

# Step fixings of vertical trench walls to prevent ground failure

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**Abstract.** The most commonly used designs for securing vertical walls of trenches and excavations in the actual conditions of work in them do not allow for strict compliance with regulatory safety requirements. To prevent ground failure in trenches and excavations, you can develop ground with a slope angle smaller than the natural slope angle. Development of excavations with vertical walls without securing them is limited to their depth depending on the strength properties of the ground. When excavating to a depth of up to 2-3 m the vertical walls of trenches and excavations must be secured. In this case, the development and backfilling of such excavations should be carried out using constructive solutions (e.g. anchoring), which in original combinations with modern construction materials and technologies allow various construction works to be safely performed in them.

**Keywords:** safety of construction works, fixing of trench walls and excavations, stability, ground failure.

## 1 Introduction

Any type of construction and installation work on new construction sites, as well as the overhaul of existing properties has a rather high level of danger and injury [1-5], which can be both potential probabilistic and real [6-10]. The prevention of accidents during excavation and zero cycle works in trenches and excavations is an important and difficult, but quite solvable task at construction and repair sites. One of the main serious and accidentally dangerous situations is the fall of slopes or vertical walls of the ground [11-14].

To prevent ground failures in excavations and trenches, excavation with slopes or installation of vertical excavation wall supports must be performed in accordance with applicable safety standards. In addition, for safety reasons, deep excavations can be excavated with stepped benches (without securing the vertical walls) as is done, for example, in road construction.

The Federal Law No 384-FL «Technical Regulations on the Safety of Buildings and Structures» adopted on December 30, 2009 in the Russian Federation regulates the necessity of safety provision for all buildings and structures at all the stages of their life cycle, including both their construction and repair and construction works during their

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overhaul and restoration. The achievement of these goals is facilitated by the performance of a comprehensive qualitative examination of the building structures, monitoring of their technical condition, the construction equipment selected for use [15-18], and the preparation of all required project documentation [19, 20].

This study is also carried out to improve the traditionally used design solutions of devices for strengthening the vertical walls of trenches and excavations, in which construction and repair-construction work should be carried out taking into account the requirements of safety standards.

At the first stage of the research, an informational and analytical review of the new buildings construction in the constricted environment of the historically established urban development was made. When reconstructing the three-storey Shamovskaya Hospital (built in the first decade of the 20th century), the experience of similar structures construction in Kazan was considered. At the same time an underground four-storey extension was built. Under it, at a distance of 0.5 m from the foundations of the old building, a 20 m deep excavation was developed [21]. In this case, soils and foundations were strengthened for embedding an underground structure. The foundations of the existing building were replanted with a 500 mm thick monolithic reinforced concrete slab. In Kazan, a project was also carried out to ensure the stability of a excavation more than 10 m deep for a single three-level underground parking lot under two 25-storey buildings and the existing 4 and 5-storey buildings in the vicinity [22].

In Rostov-on-Don, a 24-storey residential building with an underground 2-storey parking lot was erected in the immediate vicinity of century-old residential buildings [23].

In St. Petersburg, excavation with dimensions of 59x55 m and depth of 4.8 m was fenced using a sheet pile wall with 12-meter embedding into the ground [24] for the erection of a 16-storey monolithic building. The complex geotechnical engineering and geological ground conditions in the region should not be forgotten.

The article [25] deals with the construction of a 16-storey building 54.8 m high with an underground parking lot. Larsen steel sheet was used to reinforce the walls of a rectangular excavation 4.8 m deep with a penetration depth of 12 m to a firm layer of ground. The sheet pile wall was prevented from horizontal displacement by bracing the corners of the excavation with two strut belts at distances of 4 m and 8 m from the corners of the excavation.

Fencing of a rectangular excavation with dimensions of  $37.6 \times 31.3$  m and a depth of 11.45 m was made in the form of «wall in the ground» 600 mm thick, which is buried below the bottom of the excavation at 6.25 m. The construction object was an 8-story building with a three-level parking lot [26]. Active ground anchors-RIT (discharge-pulse technology) and spacer structures were designed to secure this fence. The RIT ground anchors were installed on two levels, including under the existing buildings built in the 1950s with a foundation depth of 2.1 m.

At the second stage of the study, an informational and analytical review of modern experience in the organization and technology of zero cycle works in the construction and repair of buildings in cramped conditions was performed [27,28]. Cramped conditions at the construction site, as well as cramped conditions in the nearby residential area near this construction site limit the use of powerful modern construction equipment and mechanisms. The perimeter of the future excavation is fitted into the constricted surrounding residential area by burying the sheet piles made of metal pipes, channels or I-beams in the ground. In critical cases, the vertical elements of the circular tubular sheet piling are installed in drilled holes. When the construction site is located close to the existing building foundations with an indent of 1-3 m, bored-injection piles are installed to strengthen the foundations of existing buildings. In special cases, individual piles are driven through the body of the existing foundations. When the zero-cycle works are completed, the sheet piles are

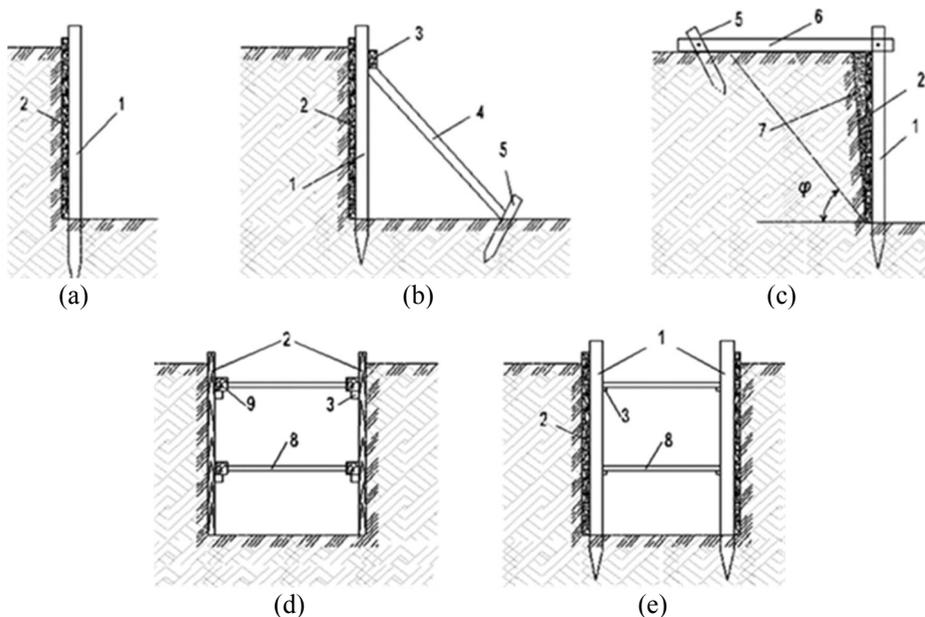
removed from the ground, while the bored piles remain. After the underground part of the building is completed, all the elements of the «wall in the ground» structure remain in the ground. The article [27] also fully describes the technological process of the zero cycle works in the conditions of the existing urban development and provides measures to ensure compliance with safety requirements.

The articles [29-31] analyze some peculiarities of modeling and structural calculations of the «wall in the ground» and assessment of its stability in terms of the quality of this diaphragm wall and ensuring further safe construction.

At the third stage of the study, an informational and analytical review of structural designs of trench and excavation wall supports [32] was performed:

- spacer fastenings (spaced or sloped), complete with wooden enclosing boards or wooden or metal panel structures;
- pile protecting barriers (reinforced concrete piles, steel pipes, plates or profiles) staggered in one or two rows every 0.5 or 1.5 m, filled or unfilled;
- «wall in the ground» used in excavations for underground levels of buildings and structures up to 30-40 m deep
- ground anchors (injected or self-drilling) used to prevent the excavation walls from collapsing;
- portable mesh wire fencing of trench and excavation walls made of high-strength steel wire and pipes for short-term anchoring and for short periods of work;
- sheet piling for fixing the walls of excavations up to 8 m deep in weak water saturated grounds with a high groundwater level. The most common are Larsen sheet piles.

Constructive solutions of fixing the walls of excavations and trenches, their development, the issues of ensuring the safety of work in them are presented in textbooks and other educational and methodological developments on technology and organization of construction and in normative and technical literature.



**Fig. 1.** Fastening of vertical walls of trenches and excavations up to 3-4 m deep (illustration by the authors): a) cantilever; b) strut; c) anchored; d) spacer with vertical bolster; e) spacer with horizontal bolster. 1 – post; 2 – gate; 3 - boss; 4 – strut; 5 – anchor; 6 – tie rod; 7 – backfill; 8 – strut; 9 – support bar.

The main purpose of this study is to ensure the stability of trench and excavation walls. This is achieved by designing them with slopes less than the angle of natural slope. When developing trenches with vertical walls without bracing and with bracing safe depth of excavation (from 1 to 2 m). Without anchoring of vertical walls - depends on the type of ground (cohesive or non-cohesive ground). If the depth of the trench with vertical walls is greater, as well as in case of non-cohesive grounds, it is necessary to arrange their fastening. The figure shows the different structural types of vertical fixing of the walls of trenches and excavations.

The purpose of this study is to develop new structural solutions to strengthen the walls of trenches and excavations to ensure compliance with safety standards when carrying out construction and installation work in these excavations.

## 2 Materials and methods

All types of excavation work performed manually or mechanically must comply with SNiP 12-04-2002 «Safety in Construction. Part 2. Construction Production» and other related regulatory documents. During the soviet period of Russian history, the safety requirements when performing earth works were chronologically contained in construction safety norms: SNiP 54/55, SNiP III-A.11-62, SNiP III-A.11-70 and SNiP III-4-80. It should be noted that the norms of the Soviet period contain more detailed technically developed requirements for the safe performance of works in comparison with the current modern norms.

The author has analyzed regulatory organizational and technological requirements for safe ground development of trenches and excavations to prevent the failure of the walls of grouting excavations.

Development of excavations and trenches with vertical walls without fastenings in soft and unfrozen grounds above the groundwater table and in the absence of nearby underground structures is allowed to a depth of not more than

- 1.0 m - in bulk, sandy and coarse clastic grounds;
- 1.25 m - in sandy loam;
- 1.50 m - in loam and clay.

Development of excavations and trenches with slopes without anchoring in soft grounds above the water table was allowed for strictly permitted depth of excavation and steepness of slopes. To ensure stability of vertical walls of earth excavations up to 3 m deep it is recommended to use inventory vertical supports, as well as supports made according to individual designs.

When installing fasteners its top part must be higher than the excavation edge by at least 0.15 m.

Supports of the fasteners should be installed at least every 1.5 m.

Fastener struts should be placed one above the other vertically at a distance of not more than 1 m, fixing bosses should be fixed to the ends of struts (top and bottom).

In grounds of natural humidity, except for sandy grounds, the thickness of boards should be at least 4 cm, and the gaps between the boards - no more than 0.15 m. In grounds with high humidity and in loose grounds, boards with a thickness of at least 5 cm should be placed without gaps.

Fasteners should be installed in the «top-down» direction as the excavation is developed to a depth of no more than 0.5 m.

Disassembly of fasteners should be performed in the «bottom-up» direction as the excavation is backfilled.

### 3 Results

At present, there are certain developments in the creation of new structural solutions for the vertical walls of trenches and pits of the following combinations:

- ground excavations without fixing the walls of trenches and excavations (with slopes or with a stepped profile) and the use of anchor-type fixings as the most promising to ensure the free production of construction works in trenches and excavations;
- change in the structural and technological application of protective shields designed to absorb vertical lateral loads of the ground on the mountings in use;
- the use of modern light metal sheet multi-profile structures with the creation of easily installed and easily disassembled elements of shield vertical fastenings.

### 4 Discussion

The choice of anchoring is conditioned by the possibility of uninhibited work in the trenches due to the lack of fastening elements of another type, such as spacers.

The analyzed construction objects of the stages of this study should be actually embodied in the original combination of carefully designed design solutions, modern construction materials and construction technologies. In any case, one should strive to develop such designs of fastening of trenches and excavations walls that it would be possible to apply them in any weak grounds. This can be achieved by determining the averaged combinatorial values of strength properties of the weakest grounds.

For further preparation for full-scale studies of the selected structural solutions for strengthening vertical walls of trenches and excavations, it is necessary to carry out preliminary model-experimental computer and full-scale studies for conditions of the formed urban development by analogy with the methods applied in the articles [33-35]).

It should also be noted that the proposed design solutions and technology of fixing the walls of trenches and excavations to a depth of, for example, up to 3 m, have economic feasibility when it is necessary to perform works on the insulation of low-depth energy-efficient foundations [36], as well as when constructing buildings using the additive manufacturing method [37, 38].

### 5. Conclusion

1. To prevent the failure of the walls of trenches and excavations up to 3 m deep, traditional and new structural solutions of fasteners, as well as modern lightweight metal multi-profile and sheet flat elements should be used.
2. It is necessary to develop easily installed and easily disassembled elements of shield vertical fasteners to the racking elements.
3. To ensure the conditions of free construction works in trenches and excavations the most optimal and promising are anchor-type fasteners.
4. Structural and technological solutions proposed for the development of anchorage of vertical walls of trenches and excavations up to 3 m deep in the direction of ground development «top-down», as well as the possibility of disassembly of anchorage «bottom-up» when backfilling the ground will ensure compliance with technological standards requirements of safety standards when performing construction and installation works.

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