Building damage from expansive steel slag backfill

Crawford, C. B.; Burn, K. N.

Publisher’s version / Version de l'éditeur:

Journal of the Soil Mechanics and Foundations Division, 95, SM6, pp. 1325-1334, 1970-01-01

NATIONAL RESEARCH COUNCIL OF CANADA
CONSEIL NATIONAL DE RECHERCHES DU CANADA

BUILDING DAMAGE FROM EXPANSIVE STEEL SLAG BACKFILL

BY

CARL B. CRAWFORD AND KENNETH N. BURN

REPRINTED FROM
JOURNAL OF THE SOIL MECHANICS AND FOUNDATIONS DIVISION, ASCE,
VOL. 95, NO. SM6, NOVEMBER 1969
P. 1325 - 1334

RESEARCH PAPER NO. 422
OF THE
DIVISION OF BUILDING RESEARCH

OTTAWA

JANUARY 1970

PRICE 25 CENTS

NRC 11158

DOMMAGES AUX BATIMENTS CAUSES PAR LE REMBLAYAGE DE SCORIES D'ACIER EXPANSIVES

SOMMAIRE

Le remblayage de scories d'acier expansives a été trouvé d'une façon inattendue comme étant la cause de soulèvement du plancher d'un édifice sans cave. Cette situation causa des dommages importants aux cadres des portes et fenêtres. Cinq ans après la construction, certaines parties du bâtiment étaient encore soulevées au rythme de 1 cm par année. Les propriétés de gonflement de la scorie, une fois exposée aux diverses conditions de la température et de l'humidité sont expliquées.

Les caractéristiques des scories de haut-fourneaux sont décrites et, sur cette base, on suggère de n'utiliser que les scories des haut-fourneaux dont le changement de volume à long terme peut être toléré. L'usage d'autres scories en de telles circonstances devrait être prohibé a moins qu'il puisse être établi qu'elles auront un volume stable.

6879 November, 1969 ANALYZED SM 6

Journal of the

SOIL MECHANICS AND FOUNDATIONS DIVISION

Proceedings of the American Society of Civil Engineers

BUILDING DAMAGE FROM EXPANSIVE STEEL SLAG BACKFILL[a]

By Carl B. Crawford,[1] M. ASCE, and Kenneth N. Burn[2]

Foundation failures caused by placing footings or floor slabs on uncompacted or poorly compacted backfill are examples of poor construction control. Failures resulting from expanding backfill are not so easy to anticipate. This paper describes a case record of building movements attributed to swelling backfill under a floor slab. Although sand backfill had been specified, the backfill actually used was slag from a steel mill that had, before its acceptance, undergone tests and appeared to be first class material for the purpose.

Blast furnace slag has been widely accepted in the construction industry as a high quality mineral aggregate. It is commonly used in portland cement concrete, as highway base course or railroad ballast, and in various bituminous mixes. Special "expanded slag" obtained by controlling the cooling process is used for the manufacture of lightweight concrete. In all these applications the common experience with iron blast furnace slag appears to be good. There are, unfortunately, other types of slag that do not possess its good qualities, notably those produced in open hearth or electric steel furnaces. The constituents of steel furnace slags vary widely; some may be satisfactory, but the

Note.—Discussion open until April 1, 1970. Separate discussions should be submitted for the individual papers in this symposium. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Soil Mechanics and Foundations Division, Proceedings of the American Society of Civil Engineers, Vol. 95, No. SM6, November, 1969. Manuscript was submitted for review for possible publication on May 22, 1969.

[a]Presented at the August 26-28, 1968, ASCE Specialty Conference on Placement and Improvement of Soil to Support Structures, held at MIT, Cambridge, Mass.

[1] Asst. Director, Division of Building Research, National Research Council, Canada.

[2] Research Officer, Soil Mechanics Section, Division of Building Research, National Research Council, Canada.

user is well advised to check the properties carefully. Details of the composition of slags are given later herein.

BUILDING

The building is located at the Canadian end of the international bridge between Michigan and Ontario at Sault Ste. Marie. A building plan is shown in Fig. 1, together with a cross section of the foundations. It is essentially a basementless, one-story structure with a partial second story. The exterior walls and interior columns are carried on spread footings at a depth of 5 ft. Footings on either side of a small service tunnel extend to depths of 9 ft and 10 ft. The excavated areas were backfilled after the foundations were in place,

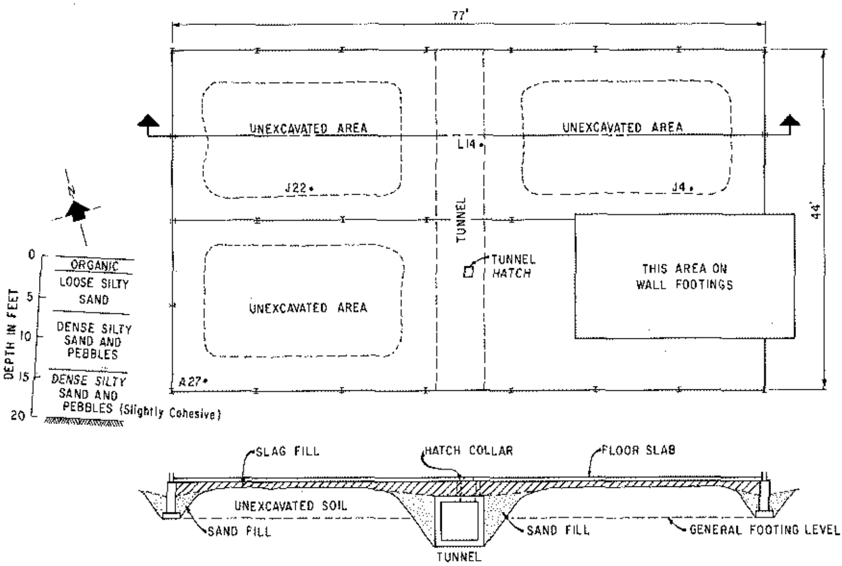

FIG. 1.—PLAN OF BUILDING AND SECTION THROUGH FOUNDATIONS SHOWING UNEXCAVATED AREAS AND DISTRIBUTION OF SLAG FILL BENEATH FLOOR SLAB

and the concrete floor slab was cast on the compacted fill. General soil conditions are also shown on Fig. 1. Ground level is just a few feet above a nearby river.

Construction of the tunnel and footings was completed during December, 1961 but with temperatures ranging as low as -30° F in January the operation was shut down and the footings were covered with an insulating layer of sand and straw. On February 5, 1962 the tunnel waterproofing was completed after much difficulty. On February 9th the daily report read "completed placing and compacting granular fill along tunnel." This was probably sand backfill. Construction work was then suspended until about the middle of March, but by the end of April the fill was in place and ready for floor construction. The upper fill material is slag from a local mill where no attempt was made to separate iron slag from steel slag. The exact thickness of slag is not known, but it probably varies from a few inches in unexcavated areas to more than two feet adjacent to the tunnel and footings. Construction of the building was completed during the summer of 1962.

BUILDING PERFORMANCE

Early in 1963 cracking of the building was reported, and following a detailed inspection some repairs were made. During the summer of 1964 some of the

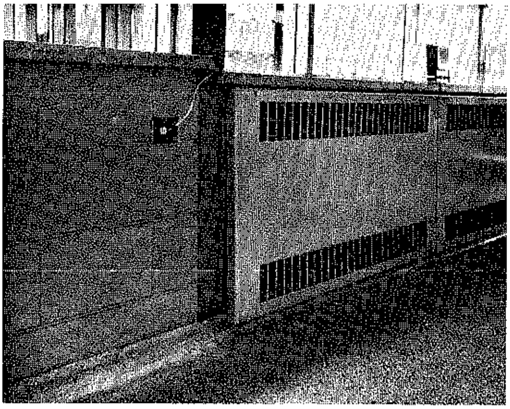

FIG. 2.—DIFFERENTIAL MOVEMENT ACROSS WINDOW SILL

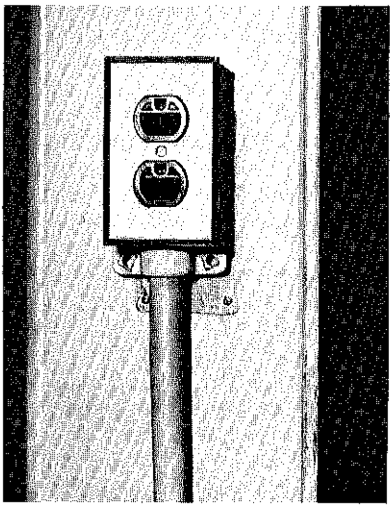

FIG. 3.—EVIDENCE OF MOVEMENT BETWEEN COLUMN AND FLOOR SLAB (MATERNA STUDIOS)

window frames and interior metal and glass partitions began to buckle. Fig. 2 shows a section of window sill that was relevelled after it had become tilted upward on the inside. At this location the edge of the floor slab rests on a recessed shelf cast in the foundation wall and the interior cinder-block facing rests on the floor slab. The window frame is carried directly on the exterior precast slab wall, which rests on the foundation wall. Differential movement between the inner facing and the outer wall caused the tipping of the window sill and some buckling of the window frame. An excavated section through the floor slab in 1965 revealed that the floor was resting on fill and that it had been raised 1/2 in. above the shelf on the foundation wall. By the end of 1967 the differential movement had exceeded 1 in. The cover for the heating unit in the background of Fig. 2 also is attached to the outer wall, and it was necessary, therefore, to detach it at the bottom to prevent buckling as the floor slab heaved.

Fig. 3 shows further evidence of differential movement between an interior column and the floor slab. The electrical conduit shown is cast in the floor slab and turns up at the base of the column. Movement and slippage between the floor and column have caused relative movement between the column and the conduit and sheared off the bolts fixing the outlet box to the column.

FOUNDATION MOVEMENTS

It was suspected at first that some of the footings had been placed on frozen ground or had been heaved out of place during the winter shutdown in 1962. This explanation became untenable, however, as time passed and movements continued. Regular level surveys initiated on October 3, 1963 showed that the outer walls and all of the structural columns were stationary and that the ground floor slab was rising. Observations on typical points on the floor slab are shown in Fig. 4 (the locations of these points are indicated on Fig. 1). Fig. 5 shows the locations of all the survey points and the contours of heave over the entire floor slab. Swelling of the natural subsoil was first suspected, but this was quickly ruled out on the basis of its classification properties. Sometime in 1964 it was suggested that the slag backfill might have been swelling and the material was re-examined. It is not clear what tests were carried out, but it was concluded that the slag was practically inert and that its physical characteristics would probably not be altered by the addition of water.

In 1965 the Division of Building Research of the National Research Council of Canada was asked to investigate the problem. During an inspection of the site in May, 1965 it became clear that swelling of the slag backfill was the most probable explanation for the movements, based on the following observations: Near the center of the building a vertical hatch extends from the roof of the tunnel through the floor slab; the space between (about 18 in.) is occupied by slag. A horizontal crack about 1-1/2 in. wide all around the hatch collar indicated a relative upward movement of the floor slab from the tunnel. Unless the slag had expanded vertically a void should have existed between the under side of the slab and the top of the fill, but removal of a small portion of the floor slab revealed that no void exists. The observed vertical movement represented about 7% of the original thickness of slag above the tunnel. By the end of 1967 the crack had increased to 2 in. in width, indicating a vertical expansion of more than 9%.

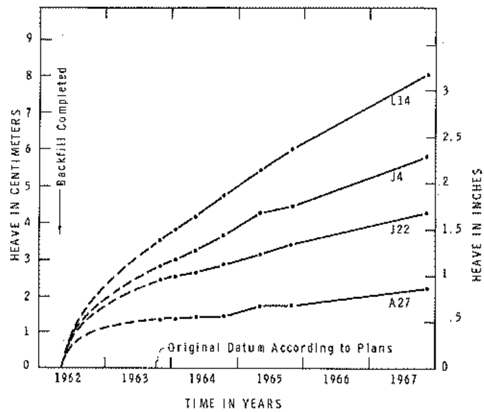

FIG. 4.—MEASURED HEAVE WITH TIME

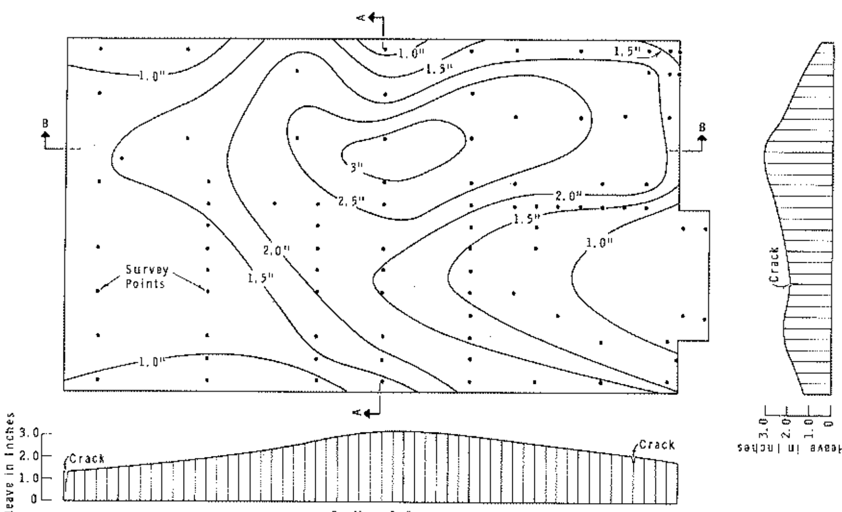

FIG. 5.—CONTOURS OF HEAVE OF GROUND FLOOR (NOVEMBER, 1967)

SLAG TESTS

Samples of iron blast furnace (BF) and open hearth steel furnace (OHF) slags were obtained from the local steel mill. The BF slag was greenish-brown and made up of angular particles, all passing the No. 4 sieve. The OHF slag was grey to black, with an occasional white particle; all particles passed the 1/2-in. sieve, but 30% was retained on the No. 4 sieve. Grain-size curves are shown in Fig. 6.

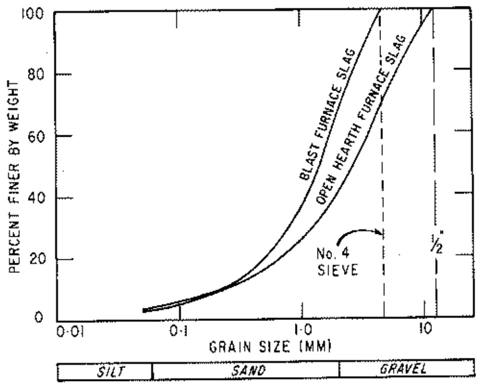

FIG. 6.—GRAIN SIZE OF SLAGS TESTED

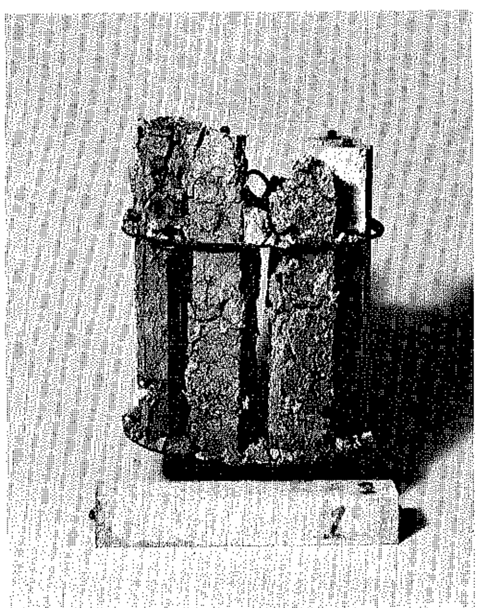

FIG. 7.—AUTOCLAVE TEST SPECIMENS

For test purposes, samples were prepared as follows: Sample A—natural BF slag (passing No. 4 sieve); Sample B—natural OHF slag with coarse particles (greater than No. 4 sieve) removed; and Sample C—natural OHF slag with coarse particles crushed to pass No. 4 sieve.

Autoclave Tests.—Autoclave tests are qualitative. Test conditions are much more severe than "in service" conditions, but the results quickly reveal any potential chemical instability in the material that might result from moisture changes. Specimens were formed from the various slag samples by mixing with ordinary portland cement in the proportions of 3 parts slag to 1 part cement. Two bars 1 in. sq in section and 6 in. in length were made from each of the three slag samples using water cement ratios of just less than 1:2 (± 5%). Two reference specimens of Ottawa sand and portland cement were prepared in the same way.

The bars were cured at 21° C and 100% relative humidity for 65 hr, removed from the molds, placed in the autoclave, and subjected to steam at

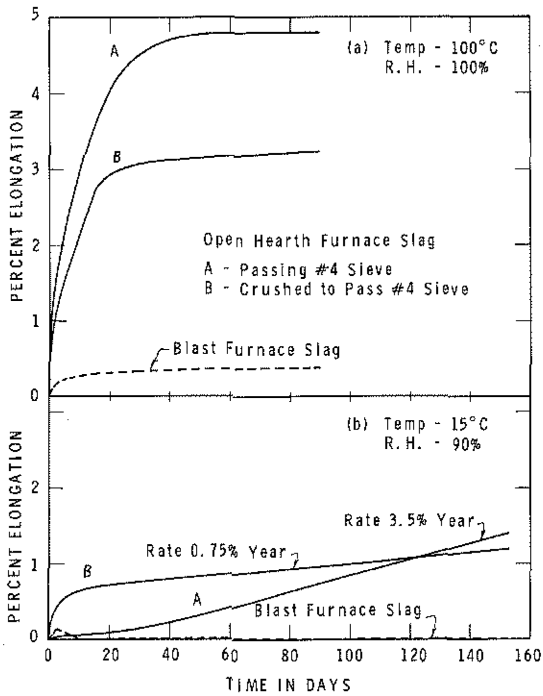

FIG. 8.—TIME-EXPANSION TESTS, BLAST AND OPEN HEARTH FURNACE SLAGS

215° C at a pressure of 300 psi for 3 hr. Except for minor variations this follows the ASTM C151—64 standard test method.

When removed from the autoclave the specimens were in the conditions shown in Fig. 7. The intact bars on the right were made from BF slag; those in the foreground and to the left that have disintegrated were made from OHF slag. One of the reference specimens is shown lying in the foreground. Linear expansion of the OHF bars was about 10%.

Moderate Temperature Tests.—Cylindrical specimens of samples A,B and C were prepared by compaction in bronze molds 2 in. in diam by 4 in. high and capped with aluminum discs set in plaster-of-paris. Following initial height measurements, the base of each specimen was allowed contact with free water through a porous stone while the surrounding atmosphere was maintained at 100° C and 100% relative humidity. Periodic measurements of elongation, made with a dial gage, are shown in Fig. 8(*a*). Approximately 3% to 5% elongation was measured for the open hearth furnace slags; the blast furnace slag showed very little change. Although the inner surfaces of the molds had been greased, it is suspected that swelling was somewhat reduced by side-wall friction.

Low Temperature Tests.—Three additional specimens were tested as for the moderate temperature tests, except that the surrounding atmosphere was maintained at 15° C and approximately 90% relative humidity. Under these conditions the open hearth slag expanded less, but was still expanding at significant rates after 5 months [Fig. 8(*b*)]. The blast furnace slag exhibed a small movement during the initial stages, but the specimen cap became loose and may have accounted for the slight movements shown in Fig. 8(*b*). No movement was observed after 10 days.

PROPERTIES AND USES OF SLAG MATERIAL

The differences of properties between blast furnace slags and steel furnace slags are caused by differences in the refining processes. The reduction of iron ore in a blast furnace is a continuous operation that results in the production of a reasonably uniform slag in which calcium oxides and magnesium oxides are always combined in silicate and alumino-silicate minerals. Steel production, on the other hand, is a batch process in which reactions are not always completed. This produces a nonuniform slag that may contain free oxides of calcium and magnesium.

The chemical composition of open hearth slag is generally variable and unpredictable. Fresh OH slag often has a substantial content of unslaked lime (CaO), which will hydrate rapidly and cause large volume expansion. Much of the hydration and volume change occurs in a few weeks, so that its volumetric stability can be improved by crushing and aging. The slag may also contain a significant quantity of magnesium oxide, which hydrates slowly causing volume changes that may continue for many years. Total volume changes of more than 10% can be expected in severe cases.

In this investigation samples of open hearth slag were obtained directly from the mill for comparison with slag material taken from under the floor slab of the building. X-ray diffraction patterns obtained by J. E. Gillott of the Division of Building Research showed similar composition. In approximate order of decreasing quantities it is as follows: calcium hydroxide, magnesium oxide, magnesium hydroxide, calcite, quartz, and dolomite. The absence of calcium oxide and the predominance of calcium hydroxide indicates rapid and complete hydration of the oxide. The appreciable quantity of magnesium oxide indicates that hydration of this oxide is not yet complete and that this is the probable basis of longterm swelling.

The mechanism of hydration of calcium oxide to form calcium hydroxide has been investigated (1).[3] It was shown that a linear expansion of 8% occurred during complete hydration of the oxide immersed in water. When, however,

[3] Numerals in parentheses refer to corresponding items in the Appendix.—Reference.

hydration was caused by exposure to water vapor the linear expansion of an unconfined sample exceeded 100%. The immersion test showed that the volume of voids decreased during hydration and it was deduced that calcium oxide was first dissolved and then recrystallized, allowing the growth of crystals within original pore space. In the vapor test transformation occurs as a solid state reaction pushing apart the constituents and maintaining a large void ratio.

Results are not available for magnesium oxide, but a similar interpretation can be readily visualized. This is, however, a qualitative assessment. The actual in-service expansion will depend on many factors, including initial density, confining pressure, degree of saturation and percentage of expansive oxides in the slag.

About 25,000,000 tons of blast furnace slag are used annually by the construction industry in the United States, apparently with complete success. Some 4 or 5,000,000 tons of steel furnace slag are also used in construction, occasionally with quite unsatisfactory results. Experienced suppliers of steel furnace slag limit its use to open fills, unpaved roads and parking areas, railroad ballast or other purposes where volume change will not cause special problems. Unfortunately, these limitations are not widely appreciated.

CONCLUSIONS

The relative vertical movement between the floor slab of the building and the roof of the service tunnel has occurred without any evidence of voids under the slab. The slag fill under the slab must, therefore, have increased in volume and it follows that the movement was caused by swelling of the slag. Other evidence of movement in the building is consistent with this interpretation. Tests on the fill material confirm that it is a steel slag and that it has a swelling potential.

It is shown that the autoclave test distinguishes good material from bad. Moderate and low temperature tests of the type described allow estimates to be made of the potential swelling although their use is limited by the time required to achieve the complete volume change. In addition the magnitude of measured swelling depends on the age of the slag and on its original chemical composition.

Little information on unsatisfactory slag material appears in the literature, although there is no doubt that the problem arises when certain slags are used in confined areas. It is hoped that this paper will direct attention to the serious damage that may result from the indiscriminate use of steel slag for backfill and thus reduce problems with its use.

Until evidence to the contrary is forthcoming, it should be considered hazardous to use any slag except blast furnace slag for fill in confined spaces or where long-term volume changes cannot be tolerated.

ACKNOWLEDGMENTS

The writers greatly appreciate the complete cooperation of the consulting architects Somerville, McMurrich and Oxley of Don Mills, Ontario, represented by P. L. E. Goering, of the structural engineers E. A. Cross and Associates of Toronto, and of the Maintenance Engineer of the International Bridge Authority, D. D. Dell. The paper is published with the approval of the

consulting engineer representing the owner, C. H. Gronquist of Steinman, Boynton, Gronquist and London of New York, and of R. F. Legget, Director of the Division of Building Research of the National Research Council of Canada.

APPENDIX.—REFERENCE

1. Ramachandran, V. S., Sereda, P. J., and Feldman, R. F., "Mechanism of Hydration of Calcium Oxide," *Nature* (United Kingdom), Vol. 201, No. 4916, Jan. 18, 1964, pp. 288–289.