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Laboratory experimental research of tension piles performance under horizontal load action

S. Yesakova
Kharkiv National University of Civil Engineering and Architecture, Kharkiv, Ukraine

1 Main tasks of the experimental research

The main task of the experimental research was to identify the peculiarities of piles performance with a horizontal load and to determine the pattern of contact strains distribution as well as deformations of pile shafts of various rigidities.

The methodology of the experiments was created taking into consideration the studies of strained and deformed state of "horizontally loaded pile – soil" system. In order to achieve that, the shift of pile body was measured during the loading, at the surface of the soil and at various depths. Contact pressures were measured simultaneously.

Various cross-sections and immersion depths of piles were adopted for the tests. The choice of such dimensions of piles allowed to obtain both qualitative and quantitative picture of stressed and deformed state changing of the system being studied. The adopted immersion depths allowed to classify the piles tested into both short (rigid) and flexible categories, which are often used in the modern construction practices.

The experimental research was carried out both with the lateral force applied at the level of soil surface and with the simulation of combined action of bending moment and horizontal force.

2 The samples of experimental piles and test equipment

With the purpose to obtain the experimental results according to the stated topic, two welded metallic trays 500x520x100 mm and 750x730x100 mm were made

from a metal sheet of 1.5 mm thickness, and two metal corners with retractable frontal wall were made from 4 mm thickness molded poly-carbonate and 6 mm thickness acrylic for 555, 600, and 750 mm long piles.
Standard metal weights weighing 50; 100; 200; 500; 1000 (g) were used for the loading of the piles.
Horizontal forces were transferred to piles heads from a set of weights vertically hanging down, with the help of rigid metal L-shaped pivot levers with the ratios of short and long lever parts 1:7 and 1:10.
The actual horizontal forces applied at piles heads by the vertically hanging weights were determined with the help of strain dynamo-meters built into flexible horizontal couplings between pile and levers and were transmitted to processor's light board (Fig. 1.) continuously throughout the entire period of each experiment.

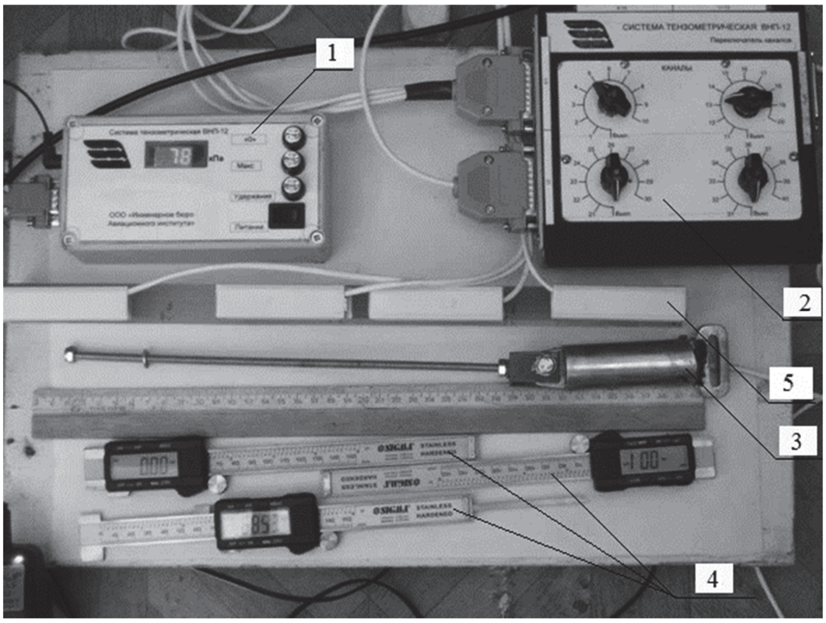

Fig. 1: Test equipment for shift measurements
1 – processor with light display; 2 – switchboard; 3 – dynamometer; 4 – electronic micrometer with indicator; 5 – pile with sensors of 2nd type

2.1 Piles

The piles were made of molded poly-carbonate possessing sufficiently high durability and deformation properties, to the same degree as reinforced concrete. The number of piles: 4 pieces. Dimensions: 555x30x24 mm; 555x40x24 mm; 600x30x20 mm; 750x30x24 mm.
The main physical and mechanical characteristics of poly-carbonate material validated by Quality Certificate:

- density - 1.3-1.5 g/cm3 ;
- stretching strength (GOST 11262-80) – 60-67 MPa
- modulus of elasticity during stretching: at least (GOST 11262-80) – 2000 MPa;

- elongation during breaking, at least (GOST 11262-80) – 30%;
- water absorption, % by weight; no more than (GOST 650-80) – 0.37.

2.2 Soil

In all the test the same sand was used: from the Bezludovskiy sand quarry, Kharkiv Region (Ukraine), γ=1,41 g/cm^3 , φ=33°.
The physical and mechanical characteristics of the soil were determined in the Certified Soil Laboratory of the Ukrainian State Institute NIINTIZ according to the standard methodologies.

2.3. Testing and measurement instruments (Fig. 2)

For continuous measurement of the actual horizontal forces affecting piles heads during the experiments, a strain dynamo-meter with measurement range 1- 150 kg was installed between the metallic grip of a pile head and the weight lever of the loading system. The maximum measurement error guaranteed by the manufacturer is 0.5 % with 100 kg force.

To measure the horizontal shifting, metallic bushings were welded into the side panels of trays, with hole diameters 2 mm. Metallic rods were installed through the bushings to reach the side surface of a pile. Rod lengths - 100-150 mm. In the process of the experiments the values of horizontal rod shifting were measured (Yesakova 2011).

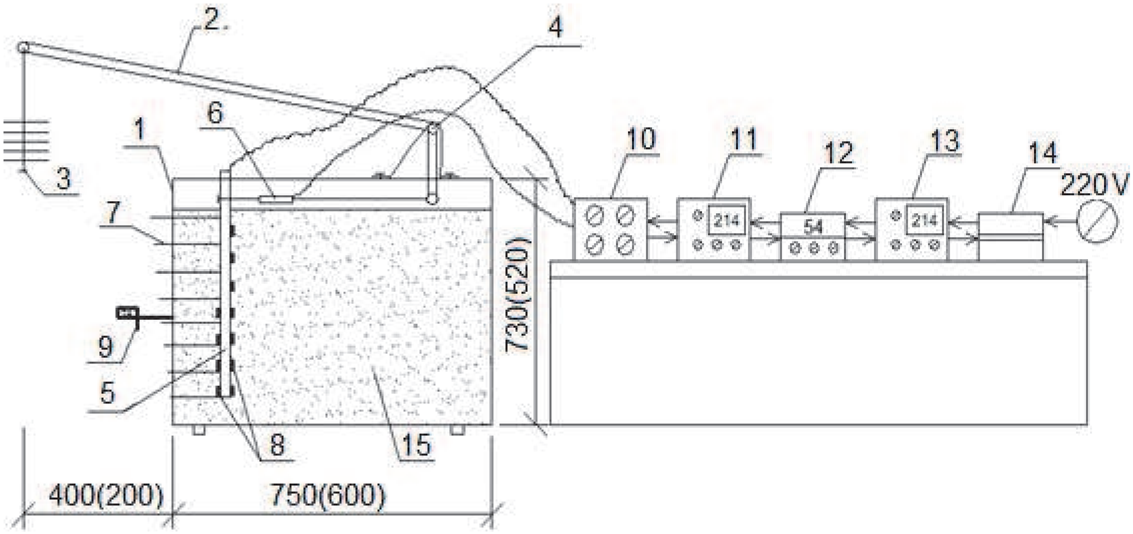

Fig. 2: Diagram of mechanical equipment and measuring devices
1 – metallic tray with frontal wall made of acrylic/poly-carbonate; 2 – L-shaped metallic pivot lever; 3 – flexible coupling with set of weights; 4 – hinge; 5 – pile; 6 – dynamo-meter in the flexible coupling; 7 – rods for shift measurements; 8 – pressure sensors; 9 – electronic micrometer with the indicator for shift

measurement; 10 – switchboard; 11 – processor with light display; 12 – stopwatch; 13 – duplicating processor; 14 – transformer 220/6V; 15 – fine-grained sand

The measurement of horizontal shifts of the rods (shift sensors) was determined by three electronic indicators (micrometers) made by “Sigma” company. The error of these instruments that is guaranteed, according to the manufacturer is 0.02 mm, i.e. with the shift ranging 3-30 mm it was no more than 0.5 %.
Before each experiment, all the instruments were checked with a metrological set of standardized weights and gauges.
The measurement of pressure values that emerge at the contact “pile-soil” was accomplished with the help of strain gauge sensors (Fig. 1.4) that were designed, manufactured and mounted at the piles by the experts from “Engineering Bureau of Aviation Institute” Ltd., Dr.Tech.Sc. Professor I. Luchkovskiy taking active part in the process.
The pressure sensors are the plates made of flexible stainless steel. Their material and dimensions were determined for a possible maximum soil pressure, the permissible deformations of strain gauges, non-accumulation of residual deformations in the plates after the load, whereas the value of their bending is no more than 2.5 mm. One end of these plates is rigidly fixed in piles’ hollows, and platforms protruding 1.5-2 mm over the loaded surfaces of piles (first piles type) are rigidly attached to the other end (Fig. 3, 4).
With the sensors at the rear plane of piles (Fig. 3) (the 2nd type of piles), the forces from the soil at the metallic deformed plates of pressure sensors attached at non-loaded surfaces of piles are transferred through the metallic platforms that are rigidly connected to metallic rods that can freely move within a pile body.
All the experiments were conducted using two types of sensors on the piles. However, more stable results were obtained during the process of experiments with piles with pressure sensors of the 2st type, which were positioned directly at the planes that are being loaded

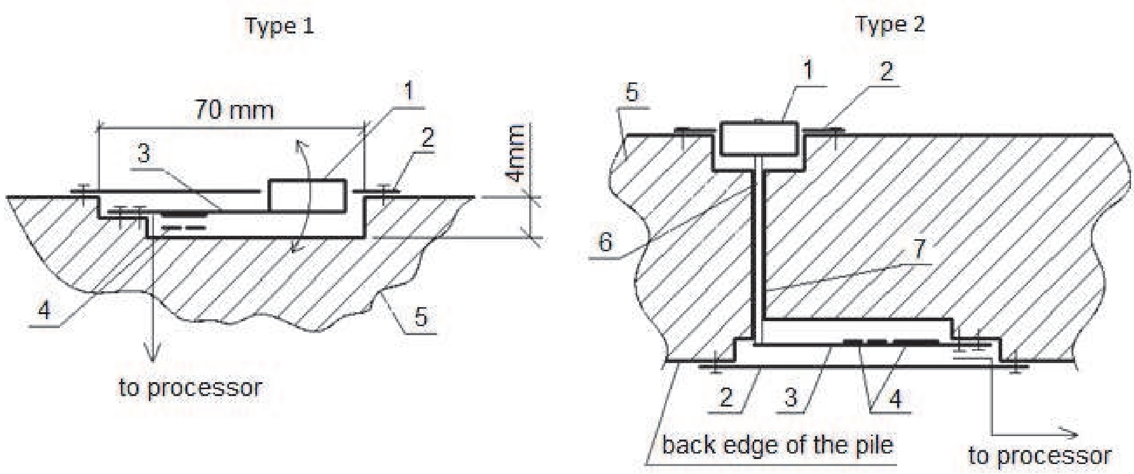

Fig. 3: Pressure sensors design

1 – Pressure sensor platform; 2 – sensor housing; 3 - plate made of stainless steel, 68x7x1.1 or 68x5x1 (mm); 4 – strain gauge with set of resistances; 5 – pile body; 6 – rod; 7 – epoxy lubricant

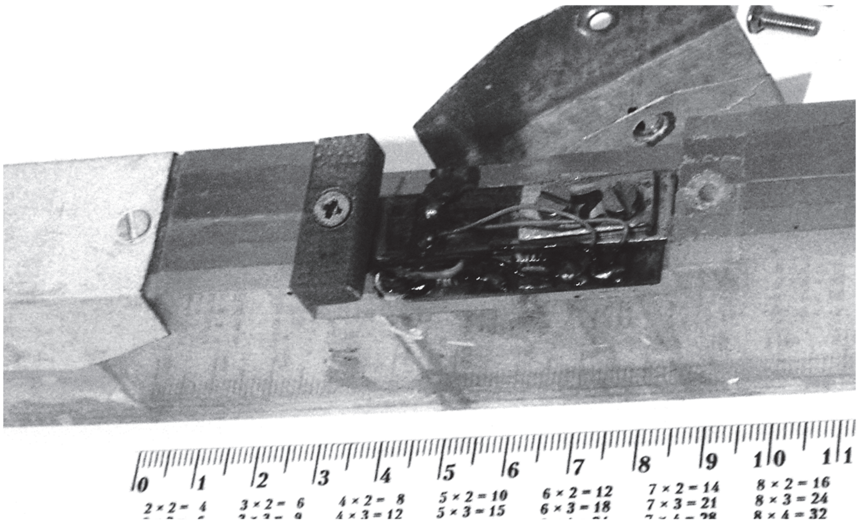

Fig. 4: Pressure sensor without its housing

At the lower side of the metallic plates of pressure sensors that work as a console, on a gasket made of heat-resistant paper imbued with phenol glue UVS-10T, strain gauges KF5P1 R-200 Ohm (Certificate UA.C.28.999 AN19997) that have limit of resistance deviation ±1 %, maximum measured deformation ±3000 μm/m, and operating temperature range -70° C… +200° C, were attached with the same glue and with subsequent thermal treatment.
As receivers of electrical signals from strain gauges and for conversion of these signals into light signals, the microprocessors VNP-12 (“Engineering Bureau of Aviation Institute” Ltd.) were used. They allow to convert electrical signals of strain gauges into digital signals shown at the light board directly in kPa for each sensor.
With the view of alignment of parameters of strain gauges and receivers of their signals (microprocessors) and the ease of use of this pair of instruments, for every sensor its own resistor was selected experimentally and subsequently attached under the steel deformable plates of each sensor.
For the ease of use of the pair of instruments sensor-receiver, a 48-channel switchboard (channel switch) was introduced into the electrical circuit. It allows to receive information from the dynamometer and from any pressure sensor at any time during the experiments.
All the instruments are connected to an uninterruptible power supply with the voltage 6V (Fig. 2).

3 Carrying out an experiment

The tray was filled with the soil layer by layer, evenly, by layers of 2-3 cm thickness over the whole area of the box, using a funnel (Fig. 5a)

The readings of all the sensors were recorded in a register, from the very beginning of the loading on the pile load system (Fig. 5b) until the end of the experiment and the process of unloading.

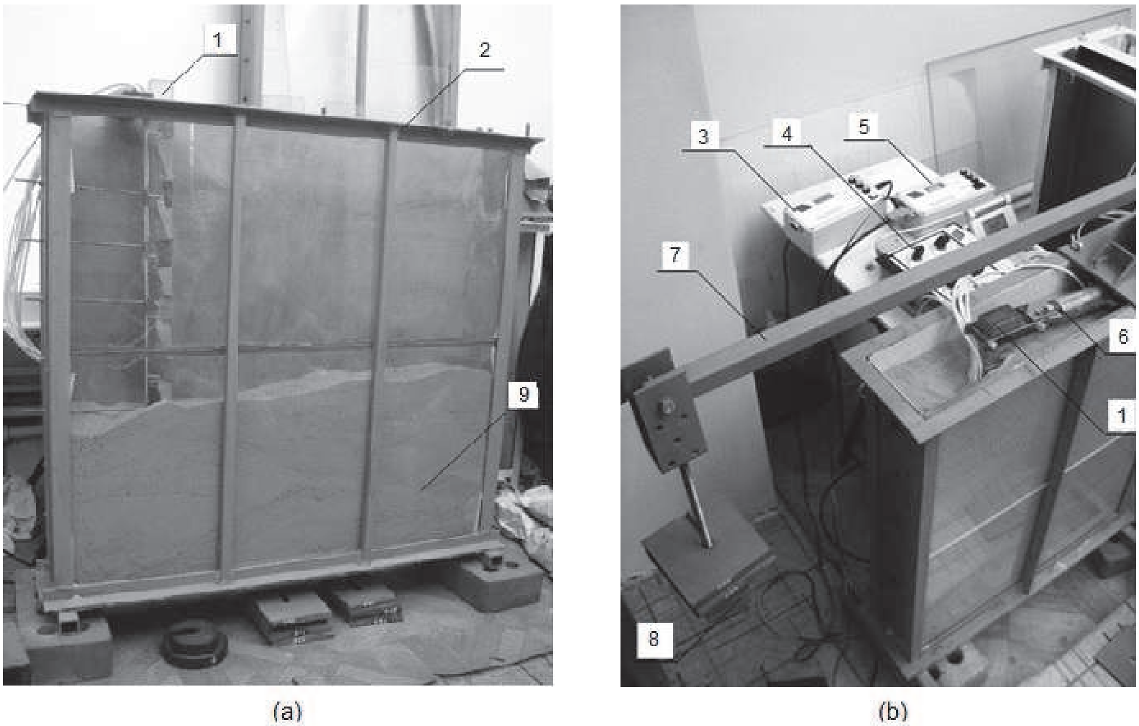

Fig. 5: View on the pile during the process of filling in the container with the soil (a) and view on the installation during the process of loading (b)

1 – pile; 2 – metallic tray with frontal wall made of acrylic/polycarbonate; 3 – processor No. 1; 4 – switchboard, 5 – processor No. 2; 6 – dynamometer; 7 – lever; 8 – weight hanging from the flexible coupling; 9 – sand soil

4 Results of the experiments

Charts of the movement of the head of the pile $y_0=f(Q)$, distributions of horizontal shifts $y_z=f(Q)$, soil response $\sigma_z=f(Q)$, in the function of external load for a horizontally loaded pile having dimensions 555x40x24 mm are shown in Fig. 6. These piles are included into the category of rigid (short) piles.

The same relationships for piles with dimensions 555x30x24 mm are shown at Fig. 7. These piles are flexible.

Models of piles with various boundary conditions were tested. A pile with a support situated 100 mm above the soil surface, the load being applied at the soil surface level, is represented in Fig. 8. Therefore, it is possible to test a pile under the shared action of a bending moment and a horizontal force. Piles dimensions are 600x30x24 mm.

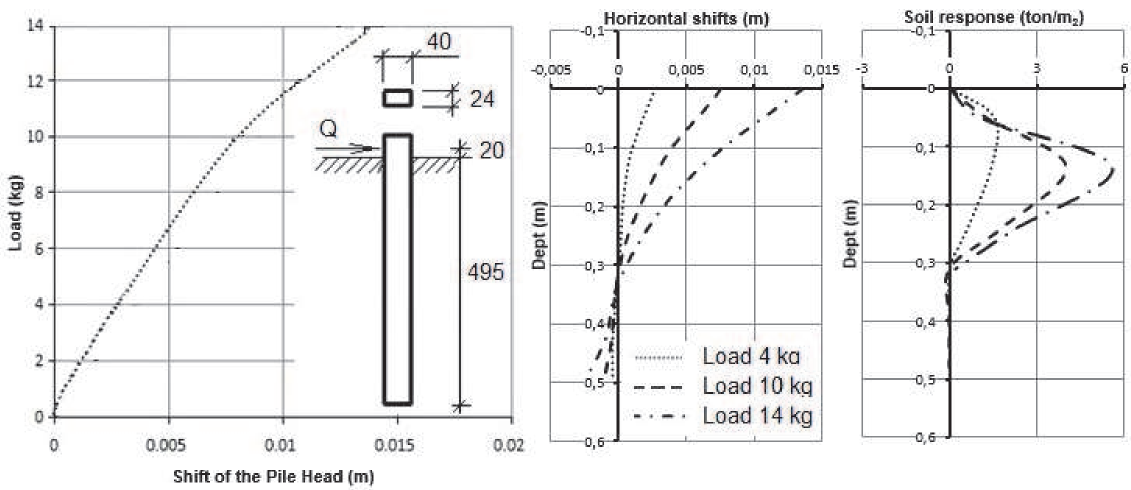

Fig. 6: Experimental data of the pile size 555x40x24 mm

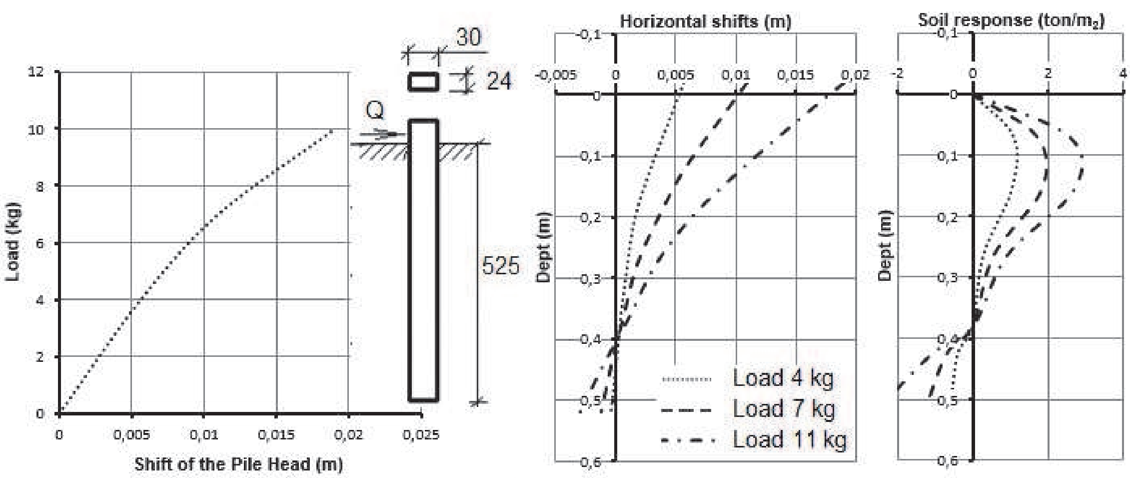

Fig. 7: Experimental data of the pile size 555x30x24 mm

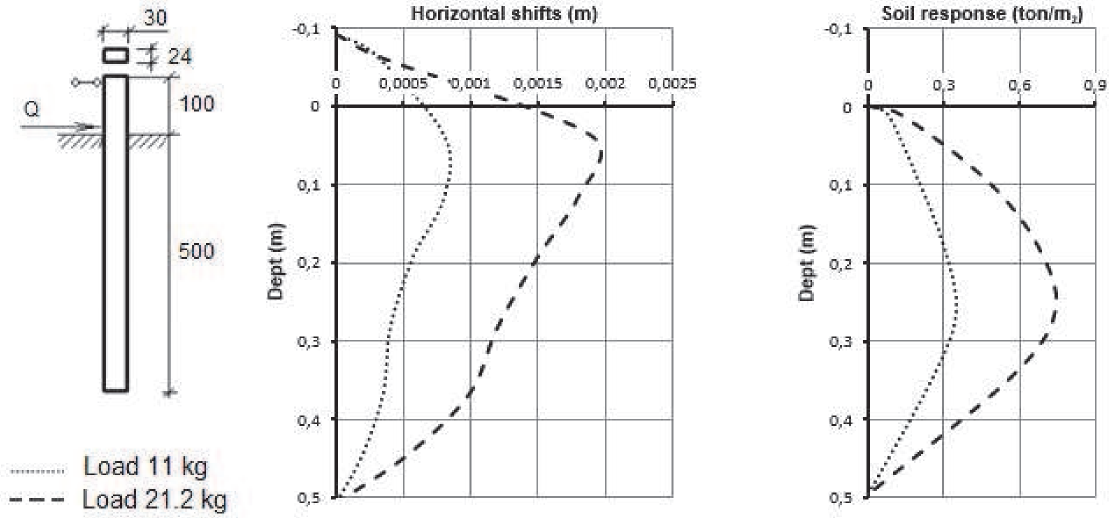

Fig. 8: Experimental data of the pile size 600x30x24 mm

5 Conclusions

During the experiments, in the process of loading, we were measuring the shifts of a pile body at the level of soil surface and at various depths, and we were determining the values of contact pressures. In the processing of the experiments and some of the full-scale tests data available Luchkovskiy & Lekumovich (1971), it has been noticed that the distribution of the base stiffness coefficient along the depth did not always correspond to the linear dependence, as it was generally understood. In many cases the pattern of the stiffness coefficient distribution along the depth could be described with these dependence: trapezoidal, exponential, or power law (Fig. 9), whereas the distribution diagram can have either concave or convex shape, depending on a soil type.

In the case of strong soils, the stiffness coefficient distribution diagram usually has a convex shape wherein the maximum value is assumed to be close to the soil surface and is left unchanged along the depth. Conversely, in weak soils the distribution diagram has a concave outline, wherein the values of stiffness coefficient along the depth increase insignificantly and reach their maximum at the lower end of a pile (Luchkovskiy & Yesakova 2014).

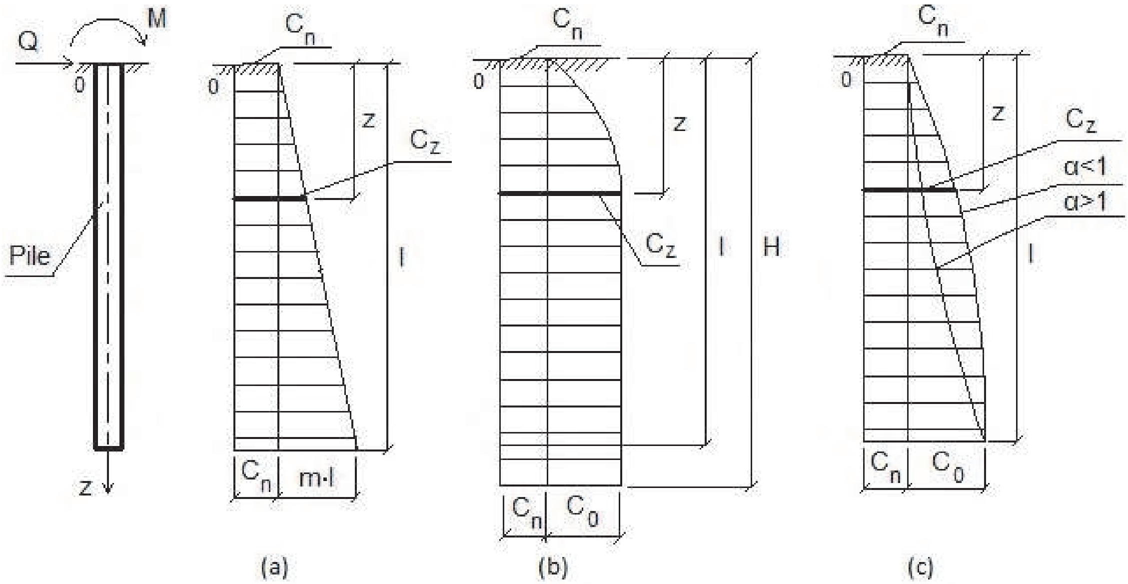

Fig. 9: Distribution of the soil stiffness coefficient over the depth of the pile:

a – trapezoidal, $C_z = C_n + m \cdot z$;

b – exponential, $C_z = C_0 \cdot \left[C_n / C_0 + \left(1 - e^{-\alpha \cdot \bar{z}}\right) \right]$;

c - power law $C_z = C_0 \cdot \left[C_n / C_0 + \left(z/l \right)^{\alpha} \right]$

The experimental data obtained help to expand the current knowledge and to adequately examine the parameters of soil base model wherein a pile works under a horizontal load and a bending moment. The research was carried out for the deformation and bearing capacity of a "pile-soil" system for sand soils. Long piles and piles of ultimate rigidity were considered

6 Literature

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