RESEARCH REPORT

Slab-On-Grade Construction: Final Draft

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Morrison Hershfield Limited
Consulting Engineers

SLAB-ON-GRADE CONSTRUCTION

FINAL DRAFT

Submitted to:

Mr. Dan O'Leary
Project Officer-Ontario
Project Implementation Division
Canada Mortgage and Housing Corporation
2nd Floor Annex
682 Montreal Road
Ottawa, Ontario
K1A 0P7

188-0117

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4 Lansing Square, North York, Ontario M2J 1T1, Telephone (416) 499-3110, Telex 06-986219, Fax (416) 499-9658

INTRODUCTION

The use of structural slab-on-grade construction is not common practice in Canada since the depth of frost penetration in most areas, and thus the required depth of footings, warrants the construction of a basement. However, in situations where a basement is undesirable, like a senior citizen's residence or a home for the physically disabled, structural slab-on-grade construction can be economical. Structural slabs can also be used when unstable, problem soils are encountered.

The usual method of constructing a structural slab-on-grade is to use a "thickened slab". At the edges of the slab, where most of the load will be carried, the slab is thickened, the thickened portion being cast integrally with the rest of the slab. Slabs-on-grade can also be constructed with grade beams supported on piers, piles or pedestal types of footings. However, this type of construction is generally not used for residential construction. One of the keys to the success of the structural slab-on-grade is the perimeter insulation which reduces the depth of frost penetration and thus reduces the required depth of the foundation.

This guide will not touch on the aspects of the structural design of slabs-on-grade. Instead, it will focus on some common construction problems, their causes and practical solutions to avoid these problems.

PROBLEM: **CRACKING OF SLAB**

CAUSE: **Poor construction techniques and practices.**

There are a number of areas where poor construction techniques and practices can later cause cracking problems, including poor placement and finishing techniques, improper curing, overwatering, inadequate cold weather protection or inadequate hot weather protection.

SOLUTION: **Follow good construction practices.**

- dampen earth before placing concrete to avoid water being sucked out of the concrete.
- avoid overtrowelling.
- do not finish concrete surfaces when bleed water is present.
- keep concrete continuously moist for a minimum of 24 hours.
- never add water on site during placement or finishing.
- maintain concrete temperature above 10 ^{o}C during placement and for three days after placement.
- protect fresh concrete from rapid drying, direct sun and wind.

For further information on correct construction techniques and practices, refer to the Builder's Workshop booklet, "Concrete Foundations".

CAUSE: **Differential or uneven settlement.**

Differential or uneven settlement is caused by variations in the subgrade. When loaded, the slab will tend to bridge over soft spots (such as over underground utilities where the soil hasn't been sufficiently compacted) and it will tend to rest on hard spots (such as over rocks or denser soil). This can cause cracking to occur, as illustrated in Figure 1.

SOLUTION: **Ensure the subgrade is uniform.**

Special care must be taken by excavating and backfilling to prevent localized hard or soft spots in the subgrade. Special care must also be taken to properly compact soil over underground utilities. If possible, underground utilities should not pass under the corner of a slab.

For further information on subgrade preparation, see Appendix A.

CAUSE: **Curling of slab.**

As new concrete dries, it shrinks or shortens in all directions. In the case of concrete slabs on grade, the top surface dries and shrinks much faster than the bottom surface so that the slab tends to curl or dish. The tensile stresses created in the top of the slab can cause the concrete to crack, as illustrated in Figure 2. Most slabs curl so little that the effect is not noticeable. However, curling can cause bumps at the joints and joint deterioration, as well as cracking of the slab.

SOLUTION: **Minimize shrinkage of the concrete.**

Curling can be minimized by keeping shrinkage to a minimum. This can be accomplished in several ways:

- use the stiffest mix (lowest slump) possible that can still be worked and consolidated satisfactorily.
- use the largest maximum size aggregate that is practical so that less water is required.
- cure the concrete as long as possible. Moist curing for 7 days is recommended.
- reduce moisture loss from the surface by using coatings, sealers and waxes.

- when polyethylene dampproofing is used under the slab, place at least a 75 mm (3 in.) thick layer of sand over the poly to allow some moisture loss at the bottom of the slab.
- ensure that there are sufficient expansion joints in the slab spaced no more than 4600 to 6100 mm (15 to 20 feet) apart. Slabs with 9200 mm (30 foot) joint spacing can be expected to curl about four times as much as similar slabs with joints spaced 4600 mm (15 feet) apart.
- use a thicker slab as thinner slabs tend to curl more.

CAUSE: **Inadequate structural strength of slab.**

Cracking can occur if the structural strength of the slab is inadequate to support the applied loads.

SOLUTION: **Ensure the slab is properly designed.**

Section 9.16 of the 1985 National Building Code (NBC) deals with Slabs-On-Ground. However, this section excludes concrete slabs which provide structural support for the superstructure. These slabs must be designed in conformance with Part 4 of the NBC, "Structural Design". Further, Part 4 stipulates that the designer shall be a professional engineer or architect as appropriate under provincial or territorial legislation. Therefore, any builder deciding to construct a structural slab-on-grade must contact the appropriate professional.

SOLUTION: **Use concrete with sufficient compressive strength.**

A minimum of 25 MPa concrete should be used. CMHC recommends 30 MPa concrete.

CAUSE: **Frost heave.**

SOLUTION: **Never pour concrete on a frozen subgrade.**

A frozen subgrade is unstable and may settle unevenly causing the concrete to crack.

SOLUTION: **Maintain above-freezing temperatures in the house during construction.**

Heaving may occur when fine-grained soil, such as clay or silt, that is saturated, freezes after placement of the concrete. It is important to maintain above-freezing temperatures in the house during construction to help prevent freezing of the soil and to provide drainage for the soil beneath the slab so it has an opportunity to dry out.

SOLUTION: **Use adequate insulation.**

The bottom of the thickened part of the slab should be below the frost line. In most cases in Canada, insulation must be used to reduce the depth of the frost line so that structural slabs-on-grade can be used. For further details on insulating options, see Appendix B.

CAUSE: **Improper placement of reinforcing and mesh.**

SOLUTION: **Use proper installation techniques.**

Because the loads imposed by residential house construction are small, often wire mesh is sufficient in slab-on-grade construction. The mesh is used to provide control of shrinkage cracks. Since the cracks will usually be wider at the top than at the bottom, the mesh should be located no more than 50 mm (2 in.) below the surface of the slab. Mesh should be lapped at least one square.

The worst way to install wire mesh is to hook it while it is on the ground and pull it up from the surface as the concrete is placed. Using this method, the mesh can bring earth up into the concrete as it is pulled into place. Also, the mesh is seldom pulled to the correct height.

A good method of placing the mesh is to use concrete, steel, or plastic support to chair up the mesh at the correct height. Do not use broken brick as it has a high water absorption rate and can cause cracking.

Another method of placing the mesh is to place most of the slab thickness, screed it off, place the mesh, then place the remaining two inches of concrete. This method is more costly.

When reinforcing steel is used, the minimum concrete cover should be 76 mm (3 in.), as shown in Figure 3. The steel should be lapped at least 24 bar diameters, but not less than 300 mm (12 in.), wired together, and supported on chairs.

PROBLEM: **DAMP OR WET FLOOR SLAB, EXCESSIVE HUMIDITY.**

CAUSE: **Moisture migration through the slab.**

If a porous material such as concrete is placed in contact with water, some of this water will rise up into the pores of the concrete, like a sponge soaking up water. This is called capillary action. A concrete slab can become saturated by the capillary action of the water in contact with the underside of the slab, yet it will not show any visible signs on the surface. After the first heating season when the slab has cured, by taping polyethylene to the slab and observing if water vapour condenses on the back of the poly, one can determine if there is moisture migration through the slab. A saturated slab can cause excessive humidity in the house.

SOLUTION: **Provide a capillary break.**

A capillary break can be provided by placing a layer of gravel below the floor slab, as illustrated in Figure 4.

SOLUTION: **Provide perimeter drainage and/or a sump pump.**

Drainage is very important in maintaining dry floors. The preferred method is the use of an interior sump pump because perimeter drains sometimes become clogged.

CAUSE: **Air leakage through the slab.**

Air will often infiltrate through any holes or cracks in the floor slab. As the air flows through the moist soil to reach these cracks, it often becomes saturated and, as a result, carries moisture into the house.

SOLUTION: **Eliminate cracks and holes in the slab.**

- all pipes, drains and ducts that penetrate the concrete floor should be completely sealed.
- follow good construction practices and techniques to prevent cracking of the slab.
- ensure that air is not leaking in from the floor drain. Install a trap primer to ensure that the trap never gets dry.

CAUSE: **Water vapour diffusion through the slab.**

During winter, the soil generally has a higher vapour pressure than the air in the house. Therefore, water vapour is continually diffusing through the concrete floor slab.

SOLUTION: **Dampproof the slab.**

The dampproofing can be applied to the top of the slab, where a separate finished floor is provided, or the dampproofing can be installed under the slab.

- When dampproofing over the slab, the concrete floor surface must be covered with at least two mopped-on coats of bitumen, 0.05 mm polyethylene or other material providing similar performance to prevent or reduce the amount of moisture entering the house. (There are also many new products being sold for this purpose.) A separate finished floor must be laid over the dampproofing.

- When installed below the slab, the dampproofing should consist of at least 0.15 mm polyethylene or Type S roll roofing. The dampproofing must be lapped not less than 100 mm at the joints. A layer of sand can be used over the granular fill to prevent puncturing of the dampproofing.

The exterior edge of the floor slab should also be dampproofed to prevent moisture from entering through the side of the slab (Figure 4).

Another method of dampproofing is to pour the floor in two layers, placing a dampproofing layer between the layers. This method is more expensive and is rarely used.

CAUSE: **Poor site drainage.**

SOLUTION: **Provide good site drainage.**

- slope the subgrade away from the house when grading and preparing the subgrade.
- slope all surface grades away from the house.
- drain downspouts away from the side of the house and provide a splashblock.

For further information on moisture problems, see the Builders' Workshop booklet, "Moisture Problems".

PROBLEM: COLD FLOORS

CAUSE: **Heat loss from the slab.**

SOLUTION: **Provide adequate insulation.**

Adequate insulation under the slab and around the perimeter of the slab may help to make the floor feel a little warmer. Appendix B discusses different insulation options for slab-on-grade construction. However, as long as the slab is several degrees cooler than body temperature, heat will flow from a person's body into the slab creating a perception of coldness. A good solution is to install carpet.

SOLUTION: **Provide radiant heating.**

Another solution that has proven successful is the use of radiant heating. Typically, hot water is circulated within 12 or 19 mm (1/2 or 3/4 in.) polybutylene pipes spaced at 300 to 460 mm (12 to 18 in.) centres under or embedded within the slab.

CAUSE: **Thermal bridging.**

Since the edge of the floor slab is exposed to the cold outside air, as illustrated in Figure 5a, thermal bridging and excessive heat loss is often a problem.

SOLUTION: **Insulate the edge of the slab.**

The exterior edge of the slab should be insulated and the top and exposed side of the insulation should be covered with some kind of protection board, coating or parging, as illustrated in Figure 5b.

APPENDIX A - SUBGRADE PREPARATION

The most important aspect to achieving a trouble-free concrete slab-on-grade is the preparation of the subgrade. The subgrade is the natural ground, graded and compacted, on which the floor is built. To assure the success of the slab-on-grade, the subgrade should be completely uniform with respect to firmness (no hard or soft spots), grade and dampness. If the subgrade is not uniform, stresses may develop in the slab causing it to crack (Figure 1). To attain uniformity, the quality of the natural subgrade can be improved by drainage, compaction or soil stabilization.

The first step in preparing the subgrade is to completely remove topsoil and any organic material, exposing the natural ground. The topsoil can be stockpiled for possible future use in landscaping. It is then important to determine the characteristics of the subgrade material. This is important for three reasons. One, the support which can be provided by the subgrade influences the expected stresses in the concrete and the resulting structural design of the slab. Two, the type of soil will affect the amount of heat transfer and thus the amount of insulation required, as discussed in Appendix B. Three, the condition of the natural soil will determine the extent of preparation required.

The strength of the soil, or its ability to carry or support the structure and resist settlement, is a function of the degree of its compaction and its moisture content. In general, the higher the degree of compaction, the higher will be the strength of the soil and the lower will be the compressibility of the soil.

Compaction is the process of increasing the density of the soil by packing the particles closer together with a reduction in the volume of air in the soil. Compaction is the lowest cost way to improve the structural properties of the soil. Compaction can be achieved by rolling, tamping or vibrating the soil with the appropriate rollers or compactors. Driving cars, trucks or bulldozers over the soil will not compact the soil uniformly and may do more harm than good.

The degree of compaction of a soil is measured in terms of dry density, or the mass of solids per unit volume of soil. The compaction characteristics of a soil can be assessed by means of standard laboratory tests, such as the Proctor test, the Modified AASHTO test, or the Vibrating Hammer test. The required standard of field compaction can then be specified in terms of a minimum percentage of the maximum dry density obtained in one of the standard laboratory tests. In addition, water content limits should be specified and compaction should only proceed if the natural water content of the soil is within these limits. The engineer designing the slab should specify the degree of compaction required.

The limits of compaction should be the entire area of the building, plus a 1500 to 3000 mm (5 to 10 foot) perimeter border, as illustrated in Figure 6. Testing is conducted as compaction proceeds to help ensure uniformity.

Any fill material added to improve the subgrade, to fill in depressed areas or to raise the existing grade should be a stable material that can be thoroughly compacted. At transition areas where soil types or conditions change abruptly, the replacement soil should be mixed with the surrounding soil by crosshauling and blending to form a transition zone with uniform support conditions. The area around the slab-on-grade should be sloped so that water will drain away from the slab rather than towards it.

Buried utility lines, water pipes, sewers, etc., should be covered with at least 50 mm (2 in.) of soil. Backfilling should be done with soils like those surrounding the utility trench and it should be compacted in layers to duplicate the moisture and density conditions of the adjacent soil. Every attempt should be made to restore as much as possible the original uniformity of the subgrade over the utility.

After the subgrade is compacted to the specified density and graded, well-graded rock or gravel can be spread over the entire subbase, including the perimeter area. While this subbase is not an absolute requirement, its use is recommended because it provides a cushion for more uniform support for the slab by equalizing minor subgrade differences. The granular subbase also provides a capillary break, helping to dampproof the slab. The subbase material should be a granular material, like crushed stone, gravel or slag. Do not use cinder, clay, or vegetation because these materials will not give firm and uniform support. A subbase layer of 100 mm (4 in.) is recommended. If a thicker layer is used, there is a risk of densification under vibration. It is very important that the subbase is compacted to a minimum of 98% maximum density at optimum moisture content to prevent settlement.

APPENDIX B - INSULATION OPTIONS

In slab-on-grade construction, there are two components of slab heat loss. First, since the top of the slab must be elevated from the exterior grade to prevent any wood members from coming into contact with the soil, heat will be lost to the air out of the side of the slab (Figure 5). Second, heat will be lost through the soil. Both these components of heat loss have to be considered in designing the insulation system.

The purpose of the insulation system is twofold. First, the insulation is used to help make the floor slab feel warmer to the occupants. Second, in most places in Canada, the frost line is several feet below the surface and to make slab-on-grade construction economically feasible, the depth of frost penetration must be reduced by the appropriate use of insulation. In this way, the required depth of footings can be reduced so that thickening the edge of the slab is sufficient to pass the depth of frost.

Figure 7 shows the typical pattern of isotherms in the soil around an uninsulated slab. Isotherms are lines of equal temperature. As can be seen, freezing temperatures in the soil can reach below the footing level and frost heaving of the building can occur. The temperatures under the slab are also considerably less than the interior temperature, making the floor slab feel cold to the occupants. Through the use of the appropriate amounts of insulation, as illustrated in Figure 8, the depth of frost penetration can be reduced so that frost heaving is unlikely. Further, the temperatures under the slab are higher, making the room feel more comfortable to the occupants.

Figures 7 and 8 represent typical isotherms. The actual depth of frost penetration depends on many factors, including: variations in the outside air temperature, inside temperature, soil type, soil moisture content, the location of the ground water table, and ground surface cover affecting the rate of heat loss from the ground surface. Many of these conditions are very site dependent which means that the amount of insulation required will vary for each application. It is best if the services of an engineer are retained to ensure that the amount of insulation used is sufficient to prevent frost from reaching the bottom of the footing, thus preventing frost heaving.

With the thickened slab, the only way to prevent heat loss from the side of the slab is to use vertical exterior insulation. The vertical insulation should be adhered firmly to the side of the slab. The depth of this insulation is limited to the depth of the slab.

Insulation extending horizontally from the edge of the slab, forming an insulation skirt, is used to reduce the depth of frost penetration. This use of insulation became possible with the introduction of moisture-resistant plastic foam insulations, like closed-cell extruded polystyrene. The horizontal insulation should be installed in at least two overlapping layers and should be pegged or spot-glued together. The thickness of the insulation at the corners of the building should be increased by 50% over the amount used around the rest of the building and should extend back from the corner by a distance equal to the width of the insulation skirt. This exterior insulation skirt should be slightly sloped to drain water away from the slab. A cover of 200 to 300 mm (8 to 12 in.) should be provided over the insulation.

In some constructions, insulation is used under the floor slab to prevent heat loss and reduce energy costs. This practice is not recommended for slab-on-grade construction. The heat loss from the slab into the soil helps to keep the soil warm, reducing the depth of frost penetration. If this heat loss is reduced, the builder runs the risk of frost heave. Likewise, placing insulation above the floor slab is not recommended. Heaving failures can also occur in an unheated building that was designed to be heated. Therefore, it is important to maintain the interior temperature in the building.

The use of the dampproofing methods mentioned in the body of this booklet can also help to reduce the risk of frost heave. Clean coarse sand, gravel and crushed stone tend to be too coarse-textured to promote the growth of ice lenses, the layers of solid ice that cause frost heave. However, the use of insulation is still the most important component to preventing frost heave.

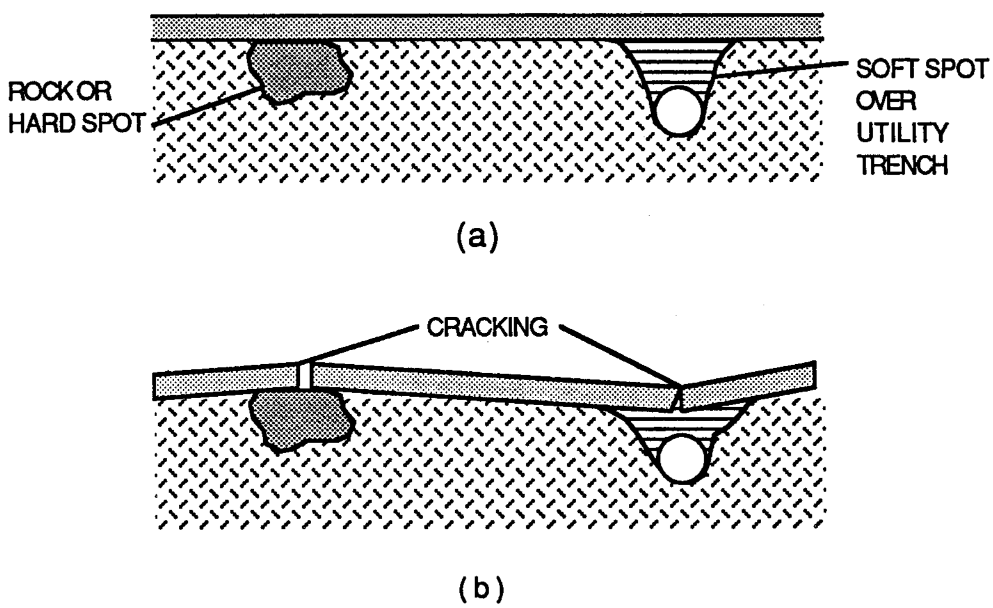

FIGURE 1

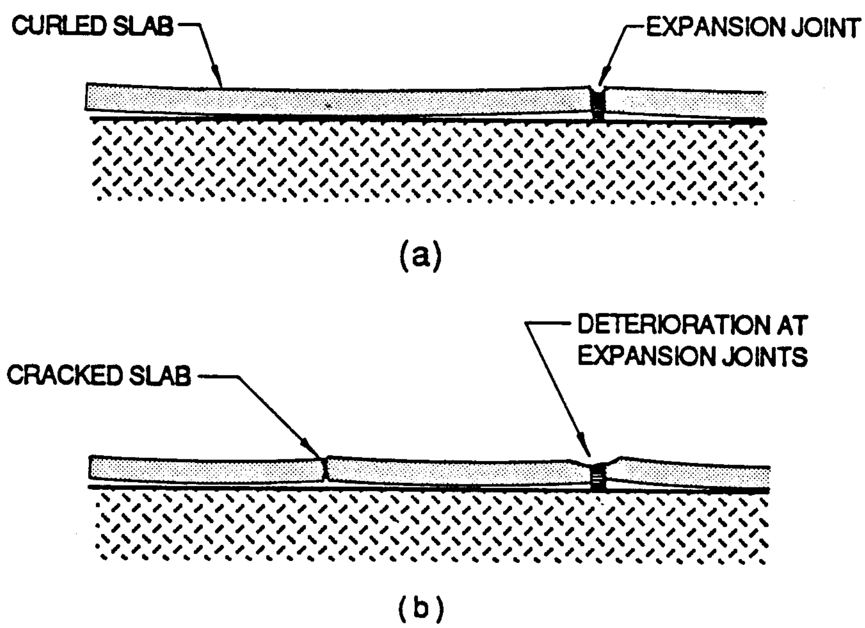
CURLED SLAB
EXPANSION JOINT
(a)
DETERIORATION AT
EXPANSION JOINTS
CRACKED SLAB
(b)

FIGURE 2

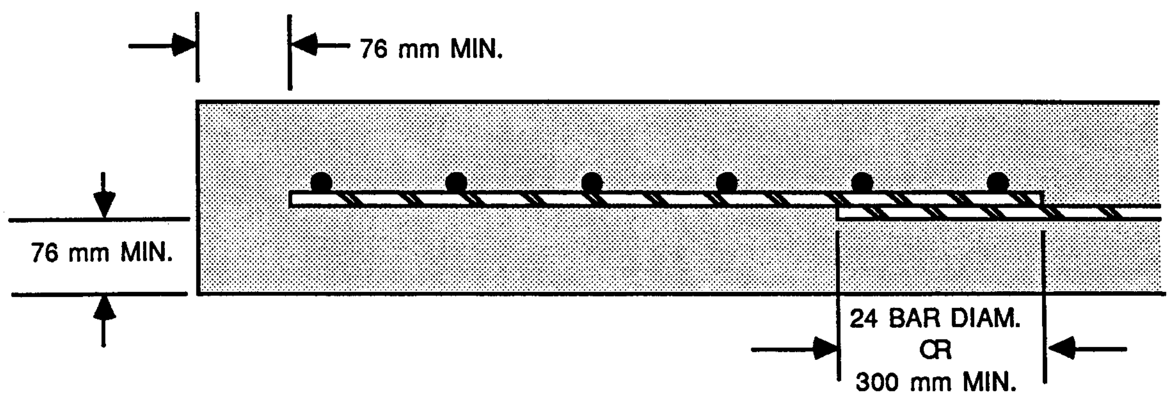

FIGURE 3

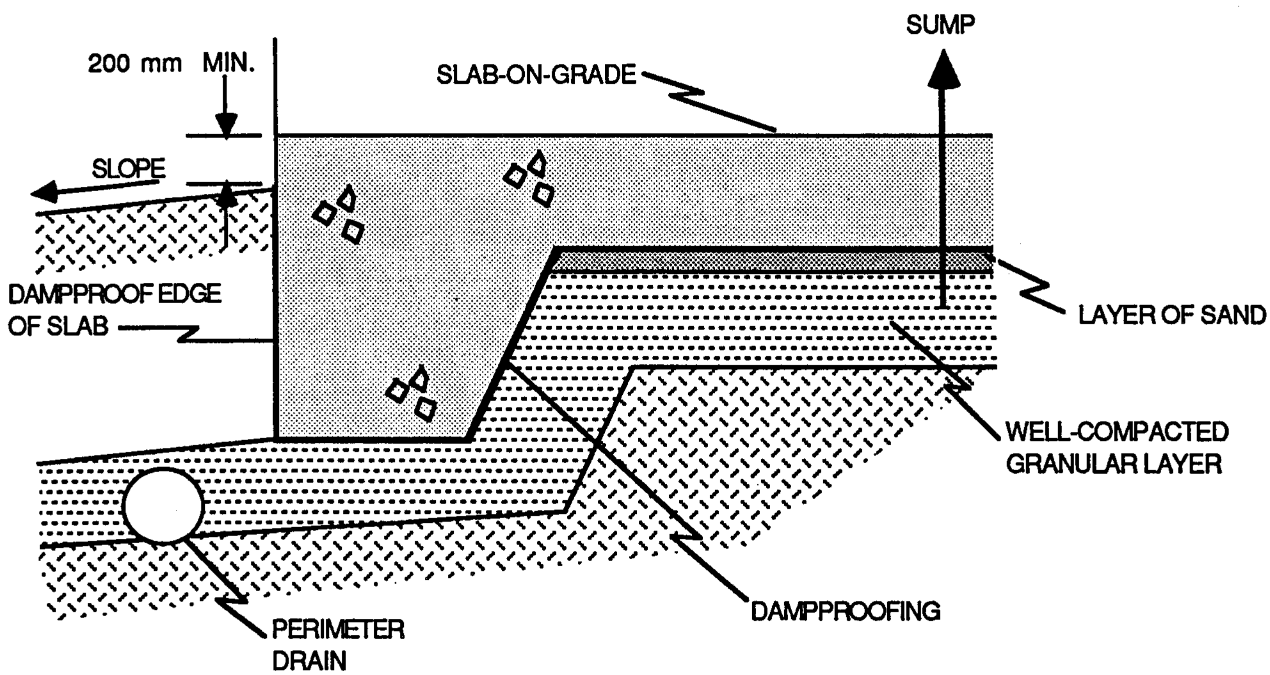
SUMP
200 mm MIN.
SLAB-ON-GRADE
SLOPE
DAMPPROOF EDGE
OF SLAB
LAYER OF SAND
WELL-COMPACTED
GRANULAR LAYER
DAMPPROOFING
PERIMETER
DRAIN

FIGURE 4

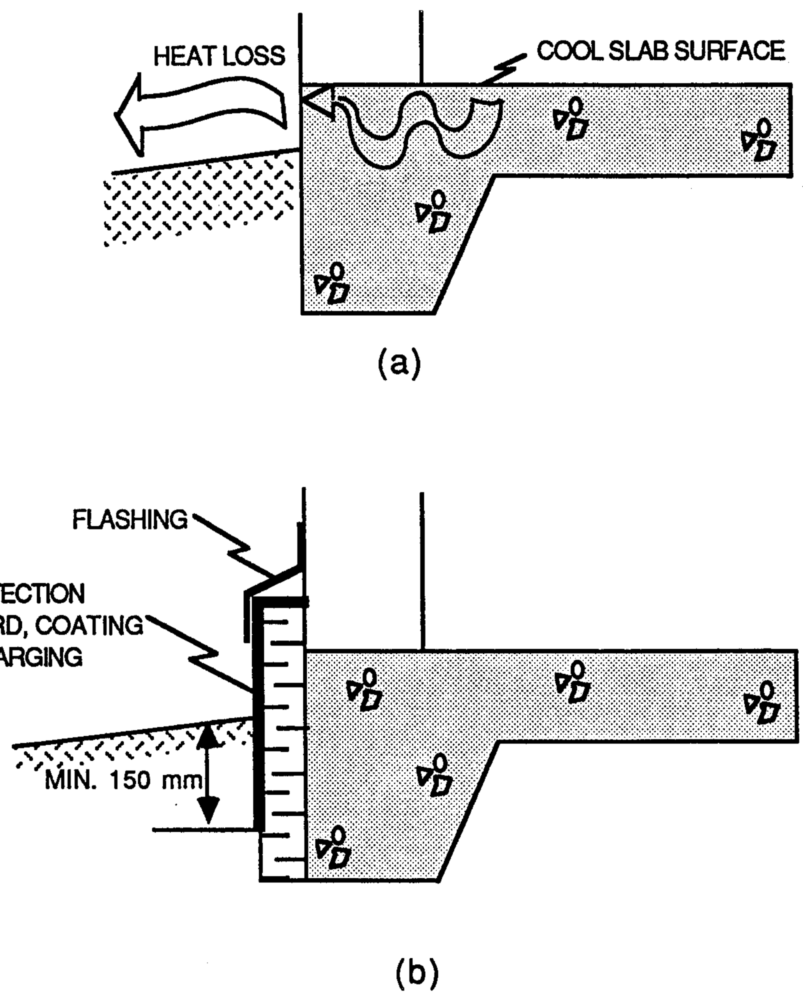
HEAT LOSS
COOL SLAB SURFACE
(a)
FLASHING
PROTECTION
BOARD, COATING
OR PARGING
MIN. 150 mm
(b)

FIGURE 5

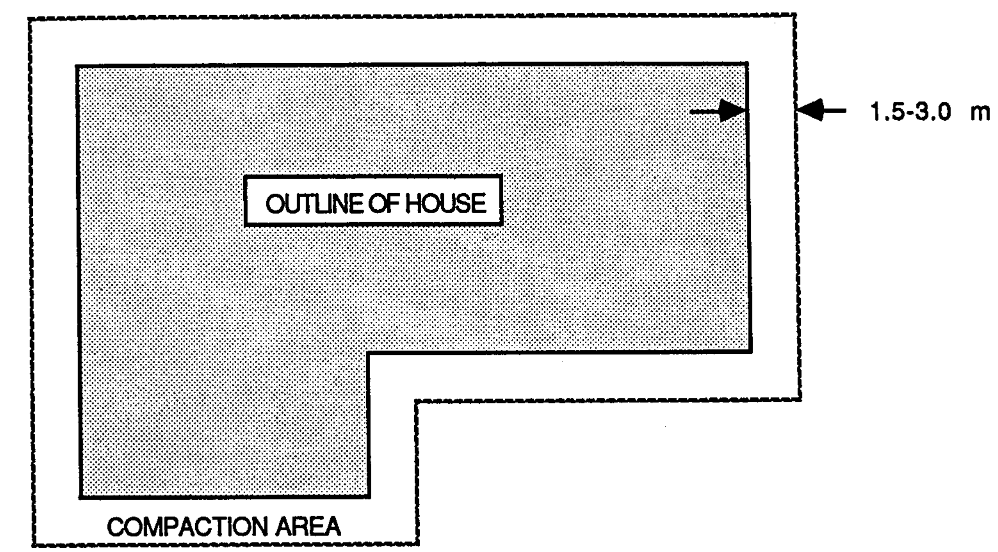

FIGURE 6

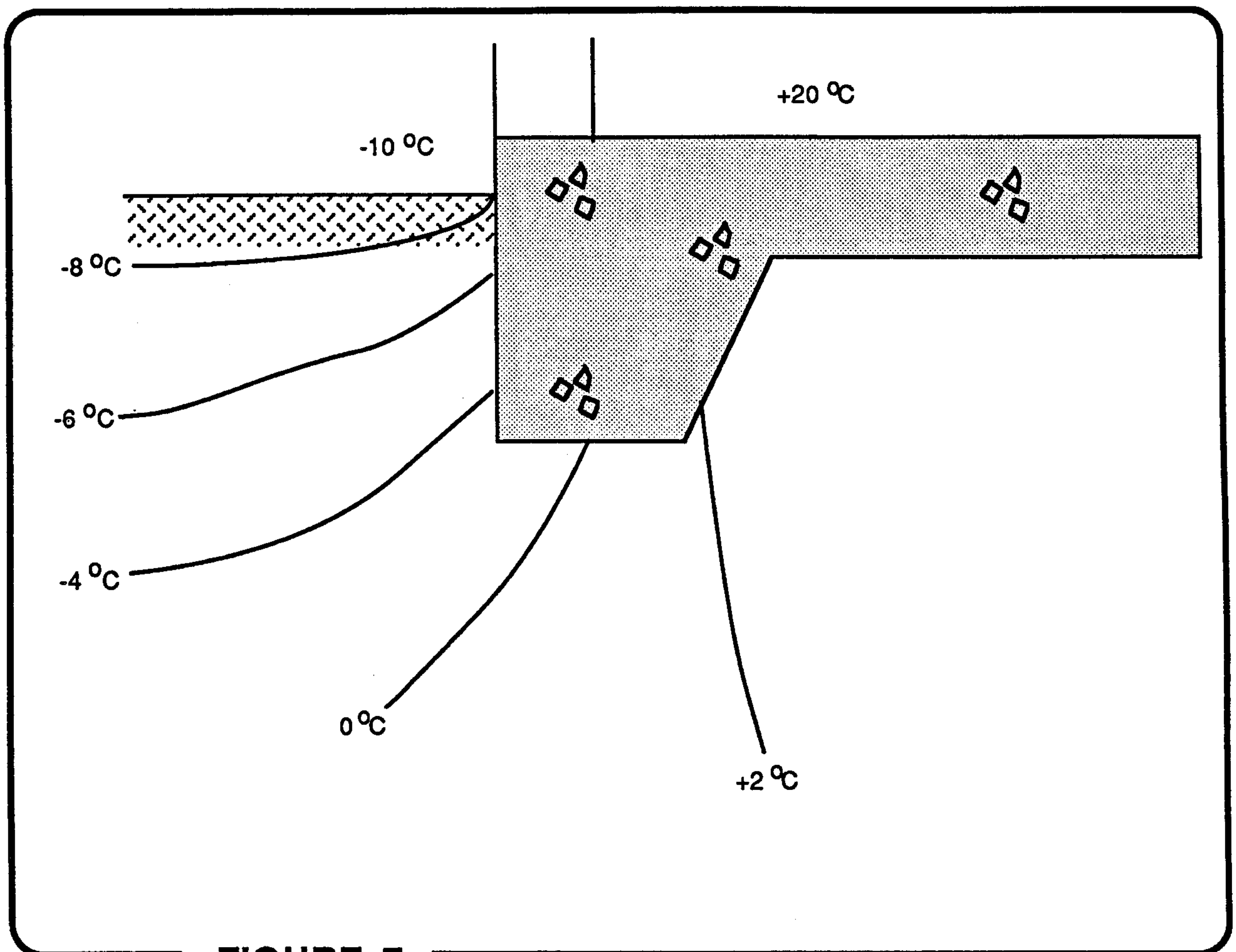

FIGURE 7

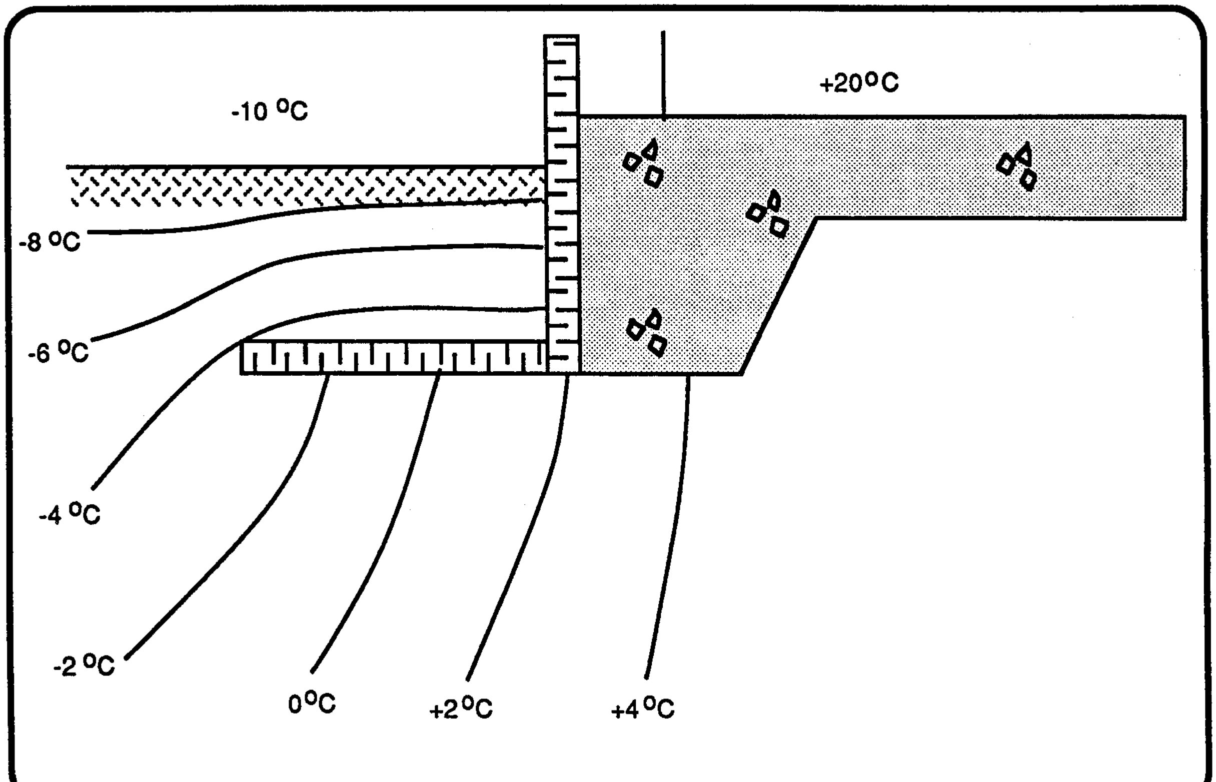

FIGURE 8