Engineering Subsurface Constructions

Dr. Niranjan Swarup, P.E.
Director General
Indian Society for Trenchless Technology

1. Introduction

In order to perform, subsurface structure is required to withstand stresses and strains and other impacts of surrounding media or soil in addition to internal loadings. These additional stresses, at times, could be solely due to the soil or media engulfing the structure, but at others could also be attributable to the interaction of such media and structure. Structure under consideration has to withstand the combined effects of these two agents over its lifetime and has to be engineered accordingly. In addition, at times, the construction process, applied to create or maintain this structure, becomes strenuous enough itself to strain or damage the structure to such levels that it could fail even before it was put to use. Such situations could occur in trenchless technology installation or rehabilitation methods resulting into another set of loading impacting the structure for a limited period of time. These stresses might become higher than the normal stresses and a special attention has to be paid to account for them.

For a structure, to be capable to withstand all these and deliver the designed services, proper engineering of the system is imperative. Engineering subsurface structures requires evaluation of all such influences and needs application of several branches of Engineering. Individual responsible for such activity needs to have proper understanding of basic engineering elements for success. Judicious application of these elements for a given set of deliverables would be able to provide the necessary directions & adequate guidance to enable the engineer to engineer the subsurface structures. Failure to recognize any impending stress agent or situations would lead to faulty engineering with reduced lives of structure, engulfing media, and also other structures in the vicinity leading to consequential damages as well. Proper design & planning of works is the essence of this engineering & this article discusses such matters briefly.

2. Engineering the Buried Structure

A buried structure has to withstand different stresses over its entire economic life & overcome the resulting strains and failures. Engineering of such structures, therefore, is the planning & execution activity set to ensure creation of the asset or it’s maintenance, in the most optimum manner ensuring efficient applications of the efforts, materials, and resources. To start, let us first define the term ‘engineering’.

Engineering, as defined, is the application of mathematics, empirical evidence and scientific, economic, social and practical knowledge in order to invent, innovate, design, build, maintain, research and improve structures, machines, tools, systems, components, materials and processes.

Engineering subsurface structure should therefore be focused at ensuring that the subject buried structure is built or maintained to have sufficient strength that enables it to provide the required service the user over the entire design life without experiencing failures. So let us define failure. Failure could be defined as the state or condition of not meeting a desirable or intended objective. For buried structures it could be categorized in four groups, *hydraulic*, *operational*, *environmental*, & *structural*. Any buried structure during its design life is required to deliver on all these four accounts and failing on any one would mean failure of the structure. In other words, each structure would have certain performance limits for each of these heads and the engineer has to ensure that the constructed structure is able to meet them. Talking of applicability, such failures could be initially isolated, but the same may lead to consequential failures on later on other accounts. The need, therefore is that such initial failures are either arrested by the structure, on its own account, or through the intervention of maintenance efforts of concerned engineers. All such actions form a part of the thought process behind the engineering of buried structure. Briefly, if a structure doesn't fail it is successful, and an engineer's job is to ensure that the structure stays that way.

Concept of cradle to grave also is an important consideration in engineering, as the buried structure remains mostly out of sight so they go out of mind very easily. They would only be noticed when they fail and would have to be replaced at that stage. If failed, a replacement structure is needed to be built, while the damaged remains need to be removed from the right of way. They must either get absorbed in the engulfing media, or have to be removed physically with the least footprints possible. Selection of construction materials, therefore, has to be as green as possible ensuring the smallest possible footprints at that stage.

With the advent of newer technologies many new working methods are getting evolved with each newer technique & as an engineer one needs to cultivate his or her knowledgebase to identity the best possible solution to a given engineering challenge by using the conventional methods or the newer ones. An overall growth of engineering process is an important ingredient for success of engineers in the current situation & engineers are encouraged to consider their role in this direction.

3. Prime Engineering Principles involved the design of Buried Structure

The buried structure, in order to render the required services, has to perform under a given set of constraint & end conditions. The ultimate aim of an engineer, therefore is to plan, design, construct, and maintain a structure in such a manner that the product thus created or managed is able to withstand the applied weathering factors, and is functioning effectively & efficiently over its entire design life, while the failures are avoided.

Objective of engineering a buried structure, therefore, is be to identify most optimum arrangement of structural elements & surrounding media leading to creation of a structural system capable of withstanding the loads, both internal as well as external during a defined lifetime while rendering the required services successfully.

Optimum expanse of resources therefore the key to the engineering of such structures. This could be ascertained by applying certain principles of core engineering. The set of prime engineering principles influencing the engineering process would include:

1. Structural Mechanics of Buried Elements
2. Soil Mechanics of the Engulfing Media
3. Soil – Structure Interaction Mechanics
4. Site Constraint Mechanics

If one evaluates the behavior of any buried structure for these four aspects under a given set of loading and constraints, he or she would be able to identify the actual end conditions & requirements that the structure will have to overcome while rendering the services and meeting the duty conditions. Based on this result, the linked numerical values to configure & size the system could be ascertained. Once such values are known, appropriate material, its configuration & other relevant attributes could be identified.

This identification would enable the engineer to adequately design the structure & identify the construction process, necessary to achieve the desired goal.

For buried structures each of these four factors are significant, as the structure's performance shall be influenced by all of them, both individually as well as in combination. If the structure, under development, is unable to withstand the stress/impacts due to internal or external factors attributable to any one or more end conditions, it could fail & may not be able to render the required service during its design life time. So for success, the engineer needs to identify all the possible situations that the structure could be subjected, & quantify the effects expected due to the set of constraints to overcome.

This quantification process forms the basis of project engineering of such structures. Now let its look at these items individually to get a clearer picture.

4. Structural Mechanics of Buried Elements

Structural mechanics could be defined as the computation of deformations, deflections, and internal forces within structures, either for design or for performance evaluation of existing structures. Any buried structure would have its characteristic behavior when subjected to loadings. By evaluating such behavior one would be able to quantify the stress & strain values on various loading scenarios and the analysis would be able to provide proper inputs for design and construction. Structural mechanics of buried elements of structures includes considerations pertaining but not limited to, internal pressure, strength requirements for handling, structural stability of form, & related stresses apart from other linked issues & the combination thereof.

By this analysis the engineers would be able to identify the stresses structure would be expected to face in its exposed state without any consideration of the effects of soil or other impacts. Based on the stress evaluation the engineer could select various properties of the inputs and size the structure to withstand the stresses.

5. Soil Mechanics of Engulfing Media

Soil mechanics is defined as branch of engineering mechanics dealing with the behavior and properties of soil as they could affect its use in civil engineering. Though applied for every civil work its importance is higher for buried structures as the behavior of engulfing media would be impacting the complete structure rather than the structure foundations in other cases. Though engulfing media provides stability to structure, but it also becomes an agent of instability due to various actions and movements leading to development of additional stresses and strains on the structure. Soil mechanics for buried structure cover considerations pertaining, but not limited, to soil plasticity, stresses induced due to soil slice above structure as well as surrounding soil, soil properties & limits, soil movements, seismic impacts, soil & ground water movement.

By this analysis the identified stresses & related strains could be identified considering only the static impacts of engulfing soil mass over the buried structure. In some cases, the resultant forces on the structures could be having reduction, balancing, or reversing effects over the naturally occurring loadings on such structures. The analysis therefore should verify the final loadings for proper design.

6. Soil Structure Interaction Mechanics

The process in which the response of the soil influences the movement of the structure and the movement of the structure influences the response of soil is termed as soil-structure interaction. The governing mechanics, that is otherwise ignored for above ground structures, plays a major role in case of buried structures and therefore needs to be evaluated for the design and construction purposes. Soil structure interaction cover considerations pertaining, but not limited, to external hydrostatics, flotation, leaks, form deflection, cover consideration apart from other linked issues & combinations thereof.

Upon conducting this analysis, the engineer would be able to evaluate the effect of the combination of the applied forces both superimposed, as well as naturally occurring during usage period of buried structure.

7. Site Constraint Mechanics

Many a times the subsurface construction wok execution is restricted or limited by site linked constraints leading to the application of extra ordinary execution methodology designed specifically to overcome the limitations. The execution or construction process, in such cases, could subject the complete structure or its parts to forces that may exceed the force/ stress carrying capacities of the structure designed for the normal loadings as discussed in earlier three sections. The engineer, in such cases, has to engineer the structure, in the whole as well as at the components levels, to withstand such additional stresses expected to be experienced by the structure during installation or construction.

Some of the major examples include trenchless technology projects. Here, as the works are executed through remotely operated trenchless techniques, the components are subjected to varying levels of installation stresses based on the working methodology, material properties, soil characteristics, and the complexities. Based on these issues, engineer has to identify the suitable system of project execution that enables one to create the subject buried structure efficiently. Analysis of this system, in turn, would help in identifying the quantum of installation stresses and strains. Such identified values then could be compared with the values identified by the earlier three mechanics evaluation and the highest of all could be chosen as the design limits for engineering of structure or its components.

Site constraints considerations include, but not limited to, the issues pertaining to site access, subsurface network density, geological & geospatial constraints, project logistics, & other linked issues & combinations thereof.

8. Subsequent Engineering Steps

Subsequent steps of engineering design of buried structure include the following major activities:

- detailing of components,
- selection of suitable materials,
- sizing of structural elements,
- defining the construction process & methodology based on the duty conditions of the structure,
- identification of critical equipment,
- documentation of the execution process,
- detailed financial analysis,
- land and right of way acquisition,
- contract condition identification,
- selection of executing agency and award of contract,
- project execution and documentation,
- Project conclusion and creation of as-built drawings.

9. Reengineering During Project Execution

Work of an engineer doesn't stop at any of these stages as the design needs to be implemented & structure has to be developed according to the plans prepared on the basis of the engineering activities conducted till then. However, as there is substantial amount of uncertainty in subsurface construction activities in general and in each of the four mechanisms discussed till now in particular, engineers need to make certain assumptions. These assumptions, may or may not be unison with real ground situation, as the site conditions may differ from the assumptions. The engineering process, therefore has to continue & one has to alter or modify the assumptions made in the earlier stages, to bring them closer to the reality. This correction process continues all through the design, planning, bidding execution & even during commissioning of & operations structures. As there could be possibilities of abrasion even after commissioning this evaluations process has to continue all through the life of the buried structure since this can provide valuable inputs to engineers maintaining and managing the structures later.

10. Third Party Supervision

Another linked issue is of work supervision through independent engineer. One of an important factor is of third party engagement. The engineer, who has desired the system, may suffer from myopic vision &

might not be able to see the impeding failure of structure or working system here the role of third party engineer assesses significance as this person can bring the basic objectively in the complete system.

11. Equipment & Manpower

Another in factor is the equipment & manpower capabilities. The system devised by the engineer would be vulnerable & susceptible to fail if proper execution is not done. This would be due to faulty equipment or unqualified executing persons need to cover this aspect as well.

12. Conclusion

Subsurface construction is the future & as construction engineer one needs to be adequately empowered capable to engineer it. Engineering the subsurface construction works would generally include developing a working scheme, designing the structure, working out the executions methodology, contracting this work, getting it executed by capable system so as to achieve successful structure. Major issues in such engineering, to be addressed, could be grouped into four clear sectors. These are the structural mechanics of the buried structure elements, soil mechanics pertaining to the surround soil mass, soil structure interaction that would define the final behavior of the buried structure, & last but not the least, the site constraints.