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Dynamic Loading-Deformation Performance of Peat Soil under Large Concrete Plates

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ABSTRACT

This paper presents data from a series of investigations performed with peat soil to determine resilient deformation under dynamic load, which has great influence on the design of connections between concrete plates that are used as pavement for rural roads. The experiments were performed both in situ and under laboratory conditions using a concrete plate, size 3m by 1m by 0.15m placed over peat. Other experiments were made with the concrete plate placed over the various thicknesses of sand fill above the surface of peat soil. Experiments were carried out under dynamic load. The laboratory experiments were conducted with a special apparatus designed and manufactured for the study. The dynamic load apparatus allowed changes in load, speed, and intensity of load. This paper describes the apparatus, which tests undisturbed peat soil samples having dimensions of 0.5m by 0.5m by 0.3m. The paper presents results of a field and laboratory study on undisturbed homogeneous and laminated samples of peat soil and fine sand under the plate. Based on the results of the field and laboratory experiments under dynamic load, an empirical equation is proposed for the resilient modulus of subgrade reaction related to peat soil properties under large concrete plates.

INTRODUCTION

The low shear strength and bearing capacity of peaty soil and its high compression (strain) rate made construction of these roads logistically difficult. The main material for construction of rural roads on peat uses mineral soil and gravel. But construction of mineral soil or gravel road subgrades incurs transportation expenses to import the subgrade material to very difficult swampy areas. Inexpensive soil for subgrades could be mineral soil excavated after construction of a drainage channel. If peat subgrades are used, then it is desirable to convert the peat soil to dry peat crumb, which compacts better and absorbs less water after rain.

Construction of rural roads on peat soils using prefabricated reinforced concrete plates (3m by 1m by 0.15m) can eliminate the need for transportation of large deposits of mineral soil for subgrade construction. Such construction has been performed in Switzerland (Route Beton, 1964), Germany (Roadloff, 1965) and Belarus (Vakher, 1979). Construction of this type of pavement for rural roads on peat soil allows reuse of the plates, by moving from place to place, thus providing access to crops during the harvest.

Observation of experimental roads using concrete plates as pavement shows their positive condition when constructed on a mineral subgrade, as well on a peat subgrade.

A crucial element to such road construction was the connection between the plates on the extremely resilient peat foundation.

Our investigation showed the rigid connection methods usually used for roads constructed on a mineral base was not satisfactory for very soft peat soil where connections are easily broken. A reliable connection can be designed only when we have information about the resilient deformation of peat soil under dynamic loads.

Field Experiments

The experiments were conducted in situ on layers of sand fill 0.0m, 0.3m, 0.6m and 1.3m thick, overlying layers of natural peat soil 1.2m, 2.75m and 2.25m thick. The field experiments studied the resilient deformation of peat foundation under reinforced concrete plates sized 3m by 1m by 0.15m. Peat soils consisted mostly of Seadge peat with Hemic fiber content of 25% to 60%, ash content 9% to 12% and water content 335% to 700%. The dry density of the in situ peat soil ranged from 94 kg/m^3 to 190 kg/m^3.

Resilient deformations under dynamic load were measured with a special recorder designed for the study. A recording apparatus was attached to reference points, which were driven through the peat into the mineral soil making the apparatus immobile. Two recording apparatuses were set up in each cross section of the concrete plate (on the center and on the ends of the plate). The first apparatus was connected to the concrete plate; the second one was connected to the reference in the peat soil. The deformation of the concrete plate and the resilient deformation of the peat foundation under the plate were recorded the same time.

Calibrations of the recording apparatus were made before experiments. Resilient deformation was retested five to six times on each cross section. The weight of the truck with load was measured with a dynamometer.

Some results of the analysis shown in Fig. 1 represent the vibro-records for two cross sections. The first result shows when the concrete plate rested directly on 1.20m thick peat soil, and the second shows results when the plate was placed on the top of the sand between the plates and the peat soil. The arrow on the vibro-record shows the direction of the truck movement. The thin line indicates deformation of the plate, and the heavy line designates the resilient deformation of peat foundation. The direction of truck movement is shown from left to right on Fig. 1, with the left side being the "front end" and the right side being the "outgoing end."

When the front wheel of the truck ran over on the "front end," the vibro-record shows positive splash. In the same manner, the outgoing end shows a negative splash. The outgoing end of the plate bulges up 0.4mm depending on the thickness of the sand fill and the amount of the dynamic load. When the wheel of the truck is on the center of the plate, the recorder shows deformation from the front and back wheel of the truck. Deformation of the peat foundation and settlement of the plate are practically equal when the dynamic load is on the center of plate. When the dynamic load from the back wheel of the truck is on the front end of the plate, the outgoing end of the plate also bulges up. Even though the load of the back wheel is more than two times greater than that of the front wheel, the bulge at the opposite side of the plate is almost the same for the front and back wheels. This could explain the impact load when the front wheel runs over on the ledge of the plate, which was exposed when the wheel moved over the near plate. At the moment of movement of the truck on the outgoing end of the plate, the front end lifted up only from the dynamic loading of the back wheel. In this case, the load from the front wheel was too small to lift up the front end of plate, because the impact load had no effect. When the wheel went off the outgoing end of the plate, the plate bearing directly on the peat subgrade did not come off the subgrade (Fig. 1). This could be explained by excellent contact of the concrete plate and the peat foundation and by the large cohesion of the plate with peat soil. The resilient deformation under the end of the plate was much larger than the deformation of the base on soil at the same place.

Figure 1B. represents the vibro-record for the soil foundation and settlement of the concrete plate under dynamic load of 20 kN and 23.5 kN. The difference between the settlement of the plate and the settlement of the base of the soil on the outgoing end of the plate was 0.4mm, on the front end it was 1.5mm. Therefore, the soil base under the plate has a convex form, and a height of about 1.5mm.

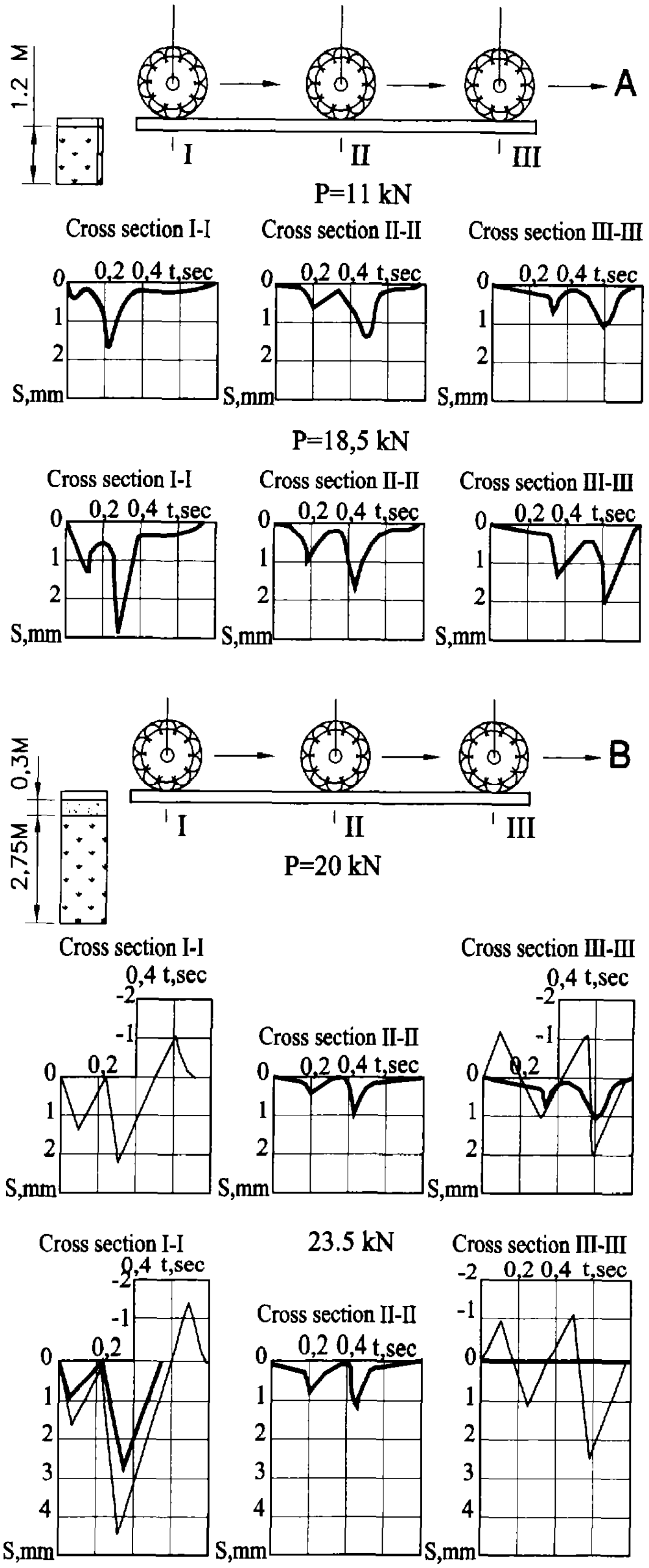


Fig. 1 Vibro-records of base and settlement of plates

—— Deformation of base

—— Settlement of plate

"Rocking" of the plate could be less when a concrete liner is placed beneath the joint between plates. Resilient deformation of the soil base under the plate depends on the thickness of sand (Figs. 1A, 1B). Sand fills of 0.3m decrease resilient deformation almost twice. As can be seen in Fig. 1A, the thickness of the peat soil is 1.2m, in Fig. 1B, the thickness is 2.75 cm. Even though the thickness of the peat soil was increased, the presence of a 0.3m thick layer of sand decreased the resilient deformation.

The influence of sand fill on the magnitude of resilient deformation is shown in Figs. 1A and 2B where vibro-records represent cross sections with the same thickness of peat soil. Analysis vibro-records show that for the test in Fig. 1B, with loads twice as large than in Fig. 2B, the resilient deformation of the soil base decreased three times as much because of the sand fill. Figure 3 represents the relation of the resilient deformation of peat soil under the center of the plate under dynamic loads. As we can see, the resilient deformation of the peat soil base varies linearly with the applied load. As the thickness of sand over the peat soil increases, tangents of angles of inclination decrease, which considerably decreases the magnitude of resilient deformation.

Laboratory Experiments

In order to study a large number of factors while performing a variety of tests, a laboratory apparatus was created using criteria similar to Sedov (1973). If the modulus of deformation in the field and in the laboratory are the same, than the relative deformation in the field and laboratory must be the same, according to the following formula (Sedov, 1973):

$$\frac{P_f}{E B_f^2} = \frac{P_l}{E B_m} \qquad (1)$$

E = modulus of deformation
P_f = applied load in the field
P_l = applied load in the laboratory
B_f = linear dimension of plate in the field
B_m = linear dimension of model

Plan dimensions of the actual plate in situ were 3m by 1m. The model of the plate tested was 300mm x 100mm for a 1:10 scale reduction. The same proportions were used when making a model of the depth of peat and sand soil. The height of the peat samples was one, two and three times the width of the plate model. The height of the sand in our experiments was 0.25, 0.5, 0.75 times the width of the plate model. The supporting area of the plate model was 0.01 of the concrete plate in situ, because the unit load in the laboratory is supposed to be in 100 times less.

The laboratory plate thickness was defined according to the plate rigidity of the cross section, of the concrete plate. The average plate rigidity in situ was (3.0 x 10^6 to 3.5 x 10^6 Nm^2.

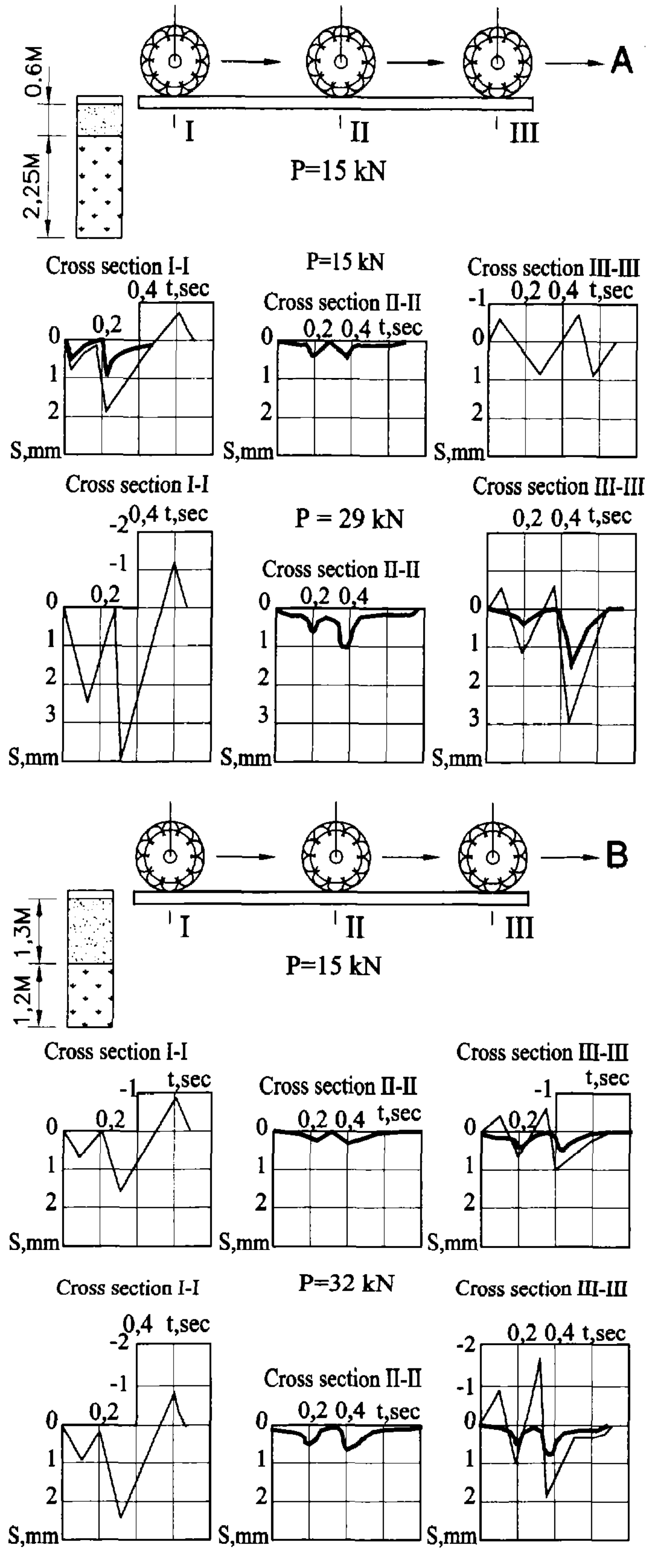
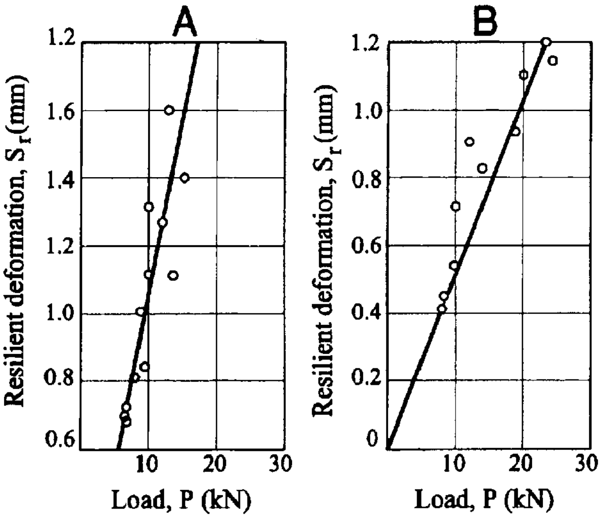


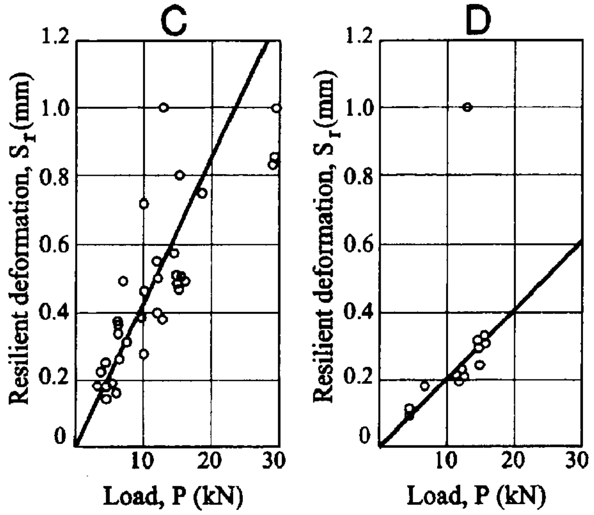
Fig. 2 Vibro-records of base and settlement of plates

▬ Deformation of base
— Settlement of plate



A $H_{peat} = 1.20$ m
$H_{sand} = 0.0$ m

B $H_{peat} = 2.75$ m
$H_{sand} = 0.30$ m



C $H_{peat} = 2.25$ m
$H_{sand} = 0.6$ m

D $H_{peat} = 1.20$ m
$H_{sand} = 1.30$ m

Fig. 3 Resilient deformation as a function of the load

The rigidity of the plate model must be ten times less than the rigidity of the concrete plate in the field. The plate model was manufactured from steel with a modulus of elasticity 2 x 10^5 MPa and a thickness of 6mm. In the laboratory the weight of the plate was taken into account (Pokrovsky and Fedorov, 1965). For this reason each cm^2 plate model was loaded with a constant additional load equal to 0.27N. The total additional load was 80N. All this was taken into account when the laboratory apparatus was constructed.

The dynamic load laboratory apparatus allowed changes in the load, speed, and intensity of the load on various different undisturbed soils. The area of the steel plate was 300mm X 100mm; the thickness was 6mm. The height of the steel mold varied from 100mm to 400mm, depending upon the size of the sample. The specimen size was 0.5m by 0.5m in plan.

The steel mold and the sample are shown in Fig. 4A. The lower part of the sample is made of peat and has a height, H_p. The upper part of the sample is made of sand and has a height, H_s. There is a plate model resting on the surface of the sample. There is a plate half the size of the plate model at each end of the plate model, to illustrate the connection between plates.

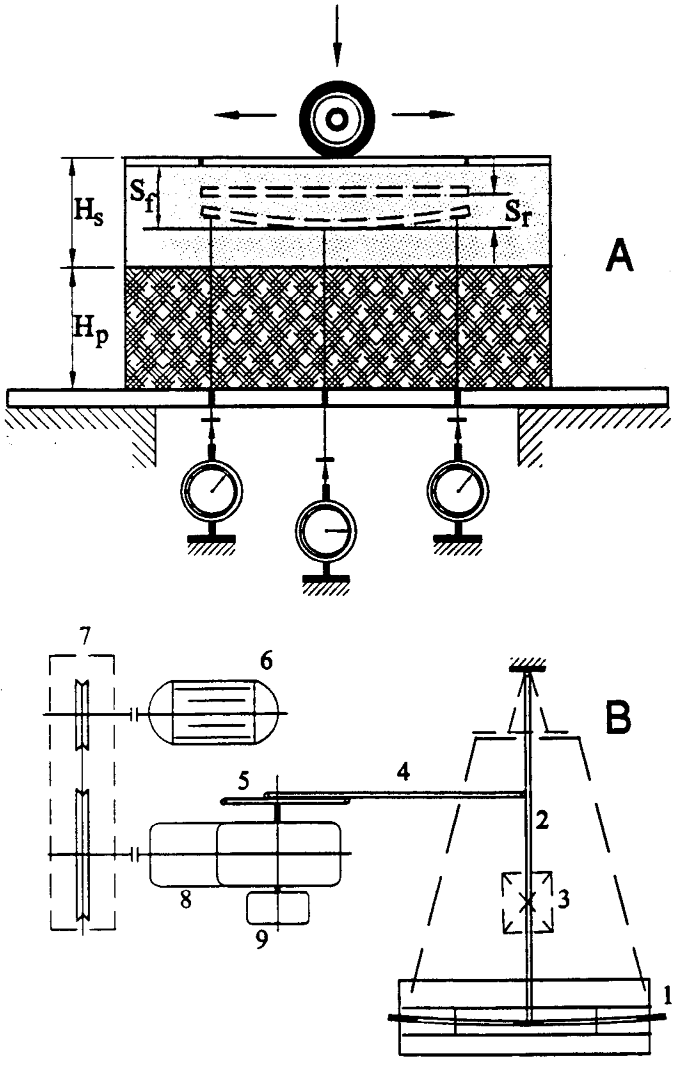


Fig. 4 Loading technique (A) and scheme (B) of laboratory apparatus

1 - Plate model
2 - Sliding arm
3 - Tray for load
4 - Pitman
5 - Eccentric at circular disk
6 - Electrical motor
7 - Speed variator
8 - Wormgear
9 - Revolition counter

Under the plate model there are thin steel rods that go through the mold under the table. The top of the plate of the table was made from steel 25mm thick. There are displacement transducers, fixed under the table, which show a vertical displacement of the rod and the plate model. When loaded by a wheel, the plate model flexes and deflects downward a height, S. The deflection depends upon the complete deformation of the sample. Once the wheel load is removed from the plate model, the plate model and the depressed soil sample expand and try to reach their initial position. The sample plate moves in the opposite direction of the size of the resilient deformation, S_r, that is connected with the resilient deformation of the sample. Since the deformation of a soil is not completely reversible, there is a residual deformation, S_{rd}, of the sample even after the first dynamic load is applied. As a result, the model plate does not come back to its initial position. The residual deformation, S_{rd}, is checked by the displacement transducer and is recorded in a laboratory book.

The above process was repeated for similar dynamic loading. According to the laboratory data, the full and residual deformations are constantly increasing with a gradual decrease. The amount and character of the settlement of the plate model on the soil sample depends upon the kind of soil and size of the sample.

The model of the wheel is a large ball bearing with a rubber tire on the outside. The diameter of the ball bearing is 140mm. The ball bearing is connected to a rod on the inner side of the bearing race. The thread regulates the length of the slide arm and the location of the wheel, which depends upon the position of the plate model on the sample surface.

Figure 4B, presents the experimental apparatus. As can be seen in Fig. 4B, one end of the sliding arm (2) is a hinged joint attached to a fixed support. When the sliding arm turns in the horizontal flat surface around the fixed support on the other end, it circumscribes an arc (or circular bend) of radius R=2250mm over the sample. Traversing along the model of the plate (1), the wheel on the path length of the 300mm wide model plate deviates from axis as much as 2.5mm along the width. At the width of the model plate of 100mm, this deviation is insignificant. The sliding arm has a tray (3) for load. The amount of load is checked by stretching of the dynamometer. To turn the sliding arm, a pitman (4) is attached to the eccentric at the circular disk (5). Each disk rotation corresponds to two wheel rotations over the plate model to the opposite side. The number of turns of the disk is recorded by a revolution counter (9) attached to the opposite side of the wormgear (8). Reduction gear, together with the electric motor (6), is attached to the speed variater (7), which adjusts the speed of the wheel.

Experiments of deformation of peat samples of 100mm, 200mm and 300mm in height with a different range of density and samples of fine sand placed directly on the peat soil were performed under an equal regime of dynamic loads 20 to 22 cycles per minute. Under this regime, the average speed of the wheel was 550mm/s, which equals a traffic flow separation of 20m, and a velocity range of 20 km/hour. Over 300 tests were performed.

In the laboratory, different undisturbed soils were used, with water contents ranging between 463%-940%, dry densities ranging from 94 kg/m^3 to 185 kg/m^3, fiber contents between 15 and 45%, and ash contents between 4 and 20%. Each test was conducted for approximately 60 minutes, which corresponds 1200 dynamic loads over the plate model. Some tests were performed using 4000 dynamic loads. During each test, the full and residual deformations were recorded after 1, 2, 5, 10, 50, 100, etc., dynamic loads.

After increasing the number of dynamic loads, the full and residual deformation of the soil under the plate model continuously increased, with high initial speed of full deformation gradually dying down in the samples of peat soils. When we tested samples of sand as well as laminated samples (sand between the plate and peat soil), the plate model settled downward into the soil with low intensive damping because the granular structure of the sand is capable of additional packing under dynamic loads, even after significant compaction. Especially perceptible settlement of the plate model downward to the soil was monitored in the tests with laminated samples. The layer of sand flexed considerably under the plate model and increases the possibility for repacking sand grains when the layer of peat soil was compressed. As the full and residual deformation of the soil samples increased, the resilient deformation in the each test remained constant. Figure 5 shows the relation plotting in the test with peat samples, as well as when sand rested on top of the peat soil.

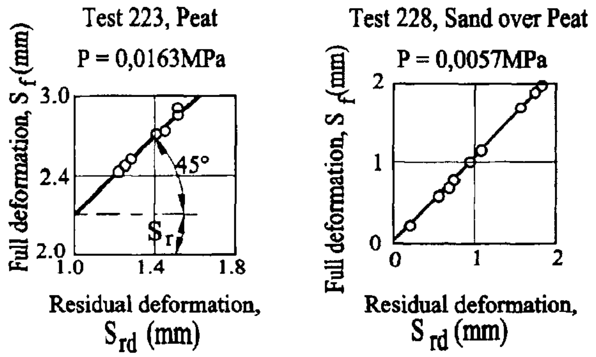


Fig. 5 Relation full and residual deformation

Lines placed under 45 degree angles, which correspond to equal increment full and residual deformation, were plotted for all of tests and for each one date acquisition of resilient deformation under equal conditions of experiments were much larger in the peat sample and smaller in the sand.

Figure 6 shows a comparison of the resilient and full deformation in each test. Line 1 in Fig. 6 is based on the tests of peat soil 300mm in height with different densities.

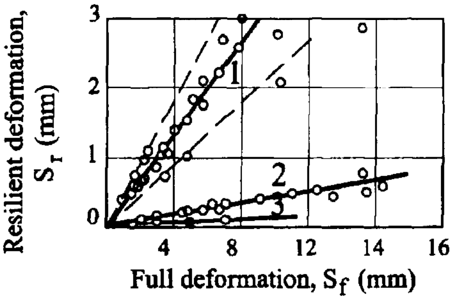


Fig. 6 Relation full and resilient deformation

1 - Peat
2 - Sand over peat
3 - Sand

Results of the tests with higher densities of peat are plotted lower with smaller densities higher (dashed lines). The graph shows that at the end of the tests (after 1,200 dynamic loading), the resilient deformation under the plate model is equal to approximately 1/3 of that for full deformation. Line 3 in Fig. 6 shows that the resilient deformation under the plate model in the samples of sand are equal to about 0.5% of the full deformation. This is ten times less than in the samples of peat soil.

In the laminated samples with sand above peat soil, the resilient deformation decreased in comparison to the peat samples, but increased in comparison to the resilient deformation in the samples from sand. In line 2, plotted results of tests with different peat soil 300mm thick under a layer of sand 75mm thick. Relation resilient deformation from full deformation in the tests was eight times smaller than in the tests with peat samples and eight times larger than in tests with sand. In the laminated samples, relations of resilient deformation as a portion of full deformation are constant and do not depend on the density of peat soil. In the peat samples, the density has a visible effect on the magnitude of relation resilient and full deformation. The tests show that in the laminated samples, there is greater effect on the magnitude of the relationship between resilient deformation and the full deformation impact size of layers and does not affect density of soil.

Figure 7 shows the decreases in full and resilient deformation that were monitored in the tests of peat soil with various densities. Each curve represents equal dynamic loads. When samples from peat soils with two times higher density were tested, the resilient deformation decreased by four times. Under the same conditions, the full deformation decreased by four times of that occurring only under small dynamic loads (170N).

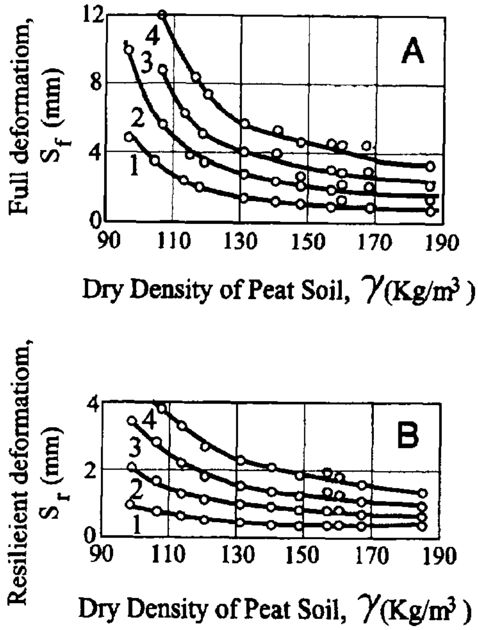


Fig. 7 Full (A) and resilient (B) deformation versus the dry density of peat soil

1 - P=170N
2 - P=270N
3 - P=380N
4 - P=490N

Figure 8 shows the influence of dynamic loads on the full (A) and resilient (B) deformation under the plate model. Line 1 shows results of test of peat soil with height of sample equal width of model plate; line 2, samples from sand height equal to 0.75 times width of plate; and line 3, laminated samples from peat with height of sample equal to the width of the model plate and sand with height equal to 0.75 times the width of the plate.

In Fig. 8B, it can be seen that resilient deformation of soil under dynamic loading has a linear relationship with load. Full deformation was more intensive than amount of dynamic load, especially in the sand and laminated samples. Notice the alternation lines in Fig. 8. Samples of peat soil had smaller full deformation and larger resilient deformation. In the samples of sand, resilient deformations were smaller and full deformation larger.

Resilient deformations are dangerous for connections between plates on the extremely resilient peat soil. Magnitude of resilient deformation depends on the density of peat soil, as well as the size of layer of samples.

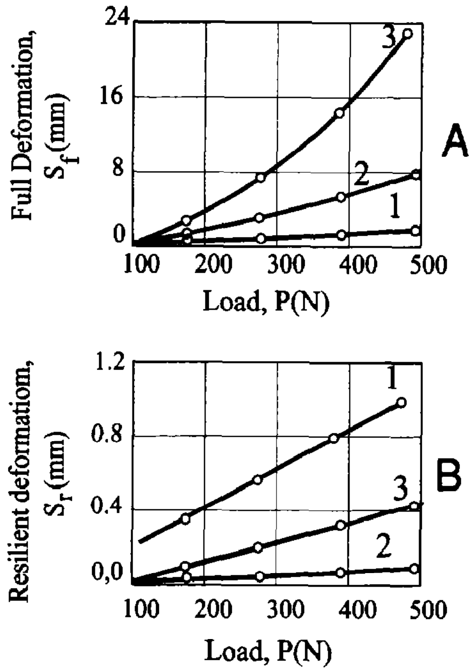


Fig. 8 Full (A) and resilient (B) deformation versus the load

1 - Peat
2 - Sand
3 - Sand over peat

Figure 9 shows character increasing resilient deformation with increased layers of peat and sandy samples, as well as decreasing them when increased layer of sand in the laminated samples. Line 4 is plotted for sand on the rigid base. Resilient deformations of sand are very small, so for convenient comparison, the ordinates of line 4 have been increased ten times.

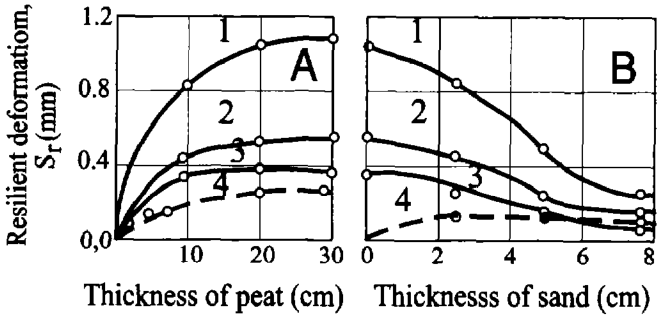


Fig. 9 Resilient deformation as a function of the ratio of the thickness of peat (A) and sand over peat (B)

1 - Peat $\gamma = 95$ Kg/m³
2 - Peat $\gamma = 120$ Kg/m³
3 - Peat $\gamma = 185$ Kg/m³
4 - Sand $\gamma = 1880$ Kg/m³

When the thickness of homogeneous samples in Fig. 9A decreases, the resilient deformation under the plate model decreases, according to the law of damping curve. Deformation of samples with heights of 200mm and 300mm were practically equal.

Figure 9B shows laminated samples with the height of peat soil equal to 300mm, and sand bearing on top of the peat. When the layer of sand was 75mm, the resilient deformation decreased by as much as three to four times, as compared to homogeneous samples of peat.

Characteristically, when the height of homogeneous samples of sand on the rigid base were increased, the resilient deformation under dynamic load is also increased. When some magnitude of sand was placed on top of the peat soil the resilient deformation decreased. It was concluded that there exists some thickness of the layer of sand where peat soil practically does not have influence on the resilient deformation under the plate. Resilient deformation under the ends of the plate was one-and-one-half to two times greater than under the center of plate.

DISCUSSION

The laboratory experiments with dynamic load enable definition of numerical values of the modulus of subgrade reaction of resilient deformation to foundation of the plate for different peat soils by the following formula:

$$K = \frac{P}{S_{av}} \cdot \frac{1}{10A_{p.m.}} \qquad (2)$$

Where S_{av} = average settlement of plate model without taking flexure into account (mm)
$A_{p.m.}$ = supporting area of plate model $A_{p.m.}$= 30,000mm^2
P = load applied (N)

Equation (2) scaled up to the size of the concrete plate on site. When the magnitudes of resilient modulus of subgrade reaction, K, for each kind of peat sample were determined, they were plotted relative to the dry density of peat soil, as shown in Fig. 10. Line 1 in Fig. 10 is based on the results of the plate resting directly on the foundation of peat soil. Lines 2, 3 and 4 correspond to the thickness of sand overlying the base of peat equal to 0.25, 0.5 and 0.75 times the width of plate, respectively.

An empirical relationship was developed to approximate the curves plotted in Fig. 10. Equation 3 shows the dependency of the resilient modulus of subgrade reaction on the dry density of peat soil as follows:

$$K = A\left(\frac{\gamma}{100}\right)^n \qquad (3)$$

K = Modulus of subgrade reaction for resilient deformation, MP a/m
A = parameter numerically equal to modulus of subgrade reaction for peat soil with dry density γ = 100 kg/m^3 (applied for resilient deformation)
n = an empirical exponent characterizing the variation of modulus of resilient reaction when the dry density of peat soil changed.

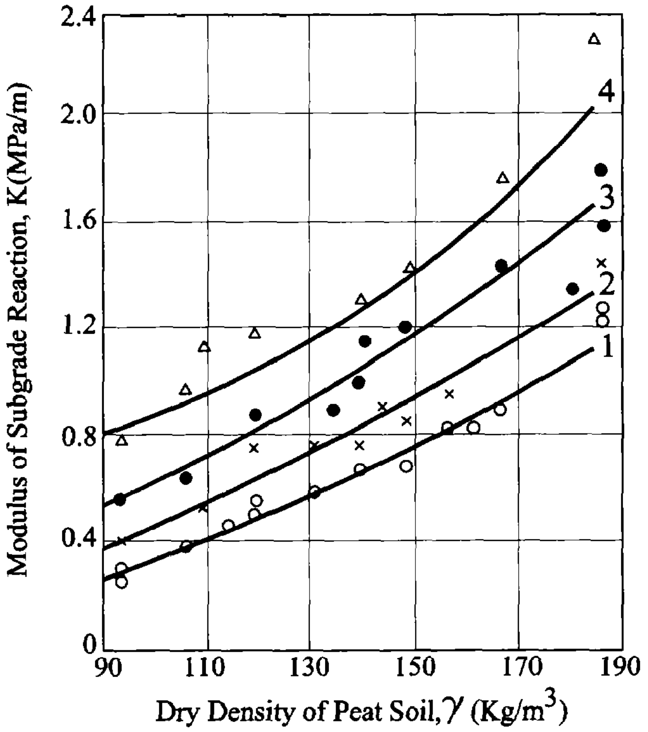


Fig. 10 Resilient modulus of subgrade reaction versus the dry density of peat soil from laboratory model tests

1 ○ - Without sand fill
2 × - Sand fill on peat soil 0.25 Wp
3 ● - Sand fill on peat soil 0.50 Wp
4 △ - Sand fill on peat soil 0.75 Wp
Wp - Width of plate

The parameters of equation (2) defined by least square method, are represented in Table 1. These are based on laboratory data

Table 1. Parameters A and n in equation (3).

Ratio of Thickness of Sand on Peat Soil to Width of Plate	Value of Parameters for Computing Resilient Modulus of Subgrade Reaction	
	A	n
0.00	0.33	2.00
0.25	0.45	1.75
0.5	0.61	1.6
0.75	0.9	1.3

Comparison of the field and laboratory data shows their distinguishing difference. The field tests with dynamic load under a plate (3m by 1m by 0.15m) were used as a standard of comparison of analogous laboratory tests. The approximation to the laboratory tests is not exact. This difference was taken into account by a correction factor. The resulting correction to equation (2) to make it applicable to field loading directly on peat soils is:

$$K = 3A\left(\frac{\gamma}{100}\right)^n \qquad (4)$$

When there is sand between the loaded plate and the peat soil, the equation becomes:

$$K = 4A\left(\frac{\gamma}{100}\right)^n \qquad (5)$$

CONCLUSION

The following detailed conclusions may be drawn from the work report:

1. Resilient deformation of the peat soil is ten times higher than the plate resting on the sand soil.

2. Resilient deformation of peat soil under dynamic loading has a linear relationship with load and does not depend on the number of dynamic loads.

3. Sand on the peat soil sufficiently decreased the value of resilient deformation under dynamic load. Minimum effective thickness of layer of sand is equal to 0.3 to 0.5 times the width of plate. Smaller layers of sand do not decrease resilient deformation of road construction. Higher layers of sand require additional construction costs and do not significantly decrease resilient deformation.

4. Deformation of the peat soil under the concrete plate, and after applying a dynamic load, is larger under the front end of the plate than under the center and outgoing ends of the plate.

5. An empirical relationship has been developed to determine the resilient modulus of subgrade reaction based on the dry density of peat soil.

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