Risk Of Retaining Systems For Deep Excavations In Urban Road Infrastructure With Respect To Work Staff Perception

Nikolaos Alamanis, Christos Zografos, Grigorios Papageorgiou, Nikolaos Xafoulis, Chouliaras Ioannis

Abstract: The purpose of this paper is to present trench retainers and to comment on their use in conjunction with the technical staff work. Initially, a general reference is made to the drainage networks and the necessity of their depth of construction while presenting the method of excavation, the preparation of the drainage trenches and any trench wall collapse. Subsequently, a brief presentation of methods and types of retainers is made, mainly bulkheads, based on the material of construction and their geometrical characteristics, while commenting on soil-bulkhead interaction as well as failure phenomena in drainage ditches. Finally, a survey - through a questionnaire - of trench workers is presented, with the extraction of the corresponding diagrams and partial results and conclusions, which link the technology of retainers and their application to the trenches with the corresponding workforce. This research has led to very interesting findings which strongly indicate that the best solution to avoid collapsing failures along with zeroing of worker deaths, is to combine three parameters, that is high level of retaining technology, appropriate application, maximum attention and responsible attitude of the work team when working in drainage ditches.

Index Terms: Bulkheads, deep excavations, road infrastructure, rainwater and sewer network, technical staff, trench retainers.

1 INTRODUCTION

In ancient times, in many cultures, the know-how of sewage disposal was developed. In Mohenjorado, a city of the first bloom of Indian culture, historically located around 5000 B.C., excavated brickwork drainage was found in the excavations that collected the sewage from houses. In Babylon, drainage networks were also found, and in the Minoan palace of Knossos (1950-1500 B.C.), sanitary sites and a drainage-sewage system were discovered [1]. In the last decade there has been a remarkable increase in the research effort on the subject of deep retained excavations in a structured urban environment [2]. The stochastic diversity of subsoil composition and the complex to unpredictable technical behavior of geomaterials make substrate support absolutely necessary for the technically and economically sound design of a drainage project. There are many dangers for the workers in the construction of a drainage project such as excavator manipulation injury, entry-exit injury, trench wall failure resulting in the sliding of workers and/or machinery -within the sliding prism- during excavation, collapse of trench walls, fall of soil and stones from stacked soil, dangers of using machine tools, fall of objects in the trench etc. But the most important - among the above - risk is the sliding of the sides of trenches which can lead to an accident or even the death of a worker. So, landslides and soil retreats are of the most significant catastrophic phenomena recorded on the surface of the earth [3].

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When the depth of the excavation is high and the soil is loose, to ensure the safety of workers against possible slope wall failure, trench retainers are used. However, apart from the safeguards to be taken into account, the responses of 52 workers with particular experience in the work of laying pipes in drainage pits are of particular interest. The purpose of this article is to present the retainers (with their respective advantages and disadvantages) and to comment on their use in drainage trenches, always in conjunction with the way technical and labor personnel work.

2 METHODOLOGY

In the introduction and in paragraphs 3.1, 3.2. there is a historical and general reference to the sewer networks. Subsequently, in paragraphs 3.3, 3.4, 3.5, 3.6. detailed breakdowns as well as methods and types of support are presented in detail. In Section 4 carry out a survey, through a questionnaire of sewage workers, from which useful results are extracted. Finally, paragraphs 5 and 6 provide suggestions and conclusions drawn from the above research. As regards the references, it should be noted that [1] and [2] provide historical as well as recent time data for deep excavations. Sources [3–7], [8], [11], [12] were used to reinforce the theoretical background of the text as work on dredging excavations and drainage are important areas of Soil Mechanics, Hydraulic and Maintenance research. The figures and photographs presents and describe briefly their species and types, while sources [10], [12], [13] and [14] provide better support for suggestions and conclusions. Finally, it should be emphasized that the closed-ended type questionnaire given to employees, is completely original and first published, and the staff responses have led to very useful conclusions in seeking solutions for avoiding accidents.

3 THE NECESSITY OF MOUNTING RETAINERS

3.1 Pipeline installation methods

Pipelines of the drainage network are in their vast majority underground and are constructed in ditches and rarely in tunnels. The construction process is as follows: Excavation-retainers, pipe laying, back-filling of trenches, restoration of roads and pavements. Sewage pipes are installed on or adjacent to the axis of the road so that the length of private connections on both sides of the road is the same. Rainwater pipes are positioned higher and adjacent to the sewage pipes, so that a single trench can be excavated (Fig. 1).

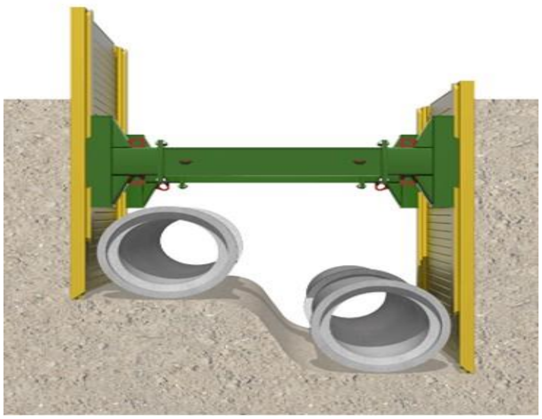

Fig. 1. *Elevation layout of pipes, rainwater and sewage, drainage network [15].*

Sewage pipes are located deeper than water supply ones. Installation depth of drainage networks varies from 1.20 meters and can reach 7-8 meters.

3.2 Retaining of trench slopes

Excavating ditches on loose soil requires retaining of the walls to prevent them from collapsing and the subsequent risk of an accident at work. Some cohesive soils keep their slopes upright without support for some time, while others, loose and erodible, require immediate support. Thus, a retainer construction includes any work in the field of civil engineering that allows for a sudden change of level on the earth's surface in such a way that the ground and construction system has limited displacements, or is marginally restrained. Retaining structures are mainly used in cases of soil continuity catalysis due to excavation beneath the existing soil surface, as in deep drainage networks (Fig. 2).

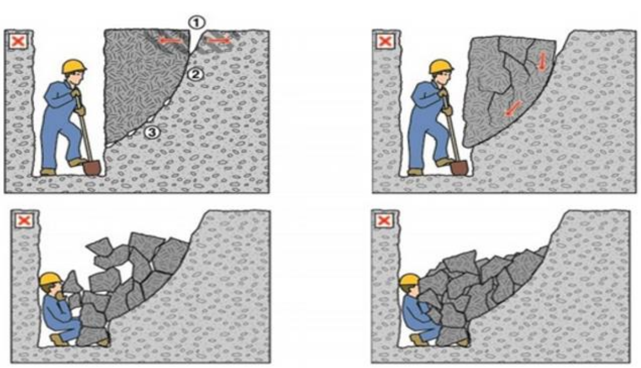

Fig. 2. *Schematic of a slope fall - worker trapping.*

In any case, it is a legal obligation to offer protection to neighboring structures, and to the wider environment of the project, which mainly relates to the risks posed by the reduction of the bearing capacity of the soil and the increase of its subsidence, resulting in a number of fatalities within the working force (Fig. 3).

Fig. 3. *Lack of retainers-fatal injuries in Taiwan, 2004 [15].*

Human intervention is only possible in the construction of the retainers and not in the geomaterials surrounding it. So, when it is not possible, lawful or economical to carry out open type digging, with free slopes, it is required to use retaining structures [5]. Particular attention should be paid to the collapse occurring in sewer trenches (Fig. 4) where, due to high geomass movement speeds [6], they render works extremely dangerous and require, along with the necessary retaining methods, utmost care and responsibility on the part of the workers (Fig. 5).

Fig. 4: *Slope collapse in drainage canal, Salaminos Street, Larissa, Greece, 2010 [15].*

Fig. 5. *Worker protection within support, Larissa, Greece, 2012 [15].*

3.3 Bulkheads-Sheet piles

Bulkheads are thin, usually temporary structures, mainly supporting the excavation fronts and are built from top to bottom. It is widely accepted that the intrinsic anisotropy of in situ geostructures (e.g. stratified clays) significantly differentiates the regime of developing pore pressures, whereas in the case where the construction of the diaphragm precedes excavation, the pore pressures increase and the degree of consolidation decreases, which, in turn, means that the sheet piles function is under undrained conditions. In conclusion, it is expected that the soil-structure interaction (Fig. 6) will be complex and even more so as the rigidity of the "diaphragm and lateral supports" system increases compared to the corresponding "response" of the soil environment. Thus, bulkheads are implemented from top to bottom with the gradual installation of their lateral supports, the flexibility of the system not being constant, but constantly changing during the implementation phases of the project.

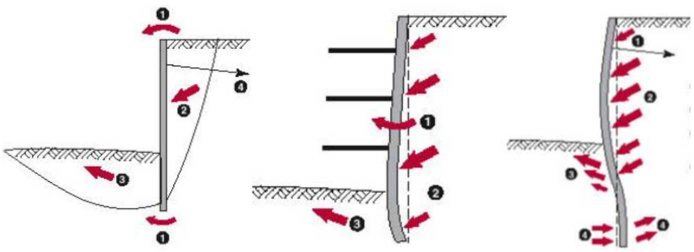

***Fig. 6**. Kinematic representation of the interaction between various retaining devices and ground [7].*

With regard to the technologies developed in the field of bulkhead supports, they vary and are summarized in Table 1.

TABLE 1
TECHNOLOGIES OF BULKHEADS [5]

Technology	Construction material
Sheet piles-Twin self-retaining bulkheads (Fig. 7, 8)	Vertical or horizontal elements, wooden, steel or aluminum
Pile walls	Reinforced concrete
Berlin type wall	Combination of steel piles and reinforced concrete
In situ injectable bulkhead	Reinforced concrete
Anchored wall	Reinforced concrete

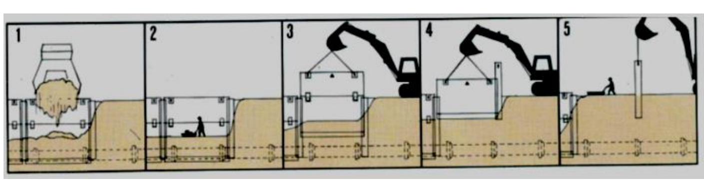

***Fig. 7**. Placement of prefabricated bulkheads [15].*

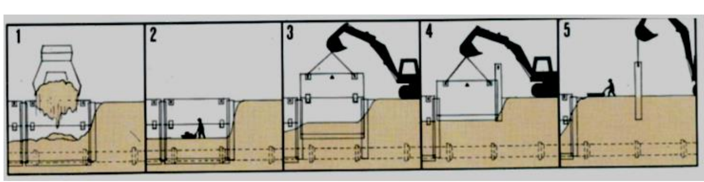

***Fig. 8**. Removal of prefabricated bulkheads [15].*

In drainage trenches, apart from the technology of twin self-retaining bulkheads, sheet piles are used as well. Piles are combinable, in the form of flat and thin non-planar elements (boards or panels), mainly metallic (steel), and in some cases, mostly in the past, wooden (Fig. 9). They are generally used in unstable soils such as soft clays, and require an obstacle-free, stone- or cobbler-free soil. Their installation is accomplished by driving the elements into the ground.

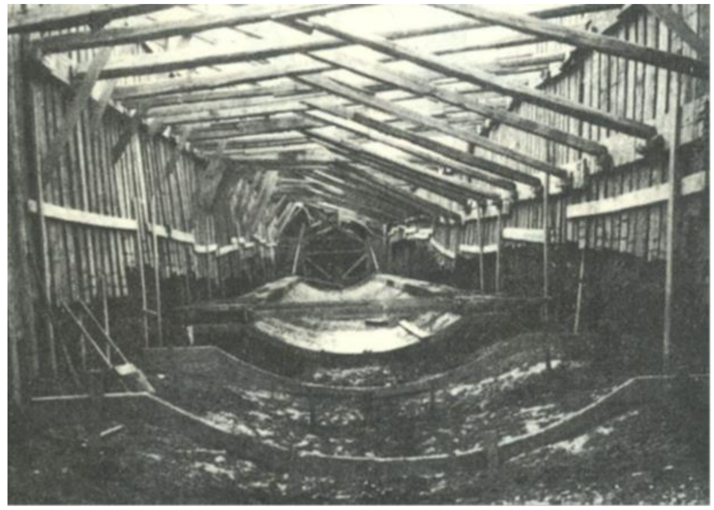

***Fig. 9**. Construction of a sewer pipe with wooden pile stands in 1968, Larissa, Greece [15].*

Their advantages include ease of handling (Fig. 10) and transport, as well as the ability to use them in lands that include minor obstacles. They are easy to reuse and to produce special elements for the implementation of special forms of diaphragms. A disadvantage of piles is the noise they cause during installation or extraction. There are cases of destructions due to significant obstacles, bending issues during installation, mainly when the resistance torque is less than 460 cm^3/m. Finally, they exhibit corrosion vulnerability and reduced aesthetics.

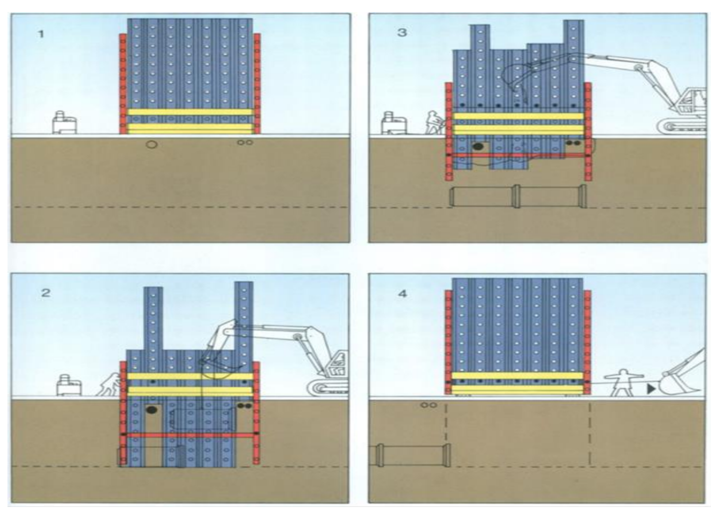

***Fig. 10**. Illustration of installation of sheet piles, excavation and removal of sheet piles after completion of the work [15].*

3.4 Metallic struts

These are linear elements, relatively rigid, constructed out of steel, concrete or, more rarely, wood, and have rectangular or circular-tube cross-section (Fig. 11). They are prefabricated prior to each excavation work and lowered in an arranged position, initially retaining the two opposite sidewalls of a temporary narrow excavation, are connected to them by longitudinal beams and small wedges of suitable construction material.

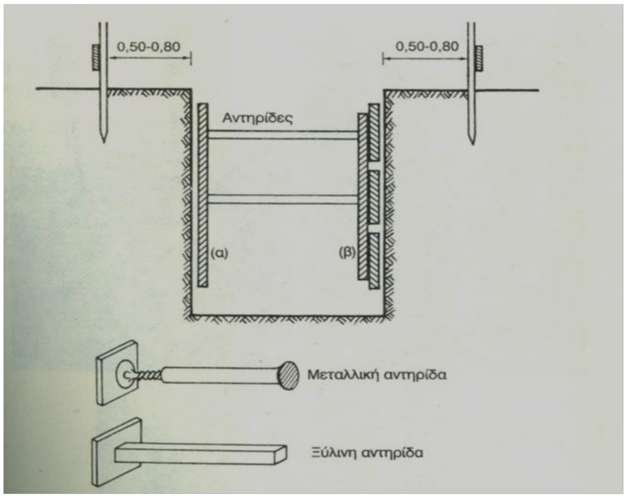

Fig. 11*. Metallic and wooden struts on bulkhead support [8].*

They are placed within the excavation, at minimum vertical distances of about 2.5 m, and at such horizontal distances as to facilitate work on the bottom of the trench (Fig. 12). They are mainly strained compressively, and also provide the capability of re-use.

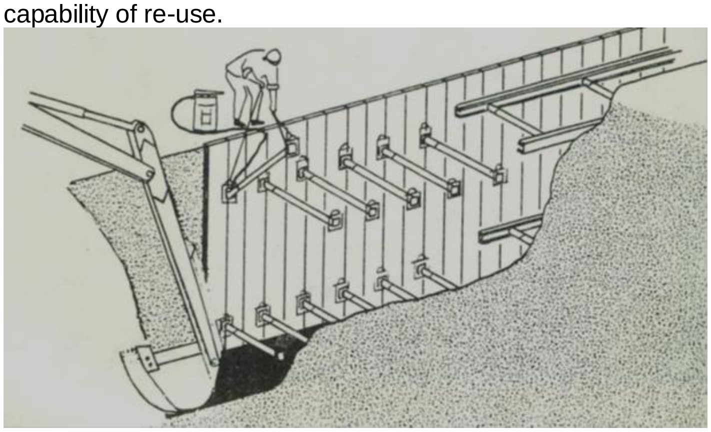

Fig. 12*. Mounting of struts [8].*

Struts are mainly used instead of anchors in cases of: unfavourable soil conditions, installations or repairs of utility networks, presence of coterminous small structures, narrow and shallow long excavations as well as limited space excavations. In recent years, the most prevalent systems for retaining sidewalls in drainage trenches are the following:

a. The Trench Box Systems with different variations, in which the brackets are firmly attached to the vertical beams. The system allows retention up to a depth of approximately 4.0 m.
b. The Side Rail System with a variety of versions, including Standard, Combined and Parallel. The system is made up of side guides, struts and curtains. Retention depths of up to 9.0 m are achieved [9].

3.5 Twin self-retaining panels of lightweight, medium and heavy type

The lightweight, medium and heavy duty Box system is intended for small-scale trench retention operations by use of the method of mounting (Fig. 13). It is designed for use by small excavators in relatively stable soils. The strength of the system varies depending on the length of the panels on each unit, ranging from 15.3 to 27.7 kN/m^2. The maximum permitted installation depth of the units varies accordingly. Usually the maximum installation depth is 3.00 m. The width of the trench ranges from 0.65 to 2.23 m depending on the type of strut we use, while the maximum free height below the strut is 0.94 m. Larger trench widths are possible with the help of brackets.

Fig. 13*. Lightweight (Aluminum) Box System [15].*

3.6 New retention technologies

In recent years new retention technologies have emerged that, by avoiding excavation, minimize the hassle of pipeline construction. These technologies are based on the gradual pushing of prefabricated pipe sections from one location to another (pipe jacking), without excavation of overlying soils. Although in many countries technology is advancing rapidly in this direction, the application of such methods has not been widespread and is limited to short lengths and mainly for pipelines below constant stream rivers and junctions with major railways or major city highways, where excavation disturbance could have serious consequences. The cost of such methods is high, mainly in the acquisition of the specialised technological equipment, and their application requires considerable technological expertise [10, 11].

4 SURVEY AMONG DRAINAGE TRENCH WORKERS

This section presents a survey, through a questionnaire distributed to drainage ditches workers. Employees' experience presented comes from Greece and has obtained from 1984 to the present, from workers in the private sector as well as in public and local entities (e.g. in the DEYA of Larissa and generally in various municipal water management companies, DEYA, EYATH and EYDAP). A number of 52 workers responded in the survey with experience in sewage trench works ranging from 11 years to 35 years as presented in Table 2 below.

TABLE 2

Questionnaire for workers in sewer trenches

QUESTIONS	YES	NO
1. During your work in a drainage trench, has a **slope collapse occurred that required the use of retainers**?	48	4
2. During your work in a drainage trench, have you ever left for a few seconds **the retained area to carry out** any work?	45	7
3. Have you worked in a sewer ditch deeper than 2 (two) meters **without support**?	24	28
4. Have you been slightly injured by a slope collapse while inside a drainage trench **inside a retained area**?	4	48
5. Have you been slightly injured by a slope collapse while inside a drainage trench **outside a retained area**?	22	30
6. Were you present when a colleague lost his life in a drainage trench due **to slope collapse, with no retainers**?	4	48
7. Were you present when a colleague lost his life in a drainage trench **due to** retainer **failure**?	2	50
8. Were you **present at a drainage trench retainer failure**?	8	44
9. Do you know a colleague who **was fatally injured** in a trench **(without retainers)** due to a collapse of slopes?	9	43
10. Do you know a colleague who **was fatally injured** in a trench **(with retainers)** due to a collapse of slopes?	2	50
11. Do you think the usual retainers used in the projects for slope support in the drainage trenches **need to be improved or not**?	11	41
12.What kind of support would you prefer for the following drainage trenches? A.Self-retaining **steel panels** B.Self-retaining **aluminium panels** C. **Steel sheet piles** D. **Wood sheet piles**	A - 37 B - 10 C - 5 D - 0	

4.1 Questionnaire and annotation of answers

Q1. During your work in a drainage trench, has a slope collapse occurred that required the use of retainers? (Fig. 14).

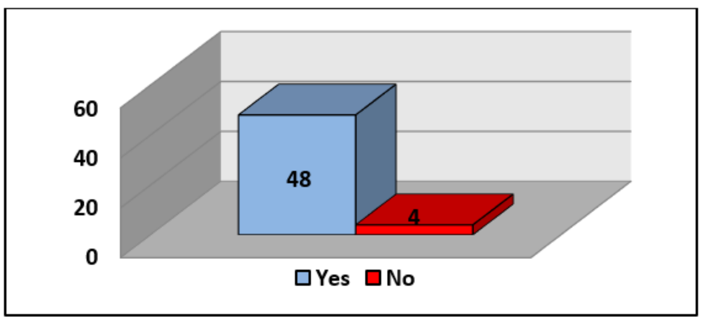

Fig. 14*. Need for retainers due to collapse.*

The overwhelming majority of workers (92.3%) believe that slope retainers are necessary, but unfortunately there are also workers (7.7%) who do not understand this necessity. Q2. During your work in a drainage trench, have you ever left for a few seconds the retained area to carry out any work? (Fig. 15).

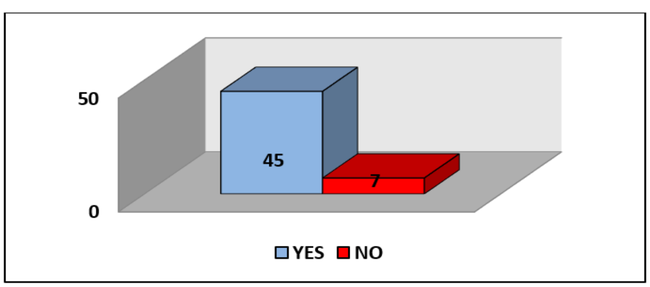

Fig. 15*. Working out of retained area for a few seconds.*

Figure 15 shows that 86.5% of the employees have left a retained area for a few seconds. Risking, unfortunately, even fatal injury. Q3. Have you worked in a sewer ditch deeper than 2 (two) meters without support? (Fig. 16).

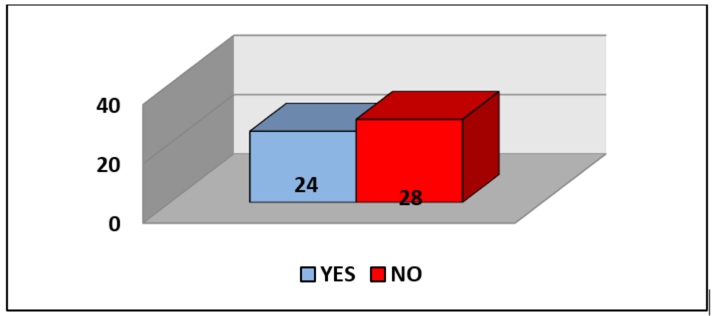

Fig. 16*. Work in trenches deeper than 2 m, outside retained area.*

The answers depict that 46% of workers have worked in trenches deeper than 2 m, without retention. Almost 1 in 2. Q4. Have you been slightly injured by a slope collapse while inside a drainage trench inside a retained area? (Fig.17).

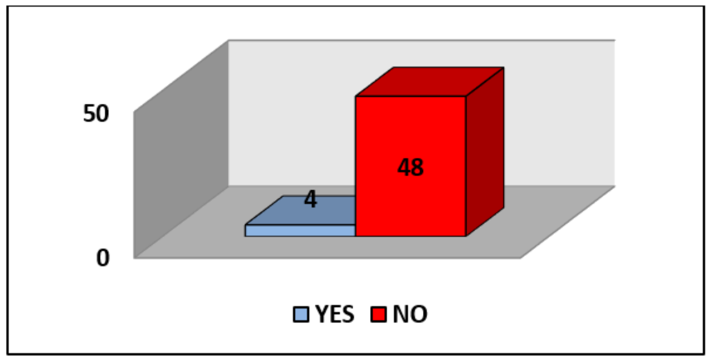

Fig. 17*. Light Injury within retained area.*

Employees responded positively (7.7%) to minor injury within restrained area. Q5. Have you been lightly injured by a slope collapse while inside a drainage trench outside a retained area? (Fig. 18).

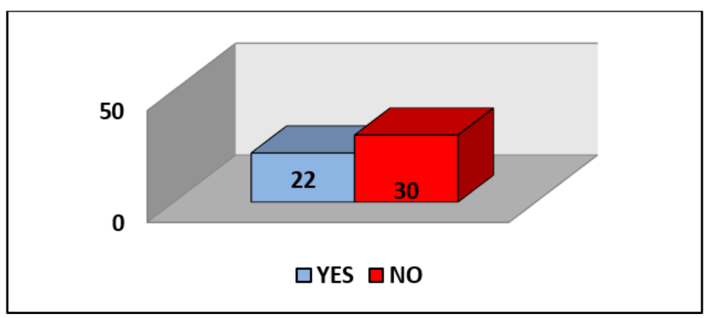

Fig. 18*. Light injury outside restrained area.*

A percentage 42.3% of the workers have experienced light injury in a ditch outside restrained area. This is a very large percentage which can become much larger if the second question result is taken into account. It is by luck alone that some workers have not been lightly injured. Q6. Were you present when a colleague lost his life in a drainage trench due to slope collapse, with no retainers? (Fig. 19).

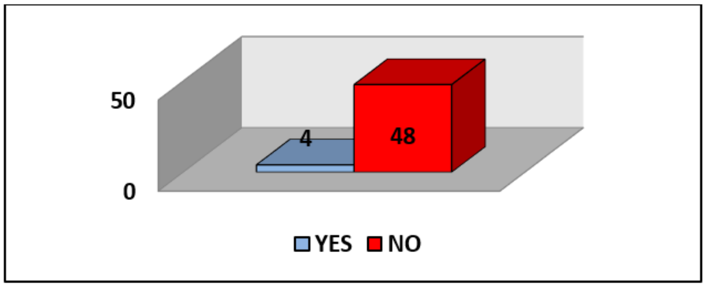

Fig. 19. *Presence in fatality in a trench without retainers.*

Remarkable percentage of workers (7.7%) was present at the death of a colleague in a trench. Q7. Were you present when a colleague lost their life in a drainage trench due to retainer failure? (Fig. 20).

Fig. 20. *Presence in fatality in a trench due to retainer failure.*
3.8% of employees were present at the death of a colleague due to retainer failure. Q8. Were you present when a retainer failed in a drainage trench? (Fig. 21).

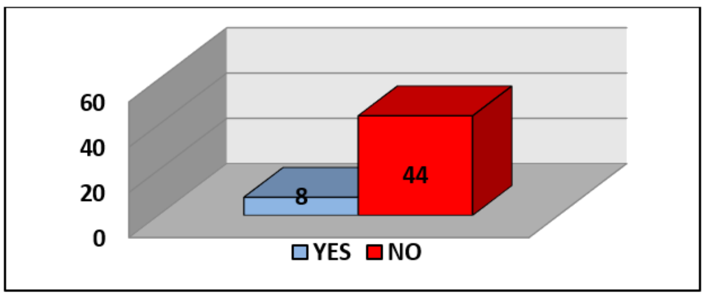

Fig. 21*. Presence in retainer failure.*

15.4% of those surveyed were present at a retainer failure. Q9. Do you know a colleague who was fatally injured in a trench (without support) due to a collapse of slopes? (Fig. 22).

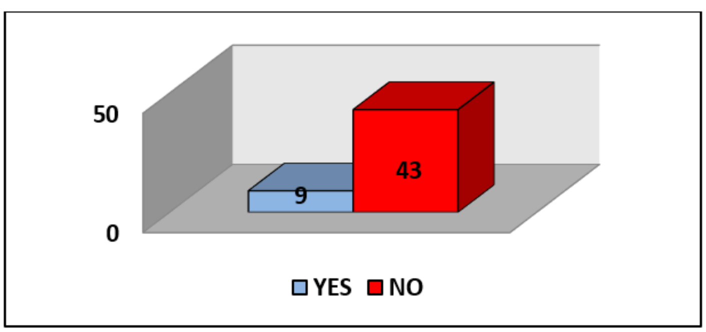

Fig. 22. *Deadly injury (no retainers).*

17.3% know a colleague who lost his life in a drainage trench (without retainers), but the respondents themselves were not present. Q10. Do you know a colleague who was fatally injured in a trench (with retainers) due to a collapse of slopes? (Fig. 23).

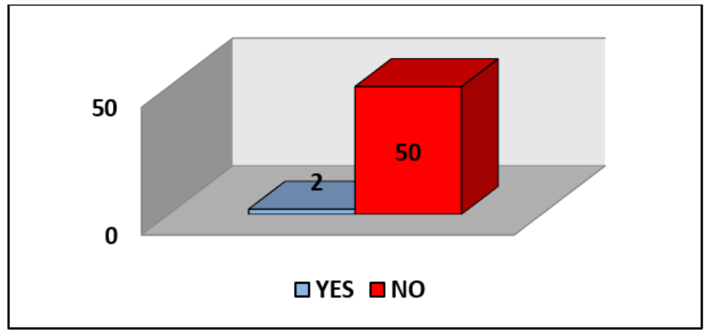

Fig. 23*. Deadly injury (with retainers).*

A 3.8% know a colleague who lost his life in a drainage trench (with retainers), but the respondents themselves were not present. The presence of the retainers decreased the percentage of fatal injuries in trenches from 17.3% to 3.8%. This means that the retainers improve the safety of the workers. Q11. Do you think the usual retainers used in the projects for slope support in the drainage trenches need to be improved or not? (Fig. 24).

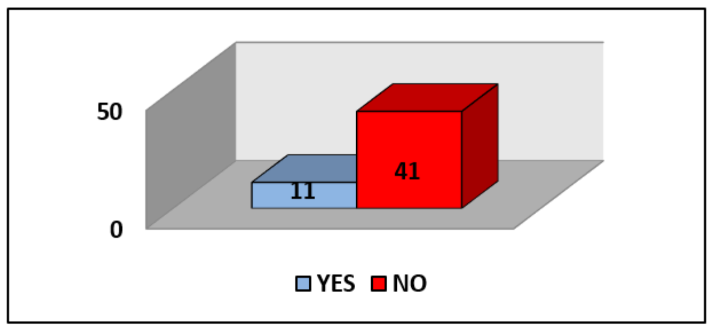

Fig. 24*. Improvement of retainer technology.*

Concerning the effectiveness of the existent drainage trench retainers, 78.8% of the workers are satisfied with their quality and believe that commercial retainers need no further improvement. Q12. What kind of support would you prefer in drainage trenches? (Fig. 25).
A. Self-retaining steel panels
B. Self-retaining aluminum panels
C. Steel sheet piles
D. Wood sheet piles

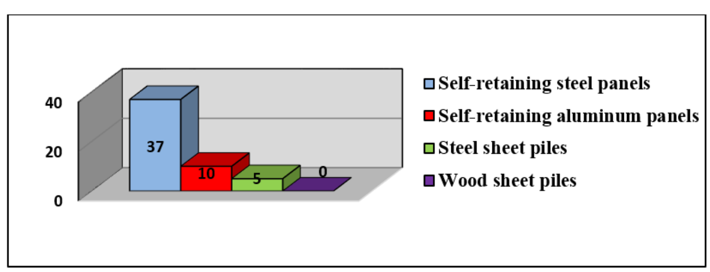

Fig. 25. *Selection of retainer type.*

In the choice of the type of support, 71.1% of workers choose self-retaining steel panels, 19.2% choose self-retaining aluminium panels, and 9.6% choose steel sheet piles, while wood sheet piles are completely rejected as obsolete at 0%.

4.2 Ten Excavation Safety Tips

To protect workers from injuries and fatalities, preventive measures should be implemented when workers begin excavating. According to OSHA, general safety measures to follow should cover the following:

- Inspect trenches daily before work begins. Don't go near an unprotected trench.
- Check weather conditions before work; be mindful of rain and storms.
- Keep heavy equipment away from trench edges.
- Be mindful of the location of utilities underground.
- Always wear proper protective equipment.
- Don't work beneath raised loads.
- Conduct atmosphere tests. If low oxygen and toxic gases were detected, workers must not enter the trench.
- Protective systems like benching, sloping, shoring and shielding must be created.
- Planning and implementation of safety measures must be done by a competent person.
- Use a checklist to perform regular self-inspections.

5 SUGGESTIONS

1. Under the Occupational Safety and Health Act of 1970, employers are responsible for providing safe and healthful workplaces for their employees. The employer must comply with the trenching and excavation requirements of 29 CFR 1926.651 and 1926.652 or comparable OSHA-approved state plan requirements.
2. Time spent in training counts as paid work time [12].
3. The two overriding priorities in selecting a trench shielding or shoring system can be summarized in a pair of familiar phrases: "dollars and cents" and "life and death." The first expression is about doing a job cost-effectively, which is an important consideration. The second is about protecting human life, which is even more important [13].
4. It is suggested to inform workers on a regular basis about the dangers in drainage trenches, through continuous training through operator seminars (e.g. DEYAL), thereby increasing the sense of responsibility on the construction site.
5. Finally, a simplified modelling of the pipe—soil system would allow the use of Monte Carlo simulation to account for the uncertainties related to the spatial variability of soil properties, the frequency content, and the [22] in order to ensure that all work in vertical sewer trenches is safe and uneventful.

6 CONCLUSIONS

1. The stochastic diversity of subsoil composition and the complex, even unpredictable technical behaviour of geomaterials make substrate retaining absolutely necessary for a technically and economically sound design of a drainage project.
2. Hazards involving excavations, in particular trenches, can lead to serious incidents involving workers at construction sites.
3. From the analysis of the survey answers, it can be concluded that the workers in drainage trenches are satisfied with the quality of commercial retainers, which have been at a high level for many years, but unfortunately serious accidents in the industry have not been resolved.
4. Utmost care and responsibility of employees is required which, together with the high level of retainer technology, could reduce accidents in drainage trenches.
5. To achieve this goal, not only employees but also employers as a whole should be more attentive and responsible in trench works.
6. Understanding the timing of manufacturing processes is crucial to avoiding the failure of a support.
7. Employers, supervisors and workers must follow the requirements set out in the Occupational Health and Safety Act (OHSA) and Regulations for Construction Projects [12].
8. The dangers of the work require employers to take extensive measures to protect workers. Likewise, owners, contractors, suppliers, workers and supervisors must help the employer maintain safe working conditions.
9. This research has led to the conclusion which strongly indicate that the best solution to avoid collapsing failures along with zeroing of worker deaths, is to combine three parameters, that is high level of retaining technology, appropriate application, maximum attention and responsible attitude of the work team when working in drainage ditches.

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