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Engineering Improvements in Reclaimed Marshland for Housing Project

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ENGINEERING IMPROVEMENTS IN RECLAIMED MARSHLAND FOR HOUSING PROJECT

by

Carl W. Garbe* & Kuei-Wu Tsai**

INTRODUCTION

The shortage of available land for residential development in the San Francisco Bay Area has led to the improvement of sites having marginal subsurface conditions. Among these sites are those with steep or mountainous topography as well as reclaimed marshlands. This article will deal exclusively with the unique engineering problems encountered in marshland development.

The reclamation of tidal marshlands or underwater areas has typically involved diking to a level above high tide and filling within the dikes with a few feet of imported fill over soft, compressible marsh soils. The ensuing behavior of the final product has been a matter of concern to both engineers and land developers. In some instances, large total and differential settlements of the surface, as well as instability within the underlying soft clay, have caused failures of structures and underground utilities.

A thorough investigation of soil conditions, combined with careful planning and analysis is necessary to produce rational and satisfactory foundation design and construction in areas formerly considered unusable. Land reclamation and development of Redwood Shores, in Redwood City, California, is showing that good planning, design and construction fitted to the soil conditions can successfully convert tidal marshes into usable land quickly and economically.

LOCALE

Redwood Shores is located in San Mateo County on the San Francisco Peninsula of California. As shown on Figure 1, it forms a part of the west shore of San Francisco Bay.

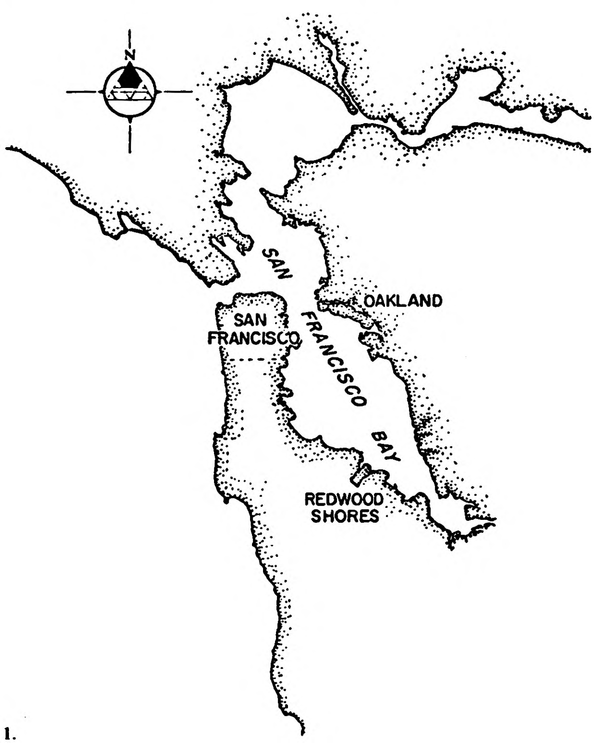

Fig. 1.

Geologically, San Francisco Bay is a deep trough that has been filled with sediments to varying depths up to several thousand feet. The water depth is shallow and the Bay has very poor water circulation. The shoreline is almost uniformly comprised of a marsh about two miles wide. The soft marsh soils, known locally as bay mud, vary in thickness from zero to as much as 85 feet in the vicinity of Redwood Shores.

SITE HISTORY

Redwood Peninsula, which occupies about one-third of Redwood Shores, was originally a tidal marshland with an average surface elevation of about 3.5 feet above mean sea level. Much of the Redwood Peninsula was diked off from San Francisco Bay about 1910 and used as pasture until 1950. It was then converted to salt evaporation ponds by the construction of interior levees. In 1964, the land was drained in preparation for the present development. The area has experienced varying periods of inundation and drying, which have had a marked effect on the surface elevation and on the characteristics of the existing surface and subsurface soils.

SOIL INVESTIGATION

A comprehensive soils investigation was conducted in the area through exploratory drilling, soil sampling, and extensive field and laboratory testing (including vane shear, moisture-density, specific gravity, consolidation, and unconfined and triaxially confined shear tests).

Borings were drilled on a grid pattern that resulted in one boring per 10 acres. In addition, probes to establish the depth of bay mud were advanced on a similar but offset grid as shown on the Site Plan in Figure 2. Typical borings were extended about

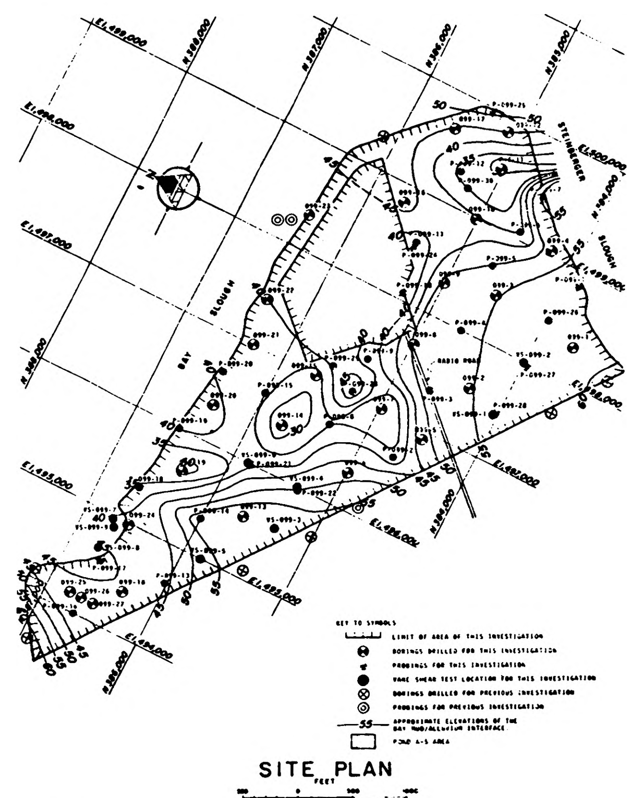

Fig. 2. Site Plan

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5 feet below the bay mud layer; deeper borings were extended approximately 25 feet beneath the clay. Relatively undisturbed soil samples were recovered at frequent intervals.

The subsurface soil profile was found to include:

1. Three to five feet of stiff to medium stiff desiccated gray organic silty clay. Vertical desiccation cracks up to 3/4 of an inch wide were visible to a depth of six or seven feet in excavations.
2. Approximately 15 to 75 feet of soft compressible gray organic silty clay (bay mud).
3. Stiff sandy clays and dense clayey sands with some silt and gravel, of alluvial origin, to the depths explored.

A typical boring log is shown in Figure 3.

The strength of the soils within the uppermost 10 feet showed the influence of desiccation; 10 feet below the surface, an apparently typical strength-depth relationship exists. Summaries of the strength data from field and laboratory tests are presented in Figures 4 and 5.

Consolidation data confirmed that the first 10 feet of soil was over-consolidated because of desiccation. Probable maximum past pressures are computed from the history of reclamation and compared favorably with the test results shown in Figure 6.

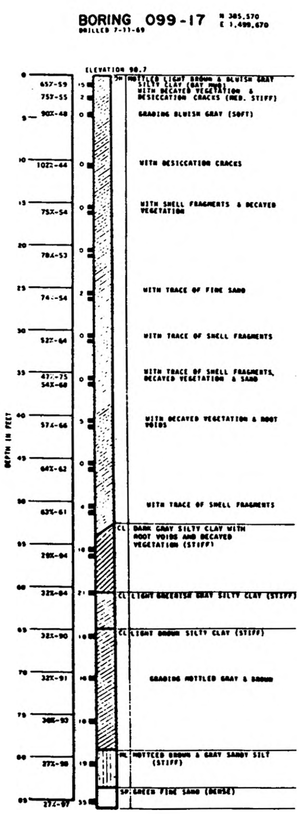


Fig. 3. Log of Boring

The relationship of the compression index C_c to the initial void ratio e_0 at various depths is shown on Table 1. A similar relationship of the expansion index C_e appears in Table 2.

The overall coefficient of consolidation C_v averages about 10 square feet per year, with a variation from about 5 to 15 square feet per year.

PLANNING AND DESIGN

Regular meetings were held during the planning, design, and construction phases of this project to coordinate the efforts of the developer, engineers, and contractors. Two major soil engineering problems, stability and settlement, were prime subjects for discussion at these meetings and required thorough analysis.

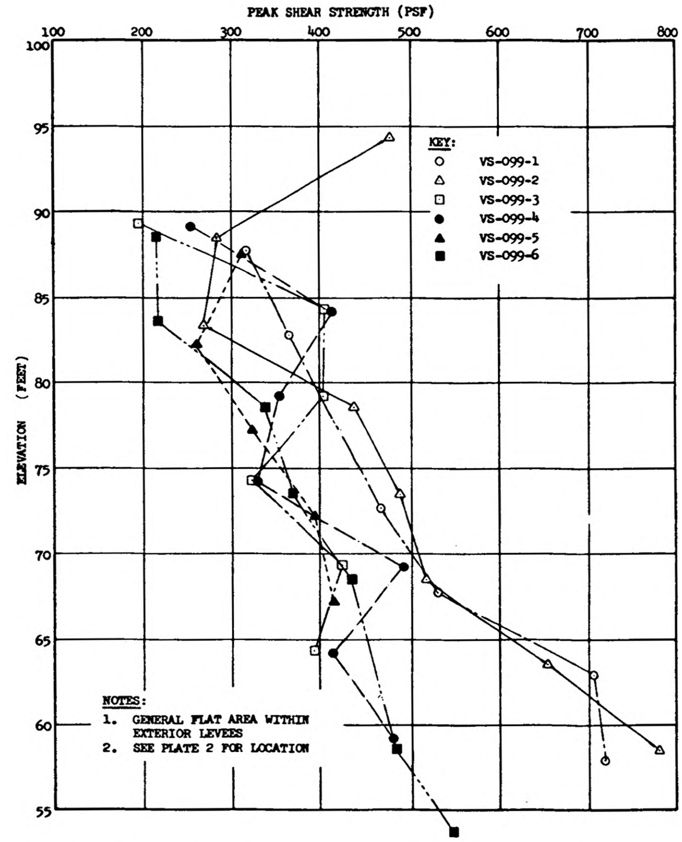


Fig. 4. Field Strength Test Data

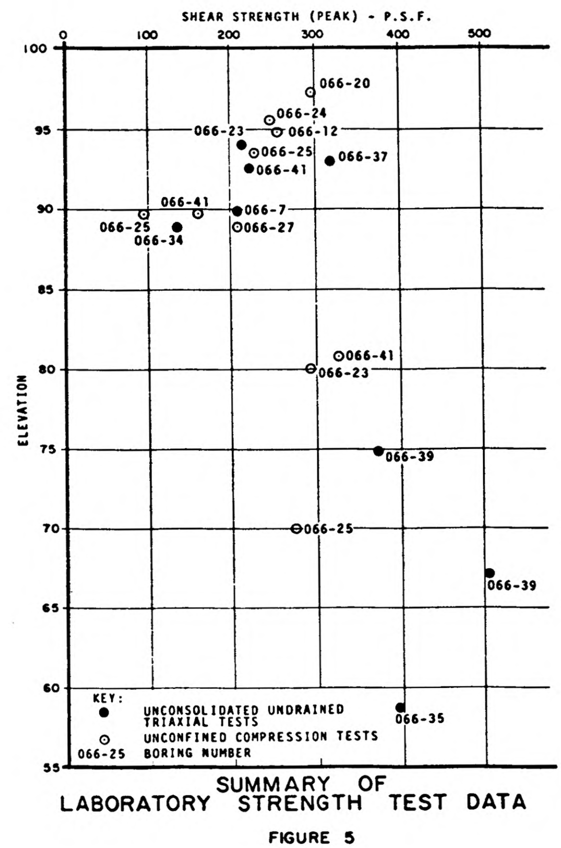


Fig. 5. Summary of Laboratory Strength Test Data

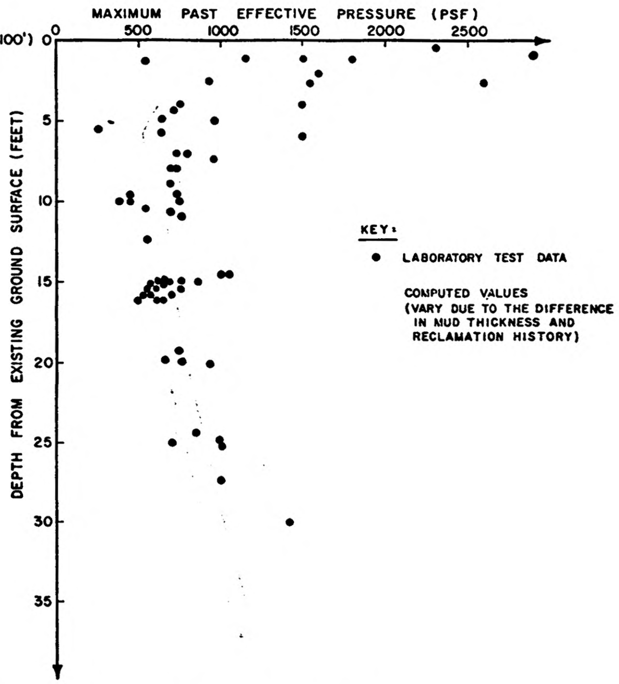


Fig. 6. Summary of Maximum Past Effective Pressures

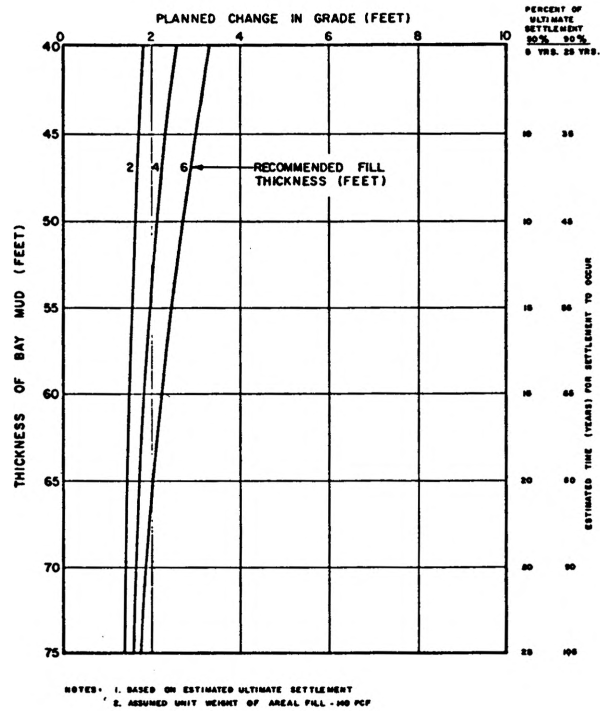


Fig. 7. Recommended Fill Thickness (with submergence correction)

TABLE 1

DEPTH (Feet)	$\frac{C_c}{1 + e_o}$
0 - 10	0.30
10 - 30	0.35
30 - 75	0.40

TABLE 2

DEPTH (Feet)	$\frac{C_c}{1 + e_o}$
0 - 30	0.035
30 - 75	0.045

Stability Analysis

Successful levee construction or waterway channel excavation requires a stable slope embankment; and it was expected that the data obtained from the subsurface investigation, combined with detailed analysis, would provide a satisfactory basis for planning and construction.

However, many difficulties were encountered in this respect, despite the testing and analyses. It was concluded that slope construction procedures produced a distribution of pore water piezometric levels different from that used in conventional stability analysis and resulted in a seepage force which lasted for a longer than normal period because of the time required to dissipate excess pore water pressure in the low permeability soil. Failure to consider the different piezometric levels properly would lead to an unsatisfactory design.

Settlement Prediction

Soil investigations revealed that the characteristics of the clay deposit throughout the whole area were relatively uniform, with the exception of thickness of the deposit and the influence of sloughs and other surface features. The primary effect of the variation in conditions was to produce large differential settlements under uniform loads.

To properly take into account the effects of settlement, a detailed analysis was performed as a guide to planning and construction. Figure 7 is a typical chart prepared for determining the thickness of the areal fills to be placed. Settlement observation plates were installed and data were collected regularly to check the predicted settlement.

Potentially severe differential settlement areas, resulting from a different consolidation history of the clay underneath

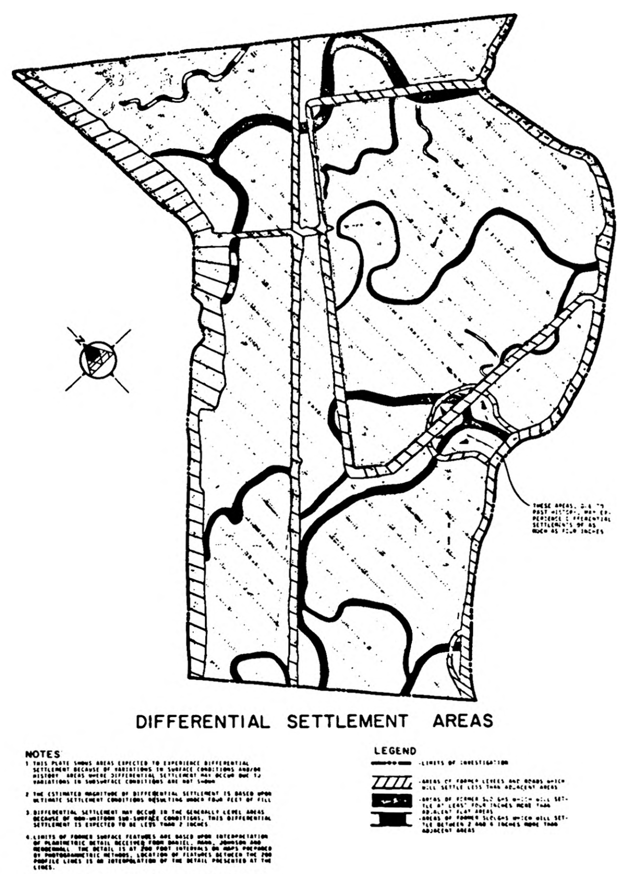


Fig. 8. Differential Settlement Areas

sloughs or levees, were delineated as shown on Figure 8. Special considerations were needed for these areas. Possible alternatives for development included:

- Using for roadways, waterways, parks, etc.
- Corrective grading
- Releveling of structures
- Preloading
- Delaying construction after fill placement
- Supporting structures on pile foundations

CONSTRUCTION

All earthwork was performed so as to produce a uniform product of acceptable quality without disrupting the uniformity of the existing soil profile. To this end, contractors were required to follow the specifications recommended by the soil engineer. The reclamation process involved the following steps:

Preparation of Site

a. Sloughs and Other Surface Irregularities required dewatering, demucking, and formation of a smooth section and profile (either by lightweight wide-tracked dozers or by draglines), followed by backfilling with conditioned bay mud compacted to the densities shown in Figure 9.

b. Generally Level Areas were cleared of excessive vegetation and other deleterious matter. The surface was then scarified, aerated to reduce the moisture content of the soils to a level of not more than 10 percent of the optimum water content, leveled, and compacted to a depth of 8 inches below finish grade with a density not less than 75 percent of the maximum dry density.

c. Interior Levees and Haul Roads no longer needed were removed and all material was conditioned as necessary and utilized as fill elsewhere on the site. The cleared areas were then prepared as described above. Haul roads were constructed, where needed, of native soils compacted to 85 percent of their maximum dry density or of imported soils compacted to 90 percent of their maximum density.

d. Damage to Native Soils was avoided by limiting loaded earth-hauling equipment traffic to haul roads only and by routing these roads to avoid pumping of the native soils. Any rutting or other damage to the native soils that did occur was corrected by:

- Excavating damaged areas to a depth of at least two feet
- Permitting the excavation to dry and form a desiccated crust (during this period, the excavated material was conditioned to the optimum moisture content for compaction)
- Backfilling the excavation with conditioned native soils compacted to not less than 75 percent of their maximum dry density.

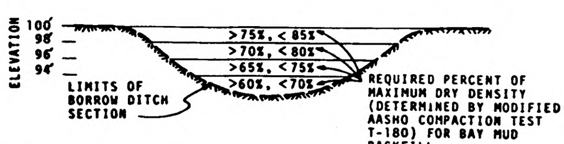


Fig. 9. Backfilling of Sloughs

Placement of Imported Fill

The site preparation phase was followed by a filling operation, which covered the site with a blanket of imported and compacted granular soil varying in thickness from about two to six feet. Imported fill was then placed over the prepared surface in an initial uniform, horizontal lift (working pad) of not more than 12 inches in loose thickness; this lift was required to be compacted by spreading equipment to a dry density of not less than 85 percent of the maximum dry density.

Succeeding lifts were loosely placed in uniform, horizontal layers of not more than 8 inches in thickness, and were compacted to a dry density of not less than 90 percent of the maximum dry density.

Heavy compaction equipment was not permitted on the site until the first lift over the working pad was ready for compaction. Loaded hauling equipment was not permitted in any area containing less than two feet of compacted fill over the prepared surface.

Trenching

All trenches deeper than eight feet below the adjacent surface were required to be sheathed continuously, with bracing installed at each level before continuing the excavation below that level. The requirements for trench backfill are shown in Figure 10.

The excavation soil was segregated by type (imported fill or bay mud) so as to permit its re-use as controlled trench backfill or as controlled fill elsewhere on the site.

Shallow Foundation

Criteria for the footing design are based on the assumption that the maximum allowable shear stress in the bay mud is 250 psf. Recommended design criteria for square and strip footings are presented in Figures 11 and 12.

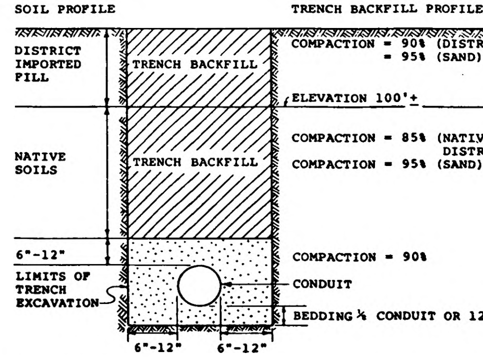
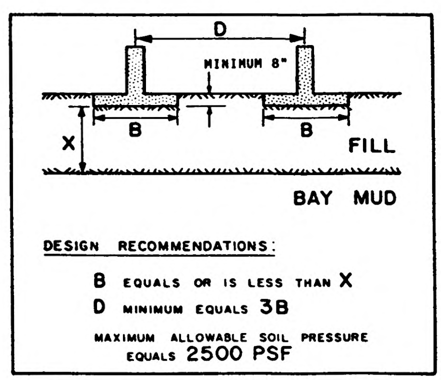


Fig. 10. Typical Trench Backfill Section



NOTE: THE CALCULATIONS FOR THE ABOVE ARE BASED UPON THE ASSUMPTION THAT THE FOOTINGS CANNOT ROTATE AND THAT THE MAXIMUM ALLOWABLE SHEAR STRESS IN THE BAY MUD IS 250 PSF.

Fig. 11. Recommended Design Criteria for Square Footings

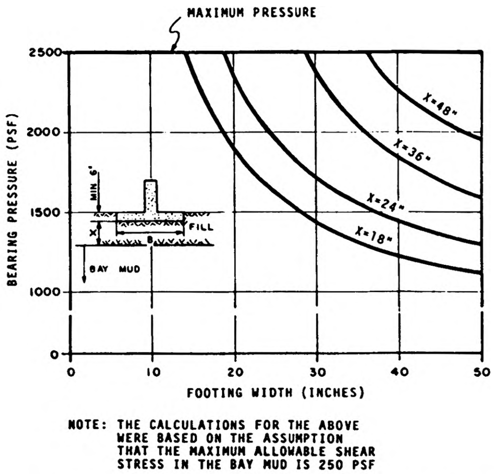


Fig. 12. Recommended Maximum Bearing Pressures (total) for Strip Footings

CONCLUSION

Reclaimed tidal marshland, underlain by soft and very compressible clay, can be developed quickly and economically into usable land. At the Redwood Shores site, for example, residential houses, recreational facilities, bridges, roads, and underground utilities have been built without major soil difficulties. Thorough subsurface investigation, detailed soils design and analysis, and strictly controlled soils construction techniques are among the key requirements to make this kind of land development successful or even possible.