Pre-loading of soft Holocene materials adjacent to shallow founded structure

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ABSTRACT

This paper describes a case study in Fiji involving the use of pre-loading to accelerate primary consolidation settlement prior to constructing buildings over soft Holocene materials. The pre-loading involved placing a surcharge exceeding the weight of the future structures. Careful monitoring took place to ensure the settlement exceeded the expected settlement which the weight of the structures would induce. Sufficient time was available to achieve the settlement without the need or expense to construct vertical drains to otherwise speed up settlement.

The site history and geology are discussed with respect to settlement inducing layers. Previous works on the site involving cutting and filling resulted in a complex stress history requiring careful evaluation of the effects on settlement.

The shape of the pre-load was designed to achieve the settlement requirements for the proposed buildings without exceeding the differential settlement criteria for the adjacent existing structure. Settlement results demonstrate that the design requirements were achieved.

1 INTRODUCTION

Over the past five years the author has been involved in the analysis, design and/or performance monitoring of some 40 pre-loads of typically 10,000m³ each at the Sofitel, Hilton, and Marriot resort developments, together with four other large projects in the Denarau Island area of Fiji. The general geology of all these sites was similar, with Holocene and Pleistocene sediments overlying basement materials at about 50m depth.

The knowledge gained from field trials in the Denarau area involving monitoring and back analysis of settlement, gave confidence in designing pre-loads and applying the use of the Asaoka graphical method for predicting the end of primary consolidation settlement as the pre-loading took place (Asaoka, 1980).

The case study was located adjacent to an existing building founded on shallow strip footings. The pre-loading was required to prepare the ground for proposed future buildings without exceeding settlement criteria for the existing building.

2 SITE HISTORY

The site is located on a reclaimed area of Denarau Island, at the southern end of Nadi Bay, Fiji. The island is separated from the main island of Viti Levu by a series of waterways, one of which is spanned by a connecting bridge. The Nadi River, in its present course, does not enter these waterways but flows to the sea about 3km south of Denarau.

Prior to the early 1990s the subject site comprised part of a sand spit, covered at high tide. A series of storm protection blankets were then constructed which extended around the entire seaward coast of Denarau Island. Over the following decade several different development options were proposed including a series of lagoons which were excavated and later backfilled. Hydraulic filling also took place within bunded areas using material excavated by dragline from the seabed within an adjacent marina area. Several pre-loads designed for an earlier layout configuration had also been placed and removed prior to the author's involvement with the project.

3 SITE GEOLOGY

The Denarau area is underlain by Holocene and Pleistocene surficial deposits, including sand, alluvium and colluvium. These materials were deposited at the Nadi river delta system, formed during previous sea level changes. They overlie a basement of undifferentiated conglomerate, marl, limestone and andesitic rocks belonging to the Nadi Sedimentary Group. The deepest borehole drilled in the area encountered these basement materials at a depth of about 50m.

The site geology was complicated by infilled meanderings of the Nadi River and ancient, randomly located, buried coral reefs. In general the site geology can be summarised as follows:

Table 1: Site geology

Layer Number	Material (Strength)	Thickness	Description
1	Fill (SPT, N = 1 to 10)	2.5 – 5m	Sand, silt, silty sand, loose to medium dense with layers of soft silty clay.
2	Estuarine Mud	11 -15m	Holocene - dark grey mud -weakly layered sands, silts and clays with shell and coral fragments. Grain sizes become smaller with depth, (indicative of a general fall in sea level during deposition)
2A	Sand (SPT, N = 1 to 19)	2 – 5.5m	Sand, silty sand, loose to med. dense, shells.
2B	Silt (SPT, N = 0 to 6)	4 – 8m	Silt, soft to firm, dark grey.
2C	Clay (SPT, N = 0)	5 – 7m	Clay, soft dark grey.
3	Residually Weathered Silt (SPT, N=11 to 26)	Approx 14m	Pleistocene – silt, very stiff to hard, green grey, coral and mudstone clasts.
4	Consolidated Estuarine Mud (SPT, N=25 to56+)	Approx 22m	Silt, clay, hard, sandy bands, coral fragments, thin gravel layers.
5	Nadi Sedimentary Group	Basement material	Claystone, dark grey, massive.

(Fitch et al, 2006).

4 SITE DEVELOPMENT

The long, crescent shape site, occupies a strip of land about 1200m long by 50m to 200m wide which arcs out into Nadi Bay. The development comprises a beach front resort of more than 500 units constructed in blocks of villas with up to eight units in each. Other buildings include central facilities, ballroom, conference facilities, swimming pools and a spa complex.

The larger structures are founded on driven pre-cast piles due to constraints on construction timing and differential settlement criteria. The development is currently proceeding on a staged basis and the resort is managed as the Hilton Fiji Beach Resort and Spa.

The area which is the subject of this paper is located at the extreme western end of the site. Following a pre-loaded exercise, a series of villas were constructed in a line along the beach front, founded on shallow footings. In the original design concept the rear row of villas were widely separated from the beach front villas. The concept then changed, moving Villa 23 close to Villa 1, as shown in Figure 1. Consequently, any pre-loading for Villa 23 would affect the adjacent Villa 1. In this particular location the depths of the soft silt and clay Holocene layers 2B and 2C totalled 9m.

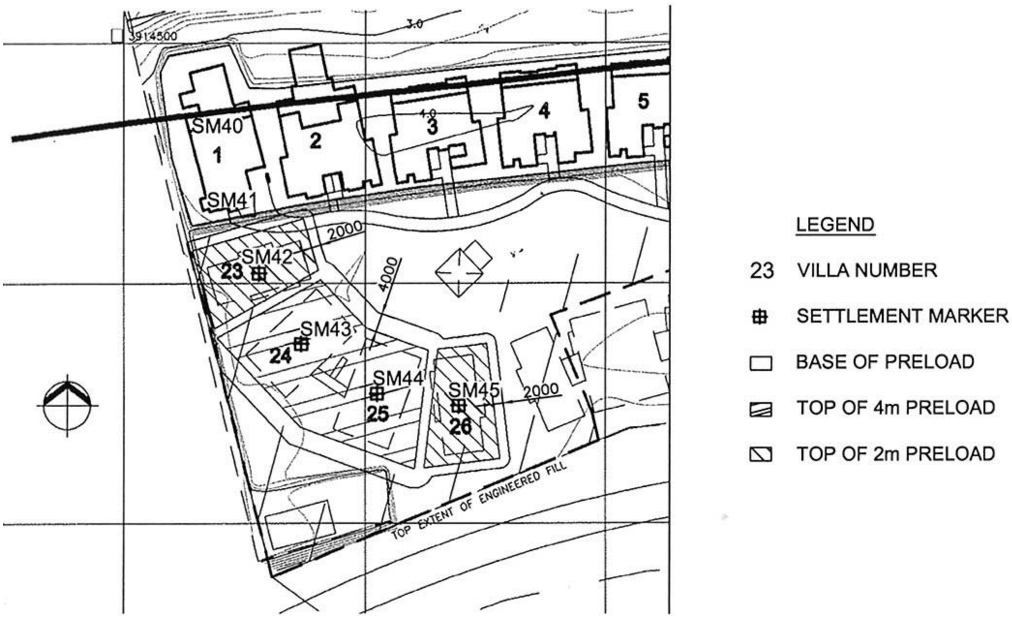

Figure 1: Site plan

5 SETTLEMENT RISK

The main risk to any shallow founded structures on the site concerns the settlement potential of the Estuarine Mud layer (2A, 2B, and especially 2C). One dimensional consolidation analysis using results of laboratory oedometer testing indicated a settlement time for 90% consolidation in the range of up to 10 years, due to the thickness of the layers. However, occasional thin bands of sand were observed in the CPT plots within the Estuarine Silt (2B) and Estuarine Clay (2C). These high permeability layers provided horizontal drainage which increased the rate of dissipation of excess pore water pressure reducing the settlement time to about 70% consolidation in four to six months, which was confirmed by settlement monitoring.

In order to reduce the post-construction primary consolidation settlement additional soil filling (pre-loading) was placed in the areas where buildings were to be founded on shallow footings. The weight of the pre-load exceeded the weight of the future buildings, plus any filling required, allowing the settlement which would have been induced to take place prior to construction. The extent of the secondary consolidation, (long term creep, following primary consolidation) in the area is expected to vary from 50mm to 100mm over the next 50 years.

6 STRESS HISTORY

Topographical plans of the reclamation, and of all cutting and filling that had taken place on the site, were reviewed relative to the location of each structure and the settlement monitoring points. Stress history plots were prepared beginning with the original ground level taken from the earliest available information. Settlement analyses were undertaken to determine the degree of either consolidation settlement, or rebound that had occurred with each historical variation in ground level. A typical completed stress history for Villa 23 (including construction) is shown in Figure 2.

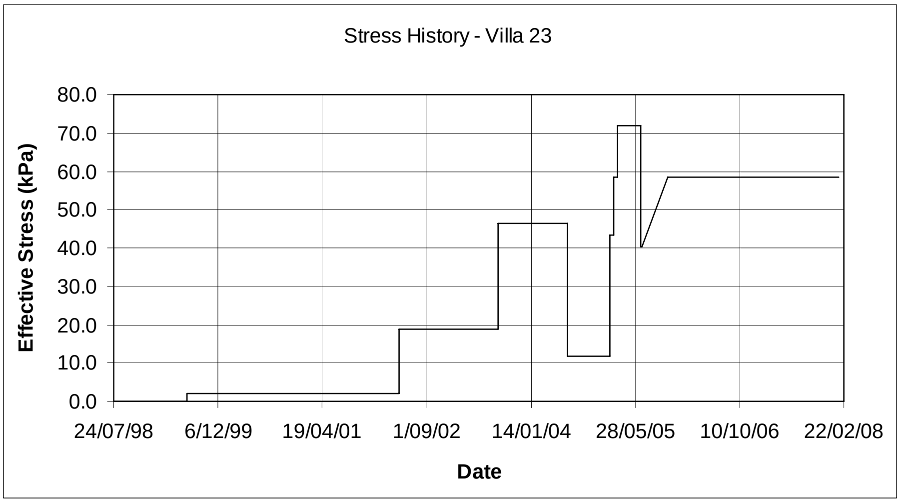

Figure 2: Villa stress history

7 PRE-LOAD DESIGN

The pre-load design was based on a number of constraints regarding the construction program and settlement criteria. Soil settlement parameters were based on laboratory data, field CPT testing and on the back-analysis of other pre-loads which had been monitored in adjacent areas of the development. An analysis of the long term primary consolidation settlement induced by the future building loads was undertaken given the requirement that future differential settlement across Villa 24 (2 storeys) and Villa 25 (3 storeys), should not exceed 25mm.

The project designers specified that a maximum differential settlement of 20mm was permitted across the 18m width of the adjacent completed Villa 1, due to pre-loading of the villas to the south. Monitoring of the lateral extent of settlement effects adjacent to pre-loads had been undertaken previously on other areas of the site, giving useful data to analyse the effects on Villa 1. From this data, the size and shape of the pre-load was fine tuned to induce a minimum settlement of at least one third more than the anticipated long-term settlement at Villas 23 to 25 (as a precaution), whilst achieving the criteria for Villa 1. The construction time frame allowed 3 months for pre-loading. A cross section through the design pre-load is shown in Figure 3.

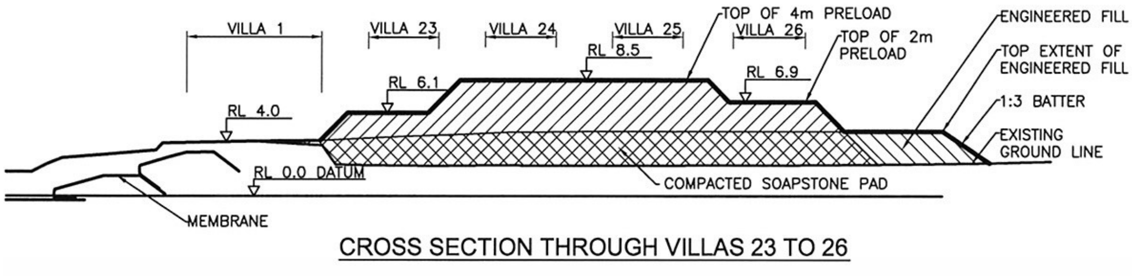

Figure 3: Pre-load cross section

8 SETTLEMENT MONITORING

Settlement monitoring plates were set up at the front and rear of the existing Villa 1 (SM40 and 41) and under the centres of the locations of proposed Villas 23 to 25 (SM 42 to 44) as shown in Figure 1. Monitoring of settlement markers took place on a weekly basis and the results are plotted in Figure 4. (The pre-load was built up over a series of weeks causing some initial irregularities in the curves).

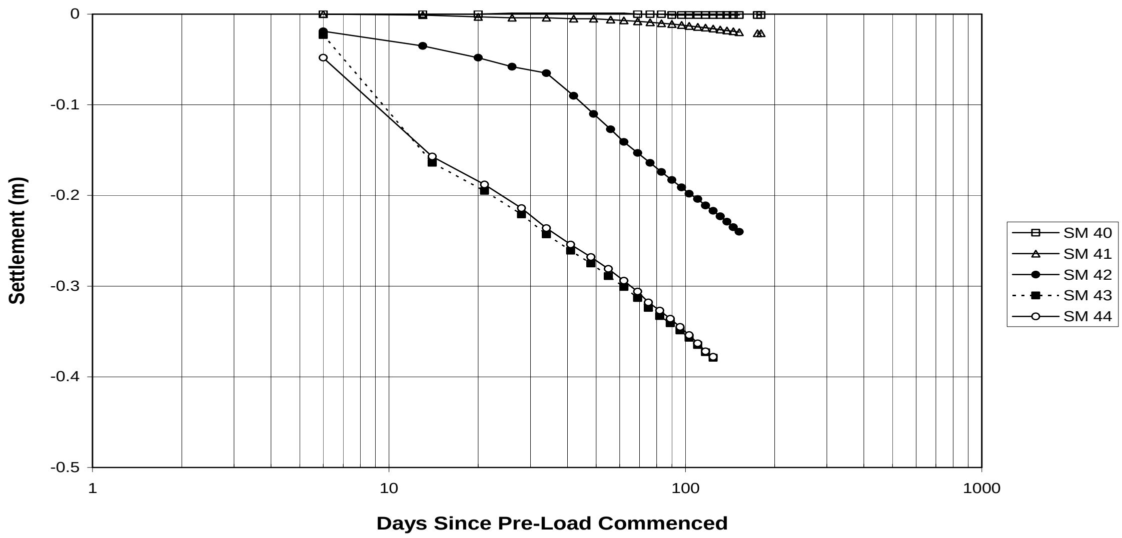

Figure 4: Settlement monitoring

During the pre-load monitoring the results were analysed to estimate the total final primary consolidation settlement for comparison with previous long term pre-loads. The Asaoka graphical method was used which gives a reasonable prediction as the monitoring period increases particularly if site specific factors are included and sufficient loading time has elapsed. A typical Asaoka analysis is shown in Figure 5. In this example the Asaoka predicted maximum primary consolidation settlement occurs at the intersection point of the linear extrapolation of the data plot (y = 0.8998x + 27.13), and the line x=y. (Refer to the attached reference list to review a detailed explanation of the Asaoka method.)

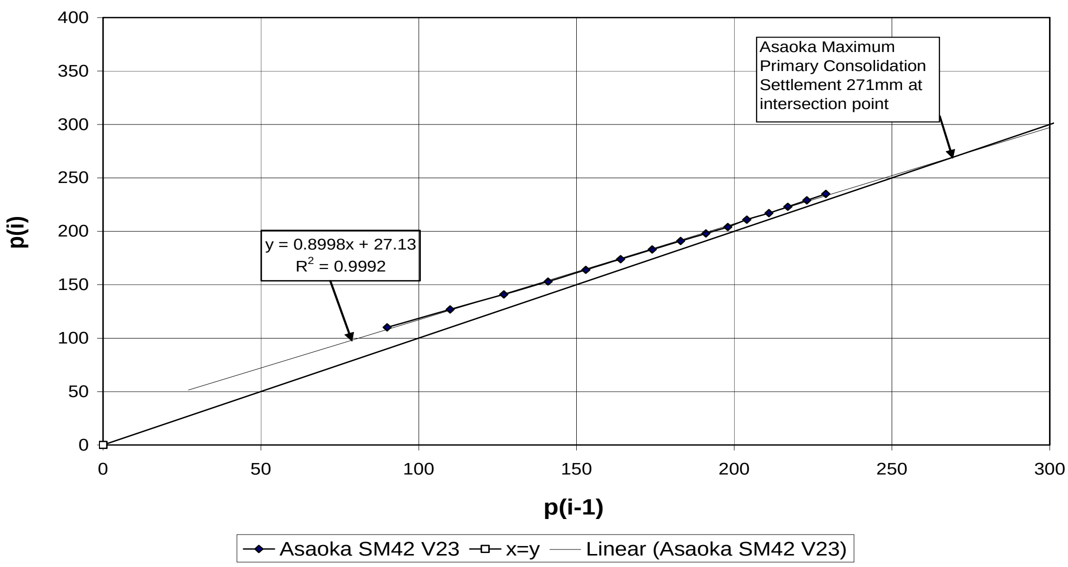

Figure 5: Asaoka analysis

After three months pre-loading the settlement at the villas varied from 1.4 to 1.7 times the theoretical future settlement requirement, exceeding the target of 1.33. A change in the construction program allowed an extra month for the pre-loading. The pre-load was then left in place for four months and, when removed, the settlement at Villa 1 measured 1mm at SM40 and 20mm at SM41 giving a differential of 19mm, within the 20mm differential settlement specified. The settlements measured at Villas 23 to 25 are given in Table 2 below:

Table 2: Settlement analysis

	Villa Number		
	23	**24**	**25**
Expected Future Settlement due to filling and building load	150mm	200mm	200mm
Measured Pre-load Settlement	240mm	379mm	378mm
Preload Ratio achieved	1.6	1.9	1.9

The pre-load removed from Villas 23 to 25 was used to increase the pre-load size at Villa 26 and the area further to the east. The construction of the villas then proceeded sequentially in a south easterly direction.

CONCLUSIONS

- The use of pre-loading provided a suitable method of reducing post-construction primary consolidation settlement for structures founded on soft Holocene materials.
- The pre-load design allowed for the stress history of the site and the proximity of the existing building using parameters from laboratory and field testing and from the back analysis of pre-loads previously monitored on site.
- A target settlement of at least a minimum of one third more than the anticipated long term settlement (ie a factor of 1.33) was required for the pre-loading exercise.
- At the conclusion of four months of pre-loading the expected future settlement due to the effects of filling and building construction were exceeded by factors of 1.6 to 1.9.

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