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Rigid Raft Slabs for Lightly Loaded Structures on Filling

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SUMMARY This paper briefly discusses the major findings of recent research into the construction of lightly loaded rigid slabs directly on filling. The more important aspects of foundation and filling investigation are presented and a generalised design approach is proposed. The reader is referred to the successful application of the soft spot design concept to a number of residential structures which have been documented in detail in earlier papers.

A selection of typical industrial, commercial and cluster housing developments using the soft spot design concept is presented.

Finally the cost benefits of appropriately designed rigid slabs directly on filling for lightly loaded structures is reinforced and the major factors in consideration of the recommended soft spot diameter are emphasised.

1 INTRODUCTION

In heavily populated areas around the world the availability of land suitable for economic development is rapidly reducing. Developers are now turning to flood prone land and placing filling to lift the area above flood levels. In addition the use of old filled quarries, sand pits and reclaimed land is becoming more common. Because of escalating land and transport costs the development of cluster housing on inner suburban filled sites is often a viable proposition.

In the past, at filled sites, the normal foundation system adopted has been to use piers or piles to carry any loading through the filling to the underlying natural soil. This has now become a very expensive approach, especially for deeply filled sites. Recently, rigid slabs placed directly on filling have been used as a more economical alternative. The cheaper cost of rigid slabs compared with the use of piers, however, must be weighed against the risk that unquestionably exists when placing foundations directly on filling. It is therefore necessary to thoroughly investigate the filling and the underlying natural soil to determine the minimum slab rigidity which will give an acceptable level of risk at the most economical cost. It is essential to accurately define the filling depth and type and to then estimate its future settlement behaviour over the area of the structure. The predicted settlement behaviour can be expressed most simply for slab design purposes, by the concept of the development of a soft spot. The greater the future uneven settlement of the filling the larger the soft spot and hence the more rigid the slab needs to be.

As outlined later, the range of soft spot diameters likely to occur under domestic slabs is from 0 to 5 metres. Unquestionably, in areas of mining subsidence or limestone sinkhole development, much larger diameters may occur. However, the behaviour of lightly loaded slabs when subjected to gross soft spot developments is outside the scope of this paper.

This paper discusses the use of this simple procedure at a wide range of sites with controlled and uncontrolled filling. The successful application of this procedure to several large multi-million dollar developments is also outlined. The monitoring of surface filling settlements together with slab movements is presented and the suitability of this design concept for light structures is reinforced.

2 DESIGN GUIDELINES

Since the late 1960's, many thousands of housing slabs have been placed directly on filling at sites throughout Melbourne (Victoria, Australia). In the late 1970's the general design details of these slabs together with the depth and type of filling was collated following an extensive survey. Details of the more relevant design factors is given in Holland and Lawrance (1980).

Based on this study and extensive consulting experience over the last few years it has become obvious that certain design parameters are of major significance in the design of a rigid raft slab.

Before attempting to design a rigid slab for a particular filled site it is essential that a competent soil engineer conduct a comprehensive site investigation. The investigation should include a series of boreholes carried through the filling and into the underlying natural soil. The number of boreholes placed depends on the type of filling encountered. The more variable the filling the greater the number of boreholes required so that the risk in using a rigid slab at a particular site can be minimized by a more accurate assessment. The type of filling encountered in the boreholes must be carefully logged, with particular attention to organic layers which could rot away and leave cavities. Estimates of strength and settlement characteristics of the filling should be obtained using appropriate soil testing techniques and experience. Because of the likelihood of gross variability in the filling properties, sophisticated and precise soil testing is unwarranted. Rather it is better to carry out many simple insitu or laboratory strength tests. Compaction testing in highly variable filling is of little value.

After the site investigation is completed, an estimate of the likely soft spot diameter that will effectively develop under the slab must be made. In making this estimation the following must be considered.

(i) The depth of filling and its variation over the slab area.

(ii) The constituents of the filling. In particular the existence and amount of gross organic matter (ie. timber pieces or large tree roots) must be considered with regard to the possibility of it rotting away and producing sizeable cavities.

(iii) The strength, general degree of compaction and age of the filling is important in determining whether the filling is in fact still settling under its own weight.

(iv) The underlying natural soil profile. The likelihood of future uneven settlement of the natural soil due to the weight of the filling must be considered.

(v) The type of superstructure to be supported by the slab. Of particular importance is the amount of movement that walls will tolerate without distress as well as the evenness and level of loading applied to the slab.

(vi) The size of the structure must also be considered, since the repair and likely associated legal costs resulting from excessive slab distortion will increase dramatically as the building cost increases.

(vii) The level of excessive and uneven slab distortion and associated superstructure distress that the owner is prepared to accept should also be considered.

There is no question that the estimate of the soft spot diameter must be based on experience, however, the positioning of the soft spot under the slab controls the amount of steel reinforcing required in it. For housing construction, the two critical positions of the soft spot are given in Figure 1. Generally, the corner soft spot gives the greatest amount of steel.

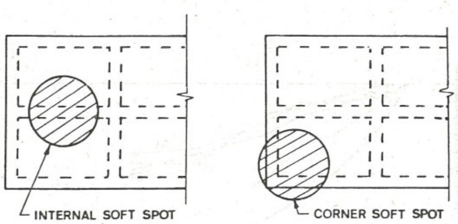

Figure 1 Critical soft spot locations for single storey housing

It should be emphasised at this stage that the soft spot design concept is a simplistic approach to a rather complex problem and hence refined structural design of the raft slab is unwarranted. In the case of a simple housing slab conservative design assumptions can be made while still providing the client with considerable cost savings. It is common practice therefore to provide equal steel top and bottom throughout the slab based on the critical soft spot location.

For typical housing or light structures of small area, conventional steel reinforcing is normally the most economical. However, for commercial or industrial buildings with high column loads, or for sites with deep poor quality filling or for large cluster housing developments the use of post tensioned reinforcement becomes economical and may offer many advantages.

The use of post tensioning in two directions throu throughout a slab provides a substantial shear flow through the cross section. This overall gives a better, more rigid slab performance and allows the use of greater cross section properties in design. Where high column loads exist, profiling post tensioned cables offers a more economical solution particularly where floor deflections are critical as is the case in warehouse raking systems. The profiling of cables can spread concentrated loads and effectively reduce subgrade contact pressures. In addition well designed post tensioning will also reduce the incidence of shrinkage cracking.

At poorly filled sites, where large soft spot diameters must be assumed, the use of rock filling under the slab is generally advisable. The rock filling should tend to reduce the size of soft spots or areas of localised settlement by flowing laterally, in addition where allowable bearing pressures are low, the depth of rock filling below the slab panel will reduce beam contact pressures.

Since the design concept for slabs on filling is far from precise, the building superstructure must be well articulated by slab to eave openings or frequent vertical expansion joints in unbroken lengths of brickwork. Extensive articulation is particularly important if solid brick construction is to be placed on the slab and/or if brittle forms of brick and brickwork are to be used. If articulation is not possible then a considerably stiffer slab is required. (ie. the soft spot diameter should be increased).

At poorly filled sites, the large uniform settlement of rigid slabs may lead to edge service piping failures. These failures could result in a sustained waste water leakage leading to the development of extremely large soft spot diameters. This potential problem can only be overcome by careful detailing of the sewerage lines, so that they can accommodate the likely level of rigid slab movement relative to the surroundings. Obviously this movement cannot be estimated with any degree of accuracy, but the two general sewerage line details outlined in Figure 2 should suffice in most situations.

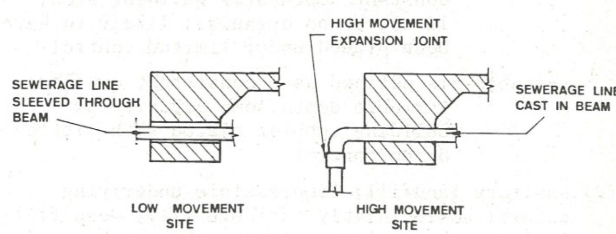

Figure 2 Movement tolerant piping connections

3 PAST USE OF RIGID RAFT SLABS

In an attempt to better understand the design and behaviour of rigid slabs on filling a series of five slabs were constructed at a range of filled sites during 1978/79. These slabs varied from housing on controlled cut and fill to football club rooms on sanitary landfill. The satisfactory long term performance of these slabs on filling depths up to 7 metres is briefly outlined by Holland and Richards (1982).

Over the last few years the authors have designed hundreds of residential raft slabs on filling on a routine basis. In particular in the south eastern suburbs of Melbourne many of the new subdivisions have controlled sandy filling placed over them during estate development. The construction of lightly reinforced raft slabs on this shallow depth of good quality filling can lead to considerable foundation cost savings.

Based on experimental rigid housing slab behaviour and considerable experience gained from consulting in this area, a series of very tentative generalised designs for use on various types of filling have been outlined in Table 1. A thorough site investigation is essential before even contemplating the use of a rigid slab. The generalised designs outlined in this Table will not eliminate the need for this investigation or the use of an experienced engineer to design an appropriate rigid slab.

TABLE 1

TYPICAL SOFT SPOT AND SLAB DETAILS FOR ARTICULATED BRICK VENEER HOUSING ON FILLING

Filling Details			Approx. soft spot (m)	BEAM	
Depth (m)	Type	Quality		$D \times B_w$	Centres (max) (m)
0 - 1.0	Sands	good	1.5	350x400	5
		variable	2.0	450x400	4.5
	clays	good	2.0	450x400	4.5
		variable	2.5	550x400	4.5
1.0 - 2.0	sands	good	2.0	450x400	4.5
		variable	2.5	550x400	4.5
	clays	good	2.5	550x400	4.5
		variable	3.0	650x400	4.5
2.0 - 3.0	sands	good	2.5	550x400	4.5
		variable	3.0	650x400	4.5
	clays	good	3.0	650x400	4.5
		variable	3.5	750x400	4.0

Notes:

(1) good - is defined as consistent quality; constant depth over building area; little or no organics; likely to have been placed under limited control

variable- is defined as inconsistent quality; variable depth, some organics or building rubble; placed with little or no control

(2) sanitary landfill; compressible underlying natural soils, highly variable fill; deep filling are not considered in the above table and require individual attention

(3) well controlled filling placement, allows a reduced soft spot.

4 RIGID SLAB DEVELOPMENTS

Due to past success of the rigid slab design concept and its proven cost saving the demand for rigid raft slabs at filled sites is increasing.

The early work based primarily on dwellings has been extended and applied to commercial and light industrial developments.

4.1 Forest Hills Village

In Forest Hills, (a suburb of Melbourne) an abandoned quarry site covering 4.5 hectares (11.25 acres) is currently being developed as a cluster retirement village by Jennings Industries Ltd. This quarry site has been filled under controlled conditions with up to 8 metres of reefy and/or sandy clay. Under strict supervision this filling was placed in 300 mm layers and compacted using a heavy weight roller, to at least 90% standard compaction.

Many of the one hundred and seven single storey retirement units and associated buildings including a community centre and 2000 square metre special accommodation hospital have been constructed directly on this controlled filling.

The majority of these brick veneer units and community centre have already been constructed mainly using conventionally reinforced slab systems designed to accommodate a 2.5 m diameter soft spot. While the large solid brick hospital has been designed using post tensioned reinforcing and a 4 m diameter soft spot.

Shortly after the filling placement was completed at this site and the first units constructed, a series of settlement monitoring stations were placed on varying depths of filling. Figure 3 shows the location of these settlement points and the magnitude of surface movements relative to the underlying bedrock. The comparatively excessive settlement at points 1 and 2 is likely to result from the difficulty in compacting the

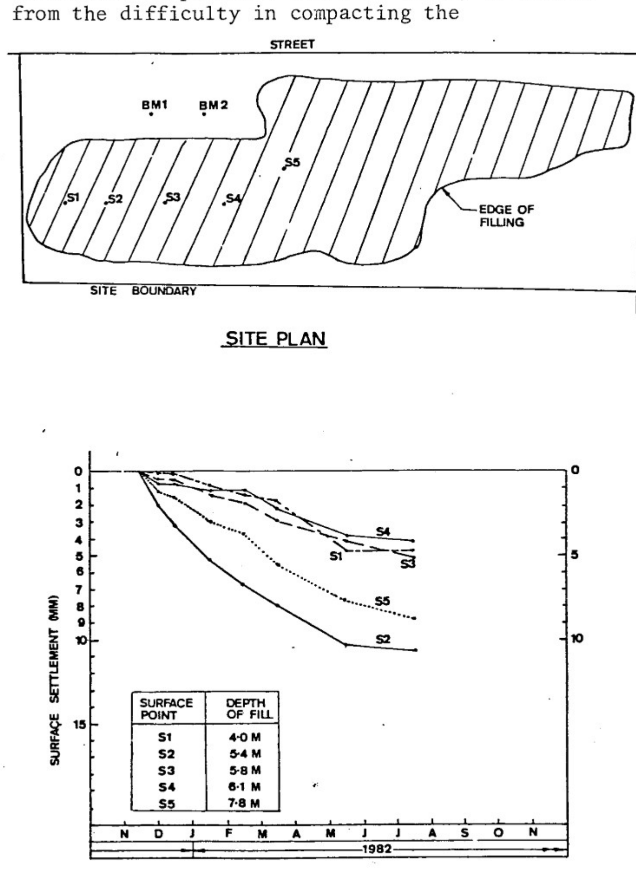

Figure 3 Settlement of filling at Forest Hills Village

filling in this area. This end of the quarry site was poorly drained and consistently wet throughout the filling operations. In the more than 10 months, however, since the filling was placed the minor surface movements that have developed indicated that the assumed soft spot diameter could probably have been reduced.

Without the use of the rigid raft slabs this site would have been uneconomical to develop and would have been left as an abandoned quarry site.

4.2 Port Melbourne

In Port Melbourne (Melbourne, Australia) three large industrial rigid slabs have been constructed on up to 9 metres of uncontrolled filling.

The major workshop building is about 80 m x 14 m, while the two associated garage structures are each about 36 m x 12 m. All buildings consist basically of a portal frame superstructure with part brick and part steel cladding walls, and the workshop in particular has industrial hoist loads which were considered in the design.

Based on the observed filling profile (Figure 4), the building superstructures and the age of this filling, (min. 10 years old) soft spot diameters of 5 metres and 4 metres for the workshop and garages respectively were adopted.

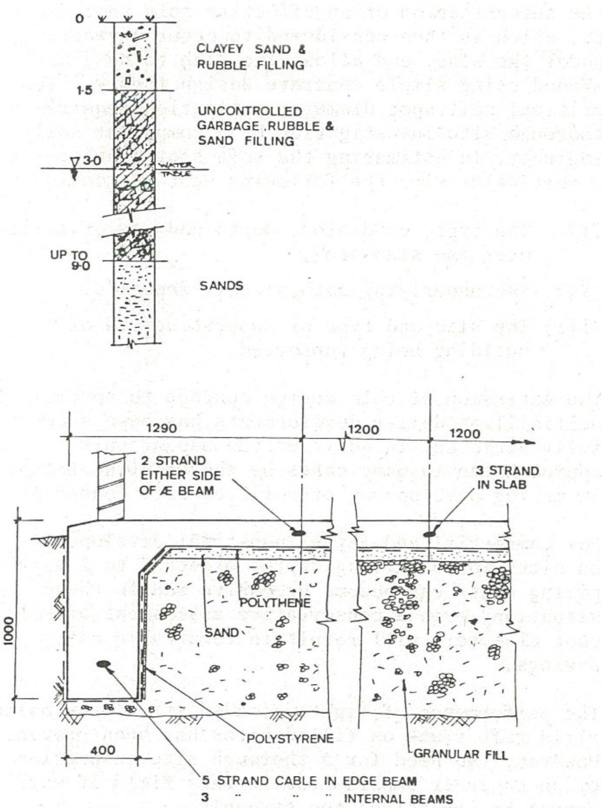

Figure 4 Soil profile and general slab details at Port Melbourne

The top 900 mm of filling beneath these slabs was excavated and replaced with a coarse granular material. When placing this granular filling, only minimal compaction was required. This would theoretically allow the granular material to flow laterally, if a soft spot should develop beneath this slab, and also reduced subgrade contact pressure.

Each rigid slab was designed using a post tensioning system of reinforcing with stiffening ribs up to 1000mm deep and 400mm wide on about 5 metre grid.

The long term performance of these rigid slabs is currently being monitored and over the next few years it is expected that this will provide further evidence to support the use of rigid slabs as an alternative to the more expensive method of pile and beam foundation. Initial readings have already been taken since the project was completed over twelve months ago and these preliminary readings clearly show that the slabs as designed are performing satisfactorily.

The cost saving using this raft foundation system compared to the alternative of deep piling was in the vicinity of A$100,000 for the entire project.

4.3 Diamond Creek Private Hospital

At a site in Diamond Creek (suburb of Melbourne) a local creek bed and catchment had been filled using very silty reefy clay filling to a depth of up to 5 metres over an existing mudstone clay with bedrock at a depth of about 7 to 9 metres.

A private hospital and nursing home of about 1000 square metres was proposed on a pile and suspended slab foundation system.

The successful tenderer for the construction of this project was, however, aware of several houses on adjacent land constructed using rigid raft slabs. An alternative design construct tender was then prepared using a rigid raft system. The total project saving on foundations costs alone was over A$50,000 or A$50/square metre.

The alternative raft was designed on the very conservative assumption of a 3.5m diameter soft spot using a post tensioned system. The approximate size of this slab cross section is indicated in Figure 5. A less conservative soft spot could easily have

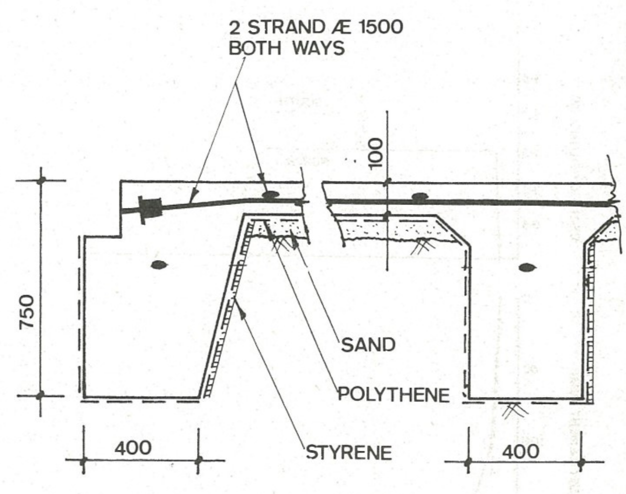

Figure 5 General slab details Diamond Creek Private Hospital

been used, however, in view of the already considerable saving, the slightly increased risk was not considered necessary.

In addition to the direct saving of A$50,000 it should also be noted that this system brought forward the completion date of this project by over 2 weeks, and saved indirectly a considerable amount of money in interest payments and rising building costs.

4.4 Patterson Lakes

At Patterson Lakes (a suburb of Melbourne) a low lying swamp area is being developed as an exclusive residential estate incorporating a complex of lakes and canals. These waterways allow boat access from the residential allotments directly to nearby Port Phillip Bay.

Up to 2.0 metres of well compacted sandy filling is being placed over the existing subgrade which in areas consists of 3 to 4 metres of a very soft, wet, sandy clay over local sands of swamp origin.

The settlement of this soft silty clay has been monitored during one of the later development stages. Settlement pads were placed on the subgrade prior to filling on both the north and south sides of a proposed road pavement. The settlement of these pads during the filling operations was monitored relative to deep bench marks and the results are presented in Figure 6.

To check the affect of the load due to a typical domestic structure on this subgrade settlement

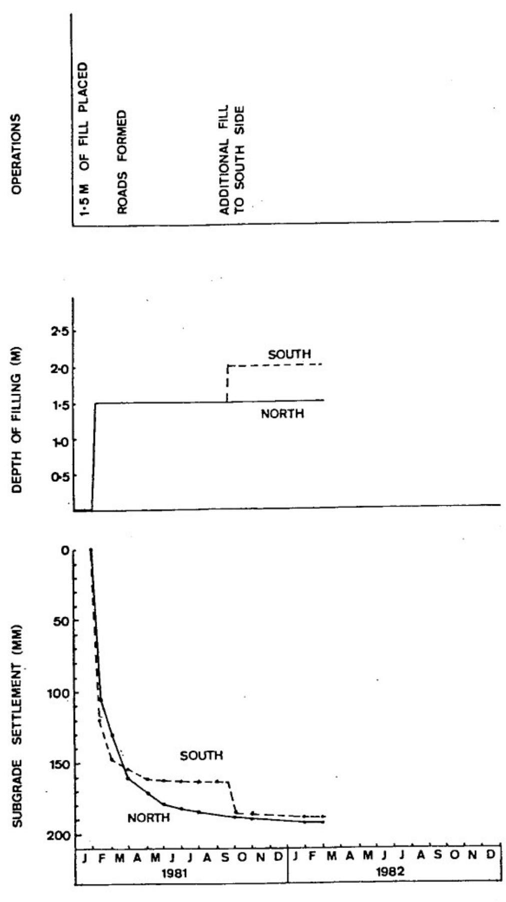

Figure 6 Subgrade settlement due to surcharge load at Patterson Lakes

an equivalent depth of filling (0.5 metres) was placed adjacent to the southern settlement pad. (See Figure 6).

In the total development of this project several hundred rigid slabs have been placed directly on filling over the last decade. One of these slabs has been extensively monitored and the slab movements relative to a deep bench mark are presented in Holland and Lawrance (1980).

During the first month this slab settled up to 8mm and the amount of differential settlement across this slab has slowly changed and increased to 18mm. This level of settlement and the period of time over which it developed corresponds closely to the observed behaviour of the loaded subgrade. (Figure 6).

To the authors' knowledge none of these slabs placed directly on filling have been unable to tolerate the uneven settlements that may have developed beneath them.

5. CONCLUSIONS

Based on the highly successful performance of thousands of rigid slabs on filling throughout Melbourne and the monitored behaviour of experimental slabs on a wide range of filled sites, a design approach for rigid slabs on filling has been outlined. The procedure basically revolves around the determination of an effective soft spot diameter, which is then considered to occur anywhere under the slab, and allows the slab to be dimensioned using simple concrete design theory. The critical soft spot diameter estimation requires a thorough site investigation by a competent soils engineer. In estimating the soft spot diameter at a particular site the following must be considered.

(i) The type, condition, depth and age of filling over the slab area.

(ii) The underlying natural soil deposits.

(iii) The size and type of superstructure of the building being supported.

The extension of this design concept to several multimillion dollar developments has been successfully achieved. In addition the use of this approach can in many cases be the critical factor in making development of a filled site feasible.

For commercial and light industrial developments on sites where filling depths exceed 2 to 3 metres piling costs can become excessive and in these situations even a conservative assessment of soft spot diameters will result in remarkable cost savings.

The performance of lightly loaded structures using rigid raft slabs on filled sites has been proven. However, the need for a thorough site inspection by an engineer experienced in this field of work cannot be emphasised too strongly.

6 REFERENCES

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