Chapter 13

THE FOUNDATION PROBLEMS ON THE GULF COAST*

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The foundation problems of the coastal region of the Gulf of Mexico are unique. Normally, a coastal region is thought of as the land area, such as a plain, adjacent to a body of water. Such a region usually is somewhat regular in its geology and because of the natural resources, terrain or climate may be given to a relatively common industry involving a somewhat similar development throughout. The coastal region of the Gulf of Mexico, as regards the United States, violates this criterion in a multitude of ways. The region is not limited to the coastal plain bordering the Gulf of Mexico, by any means, but, rather has been broadened by our commerce and the need for the development of natural resources to also embrace, the delta areas and offshore belt extending to the limit of the continental shelf, lying as far as 70 miles from the shore. The delta areas have long been avoided in the past by industry of all types; that is, with the exception of the fishing industry, because of the unstable nature of the foundation media. Likewise the continental shelf area normally is not considered for industrial development because of the availability of the more desirable coastal plain. However, the quest for natural resources, like sulphur and petroleum, in spite of the efforts toward Federal Control, has made necessary the solution of very extraordinary foundation problems in this offshore area. In addition to the foregoing unusual aspects of the foundation problems of the Gulf Coast, the coastal plain is unusual in itself because this region at one time formed the floor of the Gulf of Mexico and, as the sea receded or the land was uplifted, the residual sedimentary soils have been drained and desiccated to result in unusual formations that serve as foundation media for the industrial and domestic developments of the region. The foregoing factors combine to make the foundation problems of the Gulf of Mexico Coastal Region very interesting.

Consideration of the foundation problems of a region must logically start with a brief review of the geology of the region. The geology of the Gulf Coastal Region is fascinating. It may be divided into three broad divisions from a foundation point of view. The first broad division embraces the coastal plain area that lies some miles inland at the present time. The surface and near surface strata dip toward the Gulf. These strata are usually alternate layers of sand and clay which are well drained and somewhat desiccated to a relatively advanced state of

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consolidation, so they thus serve as reasonably desirable foundation media. The second broad division embraces the area of the former deltaic deposits of the rivers emptying into the Gulf, which lie between the coastal plain and the present shore line. This area exists in the form of a belt bordering the Gulf, varying width from a few to about 70 miles, with the exception of the major contributor; namely the former delta of the Mississippi River which extends inland many miles. This area is very significant because it is the one in which great development of natural resources has occurred and also has been the area in which the industrial development has been and will continue to be very great. The materials comprising the former deltaic deposits are generally sufficiently matured by drainage and desiccation to now be in a reasonable stable condition; however, somewhat less stable as foundation media than the materials comprising the coastal plain. The third broad division embraces the presently growing deltaic areas forming at the outlets of the rivers discharging into the Gulf of Mexico. These areas are of two categories; namely, those that have grown above Gulf level and those that have not. Those that have grown above the level of the Gulf have only begun to mature; consequently, they are in the process of draining and consolidating and, at present, are in a relatively unstable condition as regards foundation media. Those that have not grown above the level of the Gulf are still growing and have not started to mature. They have not begun to drain except for that resulting from consolidation caused by the weight of the material itself. These materials are in a very unstable state to considerable depths requiring very careful analysis when used as foundation media. The major element of this area is the offshore deltaic deposit of the Mississippi River that is fan-shaped and slopes gently toward its fringe, which lies as much as 70 miles offshore. Extensive development of the natural resources such as petroleum and sulphur have been initiated in this area.

The development of the Gulf Coastal Region for many years was paced by the growth of the agricultural industry and the commerce that flowed both to and from it and the central and southwestern portions of the United States. The discovery of very extensive natural resources, of which low cost natural fuel is an important one, has caused an industrial invasion of the region. Many well established industries have moved into the region and many new industries have been created because of the fuel and other natural resources discovered. Accompanying the industrial invasion and development of the resources there has been a great growth of the foundation problems.

The foundation problems have varied with the advance of the industrial development, the types of structures required and with the geology of the region in which the industry is located. The initial development of the petroleum, gas and sulphur industries occurred in the former or old deltaic area of the region. Likewise the industrial development had its beginning in this same area where it will be continued because it is the logical location as regards transportation, centers of population and central location with respect to the natural resources. However, with the ever increasing demand for natural resources, there has been an expansion of the petroleum, gas and sulphur industries, particularly as regards the production facilities of these resources, toward the Gulf of Mexico into the recent deltaic area and, further into the now forming deltaic areas; that is, into the waters of the Gulf of Mexico with some of the structures located as much as 30 miles from shore.

The Civil Engineering profession has followed the old economic law of "Supply and Demand", but in reverse. For with the creation of a demand, the profession has supplied the technical and economic solutions for the problems. Accordingly, during the late 1920's when the industrial and natural resource development was beginning the foundation problems were modest and our knowledge was limited, solutions that were thought to be simple and economic were used. For example, it was the rather common practice to use piles for the substructures of the then larger structures and shallow spread footings for the smaller structures involved. However, as the demand increased for larger and more economical structures in the old deltaic area, knowledge of the foundation media and means of economically transferring structural loads at these media had likewise increased so that improved methods were created to replace the expensive and questionable pile substructures except, when especially suited for a specific purpose.

The improved methods of design and construction are the outgrowth of improvements in the methods of exploration, sampling and testing so that knowledge of the pertinent factors of the foundation media can be gained as required for rational analysis. Further, knowledge has been gained of the intensity and distribution of the stresses created in soil masses by the various types of substructural elements by the researches of Dr. Leo Jurgenson and the Waterways Experiment Station so that rational analysis is possible now for foundation problems. Concurrent with the accumulation of this combined knowledge there has been the development of the machines for boring shafts, with enlarged bell-shaped bottoms, both large (maximum of 12 ft. diameter) and small to shallow or large depths (maximum of about 80 ft.) to transfer the structural loads through the unstable surface strata to the underlying consolidated and stronger strata capable of supporting the loads with the factor of safety desired. For circumstances requiring footings larger in area than can be produced by the machines, open excavations for the conventional spread footings are normally used.

The important problems to be solved in the design of this type of substructure is the determination of the depth to which the footings should extend and their dimensions. Usually one would think both of these factors would depend entirely upon the strength of the materials forming the foundation media. However, in the old deltaic area many of the surface clays, such as the Houston or Beaumont Groups, experience appreciable volume changes accompanying seasonal variations of moisture content. Accordingly it is important to extend the substructural elements into the zone of the capillary fringe of soil moisture so as to preclude the effect of volumetric changes. In addition it is important to either provide a suspended floor system or a floor that is independent of the structural frame for the ground or basement floors. Further the grade beams for the structural frame should always be designed so as to be protected from the swelling clays, which have been observed to exert vertical pressures of the order of ± 10 tons per sq. ft. It has been interesting to observe the scars left in the clay formations experiencing volumetric changes. These clays are locally termed "slickensided" because in shrinking many shear fracture surfaces are formed throughout their mass. Accordingly shear strength, as determined by the unconfined shear test, are low and very erratic, however the identical soil within the zone of the capillary fringe usually is relatively homogenous and possess considerable shear strength. A plot of the unconfined shear strength with respect to depth usually serves as an excellent means for determining the depth to which the "slickensided" condition extends. Subsequent to the defining of the depth of the fractured zone, the selection of the stratum in which to found the footing is a matter of economics. The determination of the diameter or area of the individual footings can be made in accordance with the procedure described in "Soil Mechanics in Engineering Practice" by Terzaghi and Peck.

The foregoing procedure has been used by the author for the solution of foundation problems for industrial and office buildings, large surface storage tanks, heavy machinery foundations, large incinerator plants and a multitude of other structures. The Texas Highway Department has made extensive use of essentially the same procedure for the substructures to support the bridges and elevated highways for the urban expressways of Houston and other cities in the state.

The state of consolidation of the foundation media in the old deltaic formations is generally so well advanced that the estimation of the settlement of structures in this area is of secondary importance; that is, unless such is required for a special purpose. The procedure usually used conforms to any of those described in well recognized texts on soil mechanics. A careful check of this matter is made for important structures to determine the influenoe on the structure. Numerous reports of observations of structures in the area of interest have shown the estimates of settlement based on the Terzaghi Theory of Consolidation, are valid.

The foundation problems experienced in oonnection with port structures, such as wharves, are significant to the development of regions like the Coast of the Gulf of Mexico. You may recall from your memory of the maps of this coast that most of the harbors are located on rivers or bays. At these locations the sites for the port structures are frequently either in the old deltaic formations or near their junction with the recent formations of this nature; consequently it would be opportune to discuss this type of problem.

The majority of the wharves constructed in the coastal region during the 1920's and 30's were the conventional bridge type formed of treated timbers and supported by wooden or concrete piling. At the time of their design and construction, knowledge of foundation engineering was rather limited when considered in the light of the present day status, so it was natural that conventional structures would be used. However to meet the present day criterion of "economy through engineering", it has been necessary to mobilize and apply all of our knowledge to establish the best suited structure for this purpose.

An excellent example of what can be done is the new Wharf 16 recently completed for the Port Commission of Houston. It is the second of two such structures that are new to the Gulf Coastal Region differing radically in principle from their predecessors. The prime purpose in initially advocating the new approach to this problem was based on foundation difficulties previously experienced nearby which resulted in serious damage to former wharves of the conventional type, thus a "red" traffic light was glowing in our faces when the problem was first approached. A well planned and executed examination of the site immediately adjacent to the site of the former structures disclosed the presence of a stratum of fine-grained sand, about four feet thick existed between elevations -26 ft. to -30 ft. At the time the original structures were constructed the harbor floor was at elevation -25 ft. Subsequent dredging to permit navigation by larger vessels extended the harbor floor to elevations -30 ft. and later at -36 ft. elevation. After the latter dredging and, it is understood, accompanying the difficulty with the original structures, soundings are reported to have disclosed the formation of a sizeable deposit of the previously mentioned sand over the floor of the harbor. Observation of the surface features of the sites of the original structures disclosed the presence of numerous and extensive earth slides whereby the graded areas had moved downward and harborward. These facts showed that, in the selection of the substructure for this new wharf, consideration must be given to the extension of the substructure through any sand strata that might be subsequently exposed by later improvements to the harbor, or, provide a means for the complete confinement of such sands that might be displaced by piping.

The ultimate design recommended and used was a cellular bulkhead formed of steel sheet piling or, in other words a coffer-dam type of substructure. The sheet piling forming each cell were planned to extend through the fine sand strata into the structurally sound underlying clays to form a double barrier to piping of sands into the harbor. The cellular bulkhead was greatly reinforced and appreciable economy thereby affected by filling the cells with a selected sand that was placed in layers and densified in place by vibratory methods. The use of this type of cell filling in a densified condition resulted in an increase of the strength and stability of the structure of approximately 20 per cent. The void between the bulkhead and a natural bank was also filled with densified sand placed in a like manner. The topping of the sand backfill and over the cellular bulkhead was formed of compacted earth to form the subgrade for the pavement of the open apron of the wharf.

The economy of this new type of wharf or port structure over the conventional bridge type may be of interest. Competitive construction bids were secured for the new and the old types. A net saving of approximately $550,000 was aohieved by the use of the cellular bulkhead type.

The editorial comment on the type of wharf just described, appearing in the English magazine "The Dook and Harbour Authority" published in London, August 1951 is of interest. It is quoted as follows: "It seems that oellular bulkhead substructures for wharves have possibilities in certain situations, which might well be further explored in this country."

The limitation of time precludes treatment of many of the interesting foundation problems arising in the old and new deltaic formations of the Gulf of Mexico Coastal Region. To briefly enumerate some of the types of structures involved may suffice. They are the stability examinations for the design of the banks for channel improvements and new waterways; fresh water reservoirs that are being required more and more frequently by industry in this region; large petroleum products and chemical types of industrial plants; and highway embankments and bridge structures.

One of the new types of foundation problems arising in the offshore and presently forming underwater deltaio area is most intriguing. There are others, I assure you; however, the drilling platforms required for offshore production (oil and gas) has been discussed extensively in current engineering literature and cannot be passed in this paper without brief reviews. The quest for more natural resouroes has prodded the oivil engineer to seek solutions to this foundation problem and much has been learned from these studies; however, much remains to be learned.

The majority of the sites for these structures are in the unconsolidated deltaio deposits, which are still growing, and form the bottom of the Gulf of Mexioo. Acoordingly, the materials comprising the foundation media have not been drained or oonsolidated except under their own weight and that of the overlying materials whose effective pressure is very low because of their submergence. Therefore the foundation media possess relatively low strength.

The loads to be supported by the substructures are large, approaching the magnitude of those experienced with sizeable bridges. These loads are caused by the heavy drilling maohinery required for the drilling operations and for the produotion operations if the wells develop as their planners hope.

The pile substructure has been used for these structures. It lends itself to this use admirably beoause, if properly designed, it is oapable of transferring large loads through weak materials to stronger and deeper portions of a foundation medium. Further, the pile is capable of distributing its applied load to the material penetrated either through friction or by point bearing in the event strong materials are encountered.

The design of the penetration depth of piles as for specific vertical static load supporting capacity in the past has largely been based on arbitrary formulae evaluating forces created in driving a pile and the penetration achieved. Many formulae have been proposed, used and their results evaluated with somewhat disappointing results if the information was evaluated carefully. It is understood these arbitrary formulae were used in some instances for the early platforms designed and constructed. In other instances the piles were driven to very great depths to essentially refusal in order to be sure of their supporting capacity. However, the matter of economics began to have its influence and as a consequence the spotlight of engineering attention has been directed on this problem with gratifying results. It may be interesting to note at this point that the investment involved in an offshore drilling platform alone is sizeable for it may vary from a quarter to a million and one-half dollars.

It was my pleasure about a year ago to study the substructural aspects of two pile platforms, one constructed and the other proposed, in the new deltaic area of the Mississippi River. Complete information on the kind, arrangement and strengths of the foundation media were available. The basis for the approach to the problems was that the vertical supporting capacity of a pile, whether it be formed of steel, concrete or wood, depended in these instances upon the available soil friction about the periphery and for the length of the penetration. The friction developed would be influenced by the material forming the surface of the pile. For example, in the case of a concrete pile if the skin surface was very smooth, such as would result from vibrated concrete placed in a metal form, driving would be facilitated but to produce load supporting capacity long penetration would be necessary because of the low soil friction. On the other hand, if the skin of the pile was roughened by placing burlap against the smooth metal forms when the concrete was placed, so as to produce a rough textured surface, the soil friction would be mobilized to a larger extent. In the case of steel piling the normal oxidation of the surface of the steel serves to provide a bond with the soil penetrated so as to mobilize the shear between itself and the soil. Further, the penetration of a pile into soil produces a rapid consolidation of cohesive soils adjacent to the pile and to densify oohesionless soils due to the volumetric displacement, both of which increase the shear strength of the soils immediately adjacent to the pile.

The results of both analyses showed that rational vertical loads supporting capacities could be developed. Subsequently, vertical loading tests of similar piles used in the same general vicinity showed that capacities determined by the foregoing procedure were within 10 to 15 per cent of the analytical results and for vertical pulling tests, the results were within 7.5 to 10 per cent of the analytical results. Confirmation of analysis of the order indicated is very gratifying.

The overall security of the pile substructures for the offshore drilling platforms is not only a function of their vertical stability but also the lateral stability of the piles. The structures located in the open reaches of the Gulf of Mexico are exposed to storm waves of hurricane intensity and should be designed to satisfactorily meet these conditions. Unfortunately at present, technical knowledge is very meager about the horizontal forces the structures are actually required to withstand. The assumption made by designers regarding forces exerted on the structures by the hurricane winds and waves vary with the designer. Further, the assumptions made by the designers regarding the deflections, points of fixity and how the horizontal forces are transmitted to the foundation media by the pile substructures vary somewhat in the same manner as those pertaining to the forces themselves. This lack of knowledge has been appreciated by many interested in the problem and numerous efforts have been made to initiate research that would produce the information desired. These efforts are beginning to pay dividends, for research on a modest scale is being conducted by several interests. It is hoped that by the time the ownership of the tideland area has been established the sorely needed information will be available to the profession for intelligent design purposes.

The foundation problems in the new deltaic area have been treated tersely in this paper with no intention to slight them; however, the space available precludes extensive treatment. There are many other interesting problems that warrant mention at least; a few of them are: the design of economical foundations for underwater pipelines to serve the offshore oil and gas wells; and the design of the substructures for the pumping, and processing storage facilities for oil and possible sulphur in this region.

It is hoped the thoughts expressed in this paper will stimulate the thoughts of others interested in the problems of this nature so that the progress made to date may be greatly extended in the future in achieving economical designs for the problems encountered in the practice of civil engineering.