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Evaluation of heave prevention methods for floors founded on shale in the Ottawa Region

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Heaving of floors founded on black shale in the Ottawa region is due to the oxidation of pyrite in it and the subsequent formation of jarosite and gypsum which crystallize between the layers of the thinly laminated fissile shale causing it to expand. Air must gain access to the shale for the oxidation reaction to occur. Work done in Ottawa indicates that air may be prevented from entering the shale by coating the freshly excavated surface with a layer of concrete before construction commences. This has been successful in preventing heave for at least seven years. Additional precautions which are needed to prevent entry of air to the shale after construction of the building are also discussed.

Le soulèvement de dalles, fondées directement sur le schiste noir dans la région d'Ottawa, est du à l'oxydation de la pyrite contenue dans ce schiste et à la formation subséquente de jarosite et de gypse qui cristallisent entre les couches du schiste à lamination très serrée, pour produire une expansion. Pour que la réaction d'oxydation se produise, de l'air doit avoir accès au schiste. Des travaux réalisés à Ottawa montrent que l'accès de l'air au schiste peut être empêché en appliquant une couche de béton à la surface de l'excavation fraîchement ouverte, avant le début de la construction. Ceci a permis d'empêcher le soulèvement pendant au moins sept ans. Des précautions supplémentaires pour empêcher l'accès de l'air au schiste après la construction du bâtiment sont également présentées.

[Traduit par la revue]

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Introduction

Heaving of basement floors founded on black shale of the Billings formation is well documented (Penner *et al.* 1970; Quigley and Vogan 1970; Penner *et al.* 1973*a,b*; Quigley *et al.* 1973; Grattan-Bellew and Eden 1975). When the water table is lowered at a building site air enters the shale causing the oxidation of pyrite (FeS_2), which leads through a series of chemical reactions (Grattan-Bellew and Eden 1975) to the crystallization of jarosite ($2KFe_3(SO_4)_2(OH)_6$) and gypsum ($CaSO_4 \cdot 2H_2O$) between the layers of the thinly bedded fissile shale, causing it to heave. A few percent of pyrite in the shale is enough to set the reaction in progress; pyrite occurs frequently as very fine crystals, 5–20 μm in size, that are invisible to the unaided eye. If air could be excluded from the shale foundations, it would be theoretically possible to prevent the oxidation of the pyrite and consequent weathering of the shale; the method being evaluated is based on this hypothesis.

Method of protection

To prevent freshly excavated shale below basement floors from weathering it must be cleaned and coated with a 5-cm layer of concrete, placed in the usual manner, as soon as practicable. Where the shale layer is overlain by about 100 cm of till, the concrete protection slab may be omitted provided the till does not contain too many sand or gravel layers through which air might enter. This method of heave prevention has been applied to at least six buildings in the Ottawa area and appears to be successful. Potential problems are illustrated by those encountered in a one-storey building that will be

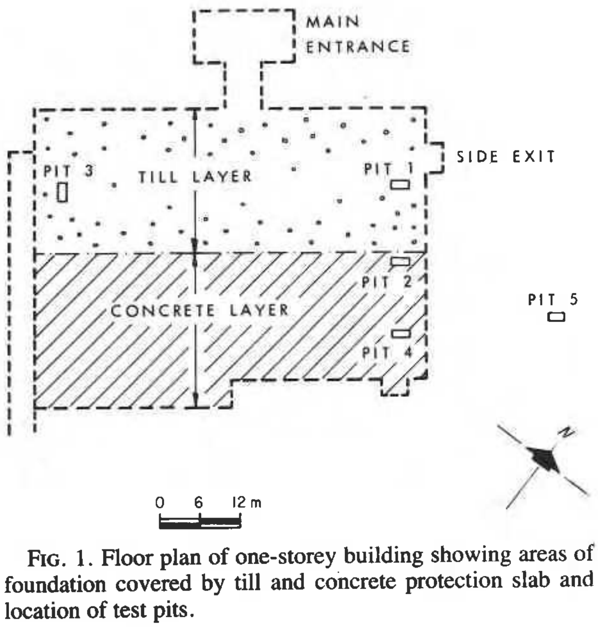

FIG. 1. Floor plan of one-storey building showing areas of foundation covered by till and concrete protection slab and location of test pits.

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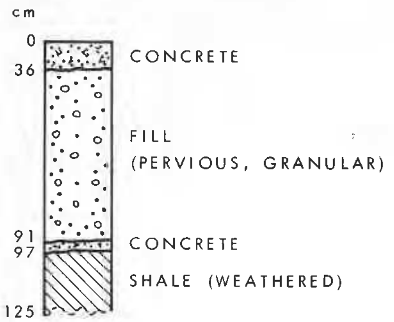

FIG. 2. Vertical profile of pit No. 2 showing weathered shale beneath concrete protection slab.

described. A plan of the building showing the location of pits excavated to evaluate the effectiveness of protective measures is shown in Fig. 1.

Evaluation of protective measures

The building is founded on a black shale known, from experience in adjacent buildings, to cause floor heaving if preventive measures are not taken. Levelling measurements and observed cracking indicated that the preventive measures had not been entirely successful. A number of pits were excavated to try to determine the cause or causes of failure.

The maximum heave was observed at pit No. 1, which is located next to a trench containing a sewer outlet. The trench had been backfilled with crushed limestone, which provided a ready path of access for air to the shale. Gypsum and jarosite were found in the shale, indicating that weathering had occurred. There was no opportunity to measure the profile of this pit before it had to be filled in. A profile of the side of pit No. 2 is shown in Fig. 2. Here the shale was protected by a layer of concrete 5 cm thick, but gypsum and jarosite were both found in it. The gypsum was very plentiful (Fig. 3). It is thought that weathering of the shale at this site, despite the concrete protective layer, may be due to air infiltrating laterally from the edge of the concrete protection slab about 1 m away. The protective slab stopped about 1 m north of pit No. 2.

Pit No. 3 was excavated in an area free from heave to check the condition of the underlying shale. A profile of pit No. 3 is shown in Fig. 4. The shale is overlain by 84 cm of undisturbed till with the 13-cm thick floor slab on top of it. The shale is unweathered, but some small, round, white lumps were observed on its surface (Fig. 5). These were identified as barite ($BaSO_4$) by X-ray diffraction. Barite is a common constituent of shales in the Ottawa area, but its presence is unrelated to the heave problem.

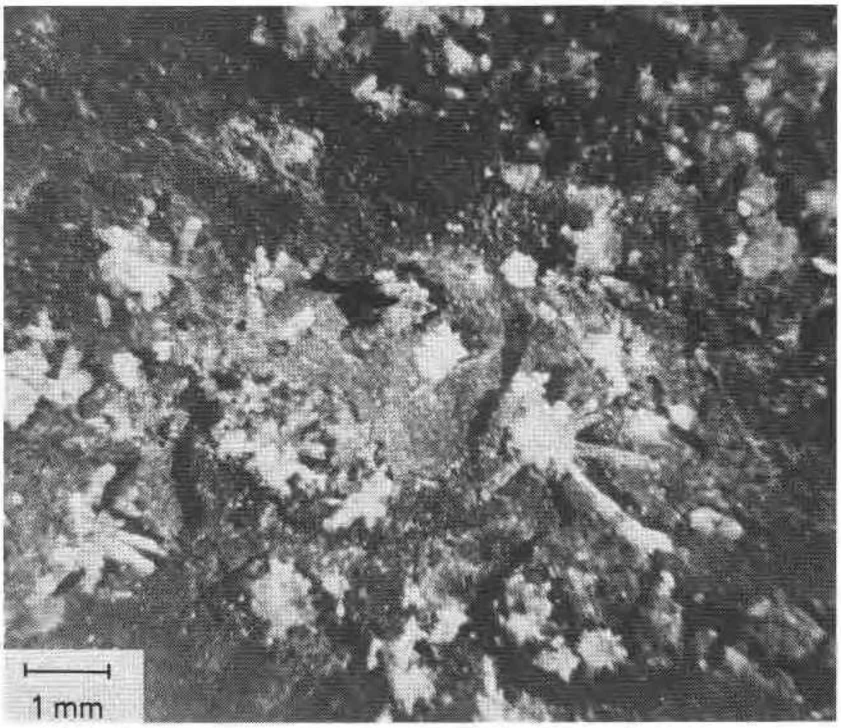

FIG. 3. Optical micrograph of spalling of shale due to growth of gypsum crystals.

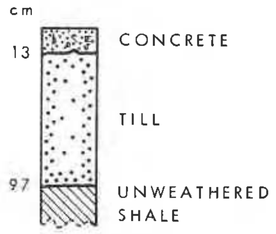

FIG. 4. Vertical profile of pit No. 3 showing unweathered shale under 84 cm of till.

A fourth pit, No. 4, was excavated in an area where the concrete protection slab had been applied but no heave was observed. A profile of the wall of this pit is shown in Fig. 6*a*. Unaltered shale was found below the concrete protection slab, but 31 cm down a 10 cm thick layer of weathered shale containing gypsum and jarosite was found; below this was unaltered shale. The absence of weathering in the top 31 cm of shale indicates that air cannot have infiltrated vertically through the shale. It is probable that oxidation is the result of groundwater percolating horizontally through the shale at that horizon, carrying oxygen with it.

Another pit, No. 5, was excavated about 20 m outside the building to try to verify this hypothesis. A profile of the pit wall is shown in Fig. 6*b*. An altered zone containing gypsum and jarosite was found under 18 cm of unweathered shale. It is concluded that oxidized zones unrelated to construction can occur in unaltered shale. Oxidation probably results from percolating oxygen-rich groundwater. Damaging upward movement of these zones is unlikely, since expansion would have taken place prior to construction of the building.

Conclusions and recommendations

It is concluded that a concrete slab protection or an undisturbed till layer with a thickness such as 84 cm over the shale is generally successful in preventing the entry of air and consequent heave of the floor, at least for a period of seven years. The long-term effectiveness of such measures, however, still remains to be demonstrated. Where heave was observed air had gained access to the underlying shale either from the adjacent edge of the protection slab, through a till layer 25 cm thick, or through the unprotected sides of sub-floor trenches carrying utilities to the building.

It is evident that in order to prevent heave of floors founded on black shale extreme care needs to be taken in the design of the excavation for the lowest floor and the foundations. A concrete protection slab over the shale surface should be included in the excavation planning and placed within one to three days of excavation. The concrete for the protection slab should be of normal quality to resist potential deterioration due to the sulfides in the shale (Grattan-Bellew and Eden 1975). The sides and bottom of any sub-floor trenches carrying utilities should be coated with a 5-cm layer of concrete continuous with the horizontal slab. Some means of preventing infiltration of air from the edge of the protection slab must also be provided, possibly by extending the slab

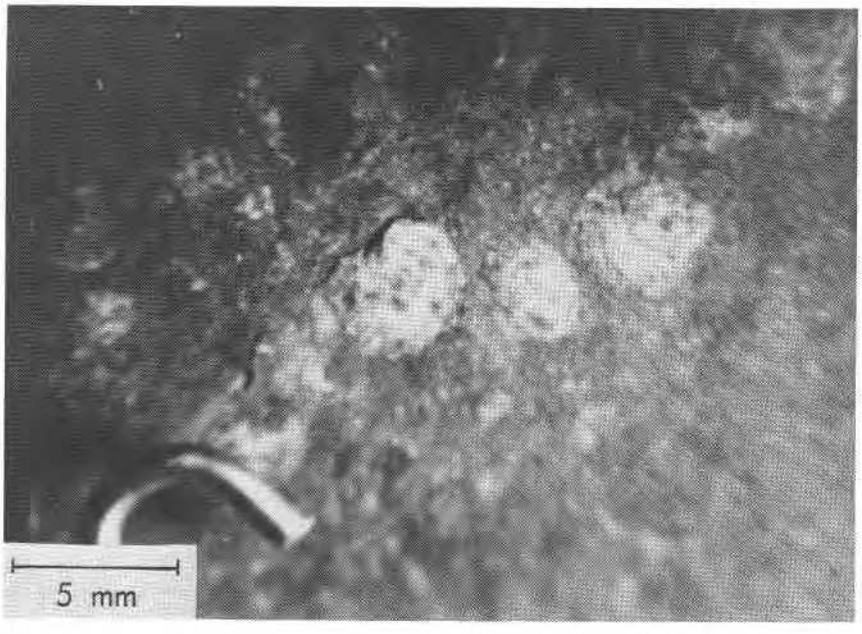

FIG. 5. Optical micrograph showing white barite $BaSO_4$ growths on the shale.

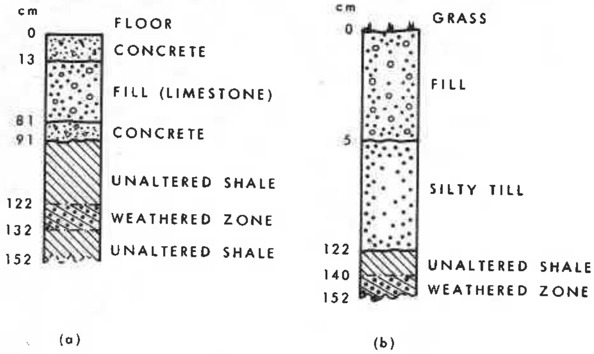

FIG. 6. Vertical profiles: (*a*) pit No. 4 showing the location of the weathered zone in the shale, below unaltered shale; (*b*) pit No. 5 which is outside the building, showing the location of the altered zone in the unweathered shale.

outside the perimeter of the building, by making a vertical cut and coating the side with concrete, or by using an impervious soil layer as backfill outside the exterior wall of the building.

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