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An Approach for Geotechnical Site Characterization of Brown Field Site of a Steel Plant

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Abstract. Geotechnical site characterization plays significant role in brownfield sites where heterogeneous materials get mixed with original soils during various stages of plant expansion over a long period. The Triad Approach developed by the United States Environmental Protection Agency (EPA) used in decision making for investigation in hazardous-waste sites is an effective strategy for site assessments. The term 'Triad' represents three elements: systematic project planning (SPP), dynamic work strategies (DWS), and use of real time measurement (RTM) technologies. This concept can be extended to geotechnical characterization of brownfield sites. This paper will describe the application of the Triad Approach for development of brown field project site inside a 100-year-old steel plant. This approach accelerates the characterization of the 45-acreproject area, which consists of construction of new process plants in an existing steel plant site. Successful brown field site development requires the planning of geotechnical tests, data collection, analysis and interpretation of field and laboratory results in timely and cost-effective manner. The planning and scheduling required to define potential criticalities and uncertainty in ground conditions allows designers to effectively use resources, optimize space constraints and develop response strategies that will mitigate risk with an eye to execution safety, ease and time. The decision on foundations system and ground improvement required during the underground construction activity have great impact on brown field project schedule and overall cost. The triad approach consists of planned geotechnical investigation combined with systematic foundation planning based on real time data that optimally uses available resources and accounts for space and time constraints. In addition, issues that were solved include the demarcation of the extent of heterogeneous fill material, determining further action for the areas of concern and specifying no action for other areas, and detailed investigation of specific impacted areas.

Keywords: Brown Field Site; Geotechnical Investigation; Triad Approach

1 Introduction

The drive towards sustainable development in production and manufacturing industries has seen many new concepts in recent times. One of the major challenges to this development has been the availability of land for setting up new plants or retrofit ting units that improve the process efficiency and environmental compliance of existing plant units. Availability of new land parcels for the new units have become difficult especially for century old establishments, further compounded by the growth of densely populated dependent townships that have developed around the industry. Developers have thus turned towards brownfield development as opposed to greenfield development for setting up new process units.

The development of brownfield sites, though a feasible solution for land availability problem is fraught with other handicaps that require a different type of approach to both engineering design and construction. Greenfield site developments are free of many of the additional challenges experienced in brownfield situations especially with reference to the amount of initial exploratory work that can be carried out to characterize the site, particularly the subsoil profile. Since there are no site hindrances, the degree of detailing in investigation depends purely on engineering considerations and a comparative study of the benefits of design optimization versus cost of additional testing. In brownfield developments however, additional constraints are imposed due to lack of clear documentation on existing underground obstructions from past facilities, multiple utility services existing in the area in live condition and

restricted access to the site for use of exploratory equipment to investigate subsoil conditions. Further, the exploration work had to be coordinated along with the plant operation fully complying with the process and safety requirements of the running plant and its scheduled maintenance program. These challenges call for different approach towards engineering design and execution in brownfield sites and is most critical for those parts of the construction that are not directly visible, namely the foundations and substructures.

The project under study in this discussion consists of a new raw material processing plant in an integrated steel plant complex that has been in operation for more than a century and has undergone various stages of development and refurbishment. To increase the plant production, a new plant unit to process one of the basic raw material inputs to the iron making process was proposed to be constructed within the existing plant area. This area was previously occupied by other manufacturing units which had been taken out of service about 15-20 years back but many of the underground constructions and utility services were in place. There were also some utility facilities in operation in part of the area which had to be mitigated through relocation.

The total area earmarked for the new process plant units is about 45 acres and is spread in two distinct zones, separated by distance of about 500m and connected by a pipe and cable gallery corridor. Various types of buildings, structures and equipment foundations were proposed by the process designer. These included main process plant structures, static equipment foundations including tall towers, large storage tanks, material handling system structures, moving equipment foundations, rotary equipment foundations, pipe and cable carrying system structures, service, utility and office buildings and facilities for maintenance of equipment and storage of spare parts. The type of foundation, sensitivity to settlement and expected bearing pressures for the various types of structures were also specified by the design engineering team at the start of the project and this formed one of the bases for identifying the need for the geotechnical investigation program, together with the expected variation in subsurface conditions across the extent of the project site

2 The Triad Concept

The triad concept was developed by the Environmental Protection Agency (EPA) of USA[1] in dealing with clean-up programs of heavily contaminated and hazardous sites. The basic concept of dealing with the uncertainty is presented in Figure 1 highlighting the three-prong approach for the decision-making process through (1) systematic project planning, (2) dynamic work plan strategies, and (3) the use of real-time measurement technologies. The triad approach is particularly suitable for brownfield project applications since the uncertainties in such sites especially in the subsurface conditions pose serious challenges to the engineering design teams. Application of the triad approach helps in identification and management of the uncertainties that could have resulted in large errors in decision making. The three elements of the triad approach in the context of geotechnical site characterization are briefly described below.

The systematic project planning element of triad approach involves identification of the variables and factors that can affect the design and project execution activities. This helps in devising cost-effective strategies to anticipate the probable adverse factors and manage them using previous knowledge of the site. The management strategy may consider aspects like level of previous knowledge, budget restrictions, project schedule, resource availability and regulatory requirements. Common-sense approach is used to process this gathered information to arrive at acceptable decisions and the associated uncertainties. The conceptual site model (CSM)is a tool to help organize the available information and identify the need for additional information through site investigation. This plan is dynamic and gets modified to reflect the level and quality of information gathered and the lowering of the associated uncertainties.

The second element of triad planning, a dynamic work plan strategy involves making real-time decision-making in field. This helps in avoiding repeating field investigations to fill gaps in data thus helping to reduce project schedule and cost increases. The field investigation plan is continuously modified during its execution through decision logic updated with accumulated data that is used to collect further information to fill in gaps.

The third element, real-time measurement, is employed in quick time frame to enable real-time decision making and real-time maturation of the CSM. It involves “out-of-box” thinking, deployment of supplementary in situ tests yielding quick and relevant results and use of software tools for interpretation and mapping of the data for enabling dynamic work plan strategies. Collaborative data that complements the results of the main investigation help provide more detailed image of the site in quicker time. This strategy helps save time and money and limit uncertainty in decision making and the decision achieved by analytical models can be supplemented with further rigorous testing as and when required.

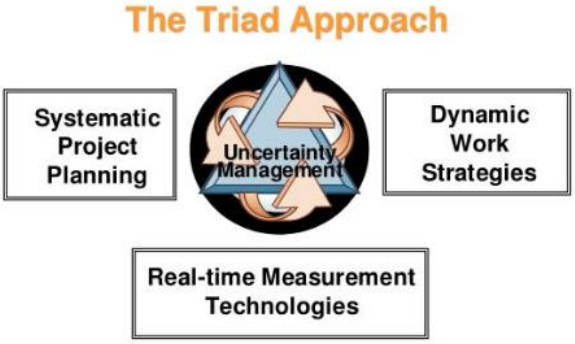


Fig.1. Triad approach

3 The Plant Layout and Site Description

The project area identified for the process plant consisted of two land parcels – one for the main process plant of area about 38 acres and the subsidiary gas cleaning and water utility plant area unit of about 7 acres located about 500metres away from the main material processing plant.

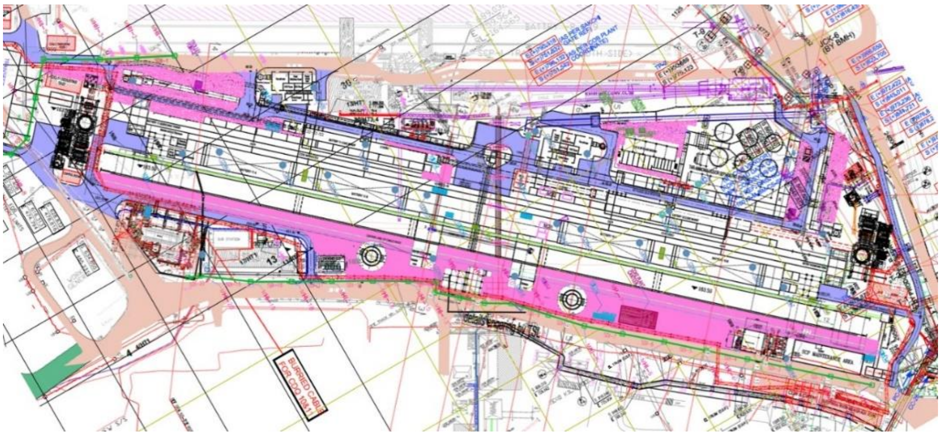


Fig.2. Main Material Processing Plant Unit – 38 Acres

The main process plant unit was planned to be developed in two phases. The first phase plant construction consisted of a raw material conversion unit, material storage structure, flue exhaust system, material conveying system, tracked vehicles for bulk raw and processed material transport, wet cooling system for hot products, dust extraction system structures, various static and rotating equipment foundations, pipe galleries, cable racks, process chemical and waste product storage tanks, storage structures, electrical and control building, and offices along with other auxiliary buildings. The anticipated foundation types for the various types of structures were specified by the designer as part of advance information for proper planning of the subsoil investigation work. In addition, some preliminary information from reconnaissance exploration in the nearby area for relocation of the existing facilities had already been carried out earlier which provided the baseline for the subsurface formation and geology of the area. This was also supplemented by reports from other projects executed in the vicinity in earlier times.

The second phase of the plant involved installation of a dry cooling system for recovery of sensible heat to generate stem both for use in the plant processes and for power generation. The closed dry system would also help establish better control of dust pollution generated during the handling of the product.

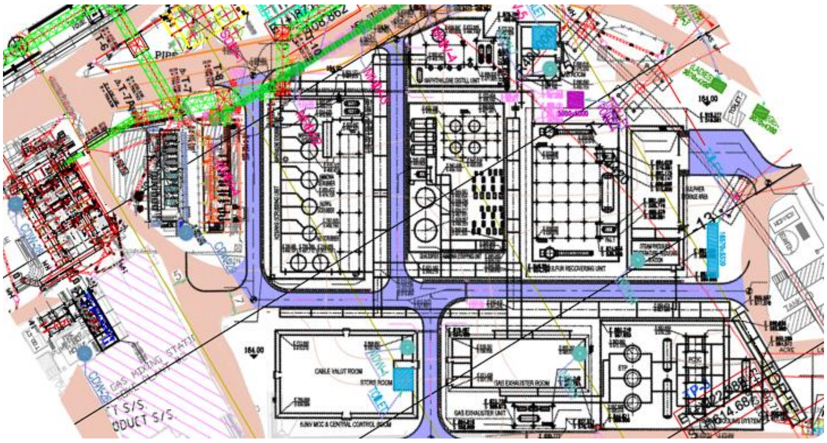


Fig.3. Auxiliary Gas Cleaning and Water Utility Plant Unit – 7 Acres

The auxiliary unit consisted of many process and chemical plant units for cleaning of the exhaust combustion gas for reuse in the plant as fuel and associated water utility system structures. It comprised of gas coolers, precipitator units, tall tower structures for scrubbing and distillation of gas and wash water, storage tanks, cooling tower, pump houses, gas compressors and exhauster units, other auxiliary units, and electrical and control building and offices. For these units also anticipated foundation requirements were indicated by the designer which was used along with preliminary subsoil information to form the baseline for further site investigation.

4 Application of Triad Concept for Geotechnical Investigation

The first element of the triad concept was utilized for the planning and execution of the geotechnical investigation work.

The systematic project planning stage involved identifying the parameters that would affect the design of the foundation systems and subsequent execution of the works. The important factors selected for the geotechnical characterization included the foundation design parameters specified by designer including structural framing, preferred foundation type and expected bottom of foundation level, expected bearing pressure and foundation size, settlement limits, and the sensitivity of the foundation and structure to differential settlement. Preliminary information on subsoil profile in vicinity was also available from earlier exploration programs. This data was used to plan the layout and depth of boreholes for the investigation program at the plant site.

The data was used to form the baseline conceptual site model (CSM) for the project. The model consisted of a detailed layout of the site obtained through a total station survey on which the process plant layout was superimposed. The preliminary foundation sizes, levels and bearing pressure values identified in SPP stage was superimposed on this layout to develop a foundation footprint of the structures. In the next step the geotechnical properties to meet the foundation design parameters was assessed. The testing plan developed included subsoil stratification through borehole logging, in-situ tests like Standard Penetration Resistance, Plate Load Test, Soil Resistivity Test and laboratory properties of grain size distribution, Atterberg consistency limits, strength and deformation characteristics. The investigation report [2] would provide foundation design data for the verification of soil bearing capacity/ pile capacity and expected foundation settlement for the structural loading from SPP phase. The layout of the investigation plan is shown in Fig.3 to cater primarily for the facilities in phase 1 development of the plant, but the test locations planned also covered the areas marked for phase 2 to minimize need for additional test points at later stage. The CSM considered the heightened risk and cost of subsequent investigation for phase 2 while the phase 1 plant would be in operation and the investigation locations were planned accordingly.

In the initial investigation plan, the boreholes were planned based on the guidelines of Indian Standard IS 1892 [3]. Total of 32 boreholes were planned for the site with 28 locations in the main process plant area and 4 locations in the auxiliary plant area. Borehole spacing was adopted at generally 50m intervals based on previous experience of uniform geologic formation of the site. The depth of exploration was decided to be 30m for 6 boreholes under critical structures, for other boreholes, termination criteria was set at 3m inside mica-schist rock with core recovery of 50%. In addition, 5 plate load tests were carried out at the location of the foundations of major structures of the proposed plant using 60cm square plates at depths of 1.15m to 2.15m below ground level, with the procedure conforming to IS 1888 [4] for in-situ verification of bearing capacity of founding soil. Maximum load applied on the plates was 600 kPa and the settlement calculated on the plate varied from 4.3mm to 16.0mm corresponding to safe bearing capacity (SBC) of 300 kPa, with a factor of safety of 2.0 on the applied load. For a prototype footing of size 3.0m square, the expected settlement under this SBC worked out in the range from 8.0mm to 80.0m

5 Applying Other Elements of Triad Concept for Site Characterization

The balance two elements of the triad concept were utilized for modification of the investigation program to meet the requirements of the foundation design and execution works.

Reports of the geotechnical investigation work as per the initial plan was provided as foundation design input to the design team. The soil stratification revealed from this investigation is presented in Table 1

Table 1. Geotechnical Parameters for Design

Strata	Description	Depth (m) below GL	Unit weight (kN/m^3)	Cohesion (kN/m^2)	Internal Friction Angle (deg)
I	Filled up soil	0.4 – 2.9	18	0.5	28
II	Residual soil	1.4 – 6.6	19	5	30
IIIA	Highly Weathered rock	0.3 – 7.9	22	25	35
IIIB	Moderately Weathered rock	0.75 – 20.5	23	35	38
IIIC	Slightly Weathered rock	Max 22.6	25	50	40

The geologic formation at the site was typified by metamorphosed mica schist rock. The rock texture was generally foliated and platy having fine to medium grained deposits. The mineralogy of the rocks showed presence of mostly mica minerals (biotite, chlorite, and muscovite) with occasional deposits of quartz and feldspar. Study of the borehole logs showed that the site had overburden of soil of mainly cohesionless nature, followed by mica-schist rock in varying degrees of weathering occurring at relatively shallow depths.

The recommendation of the report for the bearing capacity at the designated depth and the expected bearing pressure from the structure are summarized in the following Table 2.

Table 2. Foundation Bearing Capacity

Foundation for structure of	Fdn type	Size (m)	Depth (m)	Settlement sensitivity	Expected load (kPa)	Safe bearing capacity (kPa)
Main Process Plant	Raft	25 x 70	-3.0	High	300	60
Raw Material Car	Strip	3	-3.0	High	200	175
Waste Flue exhaust	Raft	ϕ 22.5	-7.0	High	250	125
Product Cooling tower	Isolated	5 x 6	-3.5	High	200	200
Raw material bunker	Isolated	10 x 12	-6.0	High	350	150

The analysis of data from the initial set of investigation showed that for the some of the major plant units, the expected foundation bearing pressures would exceed the bearing capacity computed for a total allowable settlement of 20mm. Discussion with the design team resulted in considering option of placing some of the critical and heavy loaded structures on piled foundations.

Further analysis of the bore logs revealed that in many of the boreholes across the site, weathered rock would be available at quite shallow depths. It was also understood that the suggested bottom of foundation levels was not only guided by geotechnical parameters but also due to functional requirements of the plant units with the presence of cellars and basements accommodating process equipment. The piles that could be reasonably installed from the required bottom of foundation (pile cut-off level) to the termination depth by socketing into rock would be quite short and the short piles would not provide required lateral resistance. Thus, though the piles would be effective in carrying the vertical loads from superstructure loads with desired control of settlement, they would be inadequate is resisting lateral shear from the structure loads.

To eliminate change in design of foundation a different construction technique was planned. The excavation depth was extended beyond design bottom of foundation level till suitable foundation medium corresponding to suitable match of bearing capacity and generated foundation bearing pressure shown in Table 3 was reached. The bearing capacity of the various layers were computed using standards procedures in IS 6403/ IS 8009 for foundations in soil and IS 12070 for foundations in rock. The depth between the planned bottom of foundation and the extra depth till suitable founding stratum was found at greater depth was to be filled with mass concrete filling. Detailed study on this proposal was carried out using the information from the soil investigation report, experience of foundation construction in adjacent areas and techno-economic feasibility.

The second element of triad planning, a dynamic work plan strategy, was thus brought into the picture by changing the initial foundation design and adopting a strategy based on technical merit and project parameters of cost and schedule. The modified foundation design approach was deliberated in detail and agreed to by all stakeholders in the project including the plant owner, the design team and the execution contractor as the most viable option for the project. The bearing capacity of the various strata revealed in the soil investigation program are shown in Table 3.

Table 3. Bearing Capacity of Open Foundations in Different Strata

Strata	Description	Foundation type	Depth* in layer (m)	Bearing capacity (net, kPa)	Settlement (mm)
I	Filled up soil	-	-	-	-
II	Residual soil	Isolated (B<5m)	2.0	200	25
IIIA	Highly Weathered rock	Isolated (B<5m)	1.0	350	25
		Raft (B<25m)	1.0	350	50
IIIB	Moderately Weathered rock	Rock bearing**	-	400	-
IIIC	Slightly Weathered rock	-	-	-	-

(*) The depth of foundation is measured from the top of the layer/ strata.

(**) Gross bearing on rock calculated as per IS 12070[5]

Study of the rock profile across the boreholes and the recommended bearing capacity in various strata confirmed that the highly weathered rock of Stratum IIIA would be able to bear the loads from the superstructure by transferring the loads from the desired bottom of foundation through the intermediate rigid layer of mass concrete fill. This option was analyzed in detail including the cost and time involvement and compared with these parameters of piled foundations.

It was found that the option of removal of the residual soil of stratum II and providing PCC fill from bottom of foundation till the competent bearing layer was reached in weathered rock of stratum IIIA was an optimum design. Though on purely cost basis, the relatively short piles designed for vertical loads would be less costly than the total cost of removal of the soil and replacement by mass concrete fill there would be significant gain in time for foundation construction. Piling work would involve specialized operations of drilling, pile casting, waiting for 28 days for concrete to gain strength before pile head dismantling before the foundation raft/ pile cap could be constructed. Piles would also have to be load tested – both initial load test and working pile load test would have to be carried out. The alternate foundation proposal involved less specialized and fewer number of activities. The differential cost of construction would be more than offset by the gain in project scheduled completion by about 2 months and the early production from plant after completion would give a much larger beneficial economic impact to the owner.

To implement this effectively, it was necessary to supplement the data from the first phase of soil investigation to get more closely mapped soil stratification data. The weathered rock profile of stratum IIIA which was found to be adequate for supporting the structure loads needed to be characterized across the site more accurately.

The third element of the triad approach, real-time measurement, was now brought to bear. Along with the initiation of foundation construction activity, additional boreholes were planned at the site – 18 boreholes in the main plant area and 5 in the auxiliary plant area. The bore logs were used to map the rock formation in closer grid to trace the depth of the weathered rock layer across the site under the various structures and determine the thickness of the concrete fill required under the foundations. Fig. 4 to 7 show the map of the site with the layout of the proposed plant facilities on which is superimposed the layout of boreholes, ground level at the borehole location and the elevation of top of stratum IIIA. This map was used to plan the required initial planned depth of cutting for removal of the residual soil of stratum II.

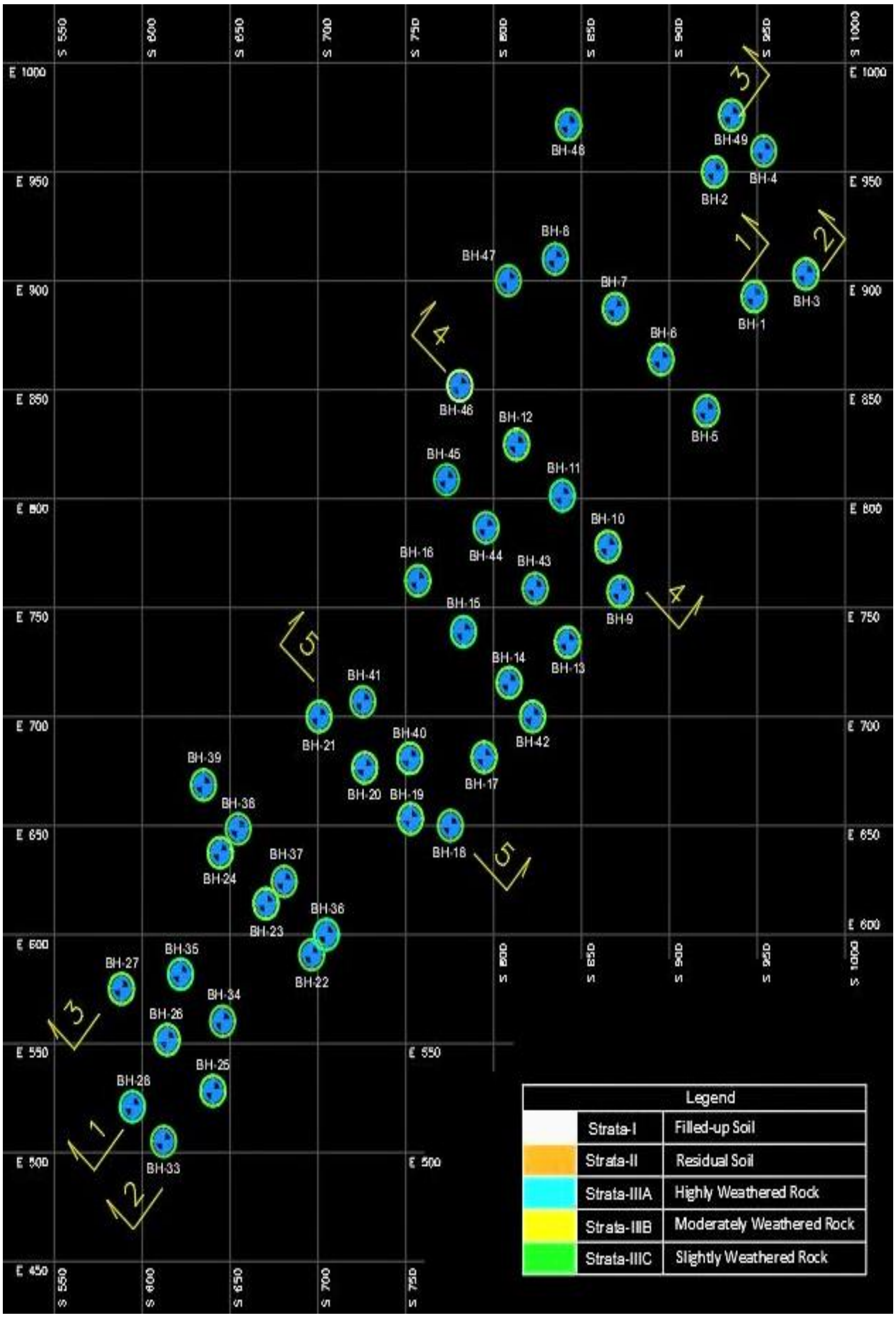


Fig.4. Map of site showing Ground Level and Rock profile across site in Main Plant Area

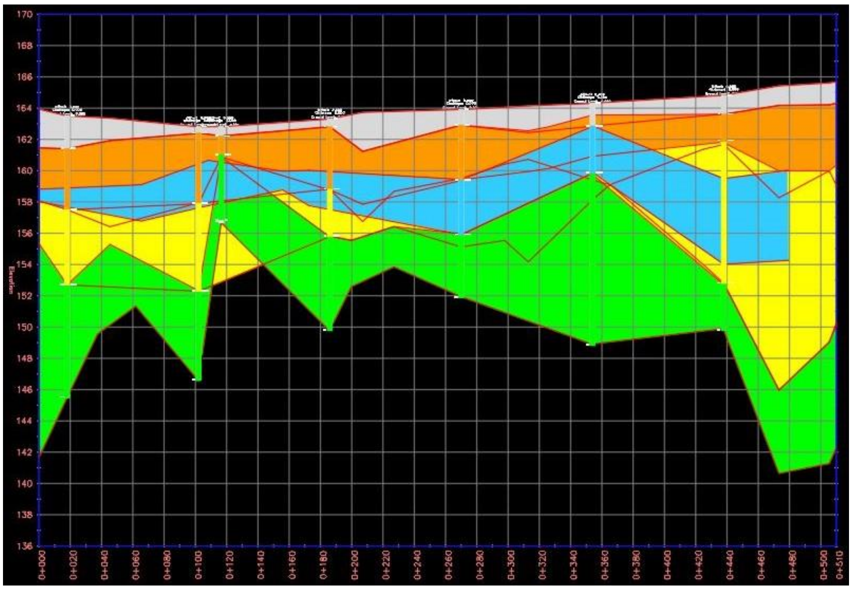


Fig.5. Section 1-1 – Subsoil profile below Main Process Plant foundation

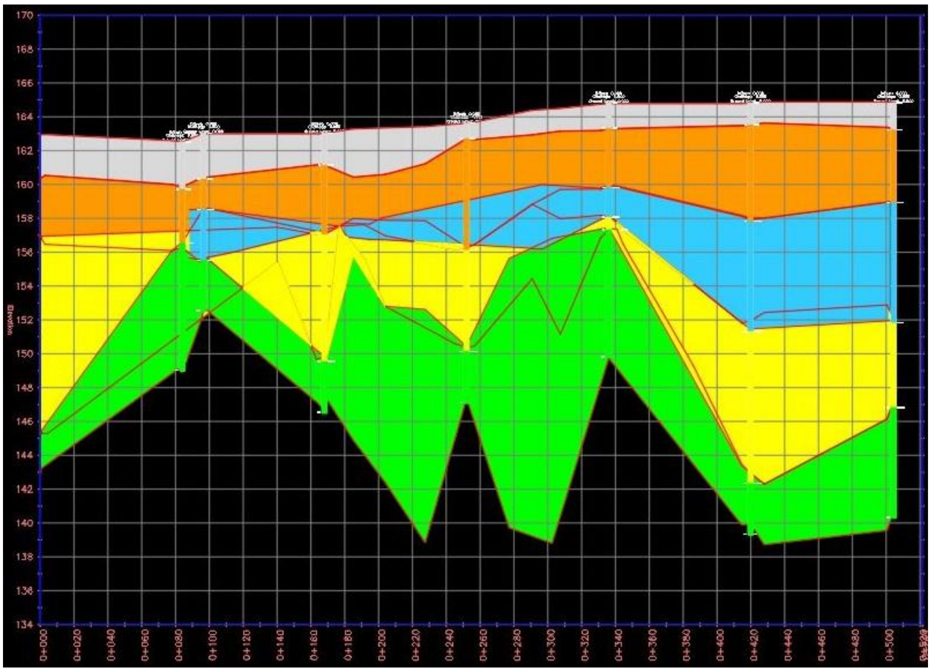


Fig.6. Section 2-2 –Subsoil profile below foundations of Raw Material Car, Raw Material Bunker and Waste Flue Exhaust

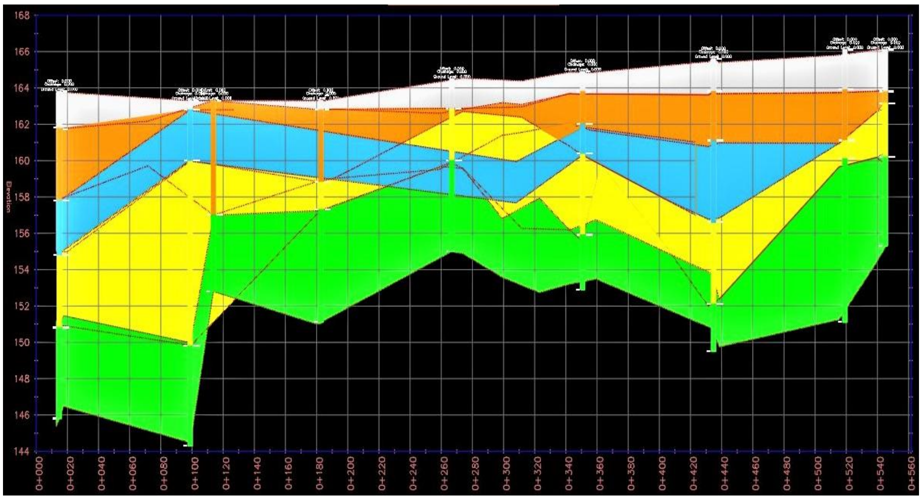


Fig.7. – Section 3-3 – Subsoil profile below Product Cooling Tower & Product Transfer Car Track Foundation

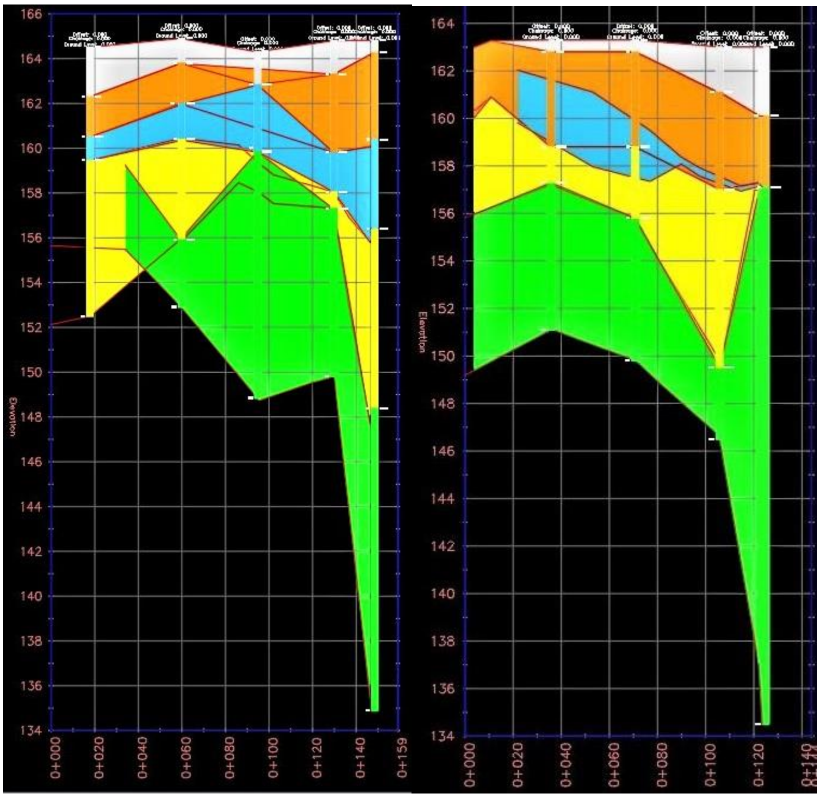
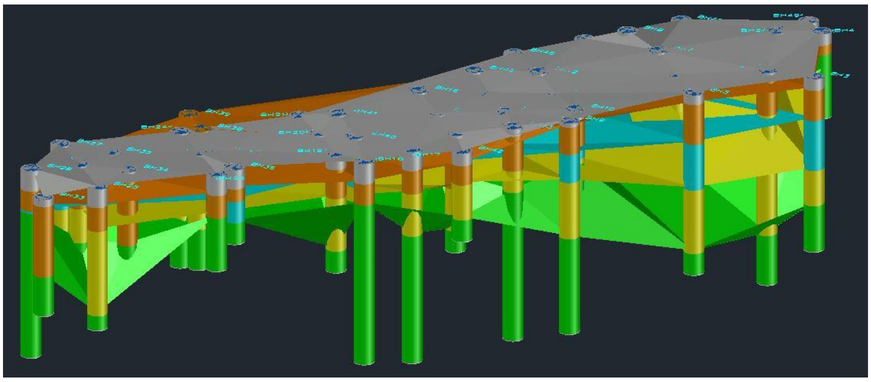
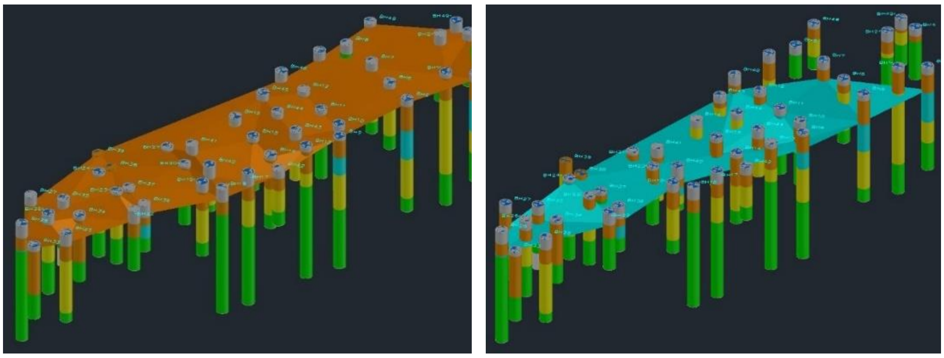


Fig.8. Section 4-4 – Subsoil profile below Product Cooling Tower & Product Transfer Car Track Foundation

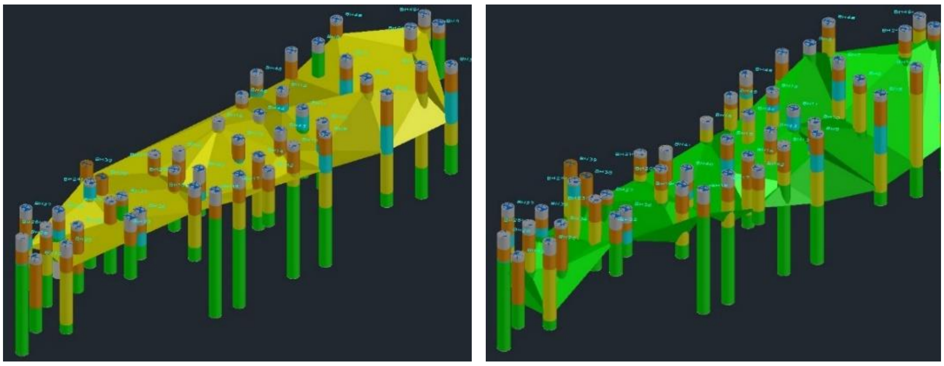


Strata - I: Filled-up Soil at Top with all Sub-soil Profiles



Strata -II : Residual Soil

Strata -IIIA: Highly Weathered Rock



Strata -III B : Moderately Weathered Rock

Strata -III C : Slightly Weathered Rock

Fig.9. Map of site showing Ground Level and Rock profile across site in Main Plant Area

The RTM approach was deployed during the actual execution of the work at site. The site characterization map shown in Fig. 8 had mapped the depth of occurrence of suitable foundation strata in terms of bearing capacity for the various structures identified in Tables 2 and 3. For successful execution of the designed foundation solution the critical activity of correct identification of the stratum IIIA/ IIIB was necessary during the excavation work at site. To effectively implement this requirement the geotechnical engineers on site had to devise simple tests for identification of the excavation having reached the weathered rock level before certifying its adequacy for foundation construction. These tests and the acceptable outcome were documented in the form of standard operating procedure (SOP)/ site instruction (SI) for the quality assurance activity by the team of geotechnical engineers. The simple tests devised comprised three approaches. The first was a visual inspection of the excavation bottom and comparing it to a pictorial representation of correctly identified formation previously marked by experienced geotechnical engineers. The second test used at site consisted of striking the excavated base layer with a Geological Hammer to check if it formed indentation on the surface. The third test comprised using the teeth of the excavator to scratch the exposed base layer and noticing when the teeth were unable to leave scratch marks on the surface with full hydraulic pressure applied on the cutting tool. The three-step quality check would ensure that the excavation had reached the desired founding strata and all records of such quality check was maintained for verification.

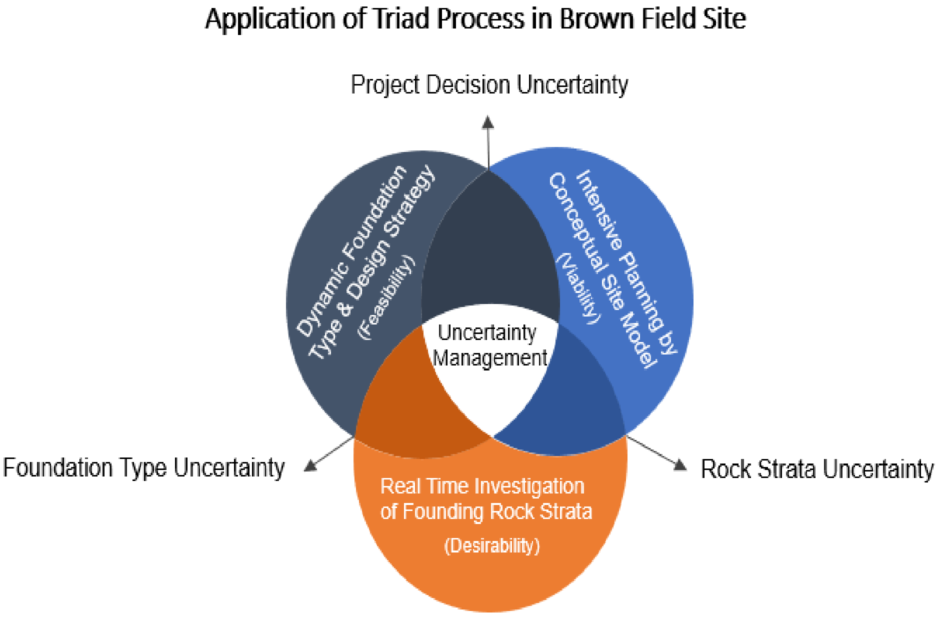


Fig.10. TRIAD application parameters for Site Characterization of Brownfield site

6 Challenges and Mitigations

Despite applying the triad principles for geotechnical characterization of this complex site and project requirements, there were other challenges to be considered during the execution stage. This required continuing with the inter-play between the three tools of the triad approach shown in Fig. 9 for the construction stage activities together with involvement of the design team. An important consideration of great concern with mica-schist rock is that the strength of this type of material decreases rapidly on exposure to atmosphere or when submerged under water. To address this potential risk of degradation of founding medium, the SOP/ SI addressed this issue also. Excavation work would be carried out in parts and not over large expanses so that the exposed rock surface is not left unprotected for long time. When the excavation in a zone would reach the mica-schist layer of stratum IIIA as confirmed by the QA/ QC engineer, the base would be levelled off and covered with lean concrete layer of minimum 150mm thickness within a time gap of not exceeding 2 hours. Excavation in other parts would proceed only after the sealing of the rock surface was completed in the exposed zone.

7 Conclusions

The execution of the project at this brownfield site threw up many complexities due to challenges posed by difficult site. The site location was amidst existing operating plant. The bearing pressure requirement for the different types of structures were widely varying. There was variation in soil layering even within the relatively small zone. There were also project requirements of execution within schedule and budget while addressing safety and quality aspects. To execute the plan for foundation design and construction successfully, proper identification of suitable subsoil stratum and using its geotechnical properties for each specific structure was of great importance. The successful application of the TRIAD approach for subsoil characterization [7] of a brownfield site resulted in the following benefits:

1. Development of geotechnical site characterization in brown field site for the process plant
2. Enabled selection of suitable foundation stratum with adequate bearing capacity corresponding to specified superstructure loading and settlement sensitivity of the structure
3. Formulate suitable strategy to deploy verification of adequate founding layer for the structures in varying subsoil conditions
4. Clear presentation of information to all stakeholders to facilitate smooth and consistent decision-making regarding foundation placement
5. Facilitate redeployment of strategies through data generation, integration and presentation in pictorial representation

6. Even in case of phase-wise plant construction, detailed subsoil characterization at initial stage can lead to significant cost and time saving on overall project from design to construction phases.

Acknowledgement

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