Behaviour and Design of Housing Slabs on Filling

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SUMMARY From a survey of the performance of housing slabs on filling and the behaviour of experimental rigid slabs at a variety of filled sites, a design method has been developed and is presented. An essential part of this method is a thorough site investigation by a competent soil engineer.

1. INTRODUCTION

An increasing number of housing allotments throughout the major Australian cities are having fill material deposited on them. This usually occurs during estate construction because of the expense of removing the excess cut soil from the road forming operation. Site spoil is placed on the lower blocks and, at least, track rolled in layers. Poorly and deeply filled lots are often found in the inner city areas. The use of old filled quarries and sand pits for housing in the established areas of the cities is now an attractive financial proposition as a result of escalating transport and housing costs.

In the past, at filled lots, the normal foundation system adopted has been to use piers to carry the house loading through the filling to the underlying natural soil. This is now a very expensive approach, especially for deeply filled lots. Recently, a limited number of rigid slabs placed directly on the filling have been used as a cheaper alternative. The cheaper cost of rigid slabs against the use of piers (Figure 1), however, must be weighed against the risk that unquestionably exists when placing foundations directly on filling. Obviously the more rigid the slab the less the risk at a particular filled site. But as the slab is made heavier its cost increases proportionally. 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 then estimate its future settlement behaviour over the area of the house. The predicted settlement behaviour can be expressed most simply for slab design purpose by the concept of the development of a soft spot. The greater the future uneven settlement of the filling the greater the soft spot and hence the more rigid the slab needs to be. For design purposes, the soft spot can be considered to occur anywhere under the slab. This design approach is obviously a simplistic model of the more complex and random support conditions likely to occur under a slab on filling. Great precision or refinement in the structural slab design using this concept is therefore unjustified.

As outlined later, the range of soft spot diameters likely to occur under housing 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

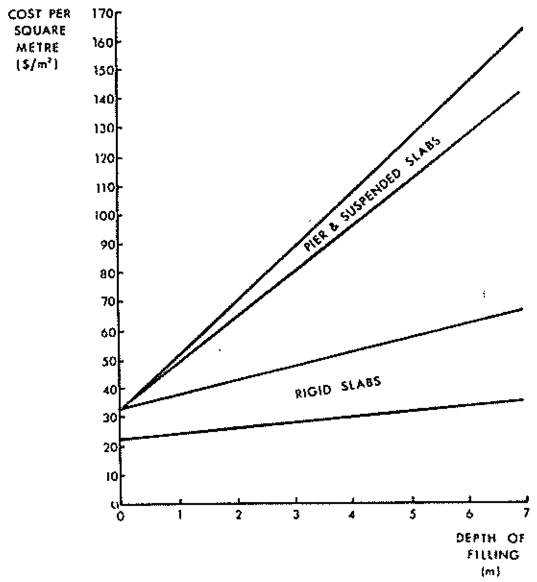


Figure 1 Relative foundation costs

of housing slabs when subjected to gross spot development from these two causes is outside the scope of this paper.

This paper will outline the details of housing slabs placed directly on filling throughout Melbourne, Victoria, Australia, over the last few years, and discuss briefly the failure of three of these slabs. A design approach for rigid slabs on filling will be suggested. Finally, the behaviour of seven experimental housing slabs on filling will be presented and discussed.

2. RIGID SLAB USAGE

Over the last ten years several thousand housing slabs have been placed directly on filled sites throughout Melbourne. The general details of the design of these slabs, together with the depth, age, type of filling, and the simplified natural soil profile are outlined briefly in Table 1. From this Table it can be seen that the soft spot diameter adopted can be related directly to the depth and

TABLE I

DETAILS OF RIGID SLABS USED IN MELBOURNE

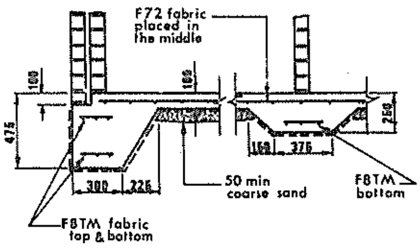
FILLING						UNDERLYING SOIL	S S Ø	RIGID SLAB DESIGN				
DEPTH (m)	AGE (yrs)	STRENGTH LEVEL	AMT. OF GROSS ORGANIC MATTER	COMPACTION LEVEL	TYPE		(m)	ROCK FILL DEPTH (mm)	BEAM DEPTH (mm)	BEAM SPACING (m)	SLAB DEPTH (mm)	SLAB STEEL
0 to 2	0 to 1	High	Nil	High	Well Controlled, clean sandy clay placed in thin layers	Deep loose sand or a thin stiff clay layer over bedrock	about 1.5	(mm) Nil	300 to 400	4.5 to 6.0	100	F62 to F82
0 to 2.5	1 to 10	Medium	Low	Medium to High	Partly controlled, track rolled, sandy and clayey filling containing a little building rubble	Wet loose sand or soft deposits overlying stiffer clay and rock	1.5 to 2.5	Nil	300 to 500	4.5 to 6.0	100	F62 to F82
0 to 7	0 to 5	Medium	Low to Medium	Medium	Partly controlled, track rolled, silty clay or clay filling containing a little building rubble	Stiff clayey soil overlying bedrock	2.5 to 3.0	Nil	500 to 600	4.0 to 4.5	100	F82
0 to 7	0 to 5	Variable, Medium	Medium	Medium	Uncontrolled sand or sandy clay filling containing building rubble	Medium dense deep sand deposits or stiff clayey soil overlying bedrock	3.0 to 3.5	0 to 300	600 to 700	3.5 to 4.0	100	F82
0 to 8	0 to 3	Variable, Medium to Low	Medium to High	Medium to Low	Variable uncontrolled silty clay or clay filling containing building rubble	Soft topsoil layer overlying loose sands or stiff clayey soils overlying bedrock	3.5 to 4.5	300 to 600	700 to 800	3.5 to 4.0	125 to 150	2 Layers of F62 to F82
0 to 10	0 to 3	Very variable, Medium to Low	High	Medium to Low	Very variable, uncontrolled filling with possibly degradable material through	Soft topsoil layer overlying loose sands or stiff clayey soils overlying bedrock	4.5 to 5.5	600 to 1000	800 to 1000	3.5 to 4.0	150 to 200	2 Layers of F82

filling properties. In particular, the variability of the constitutents and depth of filling over the house area, the method of placement and compaction adopted, the age of the filling prior to slab construction and the amount of gross organic matter present all need to be considered.

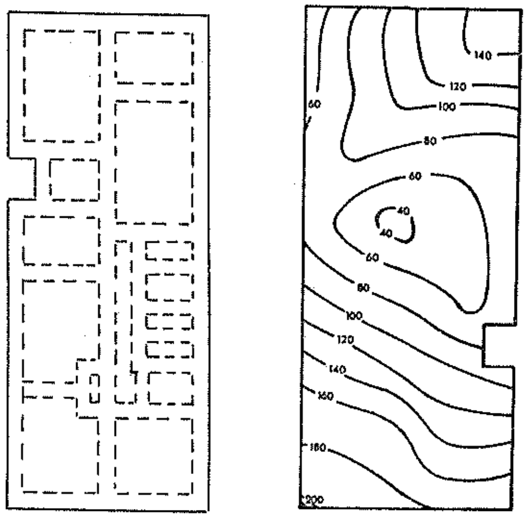
To the authors' knowledge only three failures of these housing slabs on filling have occurred. In two of these cases, it was not realised that the sites were filled until superstructure distress was evident. At the third site, localized very highly organic filling caused excessive uneven distortion of the slab. Without indicating the locations, since legal action is in progress for two of the houses, these three failures will be discussed.

Case 1 : At this site an old gully has been filled with mainly grey silty clay and topsoil to a depth of between 1 and 4 metres. The filling is underlaid by a thin layer of topsoil and silty clay over siltstone. The filling was placed in 1973 under limited control, with possibly some track rolling of 500 to 1000 mm thick layers. In early 1975 the builder, unaware of the existence of the filling, placed a very light slab directly on it. Figure 2(a) & (b). Within months of completing the single-storey, solid brick house, excessive uneven dishing of the slab (Figure 2(c)) occurred and led to extensive damage of the superstructure. In fact, the slab has settled so far in the middle that it is just below the surrounding ground surface. This has resulted in internal flooding of the house following heavy rain.

A poor layout of internal stiffening ribs was used in this slab. Obviously it would have behaved in a more uniform and rigid manner if the ribs had been continuous from edge to edge and distributed more evenly over it. A recent set of levels on this slab indicated very little change in shape over the last nine months. This appears to indicate that the



(a)



(b) (c)

Figure 2 Case 1 details

filling has ceased to settle under both its self weight and that of the house weight.

Case 2 : In the northern and western suburbs of Melbourne relatively fresh basalt bedrock occurs at very shallow depths. This has led to numerous quarries being established throughout these suburbs- Some of these were used solely for exploration and were quite small (up to 5 to 10 metres across).

The second slab failure was in an area where a series of small exploratory quarries (up to about six metres deep) were very poorly filled with large basalt pieces and very soft, wet clay (Figure 3). Again, a builder completely unaware of the existence of these exploratory pits, placed a very light slab directly on one of them. Before the single-storey,solid brick house was completed the slab failed by dishing in the middle by an estimated 75 mm. Failure in this instance occurred immediately following a period of heavy rain. The house and slab were subsequently demolished.

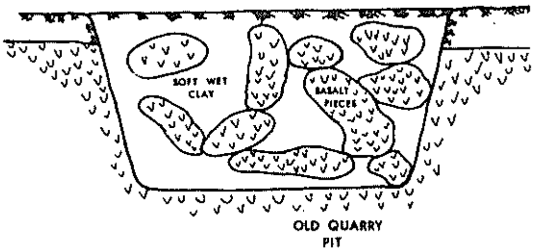


Figure 3 Case 2 subsoil details

Further, more extensive subsurface investigation of these filled pits was only possible using a large mechanical shovel. The test pits indicate that the basalt pieces are very variable in size and up to 900 mm across. The clay between the basalt pieces is kept wet and soft by the build-up of ground water in the pits.

Case 3 : In this case a limited initial site investigation indicated that between one and two metres of mainly stiff sandy clay filling exists over stiff to soft brown clay to at least a depth of seven metres. It was decided to remove the top two metres of filling and replace it in well compacted 300 mm thick layers. A modified suspended slab capable of spanning a soft spot of about two metres was then placed directly on the filling. About twelve to eighteen months after the slab was constructed, it began to settle substantially in the rear corner of the house (Figure 4). Unfortunately, the house sewerage lines were in this area and their design at the slab/soil interface was not capable of tolerating the large slab settlement and so sheared off. The leakage from these lines then aggravated the settlement problem by locally softening the filling and increasing the slab settlement. Recent subsoil investigation indicated the existence of a pocket of very poor, highly organic, filling under the corner of the slab that settled (Figure 5). It is the authors' opinion that this poor filling was created by the removal of the stump of a large tree and back filling the resulting hole with the surrounding topsoil and broken tree roots. Sandy clay filling was then placed over this extremely poor fill.

These three failed slabs form only a negligibly small percentage of the total number of rigid slabs

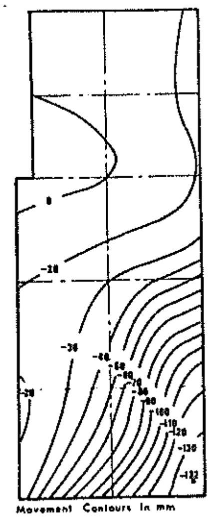


Figure 4 Case 3 slab settlement

that have been successfully placed on filling throughout Melbourne over the last decade. The extensive and successful use of about 1500 relatively light slabs on basically uncontrolled filling at Chelsea (a southern suburb of Melbourne) supports the view that the risk involved in using this foundation system on some filled sites is not excessive. The filling placed at Chelsea is generally an uncontrolled mixture of sands and sandy clays containing a little building rubble. It has been placed in a completely uncontrolled manner, then left for 5 to 7 years to settle under its own weight before the standard light Council designed slabs are constructed on it. This standard design is based on a 1.6 metre diameter soft spot and has been used for all forms of single and double-storey housing construction.

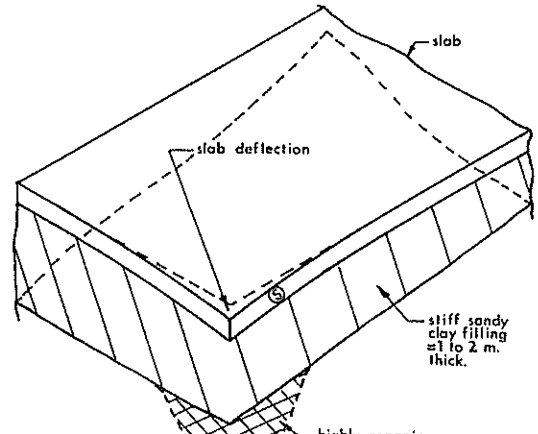


Figure 5 Case 3 filling details

Two further interesting rigid slab situations at Essendon and South Melbourne (suburbs of Melbourne), demonstrate the tremendous potential use and cost savings that can result from using this foundation system. At Essendon between 3 and 9 metres of uncontrolled mainly firm to soft, wet brown sandy to very sandy clay filling containing many large pieces of concrete, rock and steel (parts of car bodies), existed over thin layers of sandy topsoil and hard sandy clay underlaid by decomposed basalt. Initially an attempt was made to use a pier and suspended slab to support a large solid-brick, double-storey house. However, because of the numerous large pieces of concrete, rock and steel through the filling, it was not possible to drill pier holes through the filling using conventional equipment. It was then decided to place a very heavy rigid slab (Figure 6) directly on the very poor filling which had been placed about four years earlier. The use of the rigid slab foundation system saved the builder between $6,000 and $10,000 over the cost of a normally drilled pier and suspended slab system. As already stated, normally drilled piers were not possible, so if this system had been used much more expense would have been incurred using special pier drilling equipment, so increasing the rigid slab cost advantage by at least a few thousand dollars.

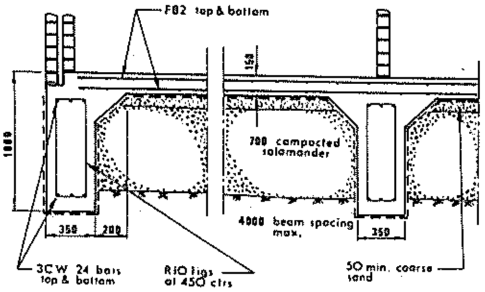


Figure 6 Essendon slab details

At South Melbourne, a light rigid slab (Figure 7) was placed about two years ago on about 1.5 to 2 metres of stiff sandy clay filling overlying about 5 metres of very soft and wet clayey silt. This is then underlain by stiff clay and siltstone. A single-storey, partly solid brick, office was constructed on the slab. Absolutely no signs of excessive uneven slab distortion exist in the superstructure of the office. However, the occupants claim the building shakes as trams pass by the front of the building. The excellent performance of this light rigid slab on a thin layer of filling over extremely soft natural deposits demonstrates again the load spreading ability and the

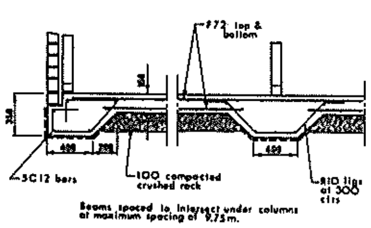


Figure 7 South Melbourne slab details

tremendous potential for the use of slabs at difficult sites. The more traditional driven piling foundation solution would be much more expensive. However, one must always be aware of the inherent risk in placing slabs directly on filling.

3 DESIGN GUIDELINES

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 under lying natural soil. The number of boreholes 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. The type of filling encountered in the boreholes must be carefully logged, particular note being taken of 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 house area.

(ii) The constituents of the filling. In particular the existence and amount of gross organic matter (i.e. timber pieces or large tree roots) must be considered as far as 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.

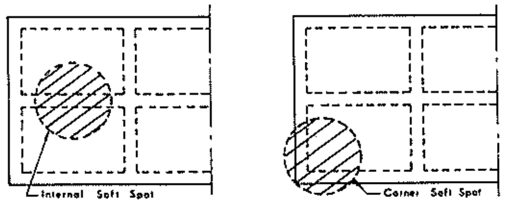
(iv) The underlying natural soil profile. The likelihood of future uneven settlement of the natural soil under the filling self weight must be considered.

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

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

(vii) The level of risk of excessive and uneven slab distortion and associated superstructure distress that the home owner is prepared to accept.

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. The two critical positions of the soft spot are given in Figure 8 (a) & (b). Generally the corner soft spot gives the greatest amount of steel. The steel must be equal top and bottom in the beams



(a) (b)

Figure 8 Soft spot positioning

and based on the worst soft spot location under the slab. At poorly filled sites where large soft spot diameters must be assumed, the use of crushed rock under the slab is generally advisable. This rock should tend to reduce the size of soft spots or areas of localised settlement by flowing laterally. The slab panel between the beam grids must be designed so that it can span the design soft spot, which means the steel must be generally placed in the middle or near the bottom of the slab. For poorly filled sites, or where heave of clayey filling is likely, layers of steel in both the top and bottom of the slab panel must be used.

In light of the difficulty in accurately predicting the soft spot diameter and the resulting uncertainty thus inherent in the total design concept, the use of simple concrete design theory is suggested. The very conservative assumption that all house loading is taken by one beam over any particular design soft spot under the slab greatly simplifies the design calculations.

Since the design concept for slabs on filling is far from precise, house superstructure must be well articulated by floor to ceiling openings or frequent vertical expansion joints in unbroken lengths of brickwork. Extensive articulation is particularly important if solid brick house construction is to be placed on the slab and/or if brittle forms of brick and brickwork are to be used.

At poorly filled sites, the large uniform settlement of rigid housing 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 9 should suffice in most situations.

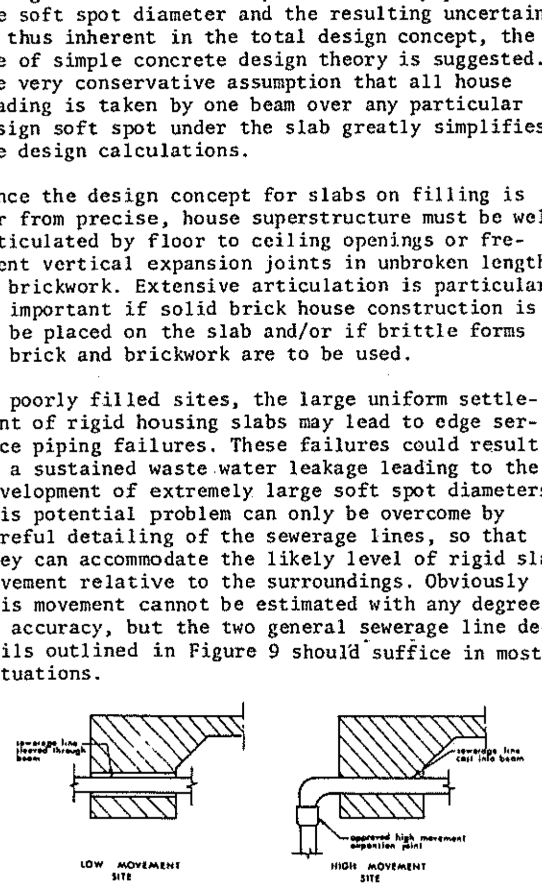


Figure 9 Suggested flexible plumbing joints

Based on experimental rigid housing slab behaviour and experience gained from a survey of the details and performance of a reasonably large number of existing housing using rigid slabs, a series of very tentative generalised designs for use on various types of filling have been outlined in Figure 10. A thorough site investigation is essential before even contemplating the use of a rigid slab. The generalised designs outlined in this Figure will not eliminate the need for this investigation or the use of an experienced engineer to design an appropriate rigid slab.

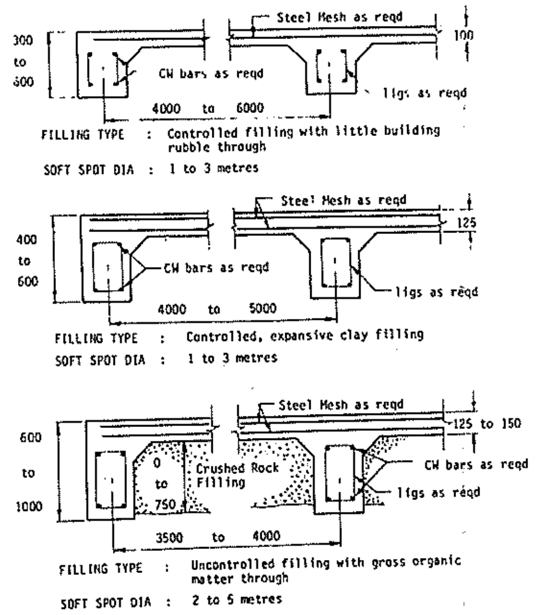


Figure 10 Generalised rigid slab details

4 EXPERIMENTAL RIGID SLABS

In an attempt to better understand the behaviour and design of rigid slabs on filling a series of seven actual housing slabs have been placed at a range of filled sites. The settlement of these slabs relative to deep bench marks is being monitored. The sites and slabs have been extensively investigated and designed according to the procedure outlined. General details of each slab design and the relevant site details are given in Table II.

At the Endeavour Hill site between 3 and 7 metres of track rolled sandy clay filling was placed about four years ago. The settlement of the rigid slab (placed in June 1978) has been relatively small (Figure 11); however, it is greatest where the filling is deepest. The movement also indicates that the filling had practically completely settled prior to placement of the slab. The major conclusion one could draw from this behaviour is that the slab was overdesigned, even though between 3 and 7 metres of only track rolled sandy clay filling existed under it.

The behaviour of the Chelsea slab in an old filled swamp area, where about 1500 houses have been constructed over the last decade using basically the same rigid slab design, is particularly interesting. The movement of the slab (Figure 12) indicates that a soft spot developed initially under the rear corner of the house. This caused a localised settlement

TABLE II

DETAILS OF EXPERIMENTAL RIGID SLABS

SITE	SLAB PLACED	FILLING DEPTH (m)	FILLING TYPE	FILLING AGE (Yrs)	UNDERLYING SOIL	S.S ϕ (m)	SLAB DETAIL BEAM DEPTH (mm)	SLAB THICK (mm)	SLAB STEEL	BEAM STEEL	BEAM SPACING (m)	COST SAVING (Figure 1) $
ENDEAVOUR HILLS (Melbourne)	June 1978	3 to 7	Track rolled, very stiff to stiff brown sandy clay to clay, with some building rubble through	4	Thin layers of grey sandy topsoil and stiff brown and grey sandy clay over granodiorite.	3	600	125	2 layers F62 top & btm	2CW 20 bars top & btm	4.0	11000
CHELSEA (Melbourne)	Aug 1978	1.2 to 1.5	Mainly stiff to very stiff brown and grey sandy to very sandy clay with miner amount of building rubble through	7 to 12	Stiff dark grey sandy clay to loose, wet grey clayey sand to at least 3 metres.	1.5	300	100	F72	F8TM btm	4.5	5000
WARRAGUL (Victoria)	Dec 1978	Up to 3	Very poor, wet. Sanitary filling overlaid by firm clay filling	5	Thin layer dark grey topsoil over stiff red brown clay to at least 3.5 metres.	3.5	750	150	F72 top & btm	2CW 24 bars top & btm	3.5	12000
WONGA PK (Melbourne)	Feb 1979	Up to 3	Well compacted very reefy clay	0.25	Thin layers of light brown and grey clayey silt overlying stiff brown and grey silt clay. This is underlaid by highly weathered siltstone.	3.0	600	100	F82	2CW 20 bars top & btm	4.0	[illegible]
PATTERSONS LAKES (Melbourne)	June 1979	1.0 to 1.8	Mainly brown and grey silty and clayey sand	1.5 to 2	0 to 1.3m of organic silty clay overlying a very soft and compressible stratum of grey silty clay then sand to at least 7 metres.	2.0	450	100	F82	2 layers F11TM top & btm	4.0	3000
KILSYTH (Melbourne)	1979	Up to 1.3	Stiff to very stiff grey and brown silty clay with some building rubble through	5	Thin layer of topsoil overlying soft to firm grey and brown clayey silt overlying stiff to very stiff light grey and orange silty clay to at least 5 m.	1.5	300	100	F82	F8TM btm	6.0	3000
MODBURY (Adelaide)	1979	0.5	Well compacted red brown to brown silty clay	-	Stiff to very stiff red brown to brown silty clay to at least 1.8 metres.	1.5	500	100	12.5mm Ø cables post^{n}	Nil	No internal beams	2500

which was gradually redistributed by the stiffening beams to the rear portion of the slab. Since June, 1979, the settlement of the slab has practically ceased. The soft spot development appears to be due to the combination of a relatively more clayey natural underlying deposit and the close proximity of the edge of the general filling. The unfilled swamp is only about five metres from the rear of the slab.

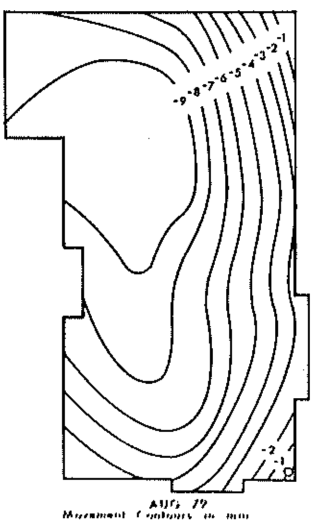


Figure 11 Endeavour Hills slab settlement

The Warragul site was used for sanitary land fill, so it represents the worst type of biodegradible filling likely to be encountered. The building is a single-storey, solid brick football pavilion. The settlement of the slab after nine months indicates that the slab has tilted towards the rear. (Figure 13). The greater settlement at the rear has resulted from the weight of the clay filling used to level the site. This clay filling was deeper under the rear of the slab. Obviously in light of the extremely poor type of filling, it is too early to draw conclusions as to the adequacy of the design used at this site. However, it has performed to date in a very rigid manner.

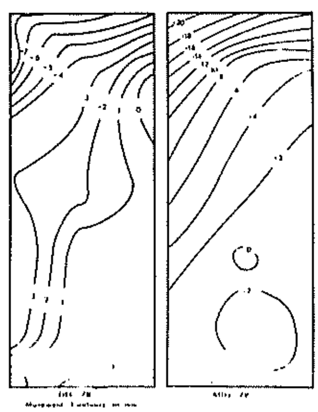


Figure 12 Chelsea slab settlement

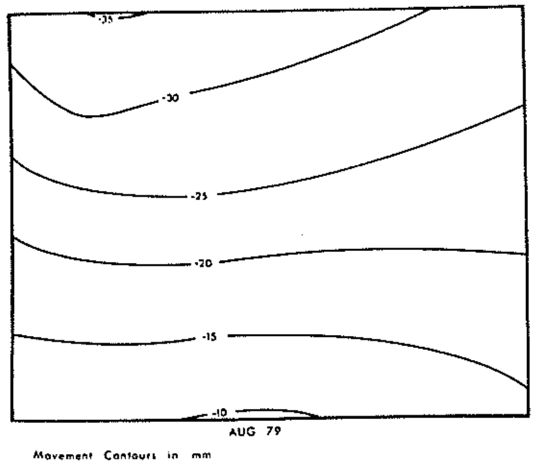


Figure 13 Warragul slab settlement

They type of filling placed at Wonga Park, in contrast to Warragul, represents possibly the best type of filling likely to be encountered. The filling consisted of basically clayey siltstone, carefully placed in thin layers with each layer being well compacted using a vibratory roller. No compaction testing was done, but the type of filling and its placement and compaction was visually monitored. The number of passes of the roller for each layer was set at a minimum of five. The filling depth varied from 0 to 3 metres, and, because of the fall over the house area, the top two corners of the slab required site cutting and are, in fact, sitting on the shallow underlying siltstone. The slab was placed about three months after the filling was completed and has not basically moved in the six months since. In light of the type of filling and the way it was placed, this behaviour is unlikely to change in the future. The slab obviously is overdesigned and a lighter design using a two metre diameter soft spot would have been more than adequate. However, the slab is supporting a large expensive house so the extra risk in using this lighter cheaper slab may not have been accepable to the owners. The excellent performance of this slab clearly demonstrates the ability of a rigid slab foundation system to perform with practically no risk, and at a much cheaper cost than the traditional pier and suspended slab system, at cut-fill sites where well controlled and suitably compacted cheap filling is available.

At the other two sites insufficient monitoring has been carried out to present any meaningful results. Monitoring of these slabs will continue until no further significant settlements occur, or until the end of 1982.

5 CONCLUSIONS

Based on the highly successful performance of thousands of rigid slabs on filling throughout Melbourne and the monitored behaviour of seven experimental housing slabs on a wide range of filled sites, a design procedure for rigid housing 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 theory. The critical soft spot diameter estimation requires a thorough site investigation by a competent soil 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 house supported by the slab.

The design procedure suggested is not applicable to excessively large soft spot development due to mining subsidence and limestone sinkhole formation. The monitored behaviour of a series of rigid slabs at a wide range of filled sites is presented and shown to support the general design procedure outlined.

In closing, the complete lack of references accompaning this paper is significant. A very intensive search of the literature using manual and computer abstracting systems failed to produce one paper where the author was prepared to offer a design approach for rigid slabs on filling. Obviously this situation results partly from the fear of the legal consequences of failures and the past lack of use of this foundation system.

6 ACKNOWLEDGEMENT

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