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UNIQUE CHALLENGES ASSOCIATED WITH MARINE STRUCTURES IN NEW ENGLAND

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Introduction

New England was one of the earliest areas of North America to be developed. Its beginnings and much of its early industrial growth can be attributed to the many fine seaports and ensuing marine related opportunities in fishing, whaling, trading and shipping, which complemented the occupations of its founders. As a result, New England's many fine seaport areas were heavily developed, and in many instances are burdened with piers, wharves and marine structures which have long outlived their usefulness and are in various stages of decay. As a consequence, development of new marine terminals in New England presents many engineering and construction problems, unique to the area, in site selection and construction. Recognition of these during initial stages of a project can greatly reduce contingencies in design and construction phases.

Design and construction of marine structures in general involve very challenging problems since we must deal with one of nature's most active energy zones. In addition, we must tread lightly in New England, since this area is in one of nature's most populated biological zones. The challenge is further complicated by the unpredictability of subaqueous and geotechnical conditions. While types of basic soil and rock materials can be ascertained fairly reliably by a review of the geologic evolution of the area, depths to suitable foundation material vary considerably over a given site primarily due to the effects of advance and retreat of glaciers. Coupled with the seemingly ever present overlying layers of soft organic silts and inorganic clays common to New England tributaries, this results in unique challenges in the design and construction of marine facilities in the region.

New England Silts

The extensive deposits of soft, highly compressible organic silt common to New England's tributaries present major problems of marine design and construction. The low shear strength and high water content of this material

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lead to its transformation into a near fluid upon minimal disturbance. Its high degree of compressibility makes it generally undesirable as a fill or foundation material. Even removal and disposal of this material presents a major problem due to environmental considerations which place severe restraints upon disposal, especially ocean disposal.

During the course of our work in New England, we have amassed a considerable amount of laboratory test data for various New England sites. Figures 1 through 5 present various relationships of index properties, along with settlement and strength characteristics. All samples were naturally deposited, organic silts. The organic content of the materials tested ranged from 1 to 20 percent; most samples had between 3 and 10 percent. Figure 1 presents the familiar Casagrande Plasticity Chart of Liquid Limit versus Plasticity Index. Most of the samples tested plotted near or slightly below the "A-Line".

Figure 2 presents the relationship between the natural water content and Liquid Limit. A 45 degree line (or Liquid Limit equal to Water Content) has been superimposed. This plot illustrates that the natural water content of most samples is very near, or greater than, its liquid limit, indicating the relative sensitivity of the in-situ mass.

Figures 3A and 3B present consolidation test results. While correlations are apparent between the compression index, Cc vs. liquid limit and Cc vs. water content, values may differ by a factor of two or more. Common methods for estimating Cc have been included. The reasonable correlation indicates that they could be used fairly well for estimating settlements.

Figures 4 and 5 present the results of consolidated-undrained triaxial tests in terms of total stress and effective stress respectively. Both figures indicate that the test results plot in a fairly well-defined band. There is very little cohesion apparent and the angle of internal friction appears relatively high. It must be remembered, however, that the material is below water level with very low buoyant unit weights and, consequently, low, in-situ stresses resulting in generally low shear strengths.

The combination of low strength, low in-situ confining pressures and the proximity of water content to liquid limit results in a soil often barely capable of supporting itself, let alone an imposed surcharge. One fact is consistent in all of the normally consolidated organic silts encountered to date: the soils are extremely compressible. Handling of the soil as in dredging only tends to increase the water content and void ratio, thereby further worsening the settlement characteristics. The high compressibility coupled with relatively low shear strengths make organic silt a relatively difficult material to work with.

Chemical properties of New England organic silts are generally extreme. The material is highly organic and laden with heavy metals (mercury, lead, and zinc) and oil and grease. Table 1 presents typical chemical properties of materials taken from several project sites throughout New England. Table 2 presents the results of "Shake Tests" for the material using water samples from sites previously used for ocean disposal. It can be seen that the sediments generally exceed EPA standards for ocean disposal particularly with regard to heavy metals and oil and grease. As a result, projects which require dredging and disposal of these materials generally encounter serious environmental challenges.

As a result, a major design criterion (or philosophy) in New England has been to minimize the amount of dredging and disposal involved in a marine project. The situation in New England is critical; many necessary projects to deepen major seaport channels have not been implemented; this hinders access to ports by newer, deeper draft vessels. Similarly, even where deeper main channels have been dredged, (for example, the Providence River), stringent environmental restraints have hindered private efforts to dredge fairways and berths resulting in a situation comparable to an "interstate highway without any off ramps."

The consequences to New England are severe. As examples: 1) our large import of petroleum products must arrive in older, shallower draft (and, some say, more likely to spill) tankers. 2) Many New England ports are losing their competitiveness to capture new marine trade and associated industrial development due to the inadequacy of their terminals to accommodate newer, deeper draft ships. 3) Lack of maintenance dredging is jeopardizing the continuance of existing marine commerce.

Many alternative disposal methods have been investigated including land disposal, recycling, salt marsh creation, creation of artificial islands, and containerized disposal. These methods have worked in isolated cases but generally have been found to be prohibitive in cost as a regional solution.

Our experience has met with success primarily in recycling of the material. The excessive natural water content is one of the major factors affecting the undesirable properties of the silt, and, therefore, removal of the water (by stacking temporarily in windrows, for example) enhances the utility of the material. However, considerable maintenance is required for areas reclaimed by this method.

Additional rehandling costs coupled with the need for a large contiguous area for dewatering the material make this a solution for a specific site rather than a regional solution. This method is currently being employed for the expansion of the Municipal Wharf Facilities at the Port of Providence, Rhode Island.

We have also had success with land reclamation by controlled placement of fill over deep layers of soft silts. In this case, the major challenge is to avoid shear failure (mudwaves) and to accurately design sculptured surcharge loads necessary to achieve the final desired finish grade after the material consolidates.

This type of construction was accomplished in the waterfront development at the U.S. Coast Guard Academy. The site for the project was underlain by deposits of soft silt in excess of 30 ft. (9m) thick. By careful placement of fill material, controlled surcharging and, in one instance, a controlled mud wave, the project was completed and final elevations after consolidation were predicted to within a tolerance of 3 inches (7.6 cm.).

Another major problem in dredging and disposal in New England arises in the deepening of main channels. Since most of New England's harbors have been developed to control depths on the order of 30-35 ft. (9-11m) MLW and it is desired to go to -40 ft. (-12 m) MLW for today's vessels, dredging here is primarily a skimming operation rather than a major excavation. Simple mathematics tells us that in dredging from Elevation -35 to Elevation -40 (-11 to -12m), even an allowed 1 foot (.3 meter) overdredge represents a 20% increase in dredge volume. This overdredge quantity, for example, on the current dredging project of the main Thames River ship channel amounts to millions of yards of excess material. A quantity comparable, for example, to the deepening of all the berths served by the channel.

Minimizing overdredge requirements could possibly leave enough room in the disposal area to complete the project; that is, to allow the berths to be dredged. The Port of Providence is currently faced with this problem, and, to date, a solution has not been found except for specific cases such as at the Providence Municipal Wharf.

While it is acknowledged that overdredging is a necessary part of the deepening operation, we, as engineers and contractors, should be seeking economical methods of minimizing this requirement, perhaps by more accurate survey methods or new post-dredge sweeping techniques.

Site Selection

The effect of glaciation on the geological features of New England's tributaries has resulted in highly unpredictable foundation conditions which call for much caution in the design and construction of marine facilities.

In Groton, Connecticut, nested boulders over bedrock resulted in some very dramatic failures during load testing of end bearing piles which had been driven to refusal. Based on past analysis, the test piles slid off the boulders during testing. Grouting and drilling were required to develop the high presumptive design loads.

Across the Thames River in New London, piles of a proposed pier at the shore end needed to penetrate a mere 10 feet (3m) below dredge depth to bedrock, while at its head, 300 feet (91m) farther into the river, pile lengths in excess of 100 feet (30m) were needed to bypass deep deposits of organic silt and reach glacial till. A similar case was encountered at a large marina in Old Saybrook, Connecticut where soft peat deposits resulted in very unusual pile driving records reflecting the very erratic firm-bottom contours. A change of as little as 10 feet (3m) in horizontal location could mean that penetration below surface of timber piles, to bypass the peat and develop capacity, could change from 20 feet (6m) to more than 50 feet (15m). Equipment and material scheduling for such field conditions poses its own challenge to the designer and contractor.

For initial site selection decisions of a proposed marine structure in New England, it is prudent, in many cases, to rely on the judgment of our forefathers. While their subsurface exploration procedures may not have been as sophisticated as today's methods, they generally were able to locate suitable sites for their pier and wharf construction. As a result, the shape of the shoreline in many of our major seaports, traces, fairly accurately, the subsurface ridges and areas of optimum foundation conditions. One lesson we learn from this is to initially treat any virgin site in a highly developed waterfront as suspect. While such a site may appear to offer advantages for new construction by virtue of reduced demolition costs, or greater flexibility in layout of the marine structure, detailed subsurface investigations could, in a majority of cases, reveal less desirable (and consequently, more costly) foundation conditions. As an example of this, we have found in Fall River, Massachusetts, evidence of third and fourth generations of pier structures at the site of its present state pier while miles of relatively virgin shoreline are available along the bank of the Taunton River. Subsequent investigations revealed extensive layers of soft, organic silts adjacent to the unused shoreline.

This same consideration caused a great deal of difficulty for a proposed extension of the Municipal Wharf in Providence, Rhode Island to expand the port's capabilities to accommodate deeper draft vessels and "roll on/roll off" ships. (Similar examples can be cited for proposed wharf extensions in Portsmouth, New Hampshire and Boston, Massachusetts.) The Providence proposal called for the extension of an existing ¾ mile (1.2km) long gravity type granite seawall approximately 1500 ft. (457 meters) farther south, thereby creating the additional required berths. The project appeared simple enough at first evaluation; upland area was available; a prototype structure (the existing seawall) was already constructed and had been tested over its estimated 75 years of existence; and extensions utilizing similar construction had already been accomplished in the past. Consequently, the project was planned and funded, based on the historical type of construction. The pilot subsurface exploration program quickly revealed why the shape of the shoreline had evolved and why developments were limited in extent. Immediately south of the existing seawall, the rock and glacial till which had served as a foundation stratum for the seawall dropped from elevation -40 ft. (-12 meters) MLW to below -100 (-30 m) MLW and in place of the till was a layer of soft, near fluid, organic silt. The structural solution developed for the new construction was an articulated pile supported structure designed to suit the site conditions, a more costly project, and a project which was considerably delayed by environmental considerations due to the unexpected dredging and disposal of a large quantity of organic silt. After a detailed analysis and evaluation of the sensitive environmental considerations, the final solution was rehabilitation of the existing wharf rather than construction of a new wharf.

Rehabilitation vs. New Construction

The trend toward rehabilitation rather than new construction appears to have merit not only for the reasons cited above, but also because it appears to be an excellent opportunity for revitalization of many blighted waterfront areas while maximizing the amount of untouched shoreline in New England and still providing the desired new terminal facilities. In many cases, this approach can also preserve the historic beauty of the 19th century New

England craftsmanship which can be seen in the granite piers and timber wharves of early whaling days. This is what was done for a project at the Mystic Seaport to provide a berth for the whaling ship Charles W. Morgan. In a majority of cases, we have found rehabilitation to be both cost effective and environmentally more acceptable than either demolition and reconstruction or new construction at a virgin site.

Rehabilitation work requires a much more broad-gauged approach both for design and construction. The designer must do considerable research into the historic performance of the existing structure and correlate its limitations with operational requirements of the new terminal. In many cases, a compromise must be considered between holding to the client's desired operational capabilities involving high costs, and accepting lesser operating capabilities and limiting the upgrading of the structure to what is basically necessary. In many cases, a benefit/cost analysis will prove to the client that a reduction in operational specifications or perhaps a revision in operational procedures is cost effective for his purposes.

An example of this was encountered in a project for Dow Chemical Company at its Gales Ferry, Connecticut, plant. The firm was using an old coaling pier for offloading, primarily liquid styrene for processing at its adjacent plant. The pier, built in the 1800's, had long outlived its design life and was in critical condition with regard to function and safety. The recommended solution was not to repair the pier, as originally had been planned, but rather to convert the structure to a specialized use. A study of terminal operations revealed that a series of mooring dolphins with an access trestle to a manifold platform would be sufficient for the primary operation at the terminal. A detailed condition survey of the pier by divers located sufficient sound piles to support the access trestle and manifold platform, and the pier was converted to a liquid cargo terminal at approximately 20% of the originally anticipated cost.

Summary

The above discussion has been presented to indicate that the marine engineer and marine contractor are faced with unique challenges by virtue of the special personality and characteristics of New England waterfront. Successful implementation of port projects in the area requires a philosophy of innovation and ingenuity. At the conceptual stages of a project, the following should be included in planning and design criteria:

1. Treat virgin sites in or near heavily developed waterfront areas as suspect until detailed studies are accomplished.
2. Consider rehabilitation over new construction.
3. Evaluate in detail operational requirements which impose stringent design criteria on the project.
4. Minimize dredging requirements.
5. Exercise caution when considering the use, or disturbance, of organic silts present at a site.

New England is at a critical stage in its marine development. On the horizon are increased fishing activity by virtue of the new 200 mile limit, offshore petroleum exploration, and the increasing economic attractiveness of waterborne transport, to name but a few. In order to serve these new possibilities, drastic upgrading of our waterfront facilities will be required. To do this in an economic and environmentally acceptable manner will require a revival of Yankee ingenuity and innovation and a thorough knowledge of the unique problems inherent in marine construction in New England.

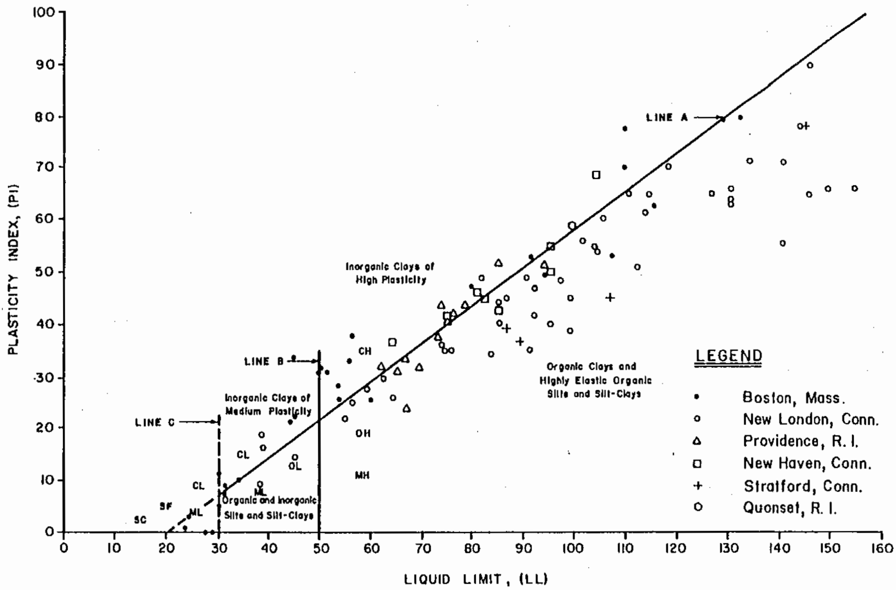

Figure 1. Plasticity Chart, Organic Silt Sediments.

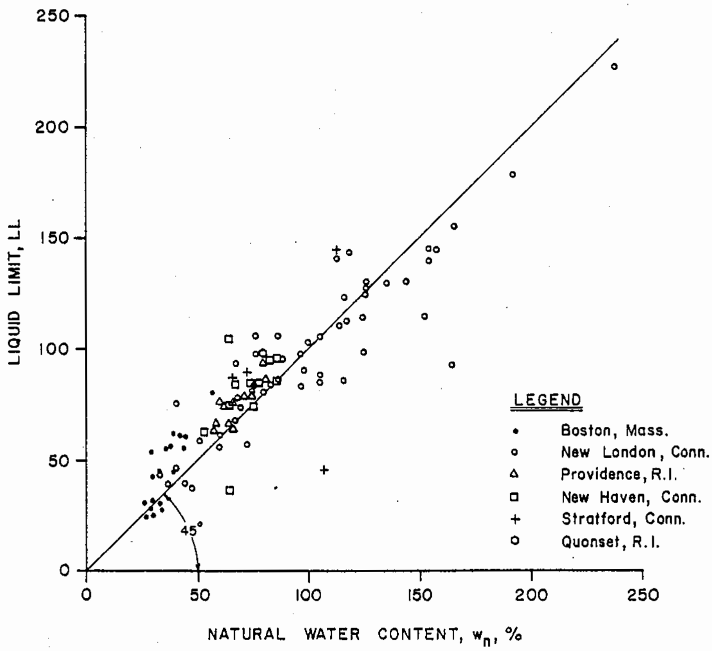

Figure 2. Liquid Limit vs. Water Content, Organic Silt Sediments.

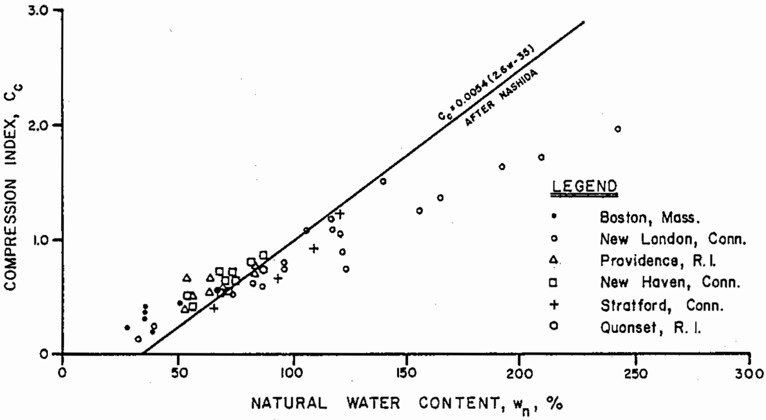

Figure 3A. Compression Index vs. Water Content, Organic Silt Sediments.

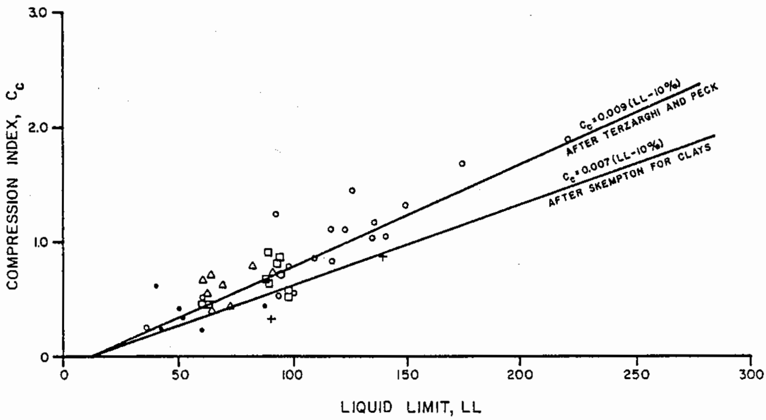

Figure 3B. Compression Index vs. Liquid Limit, Organic Silt Sediments.

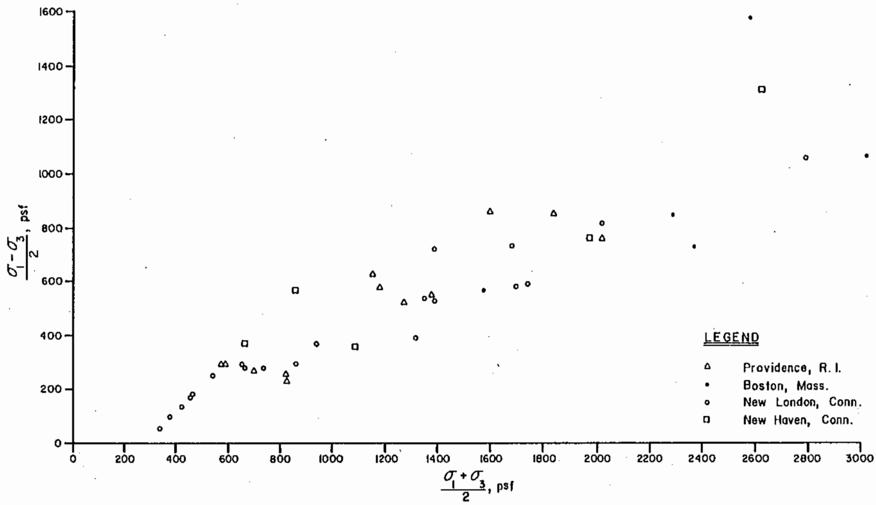

Figure 4. Triaxial Test Results, Organic Silt Sediments (Total Stress, Consolidated-Undrained).

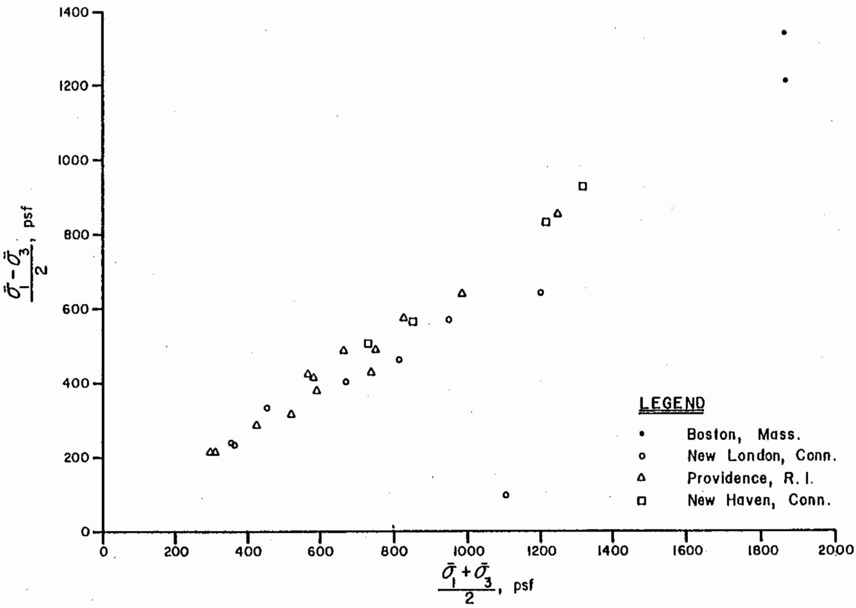

Figure 5. Triaxial Test Results, Organic Silt Sediments (Effective Stress, Consolidated Undrained).

TABLE 1
Chemical Test Data, Organic Silt Sediments

		VOLATILE SOLIDS (%)	CHEMICAL OXYGEN DEMAND (%)	KJELDAHL NITROGEN (%)	OIL & GREASE (%)	LEAD (%)	ZINC (%)	MERCURY ppm
EPA GUIDELINES 1973		6.0	5.0	0.10	0.15	0.005	0.005	100
PROVIDENCE	average	5.7*	9.0	0.18	0.23	0.0017	0.0009*	90*
	peak	14.7	218	0.48	0.49	0.0059	0.0018*	230
FALL RIVER	average	11.6	18.0	0.32	1.10	0.061	0.0831	280
	peak	15.2	25.4	0.47	1.72	0.090	0.1394	450
MOUNT HOPE BAY	average	5.1*	—	0.19	0.11*	0.0029*	0.0095	40*
	peak	6.3	—	0.33	0.18	0.0059	0.0180	210
TAUNTON RIVER	average	8.1	—	0.29	0.42	0.0141	0.0308	277
	peak	13.2	—	0.52	0.80	0.0426	0.0728	603

*FALLS WITHIN EPA GUIDELINES

TABLE 2
Shake Test Results

	VOLATILE SOLIDS (mg/l)	TOTAL SOLIDS (g/l)	CHEMICAL OXYGEN DEMAND (mg/l)	KJELDAHL NITROGEN (mg/l)	TOTAL NITROGEN (mg/l)	OIL & GREASE (mg/l)	LEAD (μg/l)	ZINC (μg/l)	MERCURY (μg/l)	CADMIUM	HYDROGEN SULFIDE (mg/l)
NEW LONDON	822	36.6	273	2.96	12.4	10.5	5.8	16.3	0.3	0	0.28
seawater	1618	25.7	262	0.26	—	7.5	15.0	6.0	70.1	—	70.01
EPA guidelines*							8.7	24.4	0.4		
FALL RIVER							940.0	100.0	75.5		
seawater							23.0	20.0	9.0		
EPA guidelines*							35.0	30.0	14.0		
PROVIDENCE							62.0	51.0	16.0		
seawater							36.0	34.0	11.0		
EPA guidelines*							54.0	51.0	17.0		

* EPA Ocean Dumping Criteria, May 1973: The concentration of the constituent in a standard elutriate after a Shake Test should not exceed its ambient concentration in the composite water by a factor of 1.5.