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RESEARCH ARTICLE

Foundation pit digging effect evaluation of combined pollution soil remediation in adjacent sites

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ABSTRACT

There are two adjacent chemical pollution sites, belonging to the first andsecond land use plan, containing 16 contaminated areas. The pollutants are hexavalent chromium and benzo [a] pyrene. The contaminated soil is excavated simultaneously and group by group, remedied respectively in offsite plant. Based on the research, a set of sampling scheme is designed which is suitable for the foundation pit digging effect evaluation of multiple combined pollution foundation pitswith different land use plan and restoration target values. The results show that the evaluation of foundation pit digging effect of the two sites isup to standard, and the schemes of first excavation and expanding excavation are feasible. Scientific and accurate evaluation of foundation pit digging effect is conducive to reducing the risk of human health in the late management and utilization of the site.

Keywords: soil remediation; effect evaluation; sampling design; combined pollution; adjacent foundation pit

1. Introduction

According to the requirements of relevant laws and regulations such as the Soil Pollution Prevention and Control Law of the People's Republic of China, if industrial land is determined as a polluted plot through soil pollution investigation and risk assessment, soil pollution remediation must be carried out. After the completion of the soil remediation project, the effectiveness of soil pollution remediation should be evaluated, and the final conclusion on whether the polluted plot can be safely used [1] is given. Therefore, the assessment of remediation effectiveness is a decisive part of the entire process supervision and management of polluted plots.

At present, the country has issued the "Technical Guidelines for Risk Control and Soil Remediation Effect Evaluation of Polluted Land Blocks (Trial)" (HJ25.5-2018), which standardizes the work content and procedures of soil and groundwater remediation effect evaluation of polluted land blocks. The guidelines are mainly based on guiding principles, but there are no clear provisions for the sampling design of adjacent contaminated land block remediation effect evaluation points, excessive excavation of foundation pits, and secondary acceptance methods. Therefore, the effectiveness evaluation of complex soil pollution remediation projects lacks systematic theoretical basis support.

In recent years, research on the evaluation of soil pollution remediation effectiveness has mainly focused on the entire process of evaluating the remediation effectiveness of individual industrial pollution plots [2-6],

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the establishment of the effectiveness evaluation index system [7], and the innovation of experimental detection methods for effectiveness evaluation [8-9]. Some studies on optimizing site layout have also mainly focused on soil pollution investigations [10-12], and there are few research cases specifically targeting the evaluation of pit cleaning effectiveness and adjacent composite pollution plot remediation effectiveness.

Due to the lack of historical data and relatively extensive production and management, pollutants in the relocation site of a chemical plant often exhibit heterogeneous distribution characteristics [13]. This project involves two adjacent chemical pollution plots with different land types, each with different restoration target values, and there are multiple composite pollution pits that overlap or are adjacent to each other. The layout of the points for evaluating the effectiveness of foundation pit cleaning is somewhat difficult. This article intends to analyze and discuss how to accurately and scientifically design the sampling plan for foundation pit layout under multiple constraints, in order to provide reference and guidance for the evaluation of foundation pit cleaning effectiveness in similar projects.

2. Overview of the plot

2.1. Basic information of the plot

The 1 # plot covers an area of approximately 2000m2 and is planned as a park green space (G1). It belongs to the first category of land specified in the Soil Environmental Quality Construction Land Soil Pollution Risk Control Standard (Trial) (GB36600-2018). The plot 2 covers an area of approximately 11000m2 and is planned for commercial office use (C8) and commercial service industry use (C2). It belongs to the second category of land specified in the Soil Environmental Quality Construction Land Soil Pollution Risk Control Standard (Trial) (GB36600-2018). The 1 # plot is located in the northwest, and the 2 # plot is located in the south. The two plots are adjacent to each other and have two shared boundaries. Two plots of land were historically used as production workshops and warehouses for a chemical plant.

2.2. Conclusion of preliminary pollution investigation and risk assessment

Plot 1: There are 12 soil exceedance points, and the detection results of hexavalent chromium and benzo [a] pyrene all exceed the screening values of Class I land in GB36600-2018. The maximum exceedance multiple of hexavalent chromium is 4, and the maximum exceedance depth is 2.5m; The maximum exceedance multiple of benzo [a] pyrene is 3.55, and the maximum exceedance depth is 1.5m. According to the risk assessment calculation results, the carcinogenic risks of hexavalent chromium and benzo [a] pyrene both exceed the acceptable level for human health, and the polluted soil needs to be remediated.

Plot 2: There are 7 soil exceedance points, and the detection results of hexavalent chromium and benzo [a] pyrene all exceed the screening values of Class II land in GB36600-2018. The maximum exceedance multiple of hexavalent chromium is 37.8, and the maximum exceedance depth is 2.0m; Benzo [a] pyrene has a maximum exceeding multiple of 0.2 and a maximum exceeding depth of 0.5m. According to the risk assessment calculation results, the carcinogenic risks of hexavalent chromium and benzo [a] pyrene both exceed the acceptable level for human health, and the polluted soil needs to be remediated.

2.3. Repair plan

Hexavalent chromium is remediated using leaching technology, while benzo [a] pyrene is remediated using advanced oxidation technology. The polluted soil in each excavation pit is separately and ex situ remediated, and then backfilled to the original foundation pit.

The restoration scope of plot 1 includes 9 polluted areas, among which A, B, C, and D are hexavalent chromium pollution areas, E, F, and G are benzo [a] pyrene pollution areas, and Zone 1 and Zone 2 are composite pollution areas, with a total restoration area of 277.7m2 and a total restoration volume of 397.45m3. The hexavalent chromium restoration target value is 11.5mg/kg, and the benzo [a] pyrene restoration target value is 0.55mg/kg.

The restoration scope of plot 2 includes 7 pollution areas, among which I, II, III, IV, V are hexavalent chromium pollution areas, VI and VII are hexavalent chromium and benzo [a] pyrene composite pollution areas, with a total restoration area of 2184m2 and a total restoration volume of 2185.5m3. The target value for hexavalent chromium restoration is 15.1mg/kg, and the target value for benzo [a] pyrene restoration is 1.5mg/kg. The specific repair scope and distribution of the foundation pit are detailed in **Figure 1**.

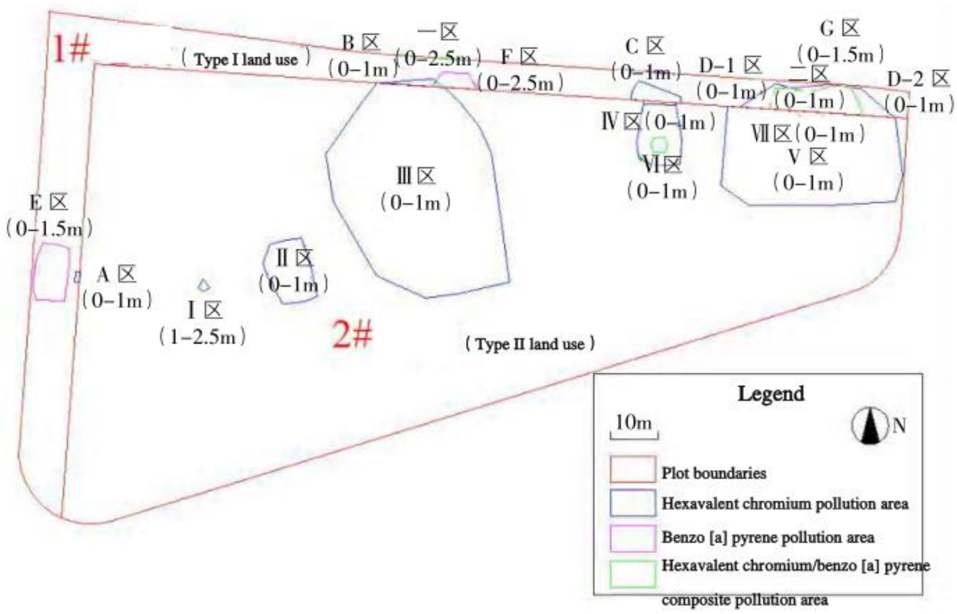


Figure 1. Diagram of foundation pit situation.

As shown in **Figure 1**, among the 16 foundation pits, Zone A, Zone C, Zone E, and Zone II are separate pits and not adjacent to other pits. The remaining four groups of foundation pits all have adjacent relationships, as follows:

Group 1: The upper clean area and lower contaminated area of Zone I are adjacent foundation pits to each other;

Group 2: Zone III, Zone 1, Zone B, and Zone F are adjacent foundation pits to each other;

Group 3: Zone V, Zone VII, Zone D, Zone G, and Zone 2 are adjacent foundation pits to each other;

Group 4: Zone IV is adjacent to both Zone VI and Zone C.

3. Design of 2-point sampling scheme

3.1. Excavation sequence

The implementation method of simultaneous construction, step-by-step excavation, and separate restoration is adopted for plot 1 # and plot 2 #, without crossing or mixing. The order of foundation pit excavation is crucial for evaluating the effectiveness of foundation pit cleaning. Different excavation sequences may result in different layout methods and detection factors, which may even affect the judgment criteria for meeting the standards. Therefore, the foundation pit cleaning work should be carried out according to the following requirements:

(1) Composite pollution area: First clean up the composite pollution area, and then clean up the adjacent single pollution area after the foundation pit passes the effectiveness evaluation and acceptance.

(2) Adjacent foundation pits: After one foundation pit has been cleared and passed the effectiveness evaluation and acceptance, another foundation pit can be cleared.

(3) Excavation at the junction of two plots: If excavating from Class I land to Class II land, the excavation should be carried out to a distance of about 5cm beyond the red line of Class II land; If the excavation is carried out from Class II land to Class I land, it shall be strictly carried out according to the restoration scope and the red line of the plot.

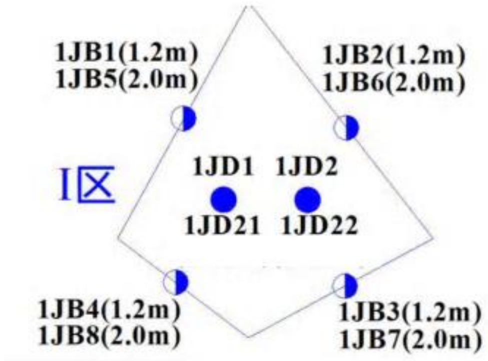
3.2. Point layout

Due to the fact that HJ25.5 only specifies the minimum number of points and working principles for layout, there is a lack of scientific and accurate guidance for the layout of multiple adjacent and compound polluted foundation pits. For the four foundation pit groups in this study, how to accurately and reasonably arrange points is the key to evaluating the effectiveness of foundation pit cleaning, especially when the points in the foundation pit group exceed the standard, how to comprehensively consider economic rationality and point representativeness is a difficult problem. The evaluation of the cleaning effect of the foundation pit in this study, on the premise of meeting the relevant requirements of HJ25.5, has formulated the principles of batch distribution and sampling, as shown in **Table 1**.

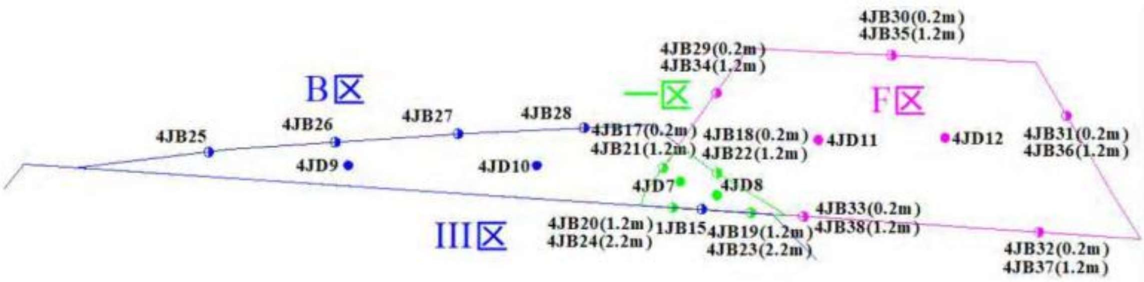
Table 1. Principles of point layout.

Location	Stationing principle
Side wall	Based on the equidistant point layout method, after dividing the sidewall equally, the points are placed at the center position. If the length of the sidewall is greater than 15m, at least one sampling point should be set. When the depth of the foundation pit is less than 1m, vertical layered sampling is not carried out on the side walls. When the depth of the foundation pit is greater than 1m, vertical layered sampling must be carried out, taking into account the soil properties of the plot and the vertical distribution characteristics of pollution. Sampling points should be set at locations where pollutants are easily enriched, and the vertical distance between sampling points at each layer should not exceed 3m. When adjacent foundation pits share the same side wall and it is determined that the target pollutants must exist or exceed the standard, the foundation pit that has been cleared first can be determined whether points are placed on the common side wall as needed. The minimum number of sampling points recommended for HJ25.5 is greater than the number of distribution points.
Pit floor	Based on the system layout method, the sampling unit at the bottom of the pit is gridded, and the points are arranged at the center of the grid, covering/approaching the initial detailed adjustment exceeding points as much as possible. If there is a clean area in the upper layer of the polluted foundation pit, the clean soil will be excavated and the bottom of the pit will be distributed. The minimum number of sampling points recommended for HJ25.5 is greater than the number of distribution points.

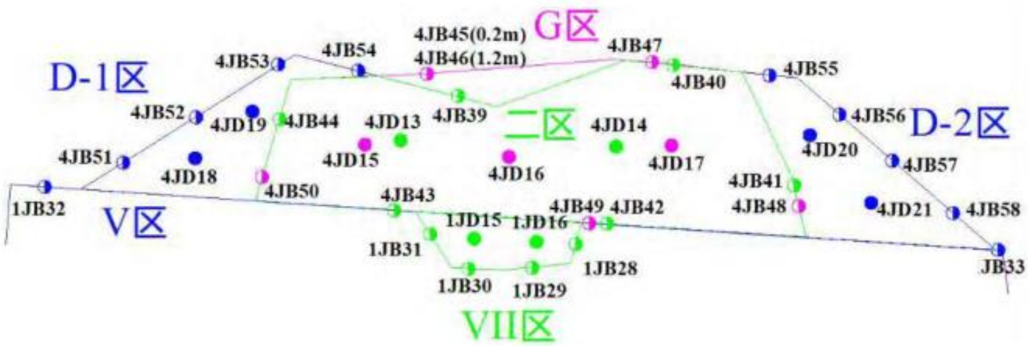
According to the above layout principles, a total of 21 bottom sampling points and 58 sidewall sampling points were set up in plot 1, while 22 bottom sampling points and 36 sidewall sampling points were set up in plot 2. The sidewalls of Zone 1, Zone E, Zone F, and Zone G are vertically divided into two layers for point distribution and sampling, with corresponding points located above and below. The layout of the points at the junction of the four foundation pit groups is detailed in **Figure 2**.



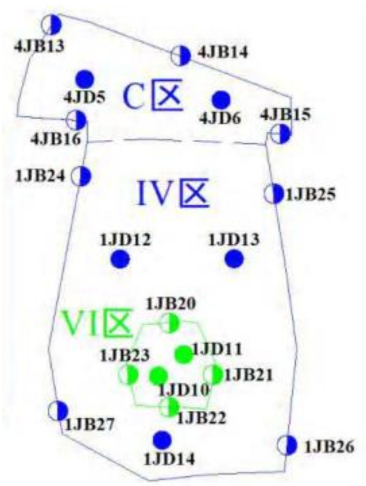
(a) Layout diagram of points at the junction of adjacent foundation pit group 1

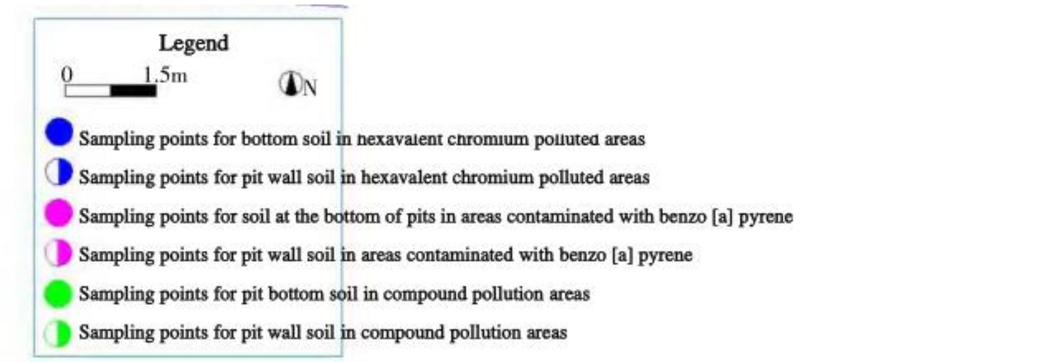


(b) Layout diagram of points at the junction of adjacent foundation pit group 2.



(c) Layout diagram of points at the junction of adjacent foundation pit group 3.





(d) Layout diagram of points at the junction of adjacent foundation pit group 4.

Figure 2. Layout of points at the intersection of adjacent foundation pit groups.

The number and numbering of each excavation site are detailed in **Table 2**. In excavation group 1, two monitoring points are set up at the bottom of the clean area in Zone I to ensure that the bottom contaminated soil is not touched during excavation; Excavation Group 2: The sampling order of the excavation is Zone III → Zone I → Zone B → Zone F. A point (1JB15) is set at the common sidewall of Zone III and Zone I to confirm whether Zone III is a single hexavalent chromium pollution area; Excavation Group 3: The sampling sequence of the excavation is Zone 2, VII, V, D, and G. Two monitoring points (4JB42 and 4JB43) are set up on the common side walls of Zone 2 and V to confirm whether Zone V is a single hexavalent chromium pollution area; In Foundation Pit Group 4, Zone C and Zone IV were originally not adjacent, but the adjacent sidewalls of the two foundation pits in Zone IV and Zone C were only 0.5m apart. During the actual excavation process, the soil in this area could not be preserved independently. To ensure the feasibility of restoration construction and the convenience of foundation pit acceptance, the clean soil in the middle of the two foundation pits was changed to Zone C of Block 1. After the change, the two foundation pits became adjacent pits, with no points distributed on the common sidewalls. The sampling order was: Zone VI, Zone C, Zone IV.

Table 2. List of layout points for each foundation pit.

Plot	**Clean up the area**	**Repair area (m^2)**	**Repair depth (m)**	**Sampling points (number)**		**Number of sidewall sampling layers**	**Point number**
				Pit floor	Side wall		
1#	Zone 1	1.5	0-2.5	2	8	2	4JD7-4JD8,4JB17-4JB24
	Zone 2	87	0-1.0	2	6	1	4JD13-4JD14,4JB39-4JB44
	Zone A	2.2	0-1.0	2	4	1	4JD3-4JD4,4JB9-4JB12
	Zone B	11	0-1.0	2	4	1	4JD9-4JD10,4JB25-4JB28
	Zone C	28	0-1.0	2	4	1	4JD5-4JD6,4JB13-4JB16
	D-1 zone		0-1.0	2	4	1	4JD18-4JD19,4JB51-4JB54
	D-2 zone	129	0-1.0	2	4	1	4JD20-4JD21,4JB55-4JB58
	Zone E	77	0-1.5	2	8	2	4JD1-4JD2,4JB1-4JB8
	Zone F	24	0-2.5	2	10	2	4JD11-4JD12,4JB29-4JB38
	G-zone	95	0-1.5	3	6	2	4JD15-4JD17,4JB45-4JB50
	Subtotal	277.7	/	21	58	/	/
2#	Zone I clean area	/	/	2	/	/	1JD21-22
	Zone I	3	1.0-2.5	2	8	2	1JD1-1JD2,1JB1-1JB8
	Zone II	111	0-1.0	3	5	1	1JD3-1JD5,1JB9-1JB13
	Zone III	1267	0-1.0	4	6	1	1JD6-1JD9,1JB14-1JB19

Zone IV	94	0-1.0	3	4	1	1JD12-1JD14,1JB24-1JB27
Zone V	691	0-1.0	4	5	1	1JD17-1JD20,1JB32-1JB36
Zone VI	9	0-1.0	2	4	1	1JD10-1JD11,1JB20-1JB23
Zone VII	9	0-1.0	2	4	1	1JD15-1JD16,1JB28-1JB31
Subtotal	2184	/	22	36	/	/

3.3. Sample collection

The soil samples at the bottom and side walls of the foundation pit are mainly the surface soil samples (0-20cm) after removing impurities such as gravel. The layering of the sidewall is determined based on the depth of pollutant pollution and the properties of the soil layer, as well as the layering situation. In each sampling unit, use shovel and sampling shovel to uniformly collect 9 surface soil samples, and obtain mixed soil samples by quartering after full mixing.

3.4. Detection factors

According to HJ25.5, the detection factor for soil samples in foundation pits is the target pollutant in the soil within the corresponding remediation range. When there are adjacent foundation pits, the target pollutants in the soil of the adjacent foundation pits should be included in the detection factor of this foundation pit. The detection factor that is inevitably detected or exceeds the target value of foundation pit cleaning based on the adjacent relationship of the foundation pit can be omitted.

4. Evaluation of the cleaning effect of foundation pits

4.1. Testing results and analysis

A total of 92 soil samples were collected from plot 1 #, and 67 soil samples were collected from plot 2 #. As shown in **Figures 3 to 4**, after the first excavation of the foundation pit, the maximum hexavalent chromium detection result for plot 1 # was 2.2mg/kg, and the maximum hexavalent chromium detection result for plot 2 # was 1.7mg/kg. After the first excavation of both plots, the hexavalent chromium detection results reached the target value for foundation pit cleaning. There are 5 sidewall samples and 1 pit bottom sample in plot 1 that exceed the standard for benzo [a] pyrene, with a maximum detection value of 1.4 mg/kg and a maximum multiple of 1.54. The detection results of benzo [a] pyrene in the remaining samples are all lower than the target value for foundation pit cleaning. There are three sidewall samples of plot 2 with excessive levels of benzo [a] pyrene, with a maximum detection value of 2.4mg/kg and a maximum multiple of 0.6. The detection results of benzo [a] pyrene in the remaining samples are all lower than the target values for foundation pit cleaning. The excavation of the foundation pit where benzo [a] pyrene exceeds the standard needs to be expanded.

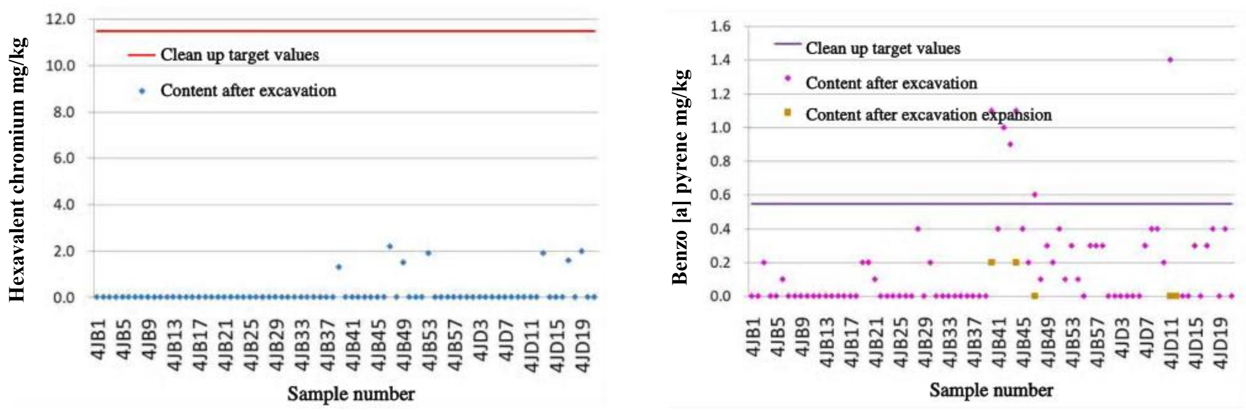


Figure 3. Test results of hexavalent chromium and benzo [a] pyrene in the foundation pit of plot 1 #.

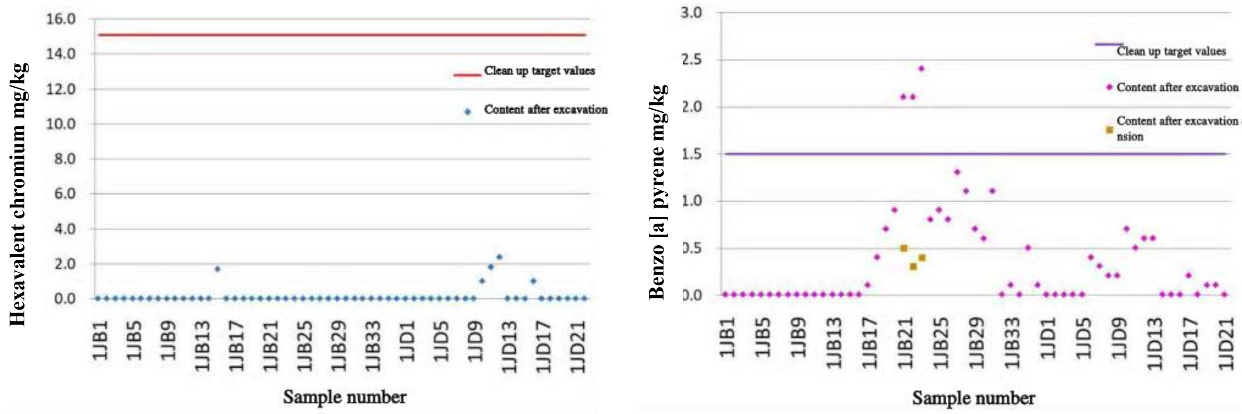


Figure 4. Test results of hexavalent chromium and benzo [a] pyrene in the foundation pit of plot 2 #.

The soil samples 1JB15, 4JB42, and 4JB43 were all taken from the common sidewall of the excavation group where they were located. The detection result of benzo [a] pyrene in sample 1JB15 was not detected, which did not exceed the corresponding target value for excavation cleaning, indicating that Zone III is indeed a single hexavalent chromium pollution area, and the excavation sidewall cleaning work represented is in place, without the need for repair treatment as a composite pollution area. The detection results of benzo [a] pyrene in samples 4JB42 and 4JB43 (0.9 mg/kg, 1.0 mg/kg) exceeded the target value for foundation pit cleaning in plot 1, but did not exceed the target value for foundation pit cleaning in plot 2. Therefore, the adjacent V area does not need to be treated as a composite pollution area for remediation.

4.2. Evaluation and analysis of the cleaning effect of the foundation pit after expansion excavation

After the first excavation, the pits with excessive levels of benzo [a] pyrene were found in Zone 2, F, G, and VI, with a total of 9 exceeding points, including 8 exceeding points on the sidewalls and 1 exceeding point at the bottom of the pit. Based on the results of exceeding the standard and the multiple of exceeding the standard, it is determined that the reason for the exceeding of the standard at the point may be due to the heterogeneity of pollutant distribution, and the first cleaning of the foundation pit was not in place. Due to the limited scope and volume of foundation pit repairs exceeding the standard, the principle of prioritizing environmental benefits is adopted during excavation expansion. Expand the sidewalls represented by the 6 exceeding limit points by 0.5m (with no change in excavation depth), without expanding the excavation range to other sidewalls. Although there is only one exceedance point at the bottom of the pit in Zone F (4JD11), the overall bottom of the pit in Zone F will be expanded downwards by 0.5m (with the same excavation area). After the excessive excavation of the foundation pit, the location, quantity, and detection factors of the secondary acceptance monitoring points correspond to the first excavation cleaning acceptance points (see **Figure 5**). In the end, the detection results of benzo [a] pyrene in all soil samples of the expanded foundation pit were lower than the target value of the excavation cleaning, and the evaluation of the excavation cleaning effect after the expansion met the standard.

Among the exceeding points, two (4JB42 and 4JB43) are located on the common sidewall of Zone 2 and Zone V (also at the junction of Block 1 and Block 2). According to the aforementioned excavation principles, this sidewall has been excavated to a distance of 0.5m beyond the red line of Block 2. The detection results of benzo [a] pyrene in two soil samples are between the cleaning target values of plot 1 # and plot 2 #. The final evaluation indicates that the cleaning effect of the second zone foundation pit meets the standard and there is no need for expansion excavation. If the detection result of benzo [a] pyrene is greater than the cleaning target value of plot 2 #, the common sidewall of zone 2 and zone V will be expanded towards the side of zone V.

The polluted soil after expansion will be included in the remediation amount of zone 2 and repaired according to the remediation target value of plot 1 # (Class I land).

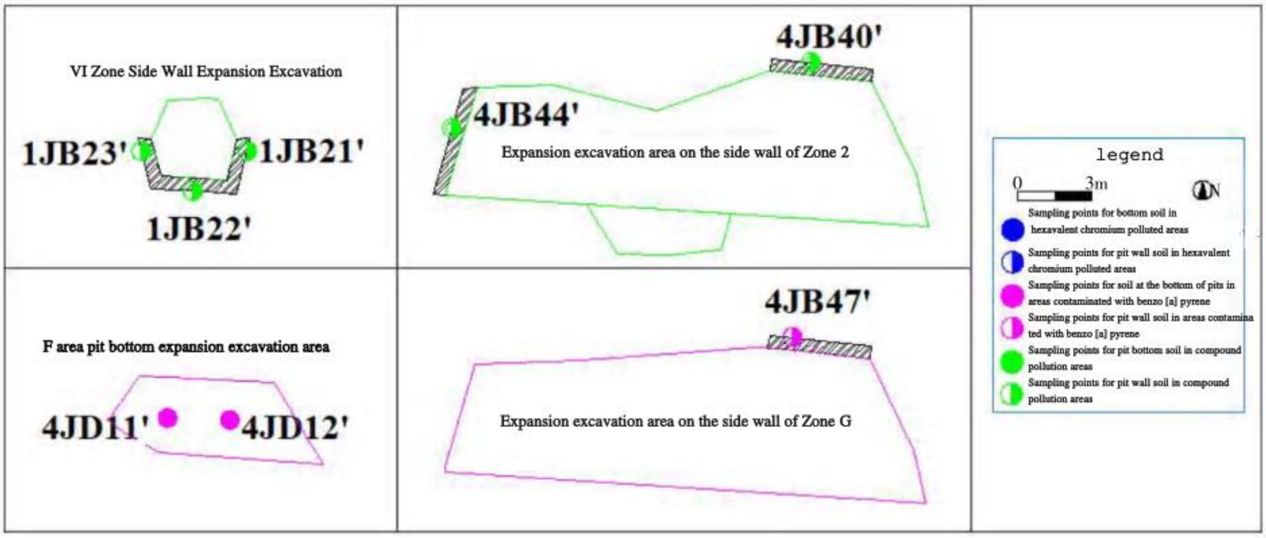


Figure 5. Layout diagram of acceptance points for foundation pit expansion and excavation.

5. Conclusion and suggestions

(1) A total of 159 soil samples were collected for the evaluation of the cleaning effect of the two plots of foundation pits. During the initial acceptance, a total of 9 soil samples exceeded the standard for benzo [a] pyrene. After expansion, the detection results of benzo [a] pyrene met the corresponding target values for foundation pit cleaning. The evaluation of the cleaning effect of the two plots of foundation pits ultimately met the standard. Zone III and Zone V are indeed single hexavalent chromium pollution areas and do not need to be treated as composite pollution areas for remediation. (2) When two or more adjacent plots have different land types and there are multiple adjacent foundation pits with compound pollution, the adjacent foundation pits should be cleared step by step, inspected in batches, arranged in a coordinated manner, and efficiency should be emphasized. Scientifically and reasonably arranging the excavation sequence is conducive to the connection of the evaluation of the cleaning effect of each batch of foundation pits and the smooth progress of subsequent repair work. (3) The expansion excavation volume of plot 1 # is 43.25 (10.9% of the theoretical restoration volume), and the expansion excavation volume of plot 2 # is 115.89 (5.3% of the theoretical restoration volume). Under the premise of project time and economic cost, an expansion excavation plan that prioritizes environmental benefits can be adopted to ensure that the cleaning effect of the foundation pit meets the standard. If the boundary of the plot involves changes in excavation and repair areas, both the excavation and repair parts should be included in the repair scope of the plot with stricter repair target values. (4) When evaluating the effectiveness of foundation pit cleaning, scientific and accurate sampling and analysis of detection results can effectively update the conceptual model of the plot, discover and make up for the shortcomings in the investigation and evaluation stage, and help reduce human health risks in the later management and utilization of the plot.

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