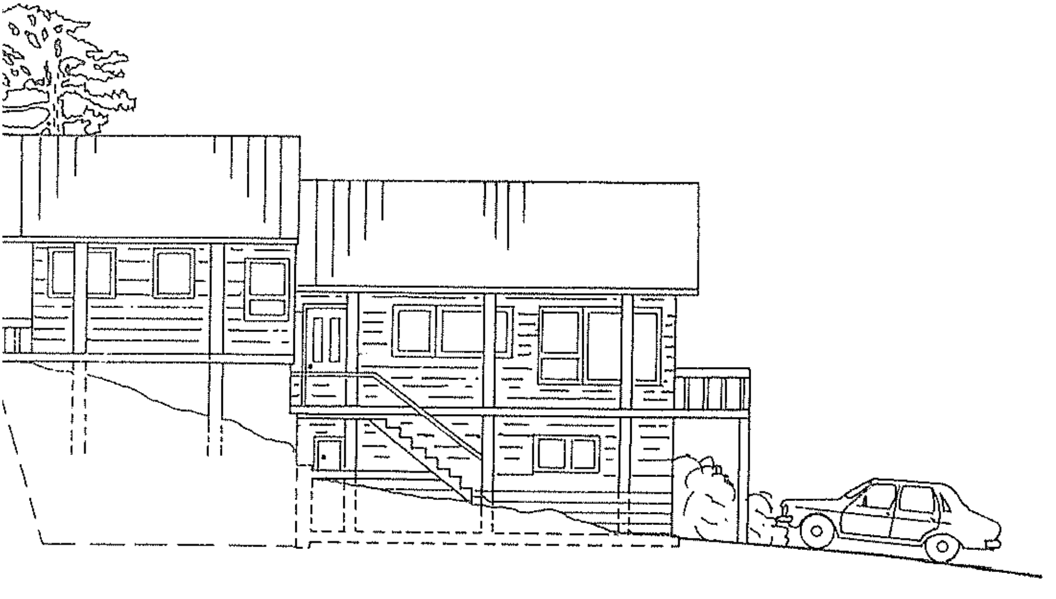
STABILITY OF HOUSE SITES AND FOUNDATIONS

Advice to Prospective House and Section Owners



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THE NEW ZEALAND GEOMECHANICS SOCIETY

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INTRODUCTION

Small movements of the ground supporting houses may cause damage which is unsightly and worrying to the occupants. More disastrous movements may result from landslips which are more likely to occur after periods of unusually heavy rainfall.

Engineers consider that many cases of damage which have occurred in the past could have been prevented by more care in the use of the ground.

This booklet sets out to present, in a straightforward fashion, the underlying principles of foundation engineering which should be considered in relation to houses. In it are listed points which should be considered – by the prospective home owner, the builder or architect – during the planning stages. Many of the principles involved – based largely on commonsense and experience – will be familiar to the reader of this booklet.

If however, this publication reduces, even to a limited extent, the anxiety and expense to home owners caused by foundation movements, then it will have served its purpose.

Foundations of large buildings are always designed by professional engineers – often after extensive investigation and testing. This publication does not, of course, apply to such structures. For house foundations, such professional advice is seldom necessary. The simple rules suggested here will usually suffice. Neglect of these rules can lead to the appearance of damaging cracks and distortion in future years, or even instability of the whole building.

PREFACE TO 3RD EDITION 1980

The first and second editions of this booklet were prepared and published by the Auckland Subcommittee of The New Zealand Geomechanics Society, which is one of the technical groups of the New Zealand Institution of Engineers, to accompany a display in the Auckland Building Centre, although most of the information included was of general applicability throughout New Zealand.

This third edition deletes the specific references to Auckland cases and includes a new section providing guidance upon small scale site filling operations.

CONTENTS

1. SELECTING A SECTION

Many factors enter into the selection of a section, the locality and the price no doubt being uppermost in mind. To avoid unforseen foundation troubles, however, it is wise to check the items listed below, before signing an agreement to purchase a section —

Many of these are dealt with in greater detail in later parts of the booklet.

Building on Filling

On some sections, areas of land have perhaps been raised by filling. This can be quite satisfactory, if it has been properly done, but can otherwise cause serious trouble.

If loosely tipped earth, or rubbish has been used for filling, serious settlement of house foundations, placed on the compressible material, can occur. It is possible to avoid this by founding on piles carried down to firm ground beneath, but this involves extra expense. Piles placed under only part of a house can result in damage if the part not piled does settle even by a small amount. All the foundation should be supported by ground of similar compressibility.

Present-day methods of land sub-division often involve much earth-moving. Material cut from high ground is used to fill in the lower parts. When this filling is placed in layers, and compacted with special rollers at a suitable moisture content, it can be satisfactory to build on. However, it is always necessary to inspect foundation excavations and provide special treatment if soft or wet areas are noticed.

It is not always easy to recognize filled grounds, when inspecting a section. Bare earth, or recently sown grass sometimes provide the clue. If there is any doubt whether or not there is filling on the site, or whether or not the filling is suitable to build on, ask the vendor for a written statement.

Most local bodies require plans showing the depth and position of filling, and reports on its quality, to be deposited by subdividers. Ask your local council if they have these records.

Low-Lying Areas

Some flat low-lying areas have been swamps in the past. Even though they may no longer be wet on the surface, the underlying soil may be soft and compressible. The only real way to check this point is to make boreholes (with a hand post-hole auger). Again, some low-lying areas may be subject to occasional flooding.

If you decide to purchase such a section, methods of overcoming the special problems involved are outlined in a later part — "Low-Lying Sties".

Sloping Areas

At times of prolonged, heavy rainfall, some steeper slopes become unstable, and every wet winter some houses are affected.

On some slopes, progressive movement downhill occurs over the years. An indication of this may be given by cracks in the surface, fences being out of line, or trees leaning downhill.

The probability that a landslide may occur is not easy to predict. Where the shope is steeper than others in the neighbourhood, there is greater risk of such a slip. It is usually possible to observe where landslides have occurred in the past. Such a site should be carefully avoided when building, as further movement, in future years, is highly probable. More detailed information is included under "Sloping Sites" below.

Cliff-Top Sites

Special consideration should be given to the problems inherent in building a house on a cliff-top. The reader is referred to the later section "Cliff-Top Sites".

2. GENERAL

(Apply to all House Sites)

Seasonal Moisture Changes

The soil extending to a depth of several feet below the surface, becomes wetter in winter and drier in summer. Particularly with clay soils, this can result in alternating vertical movements of the surface amounting to an inch (25mm) or so, as a result of shrinkage and swelling. This effect is more damaging to masonry construction (concrete blocks or brickwork) where it results in the development of cracks.

Seasonal moisture movements can be minimized by:

(a) locating the foundation at a sufficient depth so that movements are negligible, and

(b) avoiding any action which will cause unnecessary wetting or drying of the soil.

Even well-constructed houses on clay soils are likely to show minor cracking of plaster walls and ceilings and in masonry. Distortion of frames may cause doors and windows to jam. These effects usually occur after a long, dry summer. Without considerable expenditure it is not possible to eliminate entirely such troubles. Houses with a concrete floor forming a raft foundation are less prone to such movements. If they do occur, the damage caused, although annoying, is seldom of serious structural consequence.

Depth of Foundations

The minimum depth of foundations, specified in New Zealand Standards is 12 inches (300 mm). Greater depths are desirable, particularly where the foundation material is a shrinkable clay, and especially if masonry construction is proposed; but extra continuous reinforcing can help greatly.

Wetting of Foundation Soils

To avoid unnecessary wetting of the foundation soil keep discharge of downpipes and other water away from footings. Soak holes should be well clear of foundations. Soak holes in clay are often useless; irrigation drains in the more permeable topsoil are usually more satisfactory; in the summer water evaporates from them but in winter water may accumulate in the ground or run over the surface.

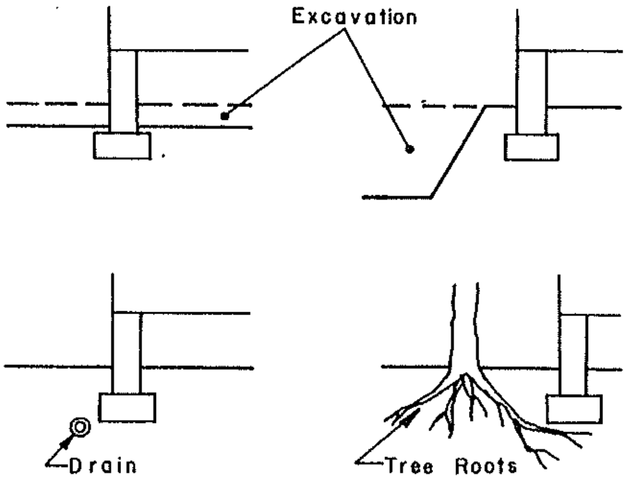


FIG. 1. CAUSES OF GROUND SHRINKAGE UNDER FOUNDATIONS

To reduce drying out of the foundation soil:

(1) Avoid reducing the soil cover above foundation level, when excavating for paths, etc.

(2) Avoid cuts adjacent to and below level of the foundations.

(3) Do not install field drains adjacent to and below level of foundations.

(4) Do not grow trees or large shrubs, especially fast growing species, close to buildings if their root runs are likely to extend beneath foundtions. Fast growing trees often have a considerable drying effect on soils. Trees that have attained maturity before the construction of the building are far less likely to cause damage.

Filling for Terraces

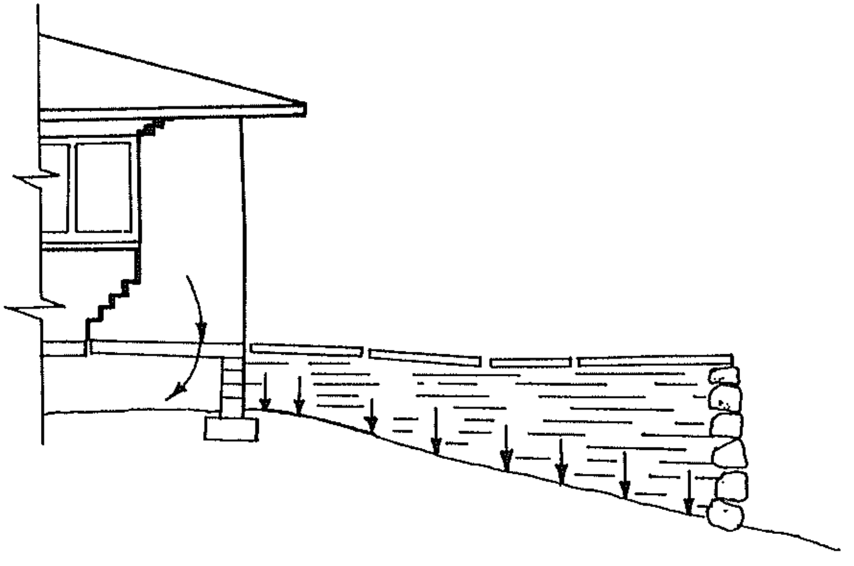


FIG. 2. 1 METRE OF CLAY FILLING IS AS HEAVY AS A 3 STORIED BUILDING

Heavy loads such as terrace fillings can cause unequal settlement of the adjacent house if the foundation soil is compressible. The weight of the terrace filling may well be very much greater than that of the house.

Adding Basement Garages and Rooms

Frequently home-owners excavate basement areas in an existing house to incorporate a garage, playroom or workshop. Some of the pit-falls to be avoided are:

(1) Avoid undermining existing foundations.

(2) Replacement of a line of jack studs by a long spanning beam results in a concentration of load at the beam ends. Are the foundations provided adequate now? Angled bracing between studs removed during excavation must be replaced by suitable bracing in another part of the house.

Retaining Walls are very expensive if they do, in fact, retain soil and not simply protect it from the weather. A building permit is needed for walls of heights greater than as little as 3 feet (1 m), depending upon the particular local by-laws. Permanent walls range in cost upwards from $50 per square metre of face area.

Retaining walls adjacent to driveways, street frontages or foundations should be referred to an Engineer.

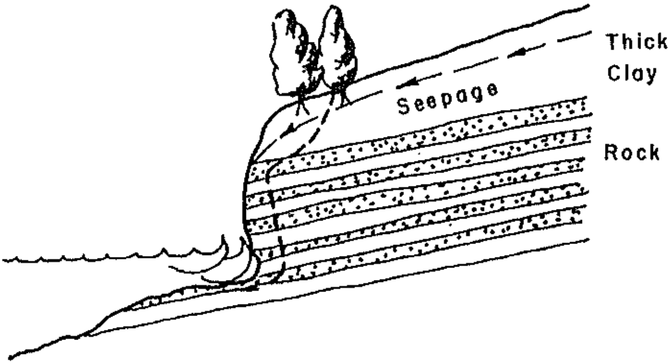
Existing Drains or Ditches

The proposed house foundations may cross existing ditches. Where this occurs, mud or soft clay should be excavated from the ditch which should then be backfilled with compacted gravel or with low-strength concrete.

Buried drains may not be obvious and may be discovered only when excavating for house foundations. Where these are field tiles or 'stone drains' (a layer of boulders) the old backfilling is likely to be compressible and should be excavated and replaced, as for open ditches.

Where the drains are closed pipes they are likely to be public sewers and must be protected to the satisfaction of the Local Body Inspector.

3. CLIFF TOP SITES



UNFAVOURABLE CLIFF

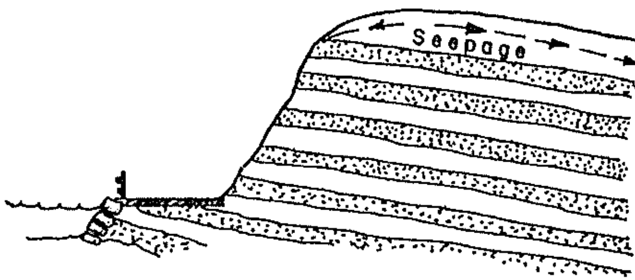


FIG. 3.

FAVOURABLE CLIFF

The general risk of building on or near cliffs is higher than on flat or gently sloping ground and the house owner must accept this and be prepared to take reasonable precautions. The exact extent of the risk cannot be calculated in most cases but some physical features of the ground are obviously worse than others. For example:

(1) Strata sloping down towards the cliff are more likely to slip than strata sloping back into the cliff or lying horizontal. Look for a bay or gulley where you can see the layers of rock 'side on'.

(2) Deep overburden of clay or silt on top of the harder rock makes it necessary to keep further from the edge.

(3) Long slopes of ground surface rising behind the cliff edge will mean more seepage of natural ground water towards the cliff and greater risk of failure.

(4) Steep slopes in the clay of the cliff edge are dangerous. No hard and fast rules can be made but slopes steeper than 3 : 1 (1 m rise in every 3 m horizontally) should be regarded with great suspicion.

Normal geological processes of erosion and weathering of the soil are always slowly at work. The effects may be so slow that they are not detected in a lifetime but may on the other hand be sudden, catastrophic and localised, apparently at random. They are not 'Acts of God' but ordinary processes too often aggravated by the Acts of Man. Where wave erosion attacks the base of sea cliffs it cuts them back at various rates. Weathering and rain erosion causes soil to dry and crack, re-wet, swell and crumble or slip off the lip and the face of the cliff. The effect is that the cliff faces move backward, where both processes are active, or become gradually flatter where waves do not attack the cliff because it is inland or it is protected by reclamation, roadways or sea walls.

On the average narrow section there is no room for earthmoving machines to get past and to work in front of the house after it is built. Shape the ground in advance and keep the house as far back from the edge as possible. Bevel the cliff lip back to a stable slope while you can; even if this means carting the soil away. It will generally be cheaper than a retaining wall.

Dispose of surface water from roofs, driveways and ground slopes via flexible (P.V.C.) or flexibly jointed (RRJ earthenware or asbestos cement) pipes to a safe discharge, either in public stormwater drains or over the cliff edge, if this is permissible. Intercept sub-surface water seeping towards the edge if there is a lot of it to wet the cliff face. It may be very expensive to install drains deep enough to do this effectively. Deep drains should not be dug across a steep slope but rather up it. Horizontal bored drains can be installed from the cliff face if there is room to make a safe working platform.

IN SHORT, IF YOU WANT TO LIVE NEAR THE EDGE OF A CLIFF,
FACE THE COST AND TAKE PRECAUTIONS BEFORE YOU BUILD;
IT WILL BE MUCH MORE EXPENSIVE OR EVEN IMPOSSIBLE AFTERWARDS

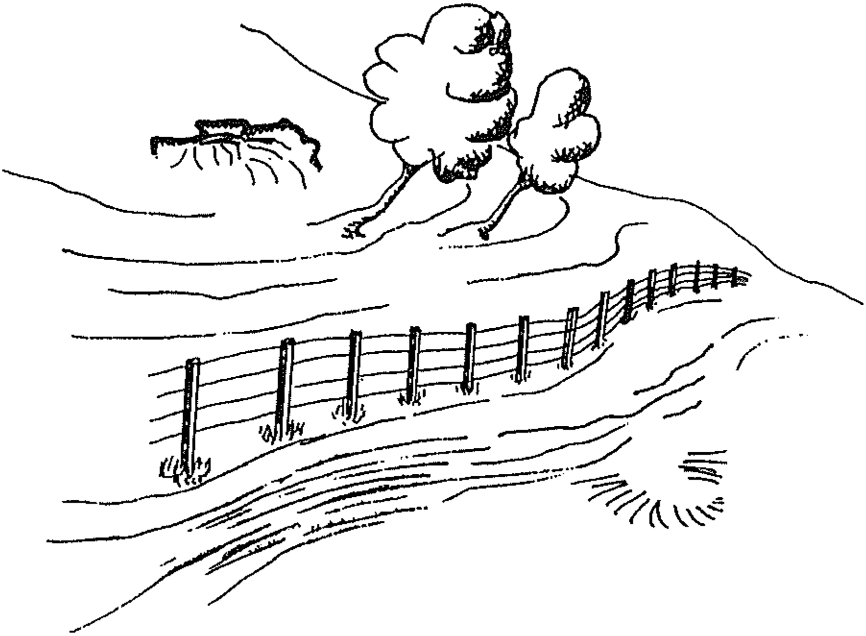


FIG. 4. SIGNS OF SLOPE MOVEMENT

4. SLOPING SITES

The advantages of a sloping site may include an interesting view and seclusion. The disadvantages are higher development cost than flat sites and the risk of slips. Compared with cliff tops sites, it is harder to see which way the strata slope, as they are not exposed. Many of the remarks in the previous section 3, apply.

A safe slope is very difficult to define. Bad slips have occurred on very slight slopes with no obvious warning signs on the surface. The best guide is the condition of similar old slopes in the vicinity; have a careful look at other properties near yours. Slopes recently formed by cutting or filling will be harder to judge as they have not been tested by time to the same extent as older slopes.

Before you buy, look for signs of instability such as cracks in the ground surface; trees leaning either uphill or downhill; fences which are crooked; water seeping out of the ground; hummocky ground; saucer-shaped depressions in the surface.

Finally, consider very carefully any changes to the slope which you may need, to build the house, landscape the section and provide access.

After you have bought, be careful not to make the slope less stable by cutting banks and leaving them unsupported or filling on the slope which has all the effects mentioned in section 2, plus the risk of sliding. The risk of sliding can be reduced by cutting benches to sit the fill on; compacting the fill so it is strong and cannot soak up water later; placing under-drains so the fill does not dam up water behind or under it.

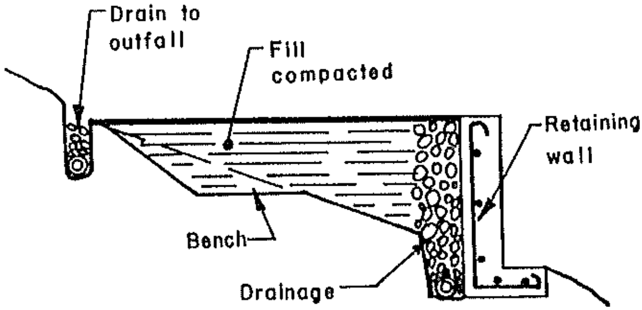


FIG. 6. PROPERLY RETAINED AND DRAINED FILL ON A SLOPE

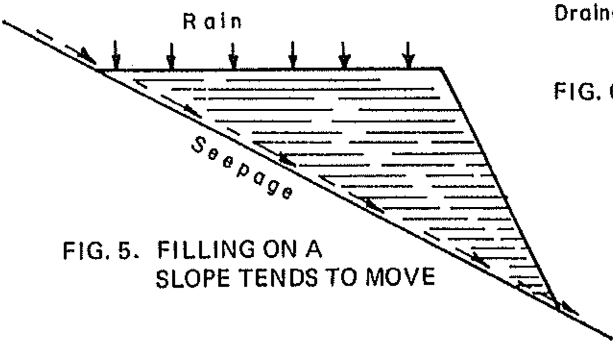


FIG. 5. FILLING ON A SLOPE TENDS TO MOVE

THE WHOLE BALANCE OF THE SLOPE CAN BE UPSET BY FILLING – USE THE LEAST POSSIBLE OR AVOID IT ALTOGETHER

Make careful provision for draining retaining walls with weep holes and back drainage; pipe roof water and surface water to a safe discharge; intercept water which would be caught by new benches and led into the ground by them.

Soak Pits are often useless or even dangerous.

5. LOW-LYING SITES

There are two sources of foundation troubles more likely to be met in low-lying areas than elsewhere. These are stormwater drainage problems, and those caused by compressible foundation materials.

Compressible Foundation Materials

Very often, large, low-lying flat areas have been formed (geologically) by the deposition of silt on a lake bottom, others by the accumulation of organic peat in swamps. Although the lake or swamps may no longer be evident, and the ground may appear stable and dry, these soft sub-surface soils can compress and consolidate appreciably when a house is built on them. Heavy concentrated loads (e.g. filling under terraces, heavy brick or concrete chimneys) and heavy brick or masonry houses should be avoided. The only real way to check whether such soils are present is to put down bore-holes (using a hand post-hole auger).

If such compressible soils are found there are several ways in which foundations can be satisfactorily constructed – but they all involve expense considerably greater than for conventional foundations.

To support foundations built over highly compressible ground (e.g. peat) reinforced concrete piles can be constructed long enough to reach considerably harder ground beneath, if this is present. This type of construction should be done by experienced persons. It may add in the order of $1,000 to the cost of a modest house.

Another much cheaper method sometimes used where the compressible soils are uniform in thickness, is to adopt a 'raft' type foundation (see Fig. 7). A suitably reinforced concrete slab, forming the house floor, is placed over the entire area. This will not eliminate settlement, but should reduce it and make it more uniform. Even so a brick or concrete house may not be satisfactory on this type of foundation, and would require special consideration.

Stormwater Drainage

Wide, flat, low-lying areas may be subject to occasional flooding in very wet periods. Discussion with residents or the local council is usually the easiest way to discover the extent of this danger.

Sections in depressions, and valley bottoms are more likely to gather stormwater. Even though the existing system of drains may be sufficient to deal with all normal flows, there is still the possibility that extremely heavy rainfall, occurring infrequently, may cause damage. If possible, build on the sides of natural flood channels, rather than in the middle of them!

Drains at the perimeter of the section may be required to deal with surface water flowing off adjacent land at higher levels.

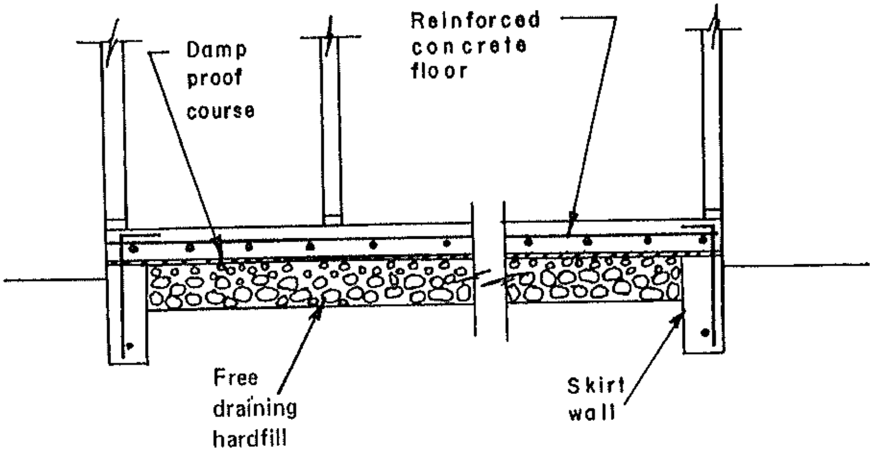


FIG. 7. CONCRETE FLOOR FORMING
A RAFT FOUNDATION

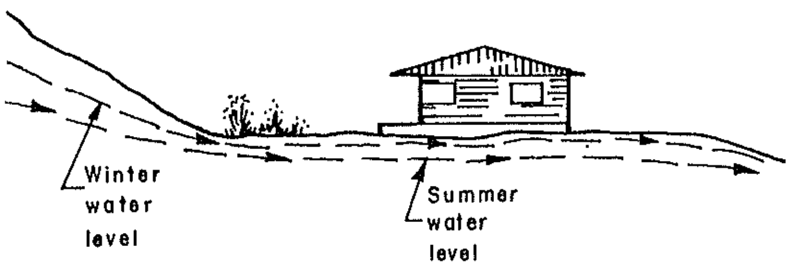


FIG. 8. GROUND WATER SEEPAGE
FROM HIGH GROUND

Seepage (See Fig. 8)

If large areas of adjacent ground are at higher levels than the house site, there will be a natural tendency for underground seepage water to flow to the low-lying area, even if the surface stormwater has been adequately dealt with. Particular care should be taken that there is adequate drainage behind basement walls and other retaining walls. If omitted at the time of construction, such drainage provisions may be very expensive to install at a later date, as a remedial measure.

6. GEOLOGICAL MAPS

The Geological Survey Section of the Department of Scientific and Industrial Research, studies and reports upon the composition and position of the 'rocks' (including the soft clays, sands and so on, which the Engineer calls 'soils') of the whole country.

Geological Maps are published which show the general nature of the surface materials and, properly interpreted, these give a broad guide to the kind of ground which house foundations can encounter.

It must be realised, however, that individual building foundations are supported by portions of the ground perhaps as small as a 300 mm square and 300 mm deep. Important local variations of ground strength in this detail can only be found by digging or boring on the spot and can never be indicated on geological maps.

7. SMALL SCALE SITE FILLING

Introduction

The New Zealand Standards Association has published a Standard NZS 4431:1973 "Code of Practice for Earthfill for Residential Development" which described means of placing, inspecting and certifying filling so that residential buildings can be erected upon the fill without special foundations and without having to conduct investigations to prove the quality of the filling after it has been placed.

The cost of the procedures laid down in the Standard will be high in the case of minor amount of filling such as would be placed by an owner within the residential lot and landowners may look for guidance as to good standards of filling in such cases. These notes are intended to provide that guidance.

If the conditions of the Standard are not met, especially as to investigation, inspection and supervision, then a Registered Engineer will not be able to certify that the filling is suitable to build upon without an investigation which will include the drilling of test bores or the excavation of inspection pits. It is unlikely that the Local Body will issue a building permit unless such an investigation is done. "Post mortem" investigations of this sort can be expensive, and in many cases not sufficiently conclusive. It is important therefore that the guidance of these notes is followed so that the subsequent investigations do not disclose evidence of bad practice in the fill construction which would tend to throw doubt on the quality of the fill as a whole.

Damage Which May Occur

Badly constructed fills cause trouble in many ways, amongst which are:

Buildings built on them are damaged.

Special foundations, including piles constructed through the fill down to firm ground, add greatly to the cost of building.

Neighbouring property can be damaged.

Why Fills May Perform Badly

The chief cause of unsatisfactory behaviour of the fill are:

Vertical settlement of the surface of the filling due to:

Compression of soft ground below the filling.

Compression of loose filling under its own weight or under the weight of things built upon it.

Decay of organic material such as timber, vegetation or rubbish including in or under the fill.

Collapse of boxes, tins, cans etc in the filling.

Erosion of ground by water seepage through the filling or below it.

Slipping of the filling down a slope or overloading an existing slope so that it slips within itself (Fig. 5).

Settlement of ground alongside the filling due to compression of soft ground below, and extending beyond the filling, thus affecting adjacent buildings or property (Fig. 2).

Damage to neighbouring property caused by vibrations from earthmoving machines during construction of the filling.

Diversion of ground water or of surface run-off water to cause flooding or erosion or increasing pressure in the ground water.

The weight of filling is commonly underestimated. A 300 mm thick layer of clay fill is about as heavy as one floor of a tall reinforced concrete building over the same area. One metre of filling for a patio for example is equivalent to placing 3 stories of concrete building right alongside the house!

Precautions

To avoid these difficulties the following fundamental precautions should be taken:

Preparation of the site before filling

Clear all vegetation, fences, obstructions and rubbish and dispose of it well away from the area to be filled (or excavated for filling).

Remove all top soil and place it clear of the working area.

Examine the ground over which the fill will be placed, remove soft ground which may compress under the fill. **If this soft ground is extensive and expensive to remove then consult an experienced civil engineer before attempting to fill over it.**

If there is evidence of water seepage then provide drains to divert it or collect it.

If the ground is steep then excavate benches along the slope for the fill to rest on (Fig. 6).

Selection of Filling Material

It is not satisfactory to commit yourself to accepting filling material which you have not examined to make sure that it does not include rubbish, and that it can be placed as required in the subsequent sections of these notes.

Remember that natural ground which appears dry on the surface may be considerably wetter deeper down.

Heavy clays are difficult to break up for placing in thin layers and this is essential, especially where only light weight compacting equipment will be used.

Clays and silts which can be moulded by strong pressure in the fingers are close to the correct moisture content for good compaction. Softer soils will be too wet and harder soils will be too dry for proper compaction and they will be very difficult to spread in thin layers.

Granular soil such as sands, scoria and gravels up to about 150 mm maximum size are easiest to compact in a wide range of weather conditions. It may be more economical to import such material than to attempt to use wet, plastic or sensitive soils available on the site.

Placing and Compaction

Fill should not be placed by end tipping but should always be spread and compacted in uniform layers, approximately horizontal and not more than about 150 mm thick.

Silts or clays which are not at the correct moisture content (as described above) should be windrowed and dried, or wetted as the case may be before they are compacted.

Clays and silty clays often (but not always) have an optimum moisture content close to or a little drier than the "plastic limit" which is the moisture content at which a thread of soil can be just rolled down to 3 mm dia. between the hand and a hard smooth surface without breaking up. If a thread thinner than 3 mm can be formed then the soil is probably too wet.

While useful compaction can be done by carryall scrapers and trucks and bulldozers these will have to devote much more time to systematically travelling over every part of each layer of fill than they normally will do in shifting the fill material. It is much better to use separate rollers or tampers specifically for compaction.

Sands and gravels are best rolled **just after flooding** with water provided the water can soak down from the surface and be disposed of conveniently.

Hard stones larger than about 150 mm can be accepted provided they are surrounded by finer material which is thoroughly compacted by the available machinery. Materials generally bigger than 150 mm required very heavy machinery to place and compact it.

Good compaction on 150 mm layers of soul generally requires 4 or more passes or a roller or a loaded vehicle over every part of the surface of each layer.

A well compacted layer will not show indentation from the wheels of a loaded truck deeper than about 25 mm, nor will it visibly 'weave' (heave up in a wave before and behind the wheels of the vehicle).

The quality of the fill can be checked by testing the effort necessary to make a reinforcing rod penetrate into it; effort should be similar to that required in adjacent firm natural ground which has already been built upon successfully.

Slope Protection

Slumping or erosion of the outer slope of the edges of the fill can cause collapse of the fill edge and silting of adjoining ground.

Compact filling right to the outer edge, and compact on the slope face if it is flat enough.

The maximum safe slope for a filling depends upon its height, amongst other things, but should not normally be steeper than 1 metre of rise in 1.5 metres horizontal distance.

The cheapest way to protect a fill slope is to apply top soil and sow grass or plant shrubs on it.

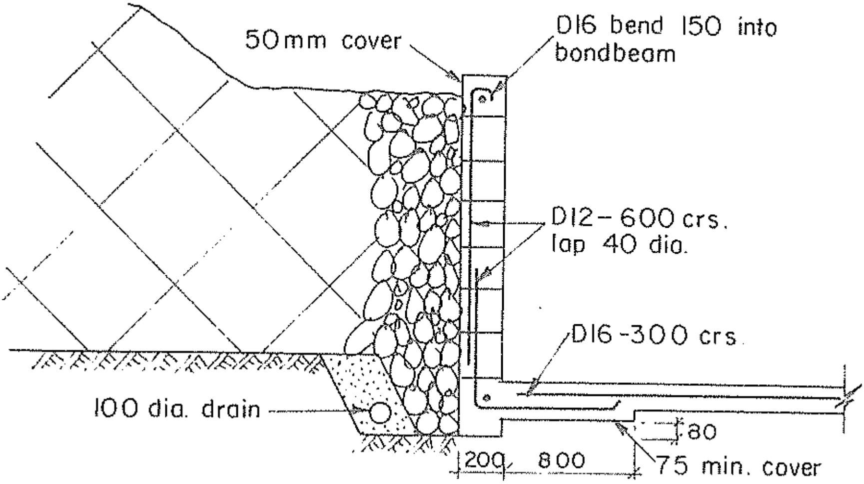
Good "Housekeeping"

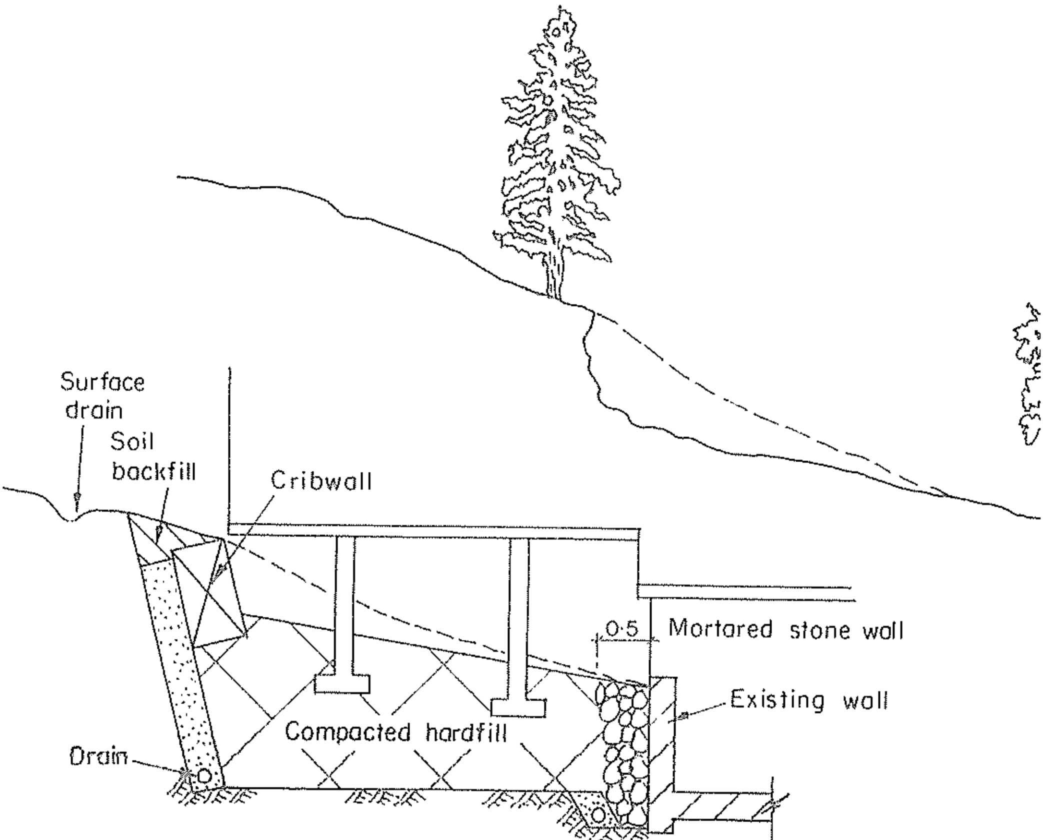
Keep the fill tidy, avoid heaps of loose material which obstruct the work or pond rainwater.

If the partly completed fill is to be left for some time, or if wet weather threatens, seal the surface of the fill by rolling it smooth so that it will not absorb water.

Dig shallow drains to divert rainwater away from incompleted filling.

Prevent dumping of rubbish on the site and keep stripped top soil, vegetation and soft or wet soil well clear of the filling so that it is not included in the fill accidentally.





RECONSTRUCTION AFTER SLIP