Shear Strength Maps of Shallow Sediments in the Gulf of Mexico

ARC GIS Version

by

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SHEAR STRENGTH MAPS OF SHALLOW SEDIMENTS IN THE GULF OF MEXICO

(ArcGIS Version)

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Introduction

In 1979, McClelland Engineers, Inc., a Houston, TX-based geotechnical engineering firm, released a series of maps portraying shear strength of sediments in the Gulf of Mexico (GOM) (Parker, et al., 1979). These maps, which provided shear strength contours at various depths below the mudline, covered the GOM from High Island area east to Main Pass area (the Central GOM). Although the primary use of the maps was deep foundation design, they did provide data at, and 10 ft. below, the mudline. McClelland cited uses of this shallow information for pipeline routing and jackup rig footing stability. Minerals Management Service (MMS) personnel have used the maps to evaluate pipeline stability, especially the potential for self-burial in soft sediments.

Since the maps were published, several major storms have pushed through the area of interest (National Weather Service, 2004) that may have influenced sediment strength by erosion, deposition or sediment mixing. As a result, MMS personnel believe the older maps need to be updated, especially in areas affected by strong storms. The Offshore Technology Research Center (OTRC) was funded by MMS to produce new shear strength maps for the Central and Western GOM. This report contains the updated maps and in ArcGIS format and describes the methodology used to develop the maps. A previous version has been submitted in Adobe Ilustrator format. The maps and explanatory information are contained on a Compact Disc (CD), which allows the information to be transferred directly to the MMS database. As opposed to hard copies, the maps can now be updated as new data become available. Consequently, the maps should never become outdated. Another advantage is that a proposed pipeline can be plotted directly on the shear strength maps, thereby allowing a quick visualization of sediment strengths to be crossed by the pipeline. Other features will be discussed later in the report.

Approach

The data used for developing the maps came from 749 geotechnical borings archived on microfiche cartridges by MMS, Gulf of Mexico Region, New Orleans, LA. “Mining” the data was originally accomplished by OTRC personnel operating at the MMS regional office in New Orleans. Each microfiche cartridge contained several hundred pages of information relating to offshore platforms in various OCS lease blocks; this included structural plans, letters of transmittal and approval, etc., as well as portions or all of the geotechnical reports for each structure. Geotechnical data required for this mapping project included: boring log, tabulated test data, boring location, type of sampling equipment, geotechnical firm involved and date of boring. Additional data recorded included platform name, lease area, name of company holding the lease and water depth at the boring location. Scrolling through a cartridge to find the appropriate data for each platform and then printing this data, was a tedious operation taking 4-6 hours, sometimes longer. After evaluating the progress made in one week of collecting data in New Orleans, it was determined to be more cost-effective to copy the remaining microfiche and continue the work at the Texas A&M (TAMU) Library, which had earlier purchased a cartridge reader for the project. Fifty-five cartridges of data were copied from the MMS originals for subsequent processing at TAMU. Although present regulations require pipeline burial from the shoreline to 200 ft. water depth, MMS personnel requested that water depths up to 300 ft. be considered. Data from water depths greater than 300 ft. were not processed. Also data used in the original McClelland maps were not used. In fact, most data selected were from 1983 onwards and most data were obtained in the 1990's after the damaging effects of Hurricane Andrew.

Processing the Data

The collected data were processed as follows:

1. Boring locations. At least five different coordinate systems were used to identify the locations of the borings. Using a coordinate transformation program, all locations were transferred to geographical coordinates (latitude and longitude).
2. Water depths. Few, if any, of the reported water depths at the boring locations were adjusted for tides. Often the statement was made in the geotechnical reports that tides in the GOM were less than 1 ft. and tide adjustments were not necessary. Consequently, the reported depths were considered to be accurate for purposes of developing the maps for this project.
3. Shear strengths. The undrained shear strength is the operable strength for pipeline stability purposes, at least for short-term after-construction effects, which includes the pipeline self-burial process. At least 10 geotechnical firms were identified who provided drilling and testing services with subsequent recommendations for pile and caisson capacity, pile driving analyses and other facets of foundation design. Sampling devices varied with the firm and ranged from 2 in. to 3 in. diameter thin wall tubes, liner samplers (thin walled tubes with encased liners) to split spoon samplers (most often used for sands). They were inserted into the sediments by percussion methods, by using the weight of the drill rod or by pushing the drill rod with a sampling tube affixed to the rod end.

Shear strengths were obtained in the field on samples using hand-held devices (torvane, pocket penetrometer) used mainly for field classification tests, and in the laboratory using unconfined compression, triaxial compression and miniature vane tests. The field tests are not ordinarily used for design purposes, although they sometimes serve as a guide for developing strength profiles when other data are sparse. The preferred undrained strength test for most offshore uses is the unconfined compression test, followed closely by the unconsolidated, undrained (UU) triaxial compression test. The next most commonly used test is the miniature vane. Results of these tests are influenced to varying degrees by the method of taking and testing the samples. This was studied in some detail by McClelland Engineers in the 1960’s and 70’s with a series of tests conducted onshore in Venice, Louisiana and in the GOM. The results of these studies (Emrich, 1971) and some later studies showed that pushed samples had higher strengths than percussion samples. Also, vane tests where the sample fails along predetermined planes, gave higher strengths than those where failure was free to occur along natural planes, such as in unconfined compression tests.

The original McClelland maps utilized a series of strength modification factors taking into account both test and insertion methods to bring the measured strengths to a common basis, that of the unconfined compressive strength obtained on a 3 in. fixed piston thin wall sampler which was pushed into the sediment. These factors are reproduced in Table 1. To bring some consistency to the comparison of the earlier maps and those presented herein, and because little additional information has surfaced to contradict the information in Table 1, the same factors were used in developing the present maps.

Table 1 – Shear Strength Modification Factors

			* Modification factor, s_u/s_u'	
Sampler Type	Method of Insertion	Strength Test	Based on Emrich '71	Adopted for this study
2 ¼” thin-walled	percussion	unconfined compression	1.56	1.5
2 ¼” thin-walled	percussion	miniature vane	1.06	1.1
3” thin-walled	push	unconfined compression	1.05	1.0
3” thin-walled	push	miniature vane	0.76	0.8
(in situ measurement)		Remote Vane	0.69	0.7

* Note: s_u = undrained shear strength determined by unconfined compression tests on 3-in. fixed-piston samples.
s_u' = undrained shear strength determined by other strength tests or with other sample types, as indicated

From: Parker et al., 1979

As mentioned earlier, many of the geotechnical firms operating in the GOM have used sampling tubes different from those given in Table 1. For example, some firms used a 2-1/2 in. thin wall tube for both push and driven samples. Since there is no data base for comparing these tubes and methods with those in Table 1, it was decided that all push samplers, regardless of diameter, would use the modification factors in Table 1 for 3 in. tubes, and all percussion samples would use those factors for the 2 ¼ in. samples.

Finally, the information collected for each borehole was entered in a Microsoft Excel spreadsheet, which is accessible as a primary file titled *datafinal.dbf* on the CD entitled “Shear Strength Maps of Shallow Sediments in the Gulf of Mexico: ArcGIS Version”. This CD includes the final report, user guide, database, and shear strength map information.

Strength Profiles

The development of strength profiles for each boring took a decided change from the approach used with most offshore projects where the primary intent is foundation design. The upper few feet of sediment, which are generally very weak, have substantially no impact on deep foundation design. Consequently, a best-fit straight line is drawn, usually termed the “interpreted shear strength”, through what may be a significant scatter of data points. For this project, shear strengths are presented at 0, 5, and 10 ft. below the mudline. Because of the anticipated use of these maps, the shear strength profile shows greater detail than in the earlier McClelland maps.

The process started by plotting the adjusted shear strength measurements versus depth for each boring, except those containing sand or silt, from the mudline to 10 or more feet of depth. For cohesive sediments, miniature vane, unconfined compression and UU triaxial test results were plotted. In cases where there was little scatter of the data, a best fit straight line, or a series of lines was visually fit to the data. Significant data scatter created a dilemma: was it created by sample disturbance, minor inclusions (say, shell fragments) or even thin silt or sand layers? If the boring log did not provide clues, then the best solution was to develop a best-fit straight line through the data.

In general, the corrections shown in Table 1 managed to reduce variances between different test types, but in some cases the difference was even greater after corrections. This was most pronounced for higher shear strengths, i.e. where the strengths were greater than 0.5 kips/sq.ft. (ksf) A large number of borings had no compression test data in the upper 10-15 ft. making it necessary to rely entirely on the miniature vane test.

It should be noted that original data never provided strengths at the mudline. Sometimes, data were provided for 0.5 or 1 ft. below the mudline, but usually the first tests were performed on samples at 2 ft. or greater below the mudline. Thus, the strengths reported on the maps at the mudline always represent an extrapolation from deeper depths. Research has shown that recently deposited cohesive sediments (Holocene) in the Gulf of Mexico have undrained shear strengths at the mudline of about 0.05 ksf. Values lower than this could represent sampling disturbance or natural events leading to sediment disturbance. Higher values could be caused by overconsolidation resulting from erosion of overlying sediments. This information was often used to aid in the extrapolation of strengths to the mudline.

The strength profiles determined for each borehole are presented in .pdf files on a second and third CD entitled “Shear Strength Maps of Shallow Sediments in the Gulf of Mexico:

Data and WAD Analysis Files Roll 3146-4294" and "Shear Strength Maps of Shallow Sediments in the Gulf of Mexico: Data and WAD Analysis Files Roll 4310-9021".

Shear Strength Maps

Several types of strength maps are presented. These were constructed using all borings, even when there were several borings in a single lease block. In contrast, the McClelland maps were drawn by assigning a shear strength profile to an individual lease block. If more than one boring was located in a lease block, the strengths at each subsurface level were averaged to provide a single strength profile for the block. Shear strength contours were drawn assuming the shear strength profile was located at the center of the block.

Treatment of cohesionless sediments – sands and silts – presented a problem in contouring sediment shear strength. The strength of cohesionless sediments is a direct function of the overburden pressure at a particular depth. More importantly, the behavior of offshore pipelines embedded in sands is more a function of scour and subsequent infilling around the pipeline than their shear strengths. Consequently, the approach taken in the report, and apparently the one taken in the McClelland report is to map the extent of the sand bodies without attempting to assign shear strength to them. This creates other problems in contouring shear strengths, primarily because of the paucity of data. It appears that the McClelland approach was to develop strength contours of the clayey sediments as if the cohesionless sediments were not present. The cohesionless sediments were then embedded into the contour map as if they were deposited after the clayey sediments. Geologically this is probably not correct. The sands and clays are more likely to have been deposited contemporaneously.

In this report, shear strength maps are presented using the method described above to consider cohesionless sediments. In addition, maps are developed considering the coheionless bodies as "barriers", not to be crossed by continuous contours of cohesive shear strengths. With this method, the sparseness of the data contributes to numerous artifacts.

Shear strengths are presented at three levels: mudline, 5 ft. and 10 ft. depths below the mudline. Shear strengths are given in kips/sq. ft. (ksf). The ArcGIS CD contains several files under *Independent project files:*

1. Shear Strength v1. Interpolated shear strength constructed with spline methodology at mudline, 5 ft. and 10 ft. below the seafloor.
2. Shear Strength v2. Interpolated shear strength constructed using sand polygons as barriers at mudline, 5 ft. and 10 ft. below the seafloor.
3. Shear strength at 0.2 with splines. This provides interpolated shear strengths below 0.2 ksf (the limit for pipeline self-burial) using spline technology at mudline, 5 ft. and 10 ft. below the seafloor.
4. Shear Strength at 0.2 with barriers. This provides shear strength below 0.2 ksf using sand polygons as barriers at mudline, 5 ft. and 10 ft. below the seafloor

Items 3 and 4 provide a quick look at those areas where the strengths are low enough to allow self-burial

Geographic Distribution of Shear Strength

The data show that shear strength values are variable but are relatively high in the broad shelf area off eastern Texas and western Louisiana, where deposition of Holocene muds has been minimal and sandy sediments containing a mixture of particle sizes are widespread (Curray, 1960). Farther east, areas underlain by an eastward-thickening wedge of Holocene Mississippi River mud (Parker, et al., 1979) yield lower shear strength measurements. This area of low shear strength extends in a broad area across the shelf at about the longitude of the Atchafalaya River. Here, surface sediments of the inner shelf are also predominantly mud (Roberts, et al., 2002). Higher shear strengths, in early Holocene deltaic sediments, characterize the shelf area around the head of Mississippi Canyon. Lower shear strengths again characterize the shelf adjacent to the presently active Mississippi Delta both to the west and to the east of the river mouth. Low shear strength measurements also characterize the outer Continental Shelf west of Galveston, and off South Texas, where silts and clays (muds) are the predominant component of surficial sediments (Shideler, 1978). Data control is sparse in this latter area. Along the Shelf edge off Texas, two areas of higher shear strengths occur SSE of Lavaca Bay and SSE of Galveston Bay. These areas apparently coincide with former shelf-edge deltas of the Brazos/Colorado River, and the Calcasieu/Sabine/Trinity Rivers, respectively (Suter and Berryhill, 1985).

Areas enclosed by low shear strength measurements are less extensive at the 5 ft. level than they are at the surface, and less extensive at the 10 ft.level than they are at the 5 ft. level. The pattern of geographic distribution as described above remains similar at all levels. This would suggest a small amount of consolidation and dewatering even though overburden is slight. Increase of shear strength in the first 10 ft. of low-strength sediments was also observed in the McClelland report (Parker, et al., 1979).

Sand Areas

Areas of sand were delineated for the three shear strength threshold maps at the mudline, 5, and 10 ft. levels. Areas of known sand were interpreted beyond the area of borehole measurements. Sand is known to occur along the shoreface (Rodriguez, et al., 2001) except in the area of the outlet of the Atchafalaya River, where mud predominates (Roberts, et al., 2002). Areas of sand along the shoreline may be more extensive than that shown. Also included within the sand area are the shelf edge banks, which have occurrences of carbonate bedrock, coral sand, coral debris, and algal nodules (Rezak, et al, 1985). Also included within the sand area are mid-shelf ridges, which are capped by former shoreline sands (Rodriguez, et al., 1999). These include Ship Shoal, Sabine Bank, Heald Bank, Shepard Bank, and Thomas Bank. Sand deposits occur locally on former river deltas abandoned at the edge of the shelf. These sand deposits may be associated with abandoned river channels and delta-front distributary bars. Such former deltas are associated with the Rio Grande, Brazos/Colorado, Trinity/Sabine/Calcasieu, and Mississippi Rivers (Suter and Berryhill, 1985; Frazier, 1967). Most of the remaining sand deposits are distributed on the broad middle area of the Shelf and exhibit some linearity parallel to the shore, conforming with the topography of former beach ridges. Map boundaries enclose all the occurrences of sand in the boreholes. Overall distribution patterns resemble those mapped by Curray (1960), but the two distribution patterns differ significantly in detail. Sands tend to occupy the largest areas on the broad East Texas/West Louisiana portion of the Shelf, well away from present and former Mississippi River outlets, and east of the area, which may be referred to as the "South Texas Mud Belt." Extensive sand areas are present on the Mississippi- Alabama portion of the shelf, an area less subject to deposition of Mississippi mud than the area west of the present river mouth.

In the majority of the boreholes containing sand, sand is encountered at all mapped levels, the mudline, at 5 ft., and at 10 ft. Overall the geographic distribution of sand is very similar between the three levels. But some significant level-to-level variations in the extent of sand do occur. Consequently, three separate sand overlays were constructed, one for each level.

Bathymetry

The primary project file on the CD entitled *bathyfi.grd* is the bathymetry interpreted from the borehole data, constrained by the coastline and the 100 meter depth contour. Borehole bathymetry was constructed using the depth measurements recorded at the 749 boreholes used in this study. Borehole bathymetric measurements are accurate, but coverage is sparse. Available acoustic bathymetric data have a much better coverage in terms of number of data points, but some of the soundings are not as accurate in some areas and sounding data from two or more surveys often do not precisely agree.

Coordinate Conversion

Five coordinate systems were used on borehole surveying expeditions for different geographic sections of the TX-LA Continental Shelf. Universal Transverse Mercator Zone 16 (UTM-16) was used off the Mississippi Coast in Mobile Bay and Viosca Knoll blocks. Blocks off of Louisiana's southern coast, on the other hand, are measured using the Louisiana South State Planes system (LA-S). Similarly, the Texas State Planes systems, both South (TX-S) and South-Central (TX-SC) are used for the western edge of the Gulf. While these coordinate systems, which use x and y components in feet from the origin, are convenient in many respects, accuracy of any one of these coordinate systems is degraded if used over a larger area such as the entire Texas-Louisiana Shelf.

The Windows program TRALAINE was used to convert borehole location coordinates from state plane and UTM coordinates to geographic coordinates of latitude and longitude. TRALAINE maintains a database of all coordinate systems ever used, including origins, units, datum, and useful extent. Any of these items may be modified for specialized use. For example, LA-S, being a land surveying coordinate system, does not have a useful extent beyond the state's southern tip. To accommodate the usage of this system in the open sea, it was necessary to correct the extent of the coordinate system. TRALAINE uses its database of coordinate systems to translate between systems mathematically.

In the rare cases that coordinates were given in degrees, they were always converted to the appropriate coordinate system for database entry, and then converted back to decimal degrees later. This allowed comparison of the station location with other locations nearby on the fly for potential errors. After the database was completed, all points were converted to decimal degrees at the same time, and the resulting values were reinserted into the database.

Disclaimers

References to the commercial software packages such as TRALAINE and ArcGIS are for information purposes only and do not constitute endorsement of these products. Shear strength maps are for information and reconnaissance purposes only, and are not to be used for siting and design of ocean floor structures unless specifically authorized by the Minerals Management Service. Borehole survey data employed in construction of the maps are U. S. government-proprietary and are not to be released to the public unless specifically authorized by the Minerals Management Service. Bathymetry is for information purposes only and is not to be used for navigation.

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