Downdrag on Bitumen Coated Piles in a Warm Climate

Tirage Négatif des Pieux Enduits de Bitume en Climat Chaud

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SYNOPSIS The Keehi Interchange in Honolulu will be built over subsiding ground comprised of very deep, soft and under-consolidated clay. The foundation engineer had to determine the magnitude of the long term downdrag that 16 1/2 inch (42 cm) octagonal prestressed piles would experience and develop practical economical means to inhibit it. A field testing program was undertaken to examine the application, behavior and effectiveness of bitumen coatings to reduce downdrag under the warm-hot Hawaiian environment. Also, local contractor handling operations were observed at the project site. Five piles were employed in a comparative study. Three of the piles were coated with different grades and thicknesses of bitumen to reduce downdrag while the other two piles acted as uncoated reference piles to measure the full downdrag. The procedure for applying bitumen and installing the piles is presented. From the data, distribution of the downdrag forces acting along the piles was established. Numerical results and practical experiences are reported.

INTRODUCTION

Five 16-1/2 in. (42 cm) octagonal prestressed piles referred to as Piles 6, 7, 8, 9 and 10 were employed in a comparative study. Piles 7, 9 and 10 were coated with bitumen to reduce downdrag while Piles 6 and 8 acted as uncoated reference piles to measure full downdrag. Because of the limited time available in which to complete the study, an embankment was placed over the area to accelerate the consolidation-downdrag process. A site plan is shown in Fig. 1.

A generalized soil profile is given in Fig. 2. Very deep and very soft, underconsolidated clay exists directly beneath a medium to compact coral/sand surface fill which was placed in the 1930's and 40's to reclaim the area. At depth the soft clay transitions to a firmer silty clay followed by a coral/sand region varying in density from very compact to loose. Some coral has decomposed to pockets of soft clay. The last stratum encountered is a stiff to very stiff silty clay.

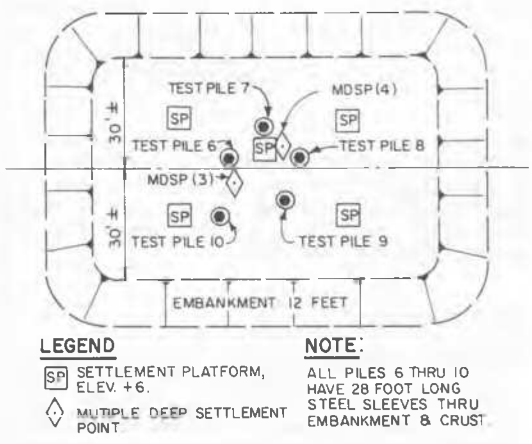

Fig. 1 Plan of Test Piles 6 to 10 and Embankment

FIELD TESTING PROGRAM

Because the soil is settling under the influence of its own weight and is expected to continue to subside for many years, the foundation engineer had to determine the magnitude of the long term downdrag that the foundation piles would experience and, if necessary, develop practical economical means to inhibit it.

While favorable experience had been gained by others with bitumen coated piles, the bulk of it pertained to steel piles, particularly to steel pipe piles, and less on concrete. One was aware that empirical observations and constants developed for steel piles might not be directly applicable to design on concrete piles and that the recorded field experiences had been obtained largely in the cold climates of Norway, Sweden and Canada.

Because of its temperature-sensitive properties and the dearth of knowledge regarding the behavior of bitumen coated concrete piling in hot weather, it was thought prudent to examine the application and response of bitumen under the unique Hawaiian environment and to observe the local constructor-contractor handling operations that could be expected at the project site.

Coating Piles With Bitumen

All surfaces to be coated with bitumen should be dry and thoroughly cleaned of dust, loose matter, flakes, etc. A suitable primer is applied to make the surface impervious, preventing the bitumen from entering the concrete. After the primer has completely dried, a hot asphalt type bitumen at a temperature between 300 to 350 deg. F (150-175 deg C) is mopped, brushed or sprayed to a uniform thickness extending over the length of pile subject to downdrag, but not over the lower bearing length where the pile is to be founded. The coating may be applied either at the casting plant or at the project site, but the piles should be protected before driving from sunlight and heat. Pile coatings should not be exposed to damage during storage, hauling or handling. The contractor must take appropriate measures to preserve and maintain the bitumen coating.

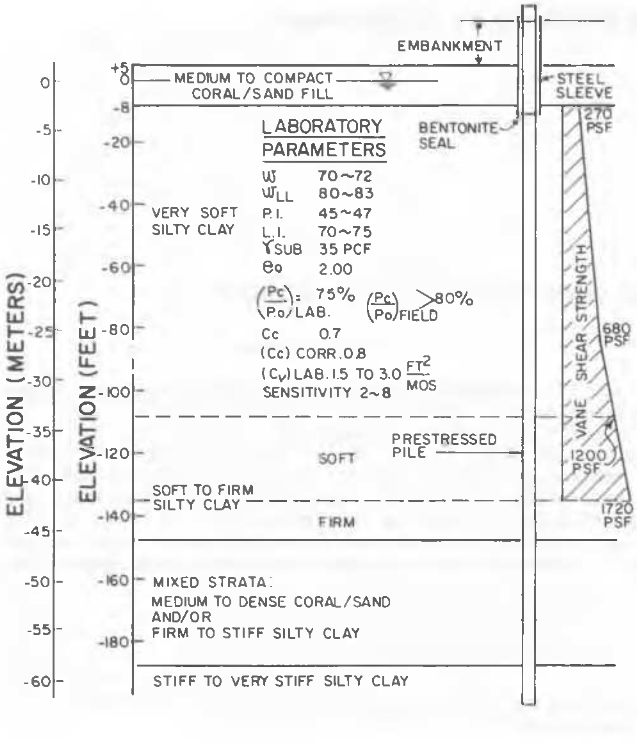

Fig. 2 Generalized Soil Profile

Pile installation should avoid loss of the asphalt through the abrasive surface coral fill. This can be prevented by either casing through the fill or by creating a slurry filled preaugered hole through the fill. The pile is then inserted under its own weight displacing the soft soil until firmer clay is reached, at which point driving will commence. Sand and gravel were not known to exist in the soft soil layers. Shells were encountered during the boring programs but these appeared to be dispersed and not capable of scraping too much bitumen from the pile.

Construction Experiences

Piles 7 and 9 were prime coated on May 31, 1977, followed by bitumen coating on June 2 and 3. The designer's intention was to compare the effectiveness of two different coating thickneses, but similar penetration range, namely 85-100. Pile 7 was to be coated to a thickness of 1/16 in. (1.6 mm) and Pile 9 to 3/16 in. (4.8 mm) Samples drawn from the bitumen melting vat yielded penetration numbers of 81 and 84.

It was quickly learned that the application of hot bitumen is not an appealing operation. The uneveness of brushing, the running of the bitumen, the lifting of the pile, and coating it from below in the heat of the day does not make for a well controlled operation, let alone a uniform application of coating. Temperatures during the daytime were usually between 85 and 95 degrees F (30 to 35 degrees C). Without protection from the Hawaiian sunlight the bitumen readily softened and ran off the pile such that the three upper faces had essentially no coating and the two side faces held oversized, variable globs dripping to the ground. The undersides when coated from below were usually too thin. After several days the running would cease but this was at the expense of loss of viscosity because the solvent evaporated leaving a stiffer residue.

Coating measurements showed that neither pile received the thicknesses that had been specified. Furthermore, the piles were not sheltered from the ambient heat and thus the bitumen softened and ran off the piles. Pile 9 was recoated in the yard to bring it up to 3/16 in. however, precautions were not taken to shield and cool the piles from sunlight and heat. Thus the piles arrived on the site containing thin, variable and dried coatings. The average coating thickness on Pile 7 was barely 1/16 in. With some apprehension the pile was driven. Concurrently, Pile 9 was recoated on the site with what was presumed to be 85-100 bitumen to bring it back up to 3/16 in. thickness. This "soft" bitumen coating was allowed to set and then a stiffer asphalt was applied on top of it to try to contain the running effect. After several days it was observed that the bitumen exhibited less flow then previously, having been partially restrained by the stiff outer layer; the pile was then driven.

Final penetration numbers reported from the laboratory on samples of bitumen removed from both piles ranged from 42 to 49 not 85-100. The penetration value of the stiffer asphalt applied as an outer layer to Pile 9 was 24.

Harder Bitumen

Pile 10 was used to evaluate the effectiveness of a harder bitumen and it received only a 1/8 in. (3.2 mm) coating of stiff asphalt; penetration number 20 was reported on a sample stripped from the pile. This stiffer material was much easier to apply uniformly and showed no desire to melt, even though it was exposed to the sunlight for more than several days before driving.

Protection of Bitumen Coating

It was decided to protect the bitumen coating from the abrasive surface crust by passing the pile through a steel sleeve. These sleeves need only extend from the ground to about one foot into the soft clay and need to be free of cobbles and boulders. Some field tests were performed to check the necessity of sleeves. In one test, two short 12 in. (30.5 cm) square pile segments were primed and coated with bitumen and then driven directly through the in-situ coral/sand fill. Upon recovery of the segments, it was observed that most of the bitumen had been completely rubbed off.

In another test two 24 in. (61 cm) holes were augered in the crust to a depth of 16 feet (5 m). Without the benefit of steel sleeves, the holes began collapsing after only one day. After driving a pile, probing indicated the holes had almost fully collapsed around the pile, under the influence of the driving vibrations. It was concluded that driving piles without the protection of steel sleeves would be too risky to the bitumen coatings.

Primer is a cost item, so a fairly dusty pile was coated directly with hot, soft bitumen, but no primer. In the cool temperature of the morning it was simple to peel and roll the bitumen off the surface just by hand, demonstrating the need for a surface primer to aid the bitumen to bind onto the pile.

COMPARATIVE RESULTS

Placement of the 12 ft. (3.7 m) high embankment began on July 28, 1977. The findings presented below are drawn from the data collected during the first six months following placement of the embankment. This data was derived from multi-rod extensometers anchored in the piles and from ground settlement platforms and multiposition deep soil settlement points.

Even while the embankment was still under construction, Piles 6 to 9 were already incurring downdrag. In less than 10 days ground settlement was 3 inches and gave rise to these downdrag values: 59 tons in uncoated reference Pile 6, 108 tons in uncoated reference Pile 8, 10 tons in bitumen coated Pile 7 and 14 tons in bitumen coated Pile 9.

As the groundline continued to settle, the magnitude of downdrag continued to increase on Piles 6 through 9. Fig. 3 and 4 show the time sequence and downdrag distributions for Piles 6 to 9.

By early September the depth of the neutral points became rather well defined and fixed on Piles 6, 7 and 8. The neutral points had already emerged at great depths: Pile 6, Elev. -100 ft.; Pile 7, Elev. -132; Pile 8, Elev. -135; Pile 9, not well defined. By December 7 the soil settlement ranged from 16 inches at the groundline to 1 inch at elevation -135 ft. (41 m). These values are compatible with the indicated downdrag loading distributions and the emergence of the rather deeply located neutral points exhibited by Piles 6 to 9.

After six months, on February 6, 1978 the groundline settlement was 18 in. Pile 6 experienced 165 tons downdrag; Pile 7, 67 tons; Pile 8, 194 tons and Pile 9, 38 tons. It is clear that the bitumen has been very effective, exhibiting reduction efficiencies from 60 to 80 percent.

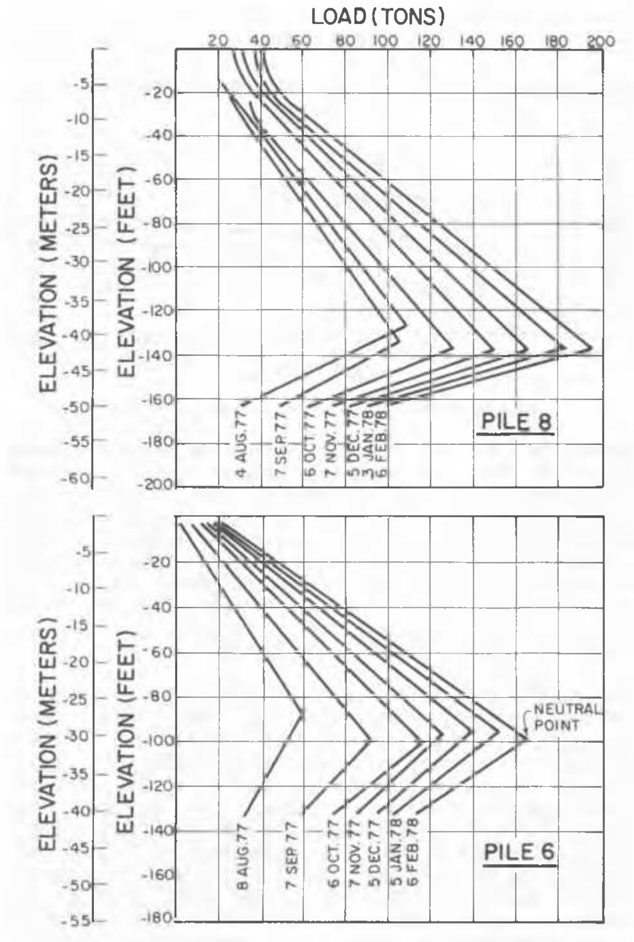

Fig. 3 Downdrag on Uncoated Reference Piles 6 and 8

The downdrag profile of Piles 6 and 8 show close agreement in both form and magnitude. The neutral point of Pile 6 is located somewhat higher than it is for Pile 8; the magnitude is less, also. This is probably because Pile 6 was not driven as deep as Pile 8 and had undergone tip settlement of 0.4 in. (1 cm) as of February 6, 1978, whereas Pile 8 shows no sign of tip movement.

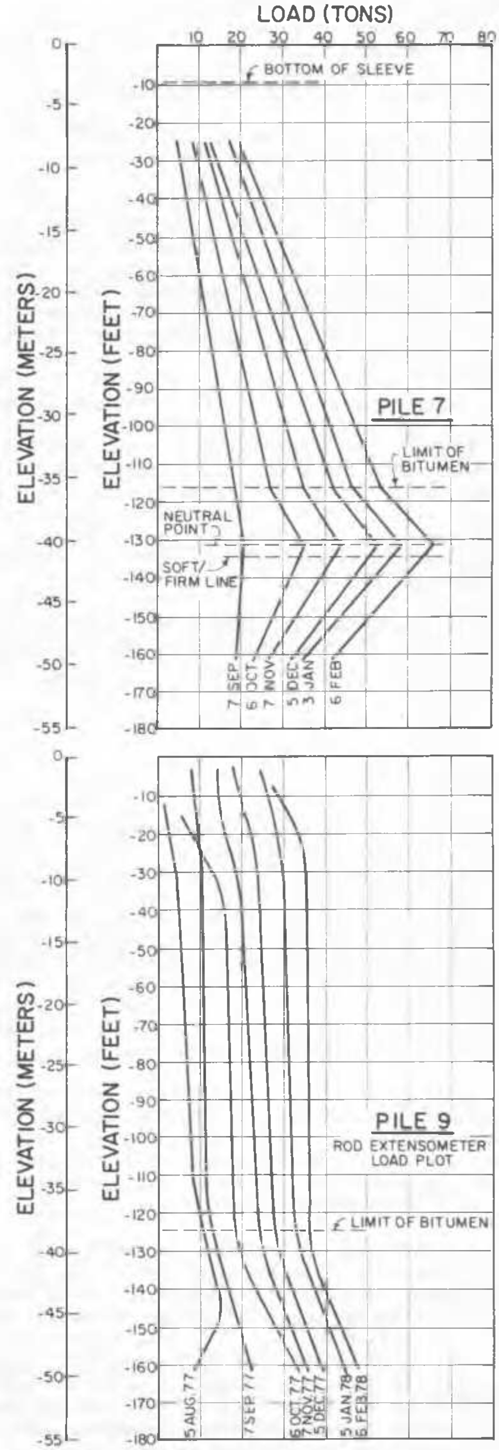

Fig. 4 Downdrag on Bitumen Coated Piles 7 and 9

Pile 7 exhibits a very plausible profile. Downdrag gradually increasing with depth to the bottom of the bitumen coating at which place an abrupt change in slope occurs, indicative of a faster buildup of downdrag below the presence of the bitumen.

Pile 9 has less downdrag than Pile 7. Below the bitumen coating the downdrag again increases abruptly, but this time there is no distinguishable neutral point. It may be that in the underlying coral/sand layer, there exists a pocket of decomposed soft coral clay near Pile 9. This clay pocket may be compressing under the influence of the embankment, inducing downdrag from above.

Fig. 5 shows a plot of the calculated loads in Pile 10 from rod extensometer deformation measurements. It is believed that the gauge lengths for Pile 10 were too short (about 10 ft.), creating a scatter of the calculated loads too wide from which to discern the pattern of the drag force distribution. However, if viewed as a whole, the plot is sufficient from which to judge at least the approximate range of downdrag experienced by Pile 10. In the least, crude boundaries exist at 20 tons and 55 tons, with the preponderance of values lying around 40 tons.

When the loads computed from the fundamental gauges (adjacent anchor combinations) are plotted against time in Fig. 6, their consistent behavior and uptrend are encouraging. When the drag force history from Pile 10 gauge combination (10-4) is plotted against Pile 7 gauge combination (7-1), Fig. 7, both of which apply to the same Elevation -60, their parallelism is striking. At this location Pile 10 has suffered only 7 or 8 more tons of downdrag than Pile 7.

The above is sufficient to confirm that the stiff asphaltic coating is quite promising in reducing negative skin friction and it deserves further attention in the future.

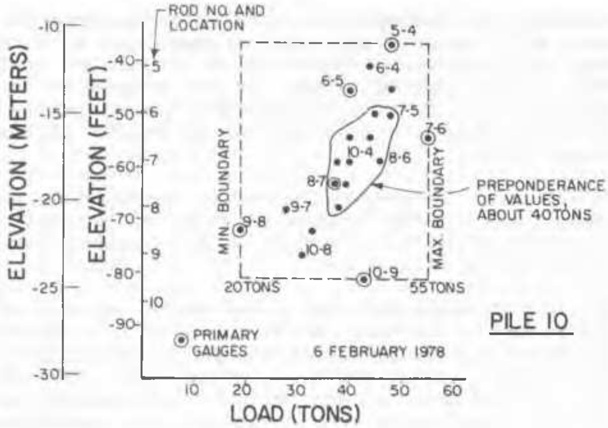

Fig. 5 Pile 10, Downdrag Values Using Harder Bitumen

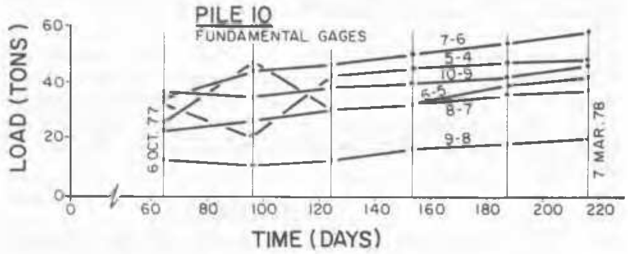

Fig. 6 Gages Exhibit Similar Uptrends in Downdrag

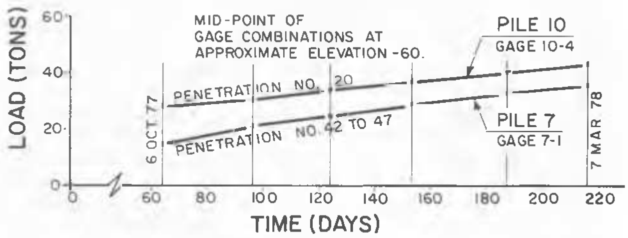

Fig. 7 Close Agreement in Downdrag Rate and Magnitude

Generally, the softer and/or thicker the bitumen coating is at the time of driving, the greater is its subsequent reduction on downdrag. Offsetting this, however, are the corresponding field difficulties in applying and maintaining softer, thicker coatings. Indeed in warm climates if measures to shelter or cool softer, thicker bitumen coatings are not implemented, then the ensuing field troubles may be disproportionately greater than the incremental reduction that is rendered by the attempt to increase thickness or softness.

Downdrag is a function of soil layering, preconsolidation pressure, compressibility, long term shear strength, pile type and method of installation. Whether bitumen is necessary, its penetration number, its reaction to the environment and the quality of the Contractor's operations will all affect the outcome. The interactions of these factors are not precisely calculable. Therefore, when local experience is lacking regarding the above factors, but a reliably close assessment of downdrag is desired, a field test program can directly resolve design and construction questions prior to a commitment to the final construction contract documents.

CONCLUSIONS

Where piles are to pass through thick deposits of clay that are either naturally underconsolidated or subjected to new fills, the potential for downdrag can be high and must be reasonably evaluated and accounted for in the foundation designs. In making this evaluation the gain in soil shear strength, and thus its potential negative adhesion, as consolidation occurs, must not be ignored. Downdrag loads arise in the earliest stage of relative movement between soil and pile and loads continue to increase considerably over time as long as soil settlement and shear strength are also increasing.

Bitumen coating, if properly specified and controlled in the field, is an economical effective medium for alleviating downdrag but can be undermined, if field preparations are not faithfully made. This includes priming, coating, protective measures and carefully considered pile installation techniques.

On Pile 7 a thin 1/16 in. coating of penetration range 42 to 49 achieved a sizeable reduction from the full downdrag values recorded on reference Piles 6 and 8. Pile 9 with a thicker coating produced somewhat better results. The data from Pile 10 is less lucid, but the 1/8 in. coating of penetration 20 may have had an appreciable effect on downdrag, though not quite as good as either Pile 7 or 9. These findings lead one to anticipate that a wide range of bitumens, depending on environmental conditions may perform satisfactorily.