave is traveling. The amplitude of this motion decreses with depth. Love waves make changes in shape of the ground surface, i.e. state of particles arrangement changes. They travel faster than Rayleigh waves.

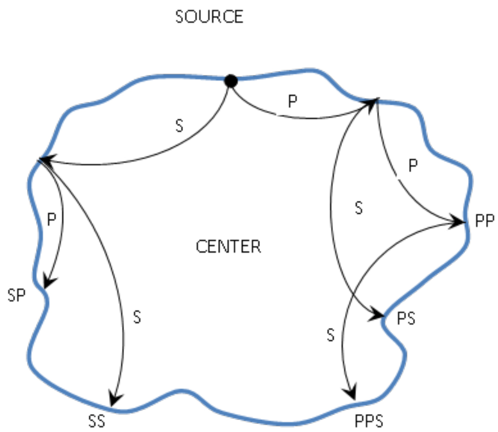

Figure 4. Propagation of bulk waves in the medium. PS – waves reflected at the interface of the medium(incident P, reflected S); SP – waves reflected at the interface of the medium (incident S, reflected P); PP – waves reflected at the interface of the medium (incident P, reflected P); SS – waves reflected at the interface of the medium (incident S, reflected S); PPS – waves after double reflection

In general, the one-dimensional wave equation [4] has the form:

$$Su = f(x,t) \tag{1}$$

where:

$$S = \frac{\partial^2}{\partial t^2} - a^2 \frac{\partial^2}{\partial x^2} \tag{2}$$

(*a* is a parameter characterizing the ground substrate, characterizes the source - [4]).

Using a non-classical operator's calculus [5], it is possible to designate function *u* describing the propagation of the wave. It looks like this:

$$u = su + Tf \tag{3}$$

where:

$$Tf = \frac{1}{2a} \int_{t_0}^{t} \int_{x-a(t-\tau)}^{x+a(t-\tau)} f(\xi,\tau) d\xi d\tau \tag{4}$$

$$su = \frac{u(x-a(t-t_0),t_0)+u(x+a(t-t_0),t_0)}{2} + \frac{1}{2a}\int_{x-a(t-t_0)}^{x+a(t-t_0)} u_t(\xi, t_0)d\xi \tag{5}$$

as far as we know the shape and speed of the wave at the time t_0.

Generally, the wave equation has the form:

$$Su = f(x, y, z, t) \tag{6}$$

where:

$$S = \square = \triangle - \frac{1}{a^2}\frac{\partial^2}{\partial t^2} = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} - \frac{1}{a^2}\frac{\partial^2}{\partial t^2} \qquad a \neq 0 \tag{7}$$

because

$$\triangle = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \tag{8}$$

Remark. The analysis of the last equation can be made using the non-classical operational calculus and generalized Taylor formula [5].

In the case of $n = 2$, Laplace operator is reduced to $\Delta = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$ and for $n = 1$ we obtain the operation $\frac{\partial^2}{\partial x^2}$, which changes last differential equation of the model e.g. in the equation of one-dimensional longitudinal elastic wave with the source function.

After a series of impacts generating these waves, the water pressure in the pores of the soil increases to the level corresponding to the state of liquefaction of the soil. The next phase causes dissipation of water overpressure and soil compaction - stronger contact between grains.

After completing the impact process - dynamic consolidation, the surface is leveled up and the compaction proceeds on subsequent possible locations. After the process, the mobile airport covering used to build the basic elements of airports or helipads can be laid out on the leveled ground surface**.**

3. Soil improvement with blasting charge

This technology aims to improve the physical and mechanical parameters of the ground by compacting granular soils or by creating vertical sand piles (improvement) in weak cohesive soils as a result of the use of explosives placed in or on natural soil or embankment to be compacted or consolidated.

The process of explosion and detonation [6] is spread by the already mentioned strong shockwave. The advantages of this method when reinforcing the ground surface for aerospace purposes include:

- short duration of compaction or improvement, which is particularly important in cases of higher necessity,
- obtaining densification of the substrate layers to a large depth, e.g. up to 40 m,
- effectiveness when there are large single boulders or stones in the ground,
- high efficiency in areas exposed to dynamic loads, e.g. large aircraft landing.

The basic feature of this method is the use of high energy generated at the moment of explosion. Detonation of the explosive is possible only when using a high voltage electrical impulse. For safety reasons, materials sensitive to detonation under the influence of fire are not used [7].

In the process of compacting granular soil, certain phases can be distinguished during explosion. At the outset, gas and shockwaves produced during the explosions (Figure 3) propagate in a ground-water medium at a speed of approx. 3000 m/s. The pressure of the detonation wave is approximately 1400 MPa. This process causes a change in the structure of the ground backbone, whose grains or particles are subject to slow or rapid rearrangement due to large shear deformations in the ground, followed by liquefaction of the soil and dissipation of the water pressure in the pores. Detonation of the load causes a sudden increase in the pressure of water in the pores of the ground, which destroys its existing unstable structure, changing it into a useful location for the airport facilities or other structures.

The triggered regrouping in ground environment entails increased soil compaction. It depends on the type of soil and its permeability, the location (placement) of the explosive and the volume of soil to be compacted. To carry out ground reinforcement operations, explosives can be placed on the surface of the reinforced soil or inside the ground. In the latter case, concentrated or extended charges are used.

In the implementations performed so far, when using concentrated charges, their weight does not exceed 10 kg, while extended charges usually have a unit mass of about 2 kg/m. The Polish experience has made it possible to work out the above empirical recommendations for the method of strengthening the soil using blasting agents (Figure 5). In the literature [8] we can also find other design parameters. The theoretical range of effective explosion impact in the case of a concentrated charge or a cluster of concentrated charges is (the dimentions of $R1$ is taken as [m]):

$$R1 = k \cdot \sqrt[3]{Q_1} \tag{9}$$

where Q_1 is the empirically determined mass of the explosive charge [kg] at depth h [m]:

$$Q_1 = 0.055 \cdot h^3 \tag{10}$$

the dimensionless parameter k is the experimental factor: $k = 2{,}5 \div 3{,}0$.

Theoretical range of the effective explosion impact in the case of an elongated charges is (the dimension of $R2$ is taken as [m]:

$$R2 = 0.71 \cdot k \cdot \sqrt[3]{Q_2} \tag{11}$$

where Q_2 is the assumed mass of the explosive charge [kg/m].

Note that equations (9), (10), (11) are empirical in shape, so that final dimensions are not compatible.

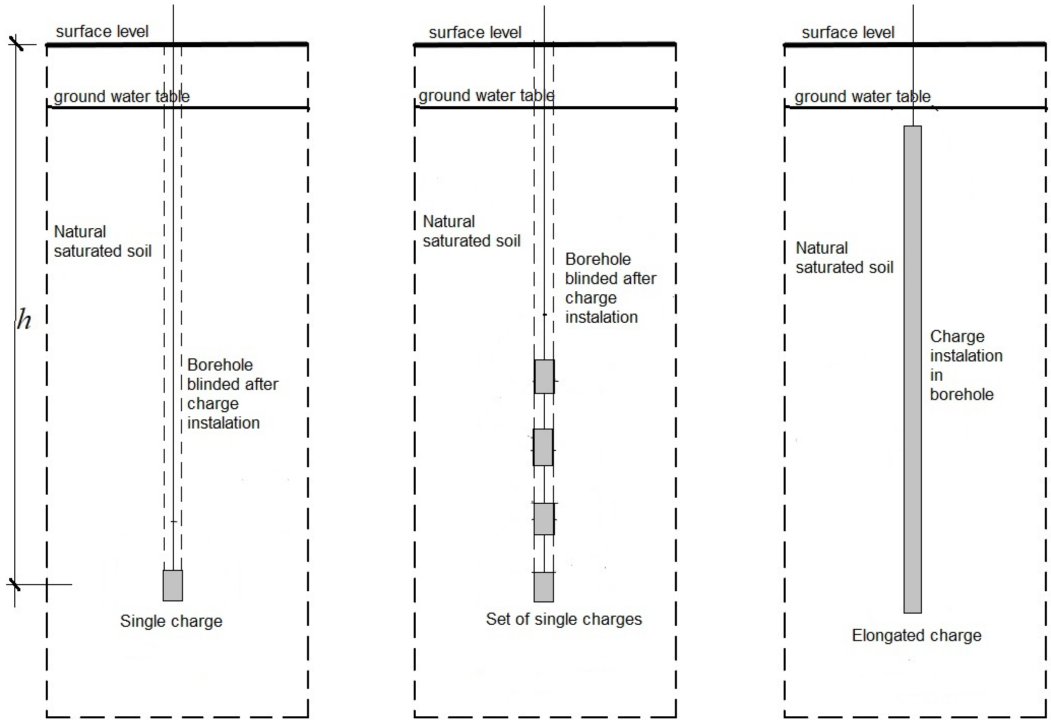

Figure 5. Blasting charge methods

Not always the single use of explosives gives the expected effects of reinforcing the ground intended for the construction of runways or access roads, etc. Then a series of explosions [5] must be used, including sequential firing of charges at various points on the surface being reinforced (compare Figure 1).

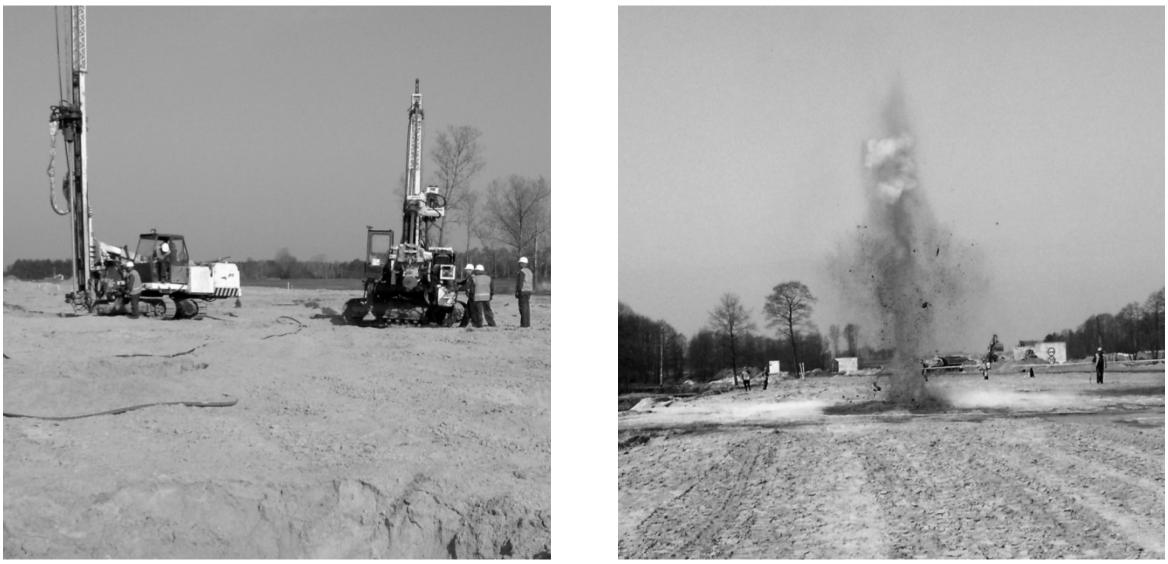

Figure 6. Blasting charge in practice.

Figure 7. Dynamic replacement in practice.

Runways are linear engineering construction objects, and similarly to different types of roads, railway lines, etc., can be implemented with the use of experience in subsoil improving for roads, railways, etc. (Figure 6 and Figure 7).

4. Application for the construction of a dispersed network of "small" airports / runways

In general, apart from airports in the vicinity of large cities, so-called regional airports (communication) we should eventually create new small airports with public access (including those with limited certification) or create airports serving so-called small aircraft with a maximum mass of 10 Mg.

All of these airports could have a complementary function and could serve passengers wanting to get to, for example, a central or regional communication airport from places that are at least 3 hours away by other means of transport. When modernizing existing runways, access roads or in new construction, innovative methods based on green geotechnics should be used - abandoning concrete and asphalt. Weak, difficult, often unsuitable for other purposes, undeveloped soils should be used - bogs, peat bogs, etc. In these cases, explosive charges can be used to strengthen them. They may be located in the coastal zone and, hence, they may be used to increase safety at sea.

Many soils in the coastal belt are poor soils, so they can be adapted for the aforementioned constructions using methods that use explosives [9]. To implement the above concept, the already mentioned planes with a maximum take-off mass of 10 Mg can be used. These are generally nineteen-seat planes plus two crew members. Their maximum speed is about 500 km / h, the maximum range is about 1,300 km.

Assuming for analysis:

- average speed of the aircraft - 400 km/h,

- range - 1000 km,

a schematic map was created (Figure 8) with areas Ω_i presented potential reaching of runways.

Figure 8. Areas Ω_i

Radius of runways influence R_i is about 600 km (travel time - about 1.5 hours).

Figure 8 shows that in area $\Omega = \Omega_1 \cup \Omega_2 \cup \ldots \cup \Omega_n$ there are many large cities, and even the capitals of several countries.

Due to the lack of location restrictions, the dispersed system can be well designed, taking into account its architecture and topology adapted to all conditions, including crisis conditions. "Small" airports and small planes are a more flexible form of air transport than air transport using traditional airports. They should complement the existing network of large communication airports. They should offer passengers comfortable and quick access to selected destinations, including large airports.

It is a competitive solution in relation to other means of transport, including even high-speed railways. It creates the possibility of creating a dispersed network of "small" airports in the Ω area, without any limitations in relation to their specific location, including location on weak soils. Here the method of reinforcing the ground with the use of explosives is really helpful. Such airports can be created and liquidated depending on the needs. The cost of this operation is low and due to the technology used, neutral to the environment.

5. Conclusions

The method of ground reinforcement using explosive materials for the construction of engineering structures designed to perform aerial operations is an innovative and effective one. The short time of consolidation of the ground, the location on poor ground and in hardly accessible areas are the advantages of using the discussed method while constructing airfields. The method described for compacting the substrate is economically viable. Difficult areas: swamps, wasteland etc. can be used to create small airports on them.

Small airports are a way to solve many communication and transport problems in all conditions. It is an air transport system that can be used by the general public. An additional advantage is the possibility of their dissipation, and this allows them to increase the availability to large groups of society, and by dispersing it increases the safety and reliability of the entire system in all conditions.

The proposed system is flexible, reliable as a whole and scalable (a feature that allows maintaining similar system performance while increasing the scale of the system - for example, the increased number of related small airports does not disturb or interfere with the quality of the system. It reduces travel time.

This unconventional and innovative approach to the implementation of air operations should be a desirable and possible direction for the development of the aviation system, in which the described method of strengthening the ground should also be used to build infrastructure in the difficult areas that complement the existing system through the construction of access roads, railway sidings, warehouses, hangars, halls, technical facilities.

There already exists a similar system in the USA and Europe. In Europe it operates under the name of the European Personal Air Transportation System (EPATS). Due to the described method of ground improvement EPATS can develop efficiently (without localization or ground restrictions).

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