F. R. Note No. 460

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

EFFECT OF RESTRAINT ON FIRE RESISTANCE OF CONCRETE FLOORS

by

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SUMMARY

A programme of co-operative research was undertaken under the aegis of CIB/CTF to determine the effect of restraint on the fire resistance of concrete floors. This note describes the tests performed and compares the results with similar tests performed in Holland and France.

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1. Introduction

The restraint conditions to which an element of structure is subjected in a building or a part of a building vary widely and in actual fires the exact nature and degree of restraint to which various elements are subject is extremely difficult to determine. Fire tests are made under standardized conditions, and in general floors are tested as simply supported structures with flat bearings. Where tests have been performed on similar structures under conditions of end restraint, the most significant phenomenon observed has been the reduction in the deflection of the restrained specimen compared with that of the simply supported floor.

At the third meeting of the CIB/CTF(1) in 1958 the effect of restraint on the fire resistance of floors was discussed and it was agreed that it would be of mutual interest to the various delegate countries to undertake a co-operative programme of research to study this effect on a selected type of floor construction, and at the same time obtain a correlation of the furnaces and methods of test used in the particular countries. France, Holland and United Kingdom agreed to participate in a limited investigation in the first place, and a floor construction having a fire resistance of 1 to 2 hours was chosen for this purpose. In order to reduce variables, a precast beam floor was used for which the precast members were obtained from a factory in Holland and the construction made to a common specification.

2. Scope of the Investigation

The tests were performed on three floor specimens constructed with precast beams with a concrete topping and without a ceiling finish. No transverse restraint was used in any of the specimens, but the following end conditions were imposed:

(1) Simply supported, other edges free;

(2) Ends longitudinally restrained, other edges free;

(3) Ends under longitudinal and angular restraint, other edges free.

It was intended that the tests would be terminated before the collapse became imminent, and after a predetermined downwards deflection had been exceeded.

3. Description of specimens

The specimen floors were constructed from precast hollow concrete beams 5.7 in (145 mm) thick, (Figure 1) reinforced with 2 - $\frac{1}{2}$ in (12 mm) dia. bars at the bottom and 2 - $\frac{1}{4}$ in (6 mm) dia. bars at the top with wire netting in the lower flange. The units, with tapering sides, were 9.8 in (250 mm) wide at the base, and when closely butted together twelve beams gave an overall width of 10 ft. Beams of two different lengths were employed in the construction of the floors, units 12 ft 9 in (388 cm) long for specimen Nos 1 and 2 to give a clear span of 12 ft (366 cm) and for specimen No. 3 12 ft (366 cm) long beams to give a clear span of 11 ft 6 in (350 cm).

After mounting the beams in the test frame an <u>in situ</u> concrete topping was cast (Plate 1) to provide an average cover of 1.18 in (30 mm) to the top of the beams giving a floor construction of a total thickness of 6.9 in (175 mm). During the placing of the concrete topping 6 in cubes were made to determine the concrete strength at 28 days and at the time of test. Details of the beams as supplied by the manufacturers and of the <u>in situ</u> concrete are given in Appendix A.

Specimens Nos 1 and 2 (Figures 2 and 3) were constructed in the standard frames normally used at Boreham Wood for supporting simply supported floors for testing. These frames are fabricated from rolled steel beams with an encasement of refractory concrete giving bearing steps on the short sides. For specimen No. 2 the space between the ends of the beams and the frame was filled with concrete to provide restraint against expansion, but it is likely that this may have also provided some restraint against angular movement.

For specimen No. 3 a different type of steel beam frame was used as shown in Figure 4, encastré conditions being provided at the two short ends (Plate 7). L-shaped continuity reinforcement of $\frac{3}{8}$ in (9 mm) bars at 10 in (254 mm) centres together with two $\frac{1}{4}$ in (6mm) dia. distribution bars were used in the encastré ends, the long edges of the floor remaining free.

The floors were loaded to produce a maximum bending moment of 7730 ft-lb (1070 Kgm), the dead weight of the construction being taken as 55.7 lb/ft^2 (270 Kg/m^2), the following loads were applied to produce the desired stress conditions.

Specimen No. 1.	68.5 lb/ft^2 (325 Kg/m^2)
Specimen No. 2.	63.5 lb/ft^2 (310 Kg/m^2)
Specimen No. 3.	70.0 lb/ft^2 (342 Kg/m^2)

The loads were applied by means of cast iron weights with short legs which permitted circulation of air on the top surface of the floor. The fire tests were made 6 weeks after the casting of the concrete screed. A floor in position on the furnace is shown in Plate 2.

4. Test results

The fire tests were carried out in accordance with the standard procedure of B.S. 476[2] and readings taken of the furnace temperatures, temperature of the unexposed face and the central deflection of the floors during the tests. Details of the observations made during the tests are given in Appendix B, and the results are summarized in Table 1, below.

TABLE I

SUMMARY OF TEST RESULTS

	Specimen No. 1	Specimen No. 2	Specimen No. 3
End conditions	Simply supported	Longitudinal restraint	Longitudinal and angular restraint
Duration of fire test	67 min.	95 min.	79 min.
Mean temp.rise on unexposed face	52°C at 60 min.	62°C at 90 min.	48°C at 75 min.
Time for central deflection to reach 4.8 in. (12.2 cm)	51 min.	74 min.	not reached

Specimen No. 1 developed some longitudinal cracks in the screed and when the test was terminated had attained a deflection of $5\frac{3}{4}$ in (14.6 cm) which was increasing rapidly. The floor did not collapse and showed some recovery in deflection on cooling. The central deflection of specimen No. 2 with end restraint against longitudinal expansion developed at a less rapid rate and reached a value of 6 in (15.2 cm) at 90 min by which time some transverse cracking on the soffit had occurred. The deflection increased very rapidly after this time to approximately 12 in (30.8 cm) and as this was beyond the capacity of the deflection gauge, no precise reading was possible when the test was terminated. No spalling of concrete was observed in either of the specimens' appearance of which after test is shown in Plates 5 and 6.

Specimen No. 3 with longitudinal and angular restraint suffered some spalling within 15 minutes of the start of the test and after another 5 minutes considerable downward deflection of the soffit was noticed whereas on top of the floor deflection of the order of 1 in was recorded. It appeared that the webs of the units had fractured and the two parts of the floor acted independently, the lower part acting as a protection to the loadbearing upper part. The test was stopped at 79 minutes as no useful information could be gained by continuing. The undersides of the floor after the fire test is shown in Plate 9 and a close-up view in Plate 10 of the top with some of the concrete removed which clearly shows the fractured webs of the hollow beams.

5. Discussion of results

As a result of the fracture of the webs of the hollow beams the third test did not give any information to show the effect of this type of restraint on the fire resistance of the floor. The failure of the webs was due to their inability to withstand the tensile and shear stresses developed by differential thermal expansion. The test showed that the conditions of end restraint are critical for this type of construction.

A direct comparison is possible, however, between the first two tests. Comparing the two deflection curves (Figure 5) for the first 25 minutes the central deflection was similar for both floors but the rate of increase of deflection was subsequently higher for the simply supported construction. It has been suggested that for floors a limiting deflection should be used as criterion of failure and an empirical value of 1/30 of the span has been proposed for this purpose. Applying this criterion the fire resistance of the simply supported floor was 57 minutes and of the floor with longitudinal restraint there was an increase in the fire resistance by about 50 per cent to 74 minutes.

Similar tests have been performed in Holland[3] on two constructions with slightly longer spans, of 14 ft (426 cm), and smaller widths of 6 ft 3 in (190 cm). One specimen was tested simply supported and the other subjected to end restraint conditions mainly angular in nature. Comparing the deflection curves for these tests as shown in Fig. 5, it will be observed that in the initial stages of the fire test the amount of deflection on the restrained specimen was less until fire damage to the end beams resulted in a substantial reduction in restraint. The shape of the curve indicates that after about 50 minutes there was little effective restraint and for the rest of the test period the specimen behaved as simply supported. The increased deflection of the restrained specimen in this part of the test was probably due to its higher loading.

The test results from the French laboratories are not available at the time of writing this note.

6. Conclusions

The results of the fire tests on concrete floors of precast units under different conditions of end restraint as described in this note show that the most prominent effect of end restraint was a reduction in downward deflection. If a limiting deflection is used as a criterion for failure the imposing of restraint tends to increase the fire resistance of the construction, and a similar increase is to be expected if collapse is taken as the criterion of failure provided that the construction possesses the necessary thermal insulation. Evidence from tests on a variety of floors under different end conditions suggests that damage by spalling of the concrete may be greater as restraint is increased, and the consequent damage may, if severe, lead to an earlier failure than would have been expected from considerations of deflection or heat transmission when spalling is absent.

The investigation described in this note represents the first attempt at correlating floor furnaces and methods of test in different countries, with particular reference to end conditions. Consideration is being given to an extension of the research to more countries and to devising types of specimen which are reproducible and suitable to yield useful information under any conditions of restraint.

7. Acknowledgments

[illegible] permission of the Director of Fire Research. The author wishes to express his thanks to his colleagues for their assistance with the tests.

8. References

1. Effect of restraint in fire resistance tests. CIB/CTF, 35/UK/3, May, 1958.

2. British Standard 476 : Part 1 : 1953. Fire Tests on Building Materials and Structures.

3. The determination of the fire-resistance of a floor consisting of prefabricated hollow beams of reinforced concrete. CIB/CTF. 59/20(N).

APPENDIX A

1. Specification for the precast concrete beams

   Concrete mix: 1 : 2 : 3 (Portland cement: Rhine river sand: gravel).
   Maximum aggregate size - 16 mm ($\frac{5}{8}$ in).
   Water/cement ratio - 0.25
   Minimum 28-day strength - 300 Kg/m^2 (4250 lb/in^2).

2. <u>In situ</u> concrete topping

   Concrete mix: 1 : 2 : 3 (Portland cement: washed river sand: gravel)
   Maximum aggregate size - $\frac{3}{4}$ in (19mm).
   Average 28-day strength - 6390 lb/in^2 (449 Kg/m^2).
   Average strength at time
   of test (6 weeks) - 6500 lb/in^2 (457 Kg/m^2).

APPENDIX B

Log of tests.

Specimen No. 1 - Simply supported floor Load 68.5 lb/ft^2 (325 Kg/m^2)

Time - min	Observations
00	Test started
07	Appearance of a longitudinal crack in the screed about 2 ft off centre.
12	Emission of vapour and moisture from the crack.
32	Another longitudinal crack approximately 3 ft from the first crack; the original crack now $\frac{1}{4}$ in wide.
52	Appearance for third longitudinal crack, maximum width of crack approximately $\frac{3}{8}$ in.
60	Slight widening of cracks; no other damage.
67	Deflection rapidly increasing and attained a value of approximately 6 in. Test stopped.

Specimen No. 2 - Restraint against longitudinal expansion
Load 63.5 lb/ft^2 (310 Kg/m^2)

Time - min	Observations
00	Test started
08	Appearance of a longitudinal crack in the screed at the centre of the specimen.
20	Emission of moisture and vapour from the top mainly from the longitudinal crack.
30	More longitudinal cracks in the screed.
35	The central crack now nearly $\frac{3}{8}$ in wide.
60	Opening of cracks, emission of vapour from the top continued.
95	Rapid increase of deflection in the last few minutes past the capacity of the deflection gauge - approximate central deflection 11-12 in. Test stopped.

Specimen No. 3 - Restraint against longitudinal and angular movement.
Load 70 lb/ft2 (342Kg/m^2)

Time - min	Observations
00	Test started.
14	Spalling of concrete from the soffit at two places exposing the wire mesh.
16	Transverse crack in the screed near one end.
20	Considerable deflection of the soffit observed.
30	No increase in the deflection of the top but the soffit continued to deflect downwards.
40	Another transverse crack in the screed.
50	The soffit has deflected nearly 6 in by now.
69	Deflection of the underside increased to about 12 in. The separated top part continued to support the test load without any significant deterioration. Test stopped.

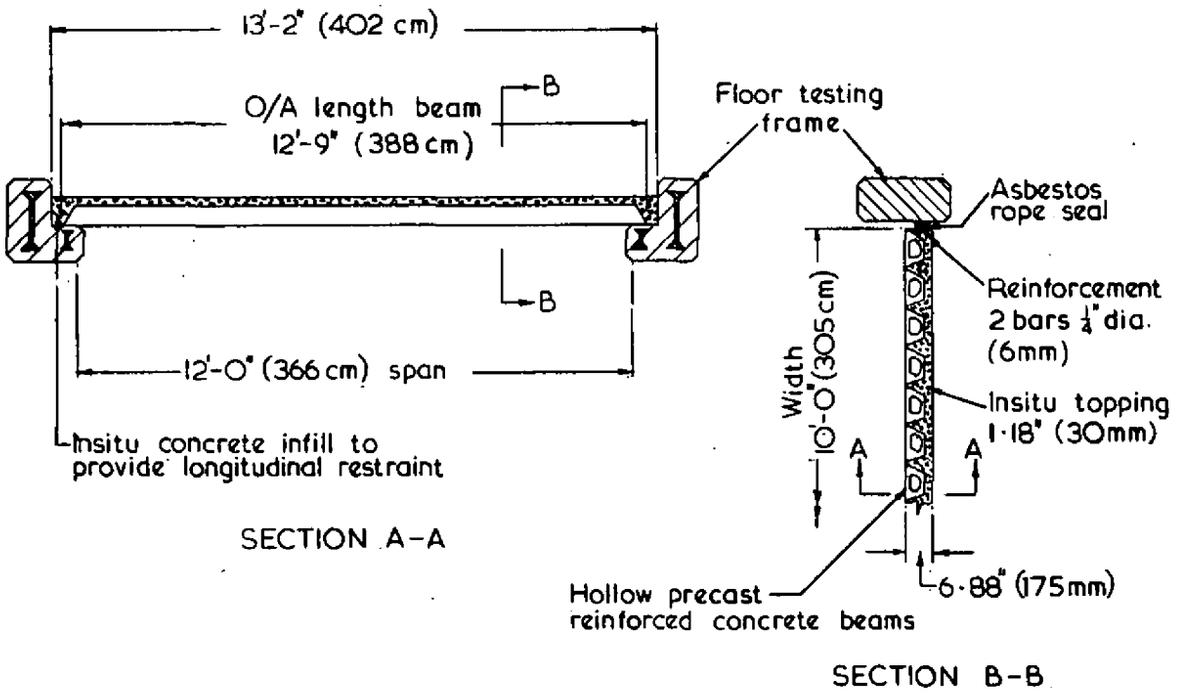


FIG. 3. SPECIMEN No. 2. CONCRETE FLOOR WITH LONGITUDINAL RESTRAINT

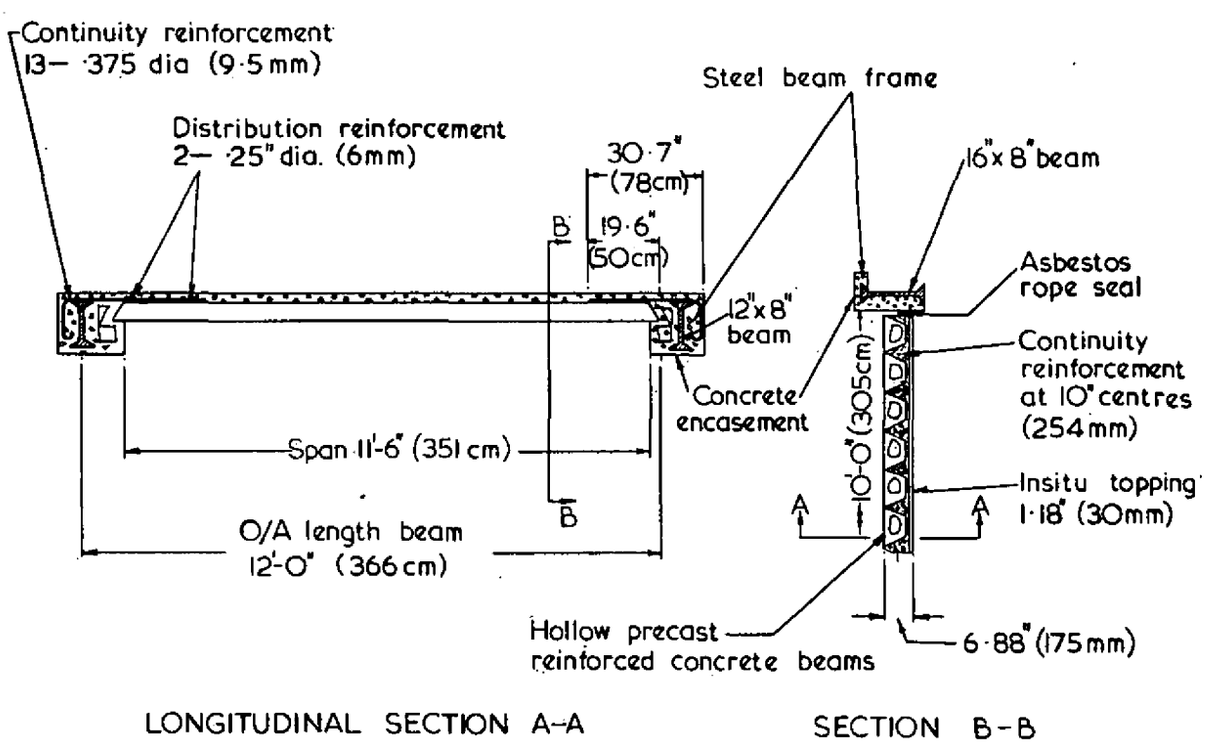


FIG. 4. SPECIMEN No. 3. CONCRETE FLOOR WITH LONGITUDINAL AND ANGULAR RESTRAINT

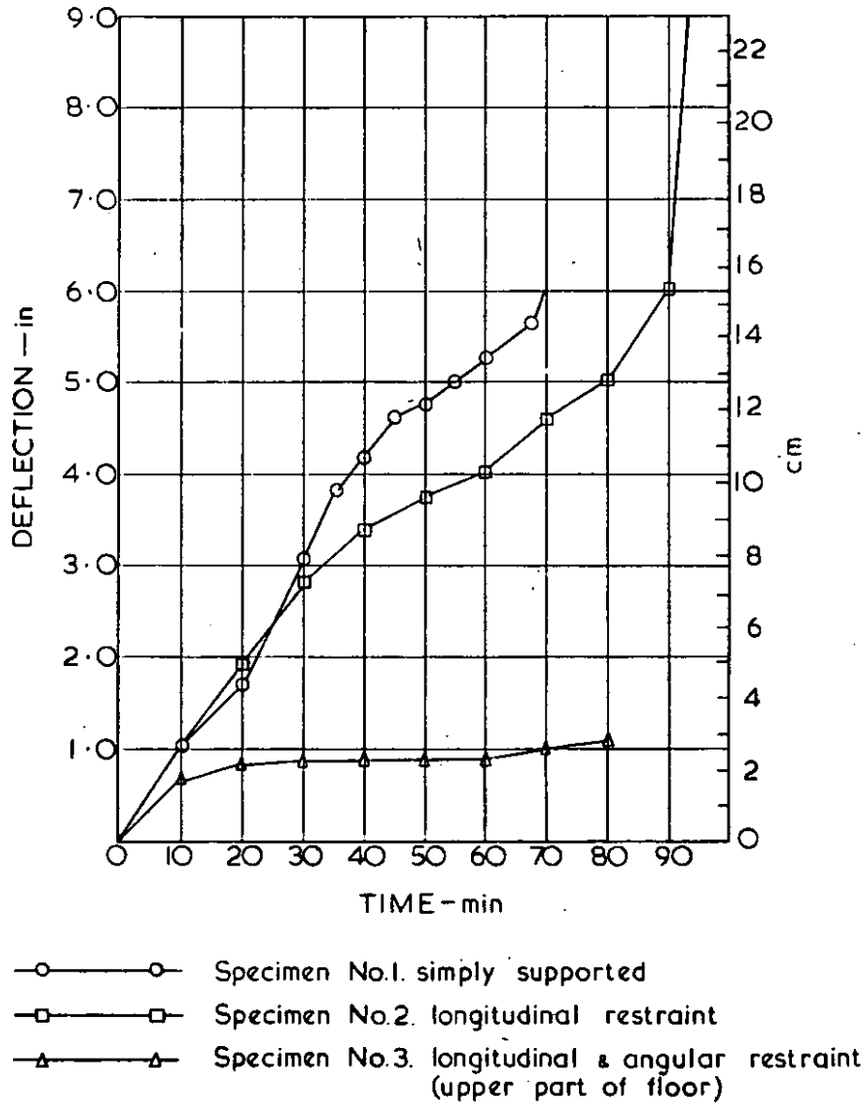


FIG.5. DEFLECTION CURVES

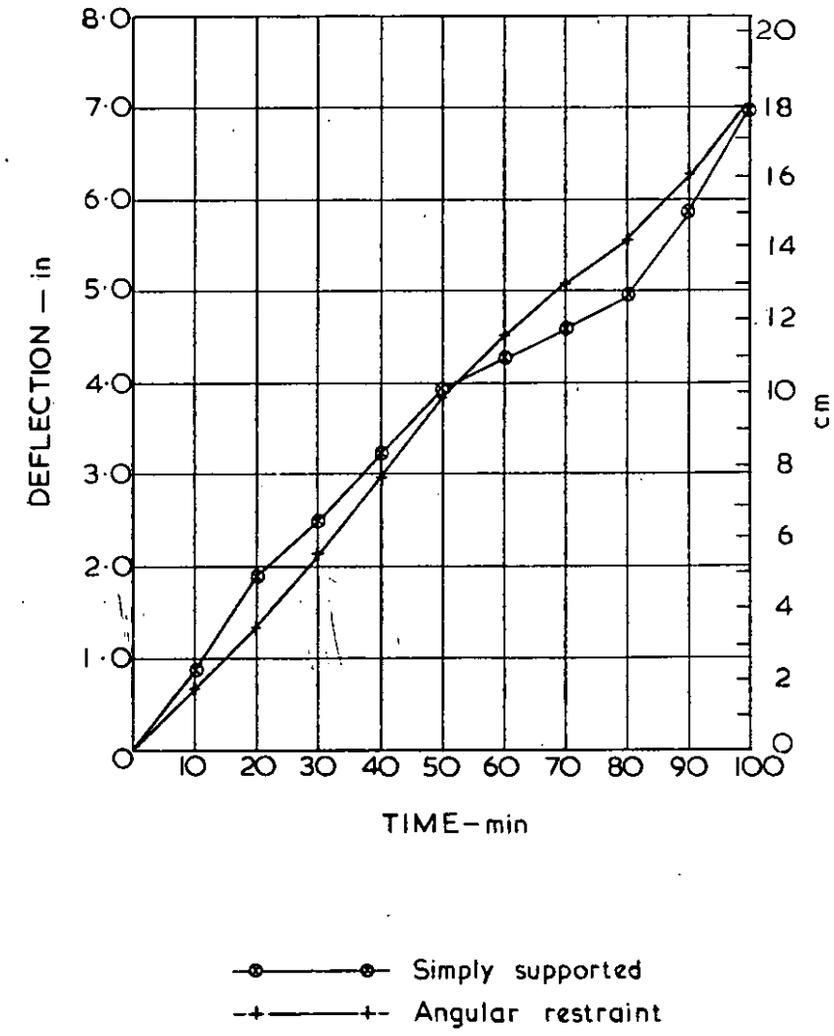
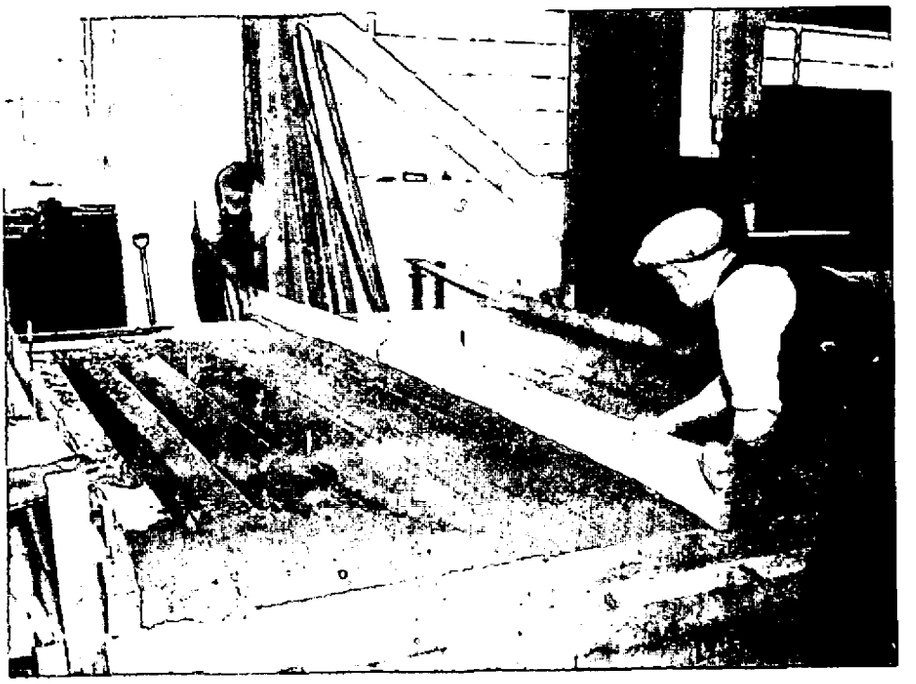
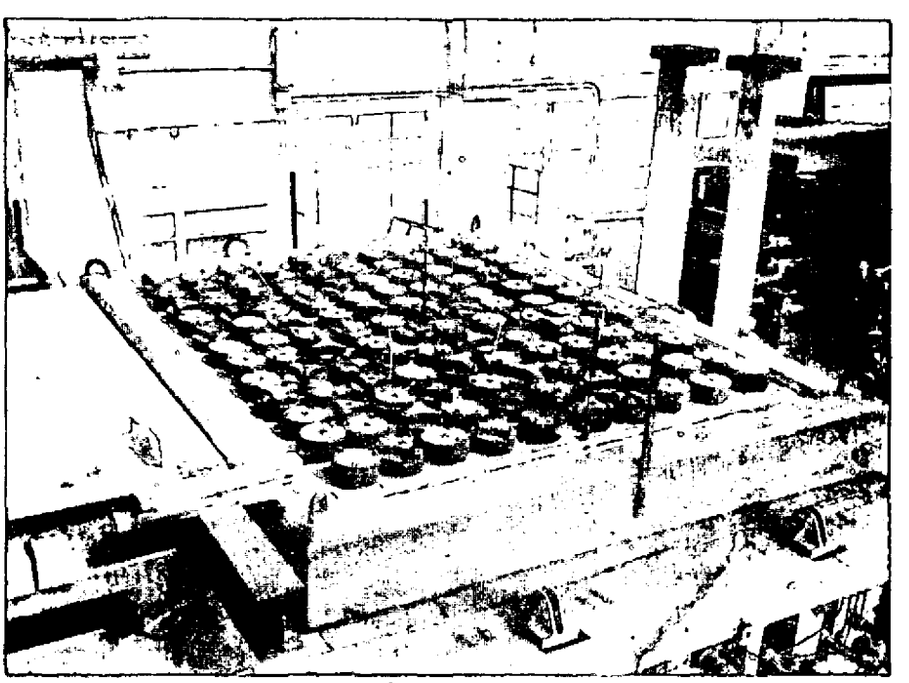


FIG.6. DEFLECTION CURVES FOR DUTCH TESTS



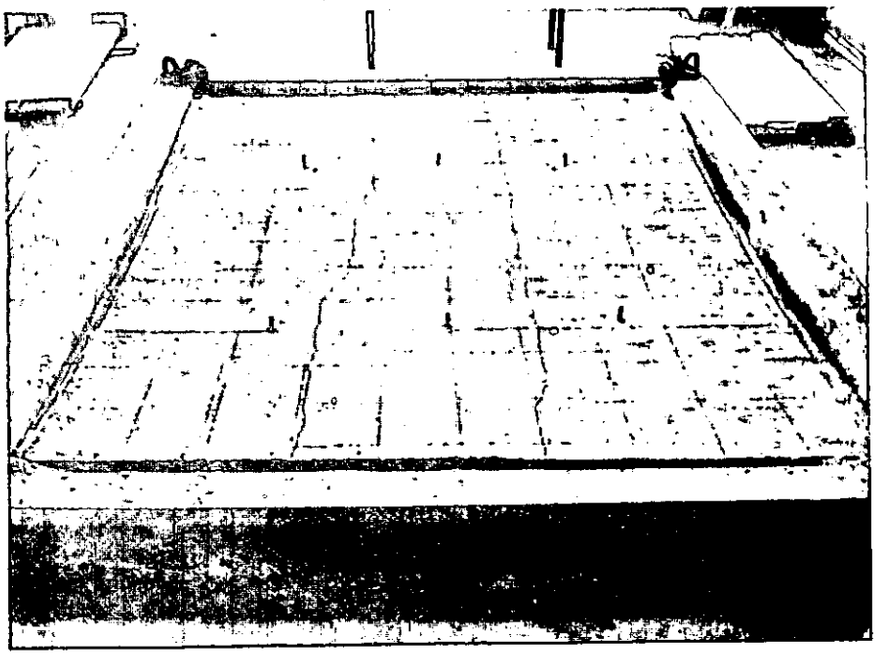
CASTING OF CONCRETE SCREED ON A
FLOOR SPECIMEN

PLATE 1.



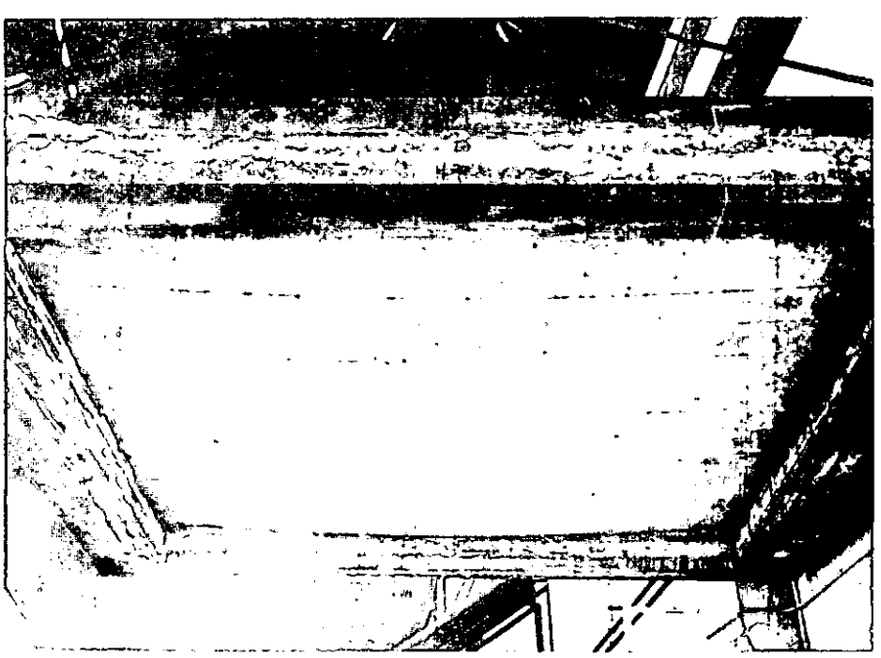
TOP VIEW OF SPECIMEN NO.1 BEFORE TEST

PLATE 2.



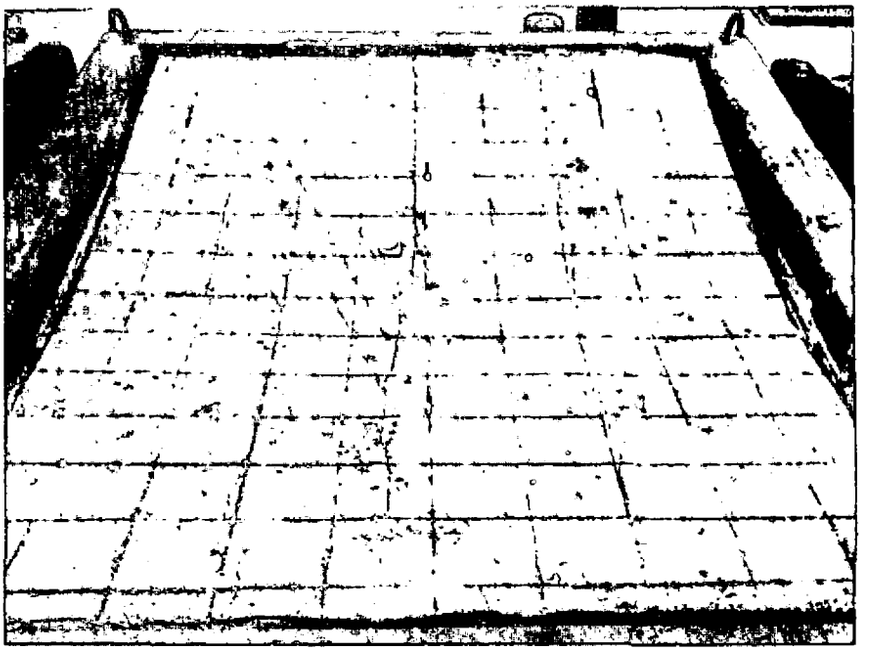
TOP SURFACE OF SPECIMEN NO.1 AFTER TEST
(WEIGHTS REMOVED TO SHOW CRACKS)

PLATE 3.



UNDERSIDE OF SPECIMEN NO.1 AFTER TEST

PLATE 4.

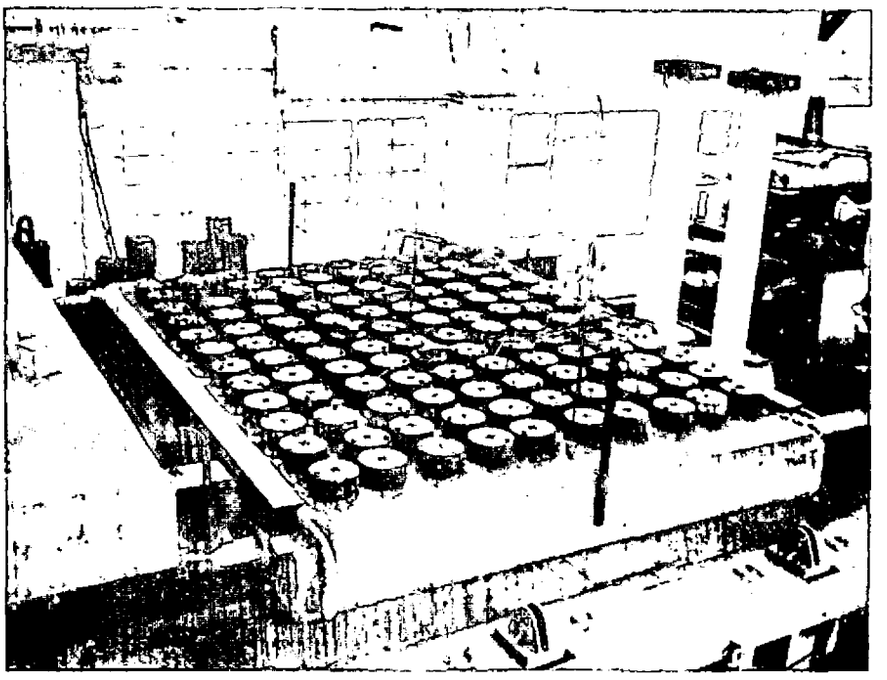


TOP VIEW OF SPECIMEN NO.2 AFTER TEST
(WEIGHTS REMOVED TO SHOW CRACKS)

PLATE 5.

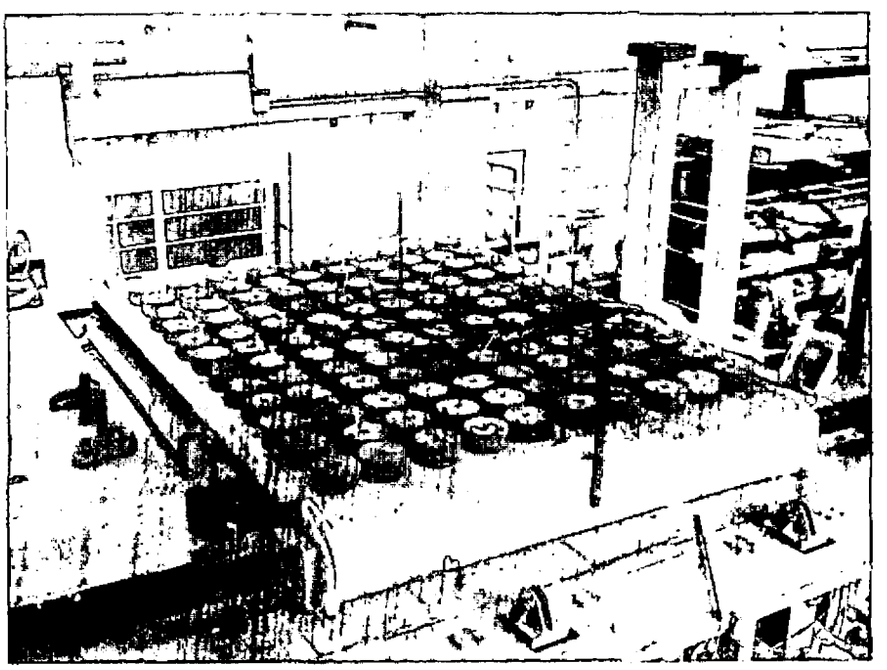
UNDERSIDE OF SPECIMEN NO.2 AFTER TEST

PLATE 6.



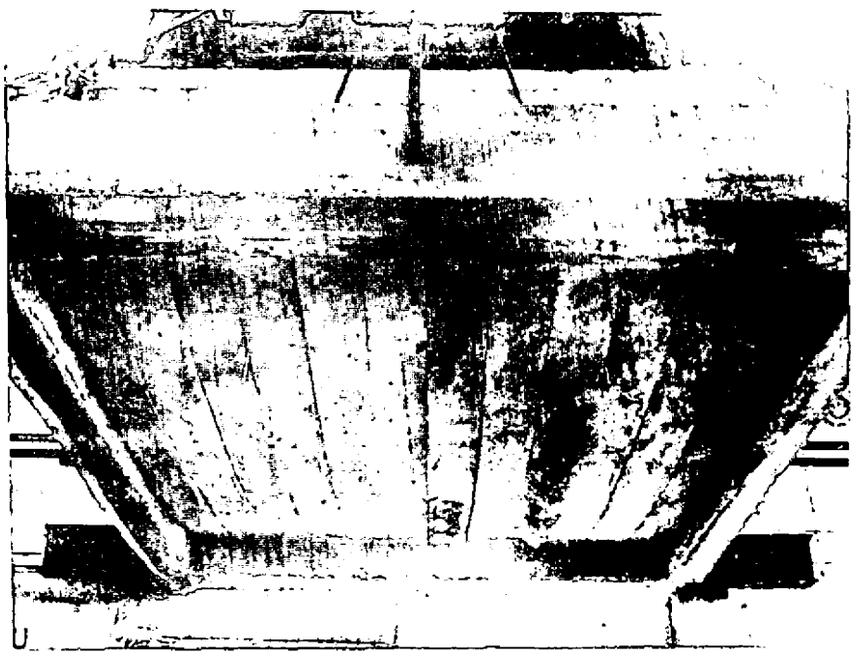
TOP VIEW OF SPECIMEN NO.3 BEFORE TEST.
ONE ENCASTRE END IN FOREGROUND

PLATE 7.



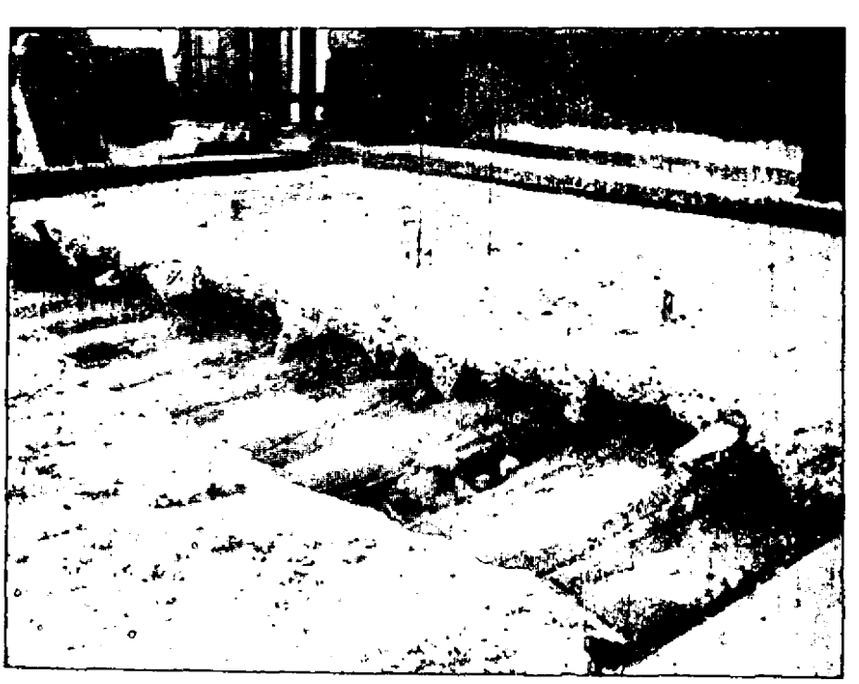
TOP VIEW OF SPECIMEN NO.3 AFTER TEST

PLATE 8.



UNDERSIDE OF SPECIMEN NO.3 AFTER TEST SHOWING
DEFLECTION OF LOWER PART AND
AREAS OF SPALLING

PLATE 9.



CLOSE UP OF TOP WITH SOME CONCRETE REMOVED
TO SHOW FRACTURED WEBS

PLATE 10.