Loads acting on the equipment’s destructive elements for removing the reinforced concrete piles’ ends

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Abstract. Cutting off the reinforced concrete piles’ column heads is an important technological operation in the pile foundation construction. High-quality reinforced concrete piles column heads cutting should be performed at a given mark, without cracking concrete below the cut level. At the same time, reinforcing rods of the pile together with concrete are not removed. The rational equipment design for cutting the reinforced concrete piles’ column heads is complicated by the lack of information on the required forces developing on the working body of the machine. The theoretical justification of these forces is not possible, due to the lack of appropriate guidelines. To this end, the article presents the experimental studies’ results to determine the loads on cutting elements when cutting a reinforced concrete pile of square cross section. The experimental work technique is described, the conclusions of the study are presented.

1. Introduction
Cutting off the column head of a reinforced concrete pile is an operation that is necessary to erect a correct and safe foundation design. A part of the concrete reinforced concrete piles located above the soil surface is removed with special equipment. At the same time, in accordance with the requirements, the vertical reinforcing rods of the pile are not removed, but, as a result, are associated with reinforcing the grillage [1]. Pile cracking below the mark is not allowed [2], and the deviation from the cut flatness should not exceed a predetermined level [3]. It is quite difficult to provide all these requirements at the same time. The situation is complicated by a wide variety of the reinforced concrete piles’ designs and sizes, the use of concrete with different strengths, the use of different sections’ reinforcing elements, strength and location inside the pile body.

Currently, there is a large constructive variety of various types of equipment for cutting reinforced concrete piles, however, almost all of them use the static destruction method of concrete when pressing the cutting elements into the material. Unfortunately, there is currently no generally accepted methodology for calculating such equipment. Among the worthy works, one can single out the experience of creating equipment for removing sheath reinforced concrete piles and round piles [4], however, the results of this work allow only a qualitative determination of the design of certain equipment elements without the possibility of substantiating such parameters as the resistance to destruction of piles, the destruction elements’ rational design and the required stroke.

2. The problem statement
Reinforced concrete pile is a complex composite material [5] with the oriented reinforcing elements’ placement [6]. The main parameter allowing to create the rational equipment designs for removing the column heads of reinforced concrete piles is the magnitude of the force concentrated on the destructive element. This force depends on the design of the destructive element, the strength characteristics of concrete, the structure of the pile reinforcement, the cut column head’s height and, of course, the size of the pile. The model describing the column head fracture workflow should take into account all of the above-mentioned indicators.

Let us turn to the pile column head destruction mechanism (Figure 1). When the teeth act on the column head of a reinforced concrete pile as a result of contact interaction, the material is deformed with a seal in the contact zone. At the same time, a stresses field of different magnitude and direction develops in the pile body. In areas of high tensile stresses local cracks occur. In the place of the initial tooth contact, a stress concentrator is formed, which also contributes to the local cracks’ development. Further, these cracks grow, uniting into large main cracks. In consequence, the pile column head breaks off.

![Figure 1](image)

**Figure 1.** cutting the column head of a reinforced concrete pile: a - general view, b - tooth penetration into the material, c - formation of local cracks, d - formation of large main cracks with the column head separation

In order to predict the resistance forces to the tip destruction, it is necessary to compare each described process with a mathematical model.

The concrete contact compression with the stress concentrator formation solves the problems of contact interaction of elastic [7] and elastic plastic materials [8]. To assess stresses, numerical solutions based on the finite element method can be used in the material body [9]. This method can also be used to predict crack growth. [10], however, experimental [11] and experimental analytical [12] approaches are more valuable.

However, it should be assumed in advance that the accuracy of such a calculation will not be high. The final accuracy is affected by the strength characteristics heterogeneity fracture toughness and the elastic modulus of concrete, the lack of data on verification of results obtained by numerical methods with experiment and the very fact of replacing a real object with a model consisting of several processes. Taking the above-mentioned into consideration, the equipment parameters’ justification requires the use of approaches based on a combination of experimental and analytical methods.
3. The experimental research methods
A field experiment was carried out at a construction site of the urban development. During the experiment, a promising model of equipment for cutting the reinforced concrete piles was used. A distinctive feature of the equipment is the ability to cut the piles to the ground level [13]. This feature provides an inclined arrangement of hydraulic cylinders with respect to the frame base plane. The equipment was installed on the Volvo BL-71 excavator (Figures 2, 3). The force concentrated on the destructive elements was determined from the pressure sensor (Figure 4) installed in front of the piston cavity of the hydraulic cylinder in the high-pressure line. From a pressure sensor with a built-in amplifier, the readings were transmitted to a spectrum analyzer ZET 017-U8 and then the data was recorded on a PC hard disk (Figure 5).

![Reinforced concrete pile column head shearing equipment mounted on the Volvo BL-71 excavator](image1)

Figure 2. Reinforced concrete pile column head shearing equipment mounted on the Volvo BL-71 excavator
Figure 3. Complete cutting of the reinforced concrete pile column head to the ground level

During the work, the column heads of square piles with a width of 300 mm were removed [14]. Reinforcement with vertical steel reinforcing bars with a diameter of 16 mm with a periodic profile was carried out at the section angles. During the experiment, column heads of various heights from 100 to 200 mm were removed. Cutting off the higher column heads could lead to the vertical reinforcing bars’ breakage, which is not permissible by the existing requirements.

Since all the data was recorded during the equipment operation at the facility, it was possible to obtain the results with a repetition rate at various points more than five times.

Cutting force was determined from the ratio:

\[ F = 0.25 \cdot \pi \cdot D^2 \cdot (p_1 - p_0); \]  

where, \( p_1 \) – is the measured pressure at the current moment of the equipment operation; \( p_0 \) – is the pressure at the initial moment of the hydraulic cylinder rods extension; \( D \) – is the hydraulic piston diameter.

The specified equipment is equipped with hydraulic cylinders with piston diameters of 125 mm.

Figure 4. Pressure sensor installed in front of the piston cavity of the equipment hydraulic cylinders

Figure 5. Measuring and recording systems
4. Results
Recording pressure values during each cutting of the tip is an oscillogram in which several characteristic zones take place (Figure 6).

In the first zone, the pressure corresponds to the closed valve spools of the excavator’s hydraulic system. In this case the pressure corresponds to the pressure in the drain line of the excavator hydraulic system.

Zone 2 corresponds to the moment of the equipment teeth extension until the stop in the body of the pile to be cut. Characteristic surges are caused by friction when extending the hydraulic cylinder rods.

After the teeth stop in the pile material, the pressure in the hydraulic system increases. Simultaneously, internal stresses develop in reinforced concrete with subsequent destruction of the material. This zone is characterized by a fairly rapid increase in pressure in the piston cavities of the hydraulic cylinders. The peak of zone 3 on the graph corresponds to the force necessary for the formation of large main cracks and the subsequent destruction of the pile element.

In zone 4, the concrete base is separated from the reinforcement, and in zone 5, concrete is disrupted in the form of a separate piece from the transverse reinforcing elements.

In zone 5 of the graph, the safety valve of the hydraulic system of the excavator is triggered.

By the points in zone 3 of the graph, it is possible to calculate the necessary effort to cut the column heads. Depending on the cut column head height, the values of these forces change. Many of the values obtained are shown in the graph (Figure 7). These values in the field of the experiment can be characterized by a linear dependence:

\[ F = 0.2253 \cdot h + 142.3; \]  
(2)

where \( h \) – is the column head height.

Figure 6. Schedule of pressure changes in the piston cavity of hydraulic cylinders of equipment for cutting pile column heads

The confidence coefficient of the approximating function is: \( R^2 = 0.522. \)

The graph does not take into account the results of cutting column heads with partial destruction from the pile driving plant’s impacts.
It should be noted that the described equipment fully provides the necessary quality of cutting. Cracking of the pile below the cut mark was not noted.

All work was carried out on piles of one manufacturer from one shipped batch. The same model of the base machine was used during the work.

5. Summary

Prediction of forces on the destructive elements of equipment for the reinforced concrete products’ destruction has so far been carried out by empirical methods. This approach requires asking a sufficiently large margin for ongoing efforts. As the results of the experiment showed, the real forces on the destructive element of the equipment for cutting the column heads of reinforced concrete piles are almost three times lower than those that could potentially be realized with the same equipment. The lack of a calculation method leads to the fact that manufacturers are forced to increase the metal consumption and select more expensive actuators for the hydraulic drive in order to guarantee the availability.

The results obtained make it possible to create the new models of equipment for cutting the reinforced concrete piles of square section with a width of 300 mm with reduced metal consumption, the cost of hydraulic equipment and, accordingly, the total cost. This, in turn, will allow the use of smaller excavators as the base machine, which will also reduce the operating costs.

![Figure 7](image)

**Figure 7.** The dependence of the force required for the destruction of the pile column head depending on the height of the cut column head

Attention is drawn to a rather large scatter of the forces values on the destructive elements depending on the column head’s height. A low coefficient of the linear function approximation reliability a indicates this. The spread of the fracture resistance forces is caused by the high heterogeneity of the strength characteristics of concrete along the pile body. Therefore, prediction of loads on destructive elements of equipment for cutting piles can be carried out with a certain error.

Unfortunately, these results do not allow predicting the loads on other types of reinforced concrete piles, but they can be useful data for assessing the adequacy of mathematical models that may appear with the development of the theory of the reinforced concrete products destruction.

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