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Structural Fill of Steel Slag Caused Heave of a Building

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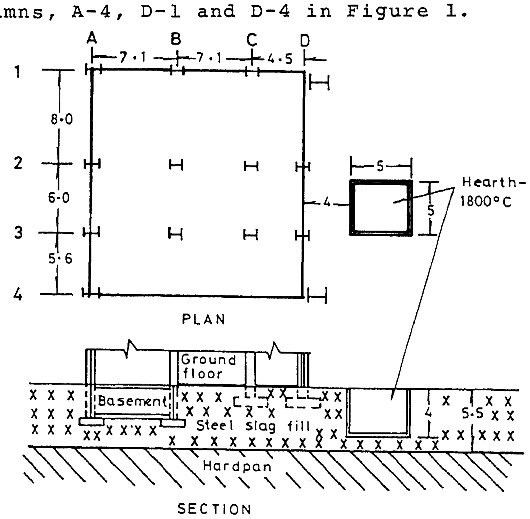
SYNOPSIS The results of an investigation on the cause of damage to a two-story industrial building supported on 5.5m of steel slag fill in the town of Monclova in the north of Mexico are presented. Since six years it was built, the floor slab heaved between 2cm and 25cm. The columns were raised up between 2 cm and 20 cm. These movements cracked the building. Chemical analysis of slag showed 22% of calcium oxide and 5% of magnesium oxide, which on hydration cause swelling. At a distance of 4m on one side of the building was a hearth-bath, a molten iron pit,5mx5m & 4m deep constructed in the same slag fill. The heat transmitted from the hearth-bath to the fill beneath the building caused it to swell. The swell was proportional to the heat transmitted. The maximum heave was 25 cm at a distance of 4 m from the heat source. The heave decreased at increasing distances from the heat source.

BUILDING

The building was part of an iron and steel mill, the Altos Hornos de Mexico, in the town of Monclova in the state of Coahuila in Mexico. It was built in the year 1971, located adjoining the basic oxygen furnace building and was used as a substation for the furnace. The building plan and cross-section are shown in Fig. 1. It is a two-story steel framed structure, 18.7 m x 19.6 m in plan, with a partial basement, exterior brick panel walls and concrete floors. The building is structurally tied to the adjacent B.O.F. building, a large industrial type structure, through three common columns, A-4, D-1 and D-4 in Figure 1.



All Dimensions in Meters

Fig. 1. Plan of Building and Section Through Foundations Showing the Steel Slag Fill

The building is supported on a slag fill whose maximum thickness is 5.5 m. The columns in the non-basement area are founded on concrete square footings at 1.75 m depth from the ground floor level, on 3.75 m thick slag fill. The columns adjacent to the basement area are founded on continuous footings at 0.5 m depth from the basement floor, on 2.3 m thick slag fill. The three common columns with the B.O.F. building are carried on footings below the slag fill, to the underlying hardpan, which is the natural soil of the site. The ground floor slab in the non-basement area and the basement floor slab are supported by the slag fill, 5.5 m and 2.8 m thick respectively. The exterior brick panel walls in the ground floor are carried on grade beams.

As shown in Fig. 1, on one side of the building at a distance of 4m is a hearth-bath, a pit 5m x 5m and 4 m deep, constructed in the same slag fill. The temperature inside the pit, where molten metal is handled in ladles is about 1800°C. This provided a source of heat which was transmitted into the surrounding slag fill which is a fairly good conductor of heat due to its iron content.

BUILDING MOVEMENTS

The ground floor slab started rising within six months after the construction. Level surveys were initiated early in 1972. By 1977, the heave of the ground floor slab was between 5 cm and 25 cm and it cracked badly. The columns too had moved up, by a maximum of 20 cm in the non-basement area and by 2 cm to 5 cm in the basement area. The basement floor slab also cracked, but not so much as the ground floor slab. Differential movements between the common columns, D-4 and D-1 which did not move as it was founded on the hardpan, and the adjacent columns, D-2 and D-3 founded on the slag fill were about 20 cm. This caused the brick panel wall between them to crack. The wall on the ground floor between columns D-4 and D-3 had to be pulled down and replaced by metal sheets. Significantly the wall between columns D-2 and D-3 which had both been raised about equally was intact. The basement wall on the axis B (see Fig. 1) supported on the continuous footings of the columns cracked to a lesser extent.

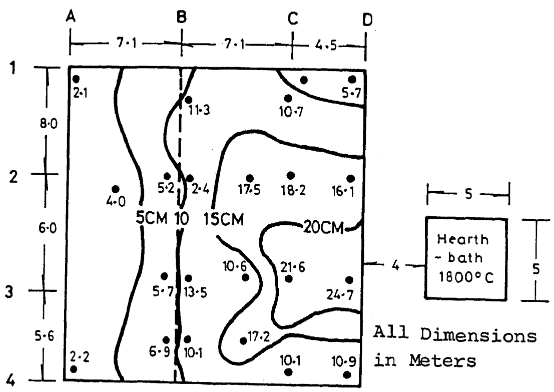


Fig. 2 Contours of Heave of Ground Floor (February, 1977)

Fig. 2 shows the contours of heave of the entire ground floor as well as heave values of survey points. The main observation regarding the contours is that they seem to be concentric about the hearth-bath which is the heat source. The heave decreases as the distance from the hearth-bath increases. The maximum heave of 24.7 cm occurred at a point 4 m from the pit while a heave half of that value occured at 16 m. The expansion of the fill beneath the above two points is proportional to the heat transmitted from the pit. The maximum heave of 24.7 cm corresponds to 4.5% expansion.

The heave was also found to be proportional to the thickness of the fill. On either side of axis B, the basement and non-basement areas, the thicknesses of the fill were 2.8 m and 5.5 m and the heaves were 5 cm and 10 cm respectively.

TESTS ON THE SLAG

The slag used for the fill is the by-product from the basic oxygen steel furnace of the same steel mill. An open pit excavated inside the building revealed a very compact fill consisting of grey coloured, 4" to 6" (10 cm to 15 cm) sizes up to gravel sizes in a matrix of fines. The moisture content of fines was between 5% and 10%. Water table was not located in the subsoil below the fill. There was no indicatio of any seepage of water into the fill from external sources. The whole atmosphere inside was one of heat.

Fresh slag samples were obtained directly from the mill. Coarse sizes were crushed to materia passing No. 4 sieve. Laboratory tests were con ducted on this prepared sample.

Autoclave Tests

Specimen bars, 1" square and 6" in length were formed by mixing with Type I portland cement in the proportion of 3 parts of slag to 1 part of cement using water-cement ratio of 0.5. The bars were cured at 21°C and 100% relative humidity for 65 hours, removed from molds, placed in autoclave and subjected to steam at 215°C at a pressure of 300 psi for 3 hours. The same test is conducted on specimen bars formed using ottawa sand with the same cement and water proportion. The results were the following:

Linear expansion of slag specimens = 0.05%

Linear expansion of ottawa sand specimens = 0.04%

Free Swell Tests

Crushed samples of slag were compacted in molds 15 cm diameter and 14 cm high (CBR molds) usinç 7% water, to a dry density of 2440 kg/m^3. The molds were submerged in water using the same setup as for CBR expansion tests. After 10 da there was no expansion.

Later on, the same test was conducted on specimens compacted using only the fine fraction (passing No. 40 sieve) of the natural slag that was not crushed. Due to tight time schedule tl test could be run only for six days. The expansion was 0.8%.

X-ray Diffraction

The x-ray diffraction patterns of the crushed slag sample showed that the major part of the material is amorphous and the little reflectio obtained correspond to minor quantities of crystallized minerals: $CaMgSi_2O_7$, $MnFe_2O_4$, Fe_3O_4, FeO, CaSiO, $FeOSiO_2$.

Chemical Analysis

Chemical analysis of the crushed slag showed a percentages of dry weight: Iron (Fe_2O_3) 40.25, Calcium oxide (CaO) 22.35, Silicon oxide (SiO_2) 16.79, Magnesium oxide (MgO) 4.8, Aluminium oxi (Al_2O_3) 4.06, Manganese (Mn) 2.01, Chromium (C 0.62 and Sulphur (S) 0.11.

REVIEW OF RESULTS

The chemical analysis showed the presence of 22% calcium oxide and 5% magnesium oxide the hydration of which is considered to be the mai cause of the expansion of the slag (Crawford and Burn, 1968). The hydration of calcium oxi when immersed in water will produce a linear expansion of 0.8%. When, however, hydration w caused by exposure to water vapour the linear expansion of an unconfined sample exceeds 100%. Magnesium oxide hydrates slowly causing volume changes that may continue for many years. The behaviour of magnesium oxide under water vapour is not known but a similar interpretation as that for calcium oxide can be readily visualised (Crawford and Burn, 1968). Samples of chromate fills containing 10% of calcium, 3% of magnesium, 32.6% of iron, 5% of silicon and 9.6% of chromium, compacted into molds and oven treated at 240°C for 4 days heaved 7% of the height (Jacob Feld, 1968). The above results show that water vapour and steam produces larger expansions in slag than that caused by moisture.

The above is consistent with the observed expansions in the slag fill beneath the building where the heat converted the moisture in the fill into steam and vapour causing the slag to swell. In this case, autoclave test should represent the 'in service' conditions better than other tests. That the autoclave on the slag under study did not show any expansive potential seems inconsistent with the reality. But it is consistent with the results obtained in free swell tests on crushed sample where no expansion was observed after 10 days. However, free swell tests on the fines (passing No. 40 sieve) showed an expansion of 0.8% after six days leads to a hypothesis that the fines in the slag might be responsible for the swelling. Due to lack of time autoclave tests could not be run on the fine fraction.

CONCLUSIONS

The following conclusions could be drawn from this study:

1. B.O.F. steel slag has expansion capabilities.
2. Heat affects the swelling of the slag.
3. The heave of a building on a uniformly thick B.O.F. slag fill located near an underground heat source decreased with increasing distance from the heat source.

ACKNOWLEDGEMENTS

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