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Footing Settlement on Alluvial Soils at the New Brisbane Airport

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SUMMARY: The new Brisbane International Airport has been constructed on imported sandfill placed over deep deposits of compressible alluvial soils. Settlement behaviour was investigated using data from previous construction in the area and from detailed site investigation work including two instrumented test embankments. This indicated the possibility of using surcharging to enable the use of shallow footings founded in the sandfill for buildings except those with intense loadings. Details of the performance of existing structures in the area are presented and the basis of the definition of the design criteria is described. Settlement behaviour of sandfill in the vicinity of the main terminal building is documented together with the monitored total and differential settlements of footing pads during and immediately after construction.

1 INTRODUCTION

The site of the New Brisbane International Airport is situated in the estuary of the Brisbane River and subsoil conditions generally comprise of approximately 30m of quaternary alluvium overlying stronger tertiary clays, sands and gravel above a basalt bedrock.

The site is lowlying, typically R.L. 1-3m AHD, and subject to flooding. In order to provide protection from flooding and storm surge and to provide sufficient strength for the proposed aircraft pavements, it was necessary to place approximately 3m of sandfill to elevate finished surface levels.

It was decided that levels of aircraft pavements 20 years after construction should be satisfactory relative to flood and storm surge levels. Therefore, allowances were incorporated in construction levels to allow for settlement in the first 20 years. As airport building levels were determined by the aircraft pavements, consideration of post construction behaviour of buildings was also related to a 20 year period.

For economic reasons and because some problems had been encountered with piled buildings at Mascot Airport, the possibility of founding the airport buildings on shallow footings was investigated.

Sandfill would be obtained by dredging in Moreton Bay. The use of surcharging would be relatively inexpensive because the surplus sand from surcharging could be utilised elsewhere.

2 INVESTIGATION WORK

An initial site investigation comprised of 18 no. continuously sampled boreholes was carried out with extensive laboratory testing (Coffey, 1972) Two instrumented test embankments were constructed to check the effects of scale relating field settlements to calculations based on oedometer test results. These embankments were monitored for a period of five years. It was found that, for this site, there was no significant scale effect on calculated settlements (Larmour, 1973).

For buildings on shallow footings the primary cause for concern was the order of differential settlements that could occur between adjacent columns (at a min. 8-10m apart) during the first 20 years. With 30m of alluvium it is easy to postulate subsoil conditions to give theoretical differential settlements of the order 75mm or more which would be very difficult or impossible to accommodate structurally.

All available monitored information was examined to check whether expectations of such abrupt variations in settlement were justified.

In 1956 the runway of the existing Brisbane Airport was extended out over alluvial deposits for approximately 900m. Constructed typically on 1.5-2m of filling (unsurcharged) and to a predominantly level grade, the runway was surveyed and resurfaced with a nominal depth of bituminous concrete in 1966 and 1977. Figure 1 shows settlements.

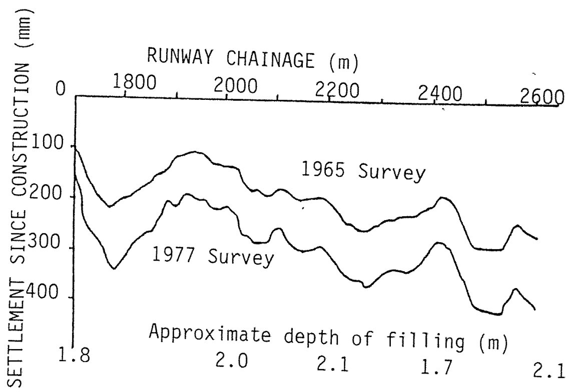

Figure 1 Settlement of the Existing Runway

For reference points on the centreline at 10m spacing the differential settlement between adjacent points after 20 years did not exceed 25mm even though parts of the runway had settled more than 400mm. The general pattern of settlement was the creation of long wavelength waves of up to approx 100-200mm amplitude. The concrete pavements at the northern runway end had settled 400mm by 1977 and were in excellent condition with a near level surface.

From the runway, the adjacent taxiway and the two test embankments there was a variety of data collected over periods of 1-21 years on differential settlements that could occur over short distances for situations where surcharging had not been used. In all cases there was no evidence of abrupt differential movement.

In 1975 a temporary International Terminal Building (ITB) was designed and constructed on approximately 1.5m of filling in an area of deep alluvium. The opening was 12 months after conception and no time was available for surcharging. The building was a single storey high roof, steel framed, clad structure with part height internal partitions. Footing pads were founded high in the filling almost immediately after fill placement. Despite this, 5 years after construction and with total settlements in the range 82-213mm (Figure 2), differential settlements for the 63 no. columns were in the range 0-51mm (Figure 3). The only structural damage was minor cracking in one interior cladding panel on the exterior wall.

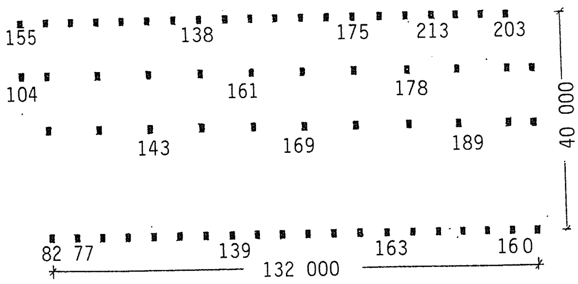

Figure 2 ITB - Total settlement of Footing Pads Five Years After Construction

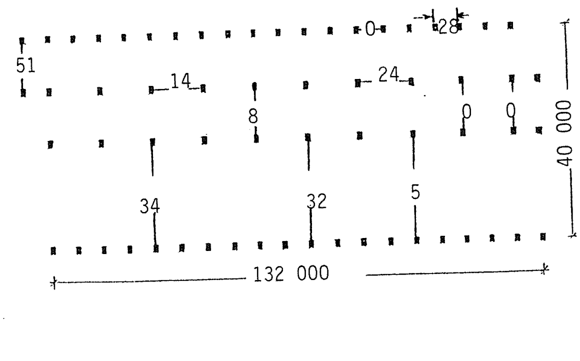

Figure 3 ITB - Differential Settlement of Footing Pads Five Years after Construction

The data in Figures 2&3, which was for unsurcharged conditions, indicated no abrupt differential settlements occurring within short distances.

From the data it was concluded that for the surcharged condition with columns at a minimum distance of 8m apart, expected differential settlements between adjacent columns for the 20 year design life of the building would generally be of the order of 25mm with a maximum of the order 50mm provided the criteria defined below were met.

3 DESIGN CRITERIA

In the planning stage in the late 1970's the details and location of the terminal building (the largest and most critical structure) were not finalised. As a result, the adopted criteria were required to be adequate at any location for any building predominantly of two stories with some three storey section:

- The building area to be surcharged with 3m of sandfill for at least 1 year with surcharge extending at least 10m outside the building perimeter.
- Allowable bearing pressure on sandfill beneath all footings = 100 kPa.
- Max. allowable pressure on original ground surface from floor and footing loads = 50kPa.
- Max allowable column load = 2000 KN
- Max. differential settlement between adjacent columns = 50mm.
- Building loads, column layout etc., to be as uniform as possible and structure to be articulated wherever possible.

The site investigation data and test embankments information indicated that clays near the original ground surface would be fully consolidated at the end of the surcharge period. Limiting the maximum allowable pressure from building loads on the original ground surface to 50kPa (ie. less than the surcharge load) prevented further primary consolidation from occuring in the upper soil layers under building loads. Maximum footing size was also controlled by this limitation.

4 BUILDING CONSTRUCTION

The design criteria were used for construction of the Terminal Building and for auxiliary buildings such as the Fire Station and Maintenance Area facilities. For the auxiliary buildings the height of the surcharge was adjusted according to the building loads but approximated to 1m of surcharge for each storey. All the buildings were constructed and have performed satisfactorily to date. The Terminal Building, as the largest and most critical structure, was monitored during construction.

Very heavy structures, such as the Control Tower were founded on piles end bearing on rock.

5 THE DOMESTIC TERMINAL BUILDING

The Terminal Building is extensive and irregular in shape (Figure 4). The building is predominantly two storey with some three storey sections. The structure is of reinforced concrete with slab-on-ground floor, waffle slab suspended floors, and a steel framed metal roof. Columns are on individual footing pads with occasional combined footings for double close spaced columns. Column spans were generally within the range 8-16m. Design footing loads varied from 830-2050 kN.

The Design Team opted to include jacking points in the Terminal Building columns just above ground floor level. This was a precautional measure to enable relevelling of the building frame at any time if necessary.

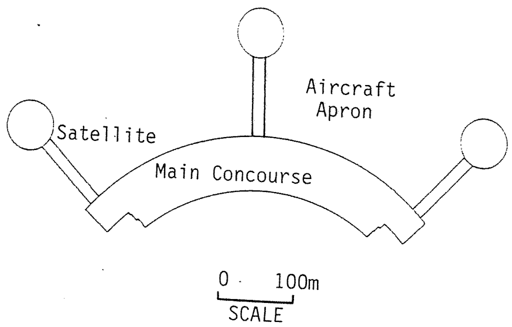

Figure 4 Plan of Domestic Terminal Building

Subsoils beneath the Terminal Building were variable (Figure 5) but in this area where rock surface was at a relatively typical 30m depth, the subsoils had relatively lower thicknesses of highly compressible soft clays (approx 12m total thickness) than most other areas of the site. The water table was generally within 1m of natural surface but after sandfill placement it rose above natural ground level into the filling.

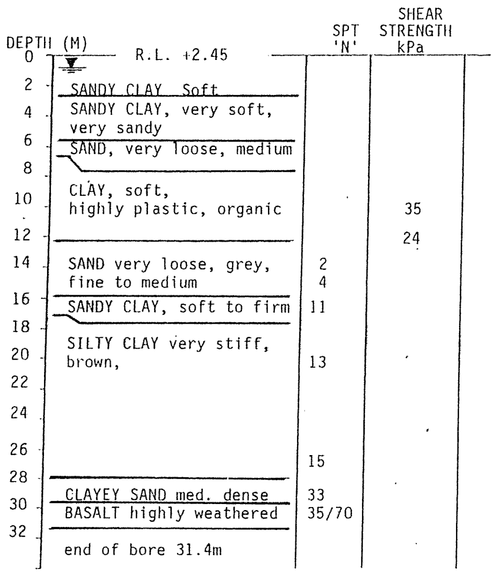

Figure 5 Typical Subsoil Conditions beneath Domestic Terminal Building (McConnell; 1980)

An initial thickness of 4.4-5.6m of filling including surcharge was placed on the building area from October 1981 - January 1982. Surface settlement points were monitored at 11 locations during the surcharge period of 12 months (minimum) and ranged from 570 - 960mm. This settlement data combined with piezometric data indicated that the estimated degree of primary consolidation near the end of the surcharge period was 83 - 94% in the building area (McConnell; 1980, 1983). The surcharge was removed in the period December 1982 - January 1983.

During construction the reduced levels of footing pads were measured when the pads and columns were complete to first floor level and the first floor beams or slab were interconnected. Footing construction took place at different times in various parts of the building and the first reduced levels were taken during the period March to November 1985. The pads were relevelled in January 1987, 14-22 months later when the building structure was essentially complete. Only settlements for the columns in the main concourse area, which were more heavily loaded and settled more than those of the satellite areas, are presented. The total settlements of the 386 no. columns during the construction period are shown in Figure 6 with differential settlements in Figure 7. Both sets of results are influenced by time factors as the time between the two sets of readings varied by up to 8 months for individual footings.

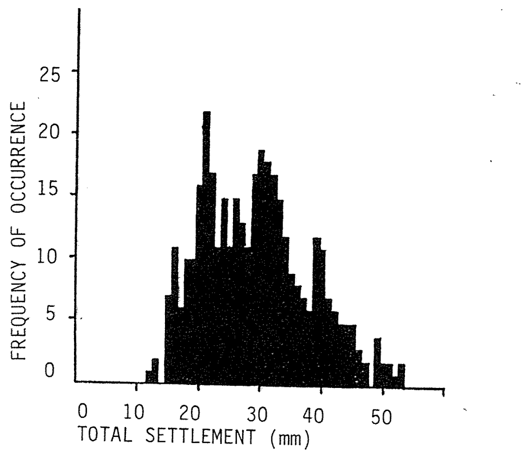

Figure 6 Total Settlements of Domestic Terminal Building Footing Pads during Construction

Approximately 7 months after building completion the first set of directly comparable readings was taken with the time interval between readings and the footing loads constant for all footing pads. Total settlements in this period are shown in Figure 8 with differential settlements in Figure 9.

6 DISCUSSION

6.1 Settlement During Construction

During the Terminal Building construction period the bulk of total settlements were in the range 15-45mm (Figure 6). This wide range was undoubtedly influenced by the variable time interval between readings for columns in different

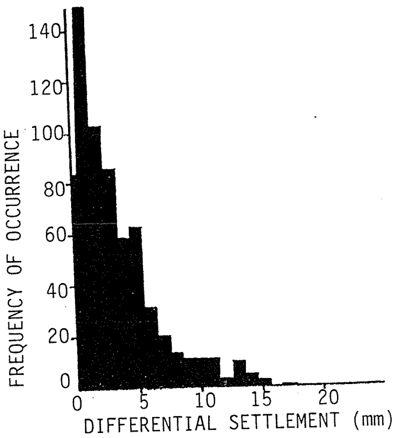

Figure 7 Differential Settlements between adjacent Domestic Terminal Building Footing Pads during Construction

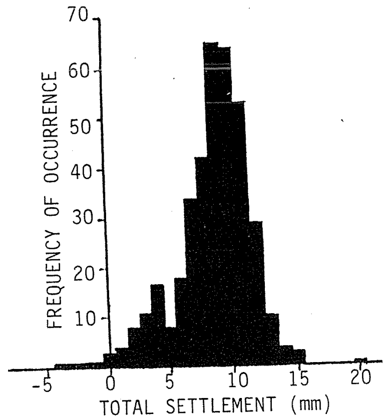

Figure 8 Total Settlements of Domestic Terminal Building Footing Pads for first 7 months after Building Completion

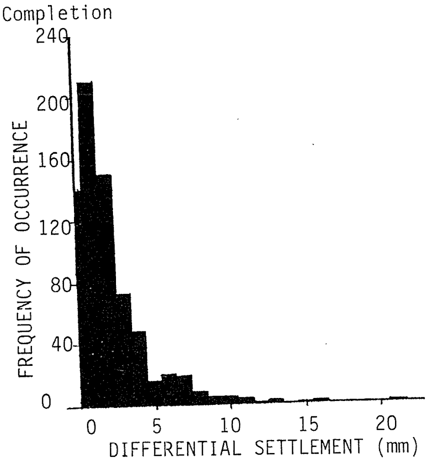

Figure 9 Differential Settlements between adjacent Domestic Terminal Building Footing Pads for first 7 months after Building Completion

areas and by differing subsoil conditions beneath the building. The total settlements recorded across the building tended to be of similar order in local areas. This is reflected in the relatively low differential settlements between adjacent columns (Figure 7: mean = 3.4mm).

The settlements recorded during construction were considered to have little potential for damaging effects. Differential settlements recorded between adjacent columns were low, a proportion of these settlements would have been built out in the superstructure during construction, and for part of the construction time the cladding would not have been in place.

6.2 Post Construction Behaviour

After completion of the building the range of recorded total and differential settlements were much reduced (Figures 8&9). The mean total and differential settlements recorded were 8.0mm and 2.2mm respectively.

Although it is early to extrapolate the probable differential settlements that may occur in the first 20 years of the life of the building, the results may be used to give an indication of the situation. Assuming that:

- future settlements will occur at a constant rate with log time relative to those of Figures 8 & 9.
- "zero time" - started when soils under full load = 18 months before building completion comprising 12.mths surcharge plus (est.) 6 mths. during building construction.
- the twenty year period started when the readings at end of construction were taken i.e. 18 mths. after zero time.

Then differential settlements would reach 50mm during the 20 year period if currently measured differential settlements equal or exceed 6.2mm.

Differential settlements of 7mm or more have been recorded for 49 (7%) of the 707 measurements. Of these, 20 no. have occurred between spans of 8-9m and the rest are for spans of 9.5-16m. The angular rotation resulting from differential settlement is considered the most likely cause of damage to the cladding in particular. The number of spans where the implied angular rotation exceeds 50mm/8m (i.e. 1/160) is 20 (2.8% of measurements). Some of these 20 locations have open space between the columns so that the effects of rotation are not so great.

The assumptions made above neglect any levelling effects which might occur due to redistribution of column loads resulting from the differential movements.

Applying the same assumptions to future total settlements the predicted mean total settlement at 20 years would be 180mm which compares well with estimates in the range 150-300mm from various sources.

6.3 Behaviour Relative to Design Criteria

It is currently considered that monitored settlement results are satisfactory relative to the Design Criteria. However, two beneficial factors occurred which could not be forseen when the criteria were formulated:

- The terminal building was located on an area of relatively less compressible subsoils than generally present at the site. Individual clay strata thicknesses were such that using classical primary consolidation theory (Terzaghi, 1967), 90% primary consolidation of the clay layers would be achieved in 1-2 years assuming double drainage. Therefore the great majority of post construction settlement could be expected to be due to secondary consolidation. This would reduce both the total and differential settlements that might be expected.

- the longer than expected time lapse of approximately 4 years between removal of the surcharge and completion of the building. For at least the first 2 years of this period the structure was not integrated and settlement occuring during this time would not affect building performance.

6.4 Potential Influence of Water Table

The long term behaviour of the Terminal Building may be affected by the level of the water table in the filling. During design it had been assumed that after hydraulic placement the sandfill would drain relatively rapidly and the water table would return to near original ground level. However, plastic sheeting was used to line sand retaining bunds controlling the sand profile during placement. This plastic is estimated to have considerably decreased the lateral permeability of the sandfill. As a result, during the construction period water tables were observed generally to be within 1m of the surface of the sandfill (and would be replenished by rainfall). The sand surface has now been sealed around the building excluding runoff. Therefore the water table may slowly drop, increasing effective pressures on the subsoils and increasing potential settlements to some degree. Some adjustment in the water table may already be taking place and be reflected in current settlement readings. There is no data available on this aspect at present.

6.5 Building Costs

The use of surcharging was anticipated to save on foundation costs by eliminating the need for deep piles. These anticipated savings were to some extent offset by increased costs in the provision for articulation in the cladding, etc. A direct comparison of relative costs is not available.

7 CONCLUDING REMARKS

The new Brisbane Airport has been constructed on sandfill placed on extensive depths of compressible alluvium. After a review of monitored settlement data, design criteria were developed for constructing buildings on footings at high level in the sandfill.

It was concluded that if surcharge was applied for a minimum period of 12 months and footing loads restricted, then 20 years after construction differential settlements between adjacent columns at least 8m apart would be expected to be generally of the order 25mm and below 50mm.

The Domestic Terminal Building and various auxiliary buildings have been constructed in accordance with the Design Criteria and are performing satisfactorily.

Data has been presented for total and differential settlements which have occurred for the 386 no. columns of the main concourse of the Domestic Terminal Building during the construction period and for the first 7 months after completion of construction.

From the monitored settlements to date and from preliminary projections of anticipated settlements 20 years after construction, satisfactory performance of the Domestic Terminal Building is expected.

For the Domestic Terminal Building both subsoil conditions and the construction schedule were more favourable regarding settlement behaviour than anticipated when determining the Design Criteria.

8 ACKNOWLEDGEMENT

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