FOUNDATION CONSTRUCTION IN ABANDONED QUARRIES

by

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Abstract. This paper presents two case histories related to construction of shallow foundations in filled-in abandoned quarries for a factory building and a public library. The factory and the library were both constructed partly over randomly filled, abandoned quarry areas and partly over natural soils. The case histories illustrate that shallow foundations, with some type of ground improvement, can be used in filled-in abandoned quarry areas. In limited cases, where a greater differential movement can be tolerated, foundations may require relatively little ground improvement. In all cases, however, where shallow foundations are planned for construction over uncontrolled fill, it is paramount to recognize the attendant risk to future settlement, incorporate measures in design for its mitigation, and communicate this to the owner and architect.

Additional Key Words: random fill, miscellaneous fill, uncontrolled fill, residual soils, sinkhole, preloading, undercutting, quarry, foundations, settlement, vibration, blasting.

Introduction

The critical issue in design and construction of foundations over filled areas is the control of differential movement due to non-uniformity in subsurface conditions. It is always tempting to control such movements through the utilization of deep foundations. However, they are costly and in certain instances not readily constructible due to the specifics of a site, e.g. due to inclusions such as boulders or other obstructions.

Two case histories are presented, related to construction of shallow foundations in quarry areas, asserting that shallow foundations are viable foundation alternatives in such cases. The terms uncontrolled fill, quarry fill, random fill, and miscellaneous fill are used interchangeably, referring to a mass of soil that is indiscriminately dumped in place without control in engineering properties, and which may include debris.

Factory Building

The building consisted of a single story structure with maximum column loads of 100 kips and floor loads of 600 pounds per square foot (psf). Commercial and industrial facilities surround the site, including a one-million gallon above-ground oil storage tank. Historic topographic and aerial photographs indicated that the site was originally a quarry, and has periodically been filled for the previous 25 years. The fill material was identified as non-hazardous.

Results of the foundation investigation by test borings indicated the presence of random fill, underlain by natural residual soils and decomposed to intact rock. The natural soils, derived from intense weathering of the bedrock, were found competent in load-bearing capabilities. However, the overlying fill material was variable in density with standard penetration test (SPT) values indicating very loose to very dense conditions. The random fill varied in gradation, was predominantly granular, and included rock fragments, bricks, furnace coke, concrete, and rubble debris. A typical subsurface profile of the site is shown in Fig. 1.

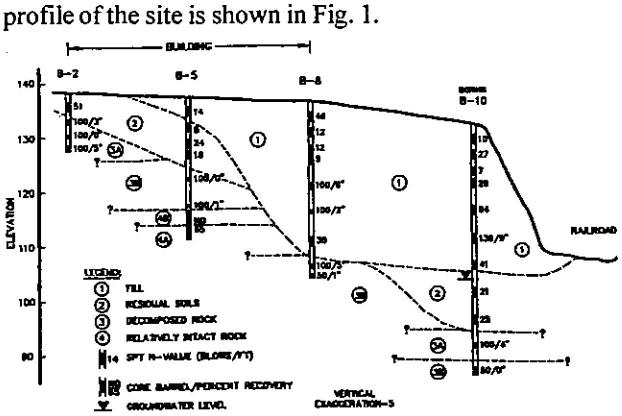

Fig. 1. Subsurface Profile at the Factory Building Site

[1] Paper presented at the 16th Annual National Conference of the American Society for Surface Mining and Reclamation, Scottsdale, Arizona, August 13-19, 1999.

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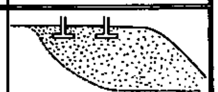
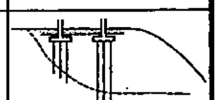
Proceedings America Society of Mining and Reclamation, 1999 pp 431-434
DOI: 10.21000/JASMR99010431

https://doi.org/10.21000/JASMR99010431

From the aspect of site development, the most significant feature at the site was the extent of the variable fill material. The thick deposit of uncontrolled fill presented unfavorable conditions that could entail significant cost premiums for the provision of adequate foundation support for the building. The random fill, covering at least two-thirds of the building area, ranged in depth from 2 to 28 feet, reaching 42 feet in some areas. The variable density of the random fill indicated that its potential for compression under the building loads could vary significantly.

Five options were considered for support of the structure in the deep fill area. They are listed in Table 1, ranked in terms of risk factor and cost. Option 1 entailed a low risk, but the cost was prohibitly large. Options 2 and 3 entailed a low risk, with moderate costs, and the potential difficulties (or higher costs) in installing deep foundations to final depth. Option 4 entailed a low risk to future foundation settlement, but a moderate risk to adjacent structures, with a moderate cost factor. Option 5 entailed a moderate risk factor to future settlement and remediation, but with the lowest cost.

Table 1. Foundation Options

Option	Risk Factor	Cost ($/ft² of bldg.)	Comments
1. Remove and replace all fill, use shallow foundations	Low	22.00	
2. Support columns, walls, floors within fill area on piles	Low	4.60 to 3.50	
3. Support columns, walls, heavy floors within fill area on piles, light floors on exchanged fill	Low	2.80 to 3.00	
4. Improve fill with dynamic compaction, use shallow foundations	Low, but risk to adjacent structures	2.85	
5. Partially exchange fill, support columns, walls, floor slabs on shallow foundations	Moderate	2.10	

The final selection of foundation type was based on economic feasibility and the willingness of the owner to accept the risks associated with potential future excessive settlement. The owner, architect, structural engineer, and the geotechnical engineer met and discussed the ramifications of each option, and to ensure that all parties understood the risks associated with each of the foundation alternatives. The owner selected Option 5, accepting certain degrees of risk. The risk entailed the possibility of future remediation costs and possible disruption of manufacturing activities during the remedial operations.

Foundations were designed for a maximum bearing pressure of 4,000 psf and were constructed following the recommendations made under Option 5. Floor slab and foundation support areas were undercut by at least 3 feet, 2 feet in light floor areas, and replaced with compacted load-bearing fill. During construction, and based on proof-rolling of the foundation areas, some areas were further undercut, by as much as an additional 4 feet, as found necessary by the geotechnical engineer.

The superstructure was raised immediately after foundation construction, and was completed in 1991. The factory building has since been in service for manufacturing purposes, and has been performing satisfactorily, with no signs of apparent distress. The owner's engineer has reported that continual inspection of the premise has not revealed any cracks or other signs of building distress.

Public Library

The library is a one-story structure with masonry and glass exterior, and with maximum column loads of 125 kips. A preliminary foundation investigation for the library indicated that the planned structure was located in a random fill area, the site of an abandoned quarry. The depth to bottom of the quarry was estimated to be at least 20 feet. Based on SPT test results, the fill density was classified as very loose to very dense. The fill was predominantly granular and included rock fragments, asphalt, concrete, bricks, metal, tires, wood, and was determined to be non-hazardous. Several options were recommended for improving the fill for foundation purposes, each with an associated cost and degree of risk to future settlement. Strong emphasis, however, was placed on relocating the library outside the abandoned quarry area. The library location was subsequently adjusted to be outside the quarry area to mitigate the risks.

A geotechnical investigation was performed at the new site, adjacent to the abandoned quarry. The new site was found underlain by residual soils and solution-prone carbonate rocks. The primary issues related to construction of foundations in the new area were associated with post-construction ground loss in undetected sinkholes, differential settlement as a result of non-uniformity in underlying strata and different compressibility of the foundation bearing materials, and the stability of the foundations near the abandoned quarry.

After decontamination (if necessary), the exposed surfaces of excavation discard material mounds and operation areas will be rehabilitated with mineral soil corresponding to the future use of the site. The present established procedure is:

Rehabilitation of operation areas (Ronneburg site: agricultural and forestrial areas)

Soil
Storage/Fill Layer (till)

Biotic Factors and Long-Term Stability

The factors of influence, which act on the long-term stability of cover systems are identical to those which influence autochthonous soils during pedogenesis. Therefore, it makes sense to separate the factors into abiotic (physical and chemical weathering, kryo- and hydroturbation) and biotic (bioturbation, root penetration) categories. In the following, the biotic factors will be viewed chiefly.

Field Investigations for Root Penetration Behavior in Cover Systems and on Autochthonous Locations

Tasks

The framework of the objective was to investigate how much substratum specific physical and chemical parameters of individual soil horizons and cover layers influence root penetration. The results should give solutions for the optimization of the insulation layer against radon exhalation and seepage water infiltration.

The investigations were carried out on existing excavation discard material mound cover systems as well as autochthonous places having a corresponding natural insulating structure against root penetration. Plant species including grasses, trees, bushes, and nutrient loving plants (ruderal plants) were investigated. The root investigation was done at the exposed profile by the profile method and to a certain extent by the monolith method. The substrata soils were analyzed both physically and chemically. The dry bulk density and hydraulic conductivity (kf-value) were also measured in place (HEINZE und SÄNGER, 1996).

Rhizosphere as a Part of the Pedosphere/Cover

The roots and their dynamic development influence soil porosity, substance, and water content. In addition to the description of the root penetration through root diagrams, the root penetration conditions were characterized by the following parameters:

- Depth of total root space
- Mean root density in total root space
- Depth of main root space
- Mean root density in main root space
- Mean root density, standardized by 1 m

To attain general vertical and horizontal gradients of the root densities, regression analyses with linear models were applied on single profiles (root density equation). Values for the following parameters were determined for every layer:

- Fraction of soil grains < 0.063 mm in the fine soil (silt and clay fraction) in %
- kf-value in m/d
- Depth in cm
- Total Content of C, N, K, Mg, Ca in the fine soil
- Cation exchange capacity
- Dry bulk density in g/cm³
- pH-value ($CaCl_2$)

Physico-chemical Boundary Parameters of the Root Penetration

The following results can be attained from the field investigations:

Significant relations always exist between profile depth and fine root density. The influence of horizontal differentials is in most cases not significant. The analogous multiple regression analysis yielded for the most part no relation to the coarse root density. The depth of the substratum has the strongest influence on the root density. This is shown by the root density, as well as the soil influence and regression analysis.

The percentage of silt and clay content has a negative influence on the fine root density. This means, the more compacted a soil is, the less dense the root penetration is. The fine root density increases with increasing kf-value and decreasing dry bulk density of the soil layer. When a root space of 1.5 m is available for the plants, there is no need to penetrate in greater depths. As these depths, dense soil layers were seldom penetrated by plants.

On natural sites, carboniferous shale debris with silty-clayey interbed proved to be an almost absolute root barrier. The barrier effect is caused by high densities (1.8 g/cm³), low kf-value (0.0058 m/d) and the high coarse soil content.

By all tested tree species an increasing pH-value and a greater amount of exchangeable magnesium support the fine root density. The determined negative effect of the exchangeable calcium is more likely caused by higher values in the scarcely or not at all penetrated mining excavation discard waste material of the Ronneburg mound than by the smaller values in penetrated cover material. For possibly the same reason, the higher pH-values and the Mg-stock of the cover material both have a more positive effect on fine root density than that of the acidic excavation material. Table 2 shows maximum detected root depths.

Growth- and Substratum Specific Model Investigations

Tasks and Aims

Since 1991, specific growth and substratum investigations on different cover systems of the WISMUT GmbH have been carried out in the soil model facility of VAFB Jena. The experimental basis for these investigations is comprised of 42 metal containers with a surface area of 1 m² each and a depth of 1.5 m. The growth is characterized by determining of yield and increase of root growing according to glass-sight-gauge method.

Table 2:
Maximum detected root depths

Group	Substratum	Root depth (maximum)
grasses	cover soil	1.20 m
nutrient loving plants (ruderal plants)	excavation material (fine grained)	1.10 m
deciduous trees	excavation material (fine grained)	1.10 m
	till (autochthonous)	1.40 m
	cover soil	2.50 m
coniferous trees	excavation material/soil (autochthonous)	0.60 m / 1.60 m

The moisture measurement is carried out by TDR (Time Domain Reflectometry) and by the measurement system SENTRY of Troxler Electronis Laboratories Inc. The physical and chemical investigations of substrata and seepage water are carried out according to DIN instructions (PITTELKOW et.al. 1997). The preliminary Ronneburg site investigations yielded results of the behavior of clay insulation layers against root penetration. Furthermore new knowledge was gained of the water content of the layered substrata by different vegetation variations.

The initial results of the first 3 years justified a test program during the rehabilitation on a larger scale. Therefore, for each site, a specific program for the cover system and vegetation variations was established in 1994.

Through use of these methods WISMUT is able to draw exact conclusions about functionality of different cover systems. Moreover, through models, there is also the possibility to simulate substratum specific root penetration intensity, quality and quantity of infiltration water, functionality of drainage and cover layers, and cultivation and fertilization measures. Starting points for cover system optimization are possible through installation density, water permeability, and field capacity. These approaches allow improvement in the storage of winter precipitation and avoidance of water infiltration and pooling of surface water in order to reach a higher structural stability.

The plausibility and proved transferability of the modeled results was also shown by the parallel running field tests on the "Absetzerhalde" in 1994.

Results

It can be concluded that species-typical root penetration intensity and depth (effective root space) depend on water demand and storage capacity and in detail the specific field capacity of the cover layers.

Soil layer: To protect the first plantation one can add fertilizer, mixed manure or sewage sludge. The plant growth is supported and the water withdraw is increased. Prevention of higher nutrient removal should be optimized at the onset of sowing and first fertilization. Therefore, the sowing in the spring should be connected with planting of nitrogen resilient plants like grass. Then, over the whole vegetation period, a high nitrogen uptake and bonding is guaranteed (PITTELKOW et.al. 1997).

Storage layer: The ashes used in the storage layer (contaminated ash, mixed- and filter ash) are generally penetrated by pH independent grass and poplar. The main root zone of the grass, and so the main zone of water withdraw, is concentrated in the upper 40 cm of the cover. Trees and bushes also use deeper ranges. In the ashes a high hypodermic drainage rate can be observed, but only minimal capillary ascent. The heavy metal content of the drainage water is strongly dependent on the pH-value (acidic-high metals, basic-low metals). The occasionally high sulfate content of the seepage water is problematic.

Insulation layer: Clay insulation layers are used for water retention and root barrier if moisture losses are not excessive.

The tested insulation layers with a clay content of approximately 60 % (two layer clay minerals) have sometimes shown cracks after desiccation (moisture changes) as well as settlement and where roots penetrated. Dry densities of 1.9 g/cm^3 in the loess loam prevent root penetration up to a depth of 1.5 m, but only for a short time. The reason is the connected decrease of the field capacity and the increase desiccation (stress for plants) in the upper layers. Dry weather periods produce an increasing root penetration and endanger the functionality of insulation layer because of high hypodermic drain. Excavation material compacted at the surface serves only for short time as a barrier for root growth.

Drain layer: Drain layers are suited for leading away infiltration water over a layer with low kf-value . They are only functional to a certain degree because of suffosion, root agglomeration and moisture changes in the insulation layer below. Infiltration water generally occurs between November and May. It depends on field capacity of the soil and storage layers, intensity of use, nutrient supply and regional meteorological conditions. To minimize the infiltration, species with long vegetation cycles are used to take up the available field capacity of the root space. Well suited for this are multi-layer vegetation, for instance erosion resistant grass-herb sowings combined with wood plants when the cover is established.

A continuous foundation system was utilized for a maximum bearing pressure of 4,000 psf. The continuous foundation was found appropriate because of its ability to redistribute loads and help control angular distortions which could occur due to non-uniformity in strata and varying compressibility foundation materials. For stability of foundations in close proximity to the abandoned quarry, it was recommended that the sloping portion of the existing quarry face be excavated and then replaced with compacted fill at a flatter slope to act as buttress against the quarry face. Rock dowels would also be installed at the quarry face to prevent lateral movements at the face.

During construction, a 20 feet deep cut was made in the abandoned quarry area, adjacent to the location of the planned library, to place the buttress fill. Upon completion, it was found that the quarry face protruded into the planned library foundation area by as much as 25 feet, and the bottom of the cut was in unstable quarry fill. The geotechnical engineer was called upon at that point to evaluate the situation. A number of options were considered for foundation support in the quarry area, including deep foundations, dynamic compaction, fill exchange, preloading by surcharge, and relocation of the library. The owner for various reasons rejected all but the latter two options. The final remediation consisted of partly relocating the library away from the abandoned quarry and preloading the remaining quarry fill underlying the foundations, as shown in Fig. 2.

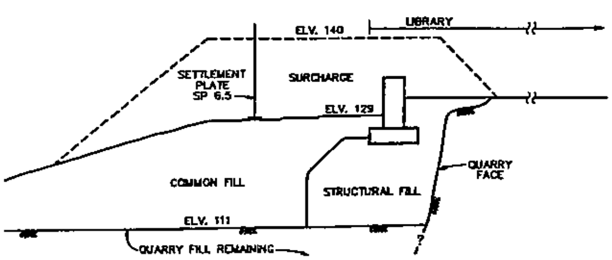


Fig. 2. Improvement of Foundation Conditions

Fill placement, compaction, and surcharging of the area were completed in about a month. Results of the surcharging, as shown in Fig. 3, indicated that after the full surcharge had been in place for about a 2-week period, at least 3 to 4 inches of settlement of the underlying quarry fill had occurred and the rate of compression had substantially reduced. After another 2-week period had elapsed with no appreciable change in compression, the surcharge was removed and foundation construction started.

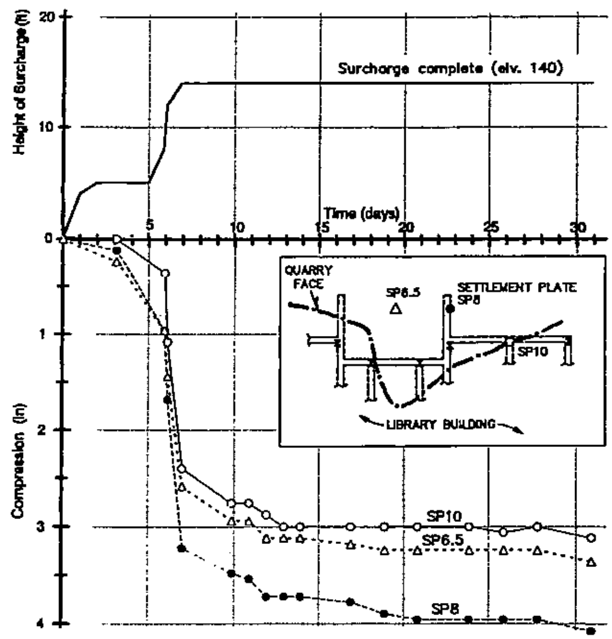


Fig. 3. Compression of Quarry Fill Due to Surcharging

The superstructure was completed in 1994. It has been performing satisfactorily with no reported signs of movement or distress.

In 1997, new construction adjacent to the library required blasting for rock excavation. This raised concerns for compression of the quarry fill still underlying some of the library foundations. Coordinating with the blasting contractor, the vibration was monitored at different library locations, including at foundation areas overlying the quarry. The vibration monitoring results indicated that the vector sum of peak particle velocity was consistently less than 0.5 in./sec. anywhere in the library area, and less than 0.25 in./sec. in foundation areas overlying the quarry. Additionally, over 70% of the recorded data indicated that the peak frequency of the vibration was in the range of 30 to 50 Hz. The vibration monitoring was combined with optical survey of the building throughout the blasting operation. The surveyor reported that the building corners remained plumb throughout the period. In addition, the owner, who performed a pre-blasting survey of the library, did not report any adverse impact on the structure subsequent to the post-blasting survey.

Conclusions

The above case histories illustrate that shallow foundations can be safely used over areas that have been the site of previous quarrying operations, provided that the potential risks for any future foundation settlements are recognized and properly mitigated.

In unstable soils, such as in filled-in quarry areas, especially for heavily loaded or settlement-sensitive structures, deep foundations are preferred. However, deep foundations are not only expensive, but in quarry areas are also subject to constructibility issues due to the presence of obstructions, resulting in pile damage, lack of plumbness, or "hang-up" above the bearing stratum. Thus, deep foundations become feasible if the cost and constructibility issues are acceptable.

Shallow foundations, however, can often be used in conjunction with ground improvement. Except for critical facilities that are very sensitive to movement, shallow foundations can become even more cost-effective if the engineer's endeavors for economy are met by the owner's understanding and acceptance of certain risks due to future settlement. The process requires that the geotechnical engineer carefully evaluates the available information and recommend suitable, yet economical, foundation alternatives. It is imperative that the engineer is ever-conscious of the risks and exercises sound engineering judgment to successfully "draw-the-line" between acceptable risk and economy.

For design of shallow foundations in abandoned quarry areas, the following points merit consideration.

- Delineation of the fill extent and conditions.
- Recognizing the possibility of contamination being present in the fill.
- Evaluation and comparison of several foundation options, including shallow foundations.
- Qualifying foundation options with respect to risk to future foundation movements.

For technical considerations, and to primarily control post-construction settlement, the following deserve notice.

- Improvement of foundation soils to help mitigate risk to future foundation performance.
- Continuous foundations for enhanced load bearing distributions.
- Full-time resident engineering during foundation construction to address unanticipated conditions.