Swinden Laboratories

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Shelf-Angle Floor Systems Based on 406 x 178 mm x 54 kg/m and 305 x 165 mm x 40 kg/m Universal Beams

British Steel Technical

Research Organisation

SHELF-ANGLE FLOOR SYSTEMS BASED ON 406 x 178 mm x 54 kg/m AND 305 x 165 mm x 40 kg/m UNIVERSAL BEAMS

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SYNOPSIS

Design tables have been developed from which it is possible to read off the fire resistance times of shelf-angle floor systems as a function of the imposed load and the depth of beam exposed to the flames. The tables cover the range of likely configurations based on the 305 x 165 mm x 40 kg/m and 406 x 178 mm x 54 kg/m universal beams and are calculated from a mathematical model which has been validated by two standard fire resistance tests. The designer can use the tables to adjust either the design load or the floor slab thickness to achieve the fire resistance required by the Building Regulations.

KEY WORDS

26
Fire Resistance
Shelf Angles
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Mathematical Models
Design Tables
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1. INTRODUCTION

An earlier report[1] gave details of a mathematical model which has been developed at Swinden Laboratories to calculate the fire resistance times of shelf-angle floor systems. The present report gives the results of the simulation of standard fire resistance tests on shelf-angle floor systems based on 406 x 178 mm x 54 kg/m and 305 x 165 mm x 40 kg/m universal beams. The information obtained from these calculations illustrates the effect, on fire resistance time, of variations in concrete floor slab thickness and live load. Combining the results has enabled design tables to be produced for shelf-angle floor systems based on the two beam sizes. Interpolation of data between these tables and the previously reported 254 x 146 mm x 43 kg/m results should cover the majority of medium sections used in floor systems for multistorey buildings.

2. MATHEMATICAL MODELLING

As part of the fire engineering work carried out at Swinden Laboratories a computer package has been developed to calculate the fire resistance times of shelf-angle floor systems and thus reduce the need for expensive experimental tests. The package is based on two commercially available finite element programmes, FIRES-T2 and FASBUS II, together with a number of in-house pre and post processor programmes to facilitate data preparation and the extraction of user selected information from the computed results.

2.1 FIRES-T2[2]

FIRES-T2 is a computer programme which evaluates the temperature distribution history of two dimensional structures in fire environments. Transient thermal situations are modelled by the heat conduction boundary situation. These equations are non-linear because of the temperature dependence of the thermal properties of structural materials and the heat transfer mechanisms associated with fire environments. The solution technique used in FIRES-T2 is a finite element method coupled with time step integration. The non-linearity of the problem requires an iterative solution process within each time step. The structure is modelled by 4-noded isoparametric quadrilaterals and 3-noded triangles. Fire environments are represented by a non-linear model that includes both convective and radiative mechanisms.

2.2 FASBUS II[3]

FASBUS II is a non-linear structural analysis programme especially written for the analysis of floor systems (of which a shelf-angle floor is a simple example) subjected to both mechanical and thermal loading. It is a programme which accepts a temperature history of the configuration as input and calculates the resulting deflection and stress history. The floor system is modelled using beam finite elements. Element stiffnesses are calculated using temperature dependent non-linear stress-strain curves. The resulting structural stiffness is used in an iterative process to find the deflected shape of the structure which satisfies the non-linear equations of equilibrium for the floor system.

The computer programmes described above were used to simulate the two fire tests. A number of assumptions were made in the calculations.

In FIRES-T2 it was assumed that:-

(a) the screed which covered the universal beam and filled the gaps between the concrete floor slabs and the steelwork had the same thermal properties as the floor slabs.

(b) the thermal properties of BS4360: Grade 43A steel and concrete were as listed in Tables 1 and 2 respectively.

(c) the furnace gas temperature followed the ISO time-temperature curve

$$T = 20 + 345 \log_{10}(8t + 1)$$

where T = furnace temperature, °C
t = time, min

The temperature of the air above the floor structure was taken to remain at a constant temperature of 20°C throughout the test.

(d) the profiles of the universal beams and the 125 x 75 x 12 mm angles used in the construction of the floor systems were at their nominal dimensions.

A schematic diagram of the model used in the two analyses is shown in Fig. 1. The symmetry of the assembly means that only one half of it needs to be modelled resulting in considerable savings in computational times.

The structural analysis programme, FASBUS II, also requires certain assumptions. These included:

(a) The following material properties of BS4360: Grade 43A steel are as listed in Table 3:- Young's Modulus, Yield stress and the coefficient of thermal expansion. Figure 2 shows the stress-strain characteristics used in the model and their variation with temperature

(b) The model assumes that the steelwork consists entirely of one grade of steel.

(c) It is assumed in the model that the shelf-angle is uniformly loaded along its central axis rather than in the manner used in the actual fire test. This greatly simplifies the problem and reduces computing time dramatically. The load chosen in each case was that which would produce a maximum stress value of 165 N/mm^2 in the lower flange of a conventional universal beam with a span of 4.5 m. The presence of the angles bolted to the web would, of course, cause the actual value in the assembly to deviate from this value.

(d) The model assumes a uniform temperature distribution along the length of the steelwork.

3. RESULTS AND DISCUSSION

The first stage of the project involved the validation of the model against the limited amount of experimental data which is available. Two comparisons were possible, i.e. one for each of the two universal beam sizes under analysis. In each case the fire tests involved fully loaded shelf-angle floor systems with 200 mm deep concrete floor slabs.

Figure 3 shows the vertical deflections at the centre of the floor system utilising the 305 x 165 mm x 40 kg/m universal beam. A careful examination of the experimental data[4] reveals that the floor was slightly over loaded and that a value of 107% of the target operating load was applied in the fire test. The diagram illustrates the fact that the predicted fire resistance times for loads of 100% and 115% straddle the test result of 83 min. The calculated values for the two load cases were 86.1 and 76.6 min respectively.

The results of the second comparison are shown in Fig. 4. In this case the computed results show a somewhat conservative estimate of 61.2 min for the fire resistance time compared to the measured value of 67.5 min. It should be noted, however, that the dimensions of the beam used in the actual test were some 8% oversize compared to the nominal figures used in the analysis and this would be anticipated to be reflected in an increased fire resistance time.

TABLE 1
THERMAL PROPERTIES OF GRADE 43A STEEL

Temperature °C	Thermal Conductivity W/m K	Specific Heat J/kg C	Density kg/m³
20	52.0	440	7850
50	51.7	450	7840
100	51.0	480	7830
150	50.0	505	7810
200	48.8	530	7800
250	47.5	550	7780
300	46.0	565	7770
350	44.5	585	7750
400	42.7	610	7730
450	41.0	640	7710
500	39.2	675	7700
550	37.5	715	7680
600	35.5	760	7660
650	33.8	820	7640
700	32.0	1010	7620
725	31.0	1600	7610
750	28.5	1300	7620
775	26.5	1010	7620
800	26.0	810	7630
825	25.8	730	7630
850	26.0	685	7620
875	26.2	660	7610
900	26.5	650	7600
950	27.0	650	7570
1000	27.5	650	7550

TABLE 2
THERMAL PROPERTIES OF CONCRETE

Temperature °C	Thermal Conductivity W/m K	Specific Heat J/kg C
20	1.95	916
100	1.77	976
200	1.57	1040
300	1.39	1100
400	1.31	1160
500	1.10	1200
600	0.99	1240
700	0.91	1260
800	0.85	1280
900	0.81	1300
1000	0.80	1300

Density - 2200 kg/m^3

TABLE 3
MATERIAL PROPERTIES OF GRADE 43A STEEL

Temperature °C	Young's Modulus N/mm^2	Yield Stress N/mm^2	Coefficient of Thermal Expansion °C^{-1}
20	210000	292	0.0000112
100	208000	268	0.0000117
200	202000	257	0.0000124
300	195000	230	0.0000131
400	186500	205	0.0000139
500	176000	178	0.0000142
600	165000	110	0.0000148
700	152500	53	0.0000151
800	127000	31	0.0000122
900	117500	25	0.0000135

TABLE 4
VARIATION OF FIRE RESISTANCE TIME WITH DEPTH OF FLOOR

(a) 305 x 165 mm x 40 kg/m systems

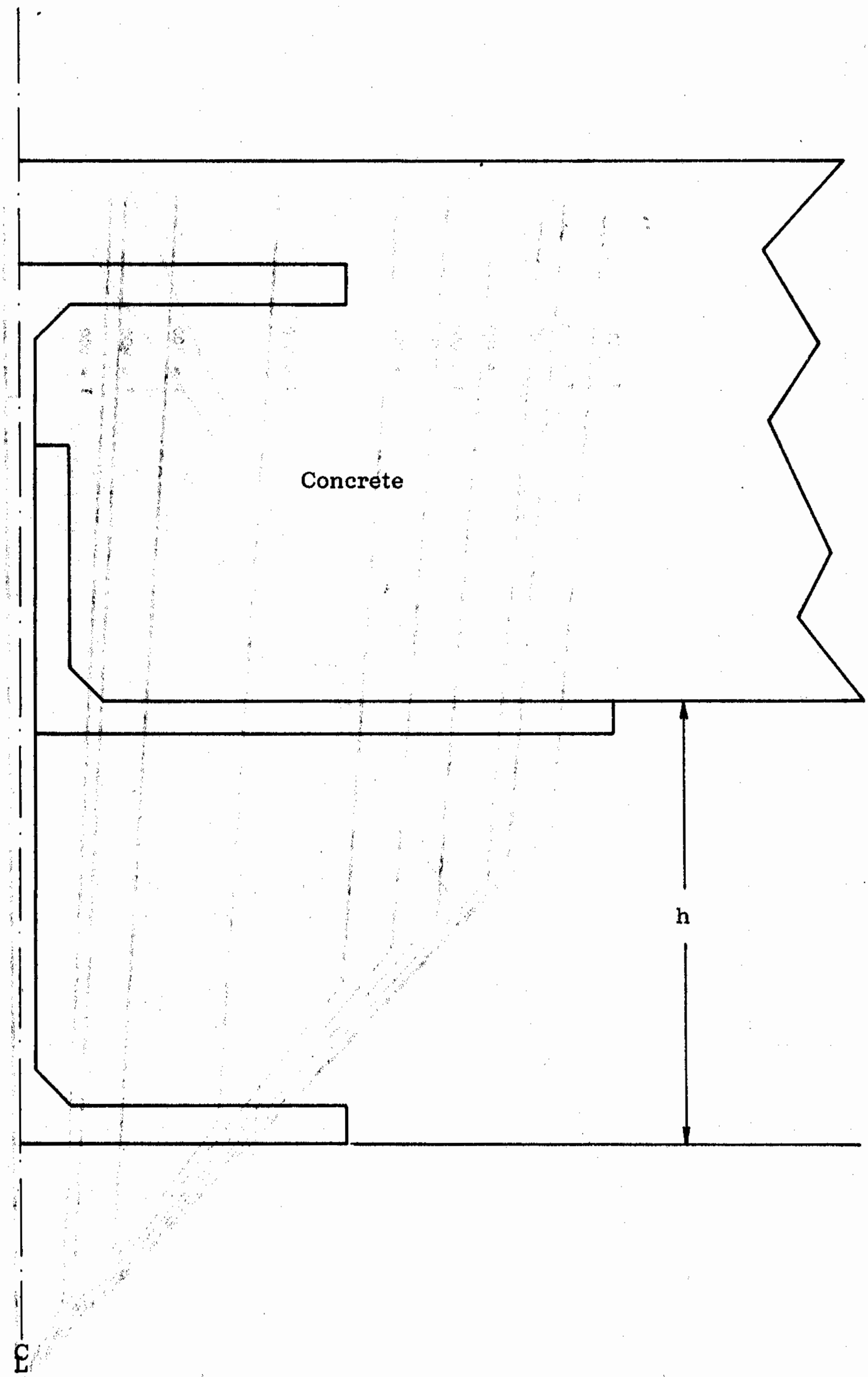
Floor Depth mm	h mm	Total Applied Load (100% = 165 kN)				
		115.5 kN (70%)	140.25 kN (85%)	165 kN (100%)	189.75 kN (115%)	214.5 kN (130%)
200	83.6	106.8[1] 153.9[(2)]	95.0 129.9	86.1 113.5	76.6 99.8	68.3 88.5
175	108.6	83.2 129.3	74.2 106.9	65.6 91.3	57.1 77.9	49.9 65.3
150	133.6	64.1 102.4	58.3 85.6	50.7 71.8	43.2 60.4	38.0 52.7
125	158.6	47.8 75.2	43.7 64.1	39.4 53.5	34.3 45.6	30.0 40.1
100	183.6	33.1 57.0	30.6 47.3	27.5 39.4	24.0 33.8	21.3 29.3

(b) 406 x 178 mm x 54 kg/m systems

Floor Depth mm	h mm	Total Applied Load (100% = 271 kN)				
		189.7 kN (70%)	130.35 kN (85%)	271 kN (100%)	311.65 kN (115%)	352.3 kN (130%)
200	181.7	85.1[(1)] 125.7[(2)]	72.3 101.2	61.2 83.6	52.4 65.7	46.3 57.0
175	206.7	70.4 108.9	60.1 86.6	50.0 67.2	43.1 56.4	36.8 49.4
150	231.7	52.0 83.3	45.0 67.3	37.9 55.1	31.9 45.4	27.9 38.9
125	256.7	42.0 71.7	36.4 56.4	30.7 44.9	26.4 38.0	23.0 31.9

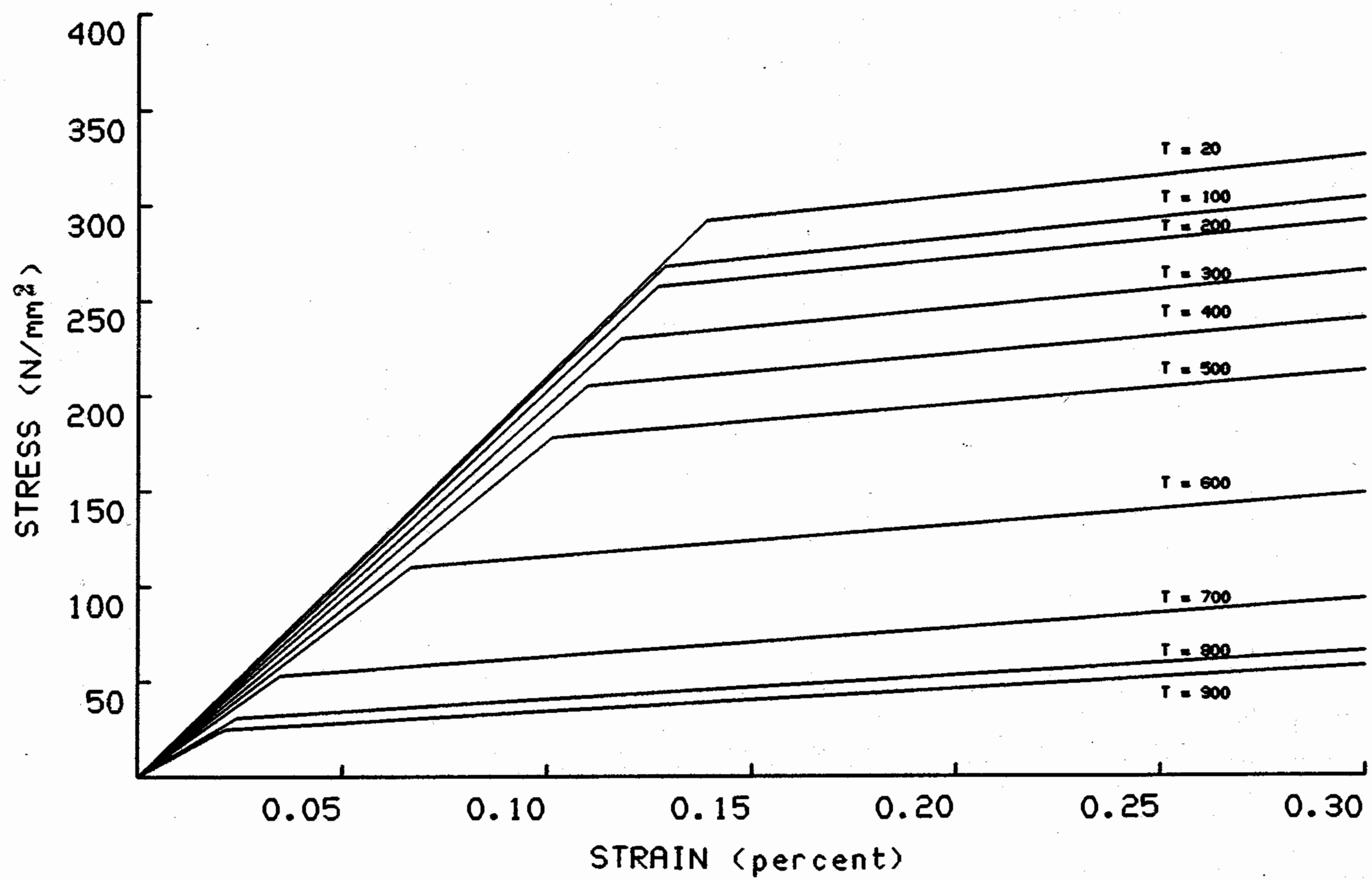
1. Time to reach span/30, min
2. Time to reach span/20, min

h = height of exposed steelwork

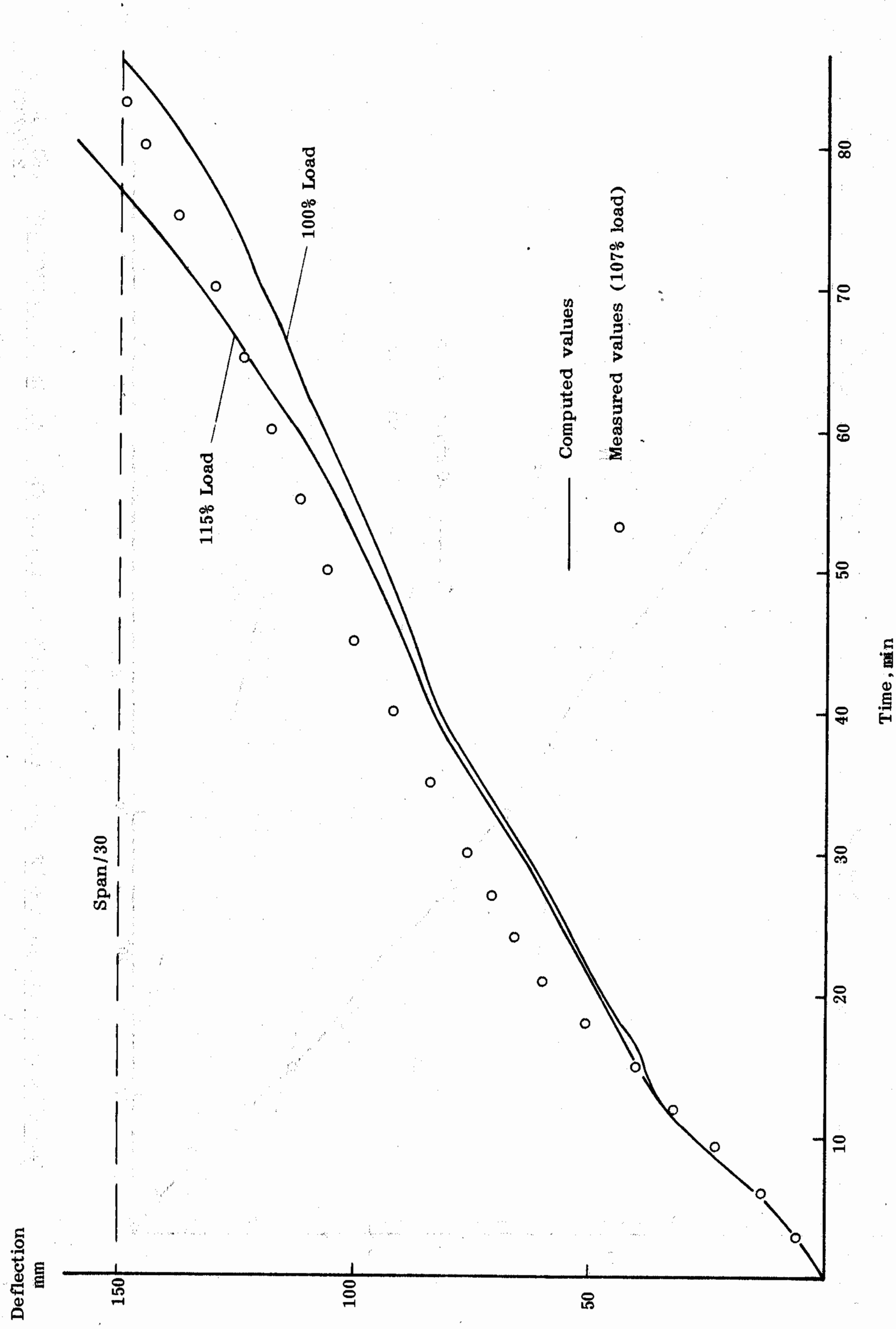


SCHEMATIC MODEL OF SHELF-ANGLE FLOOR STRUCTURE USED IN FE ANALYSIS

FIG. 1

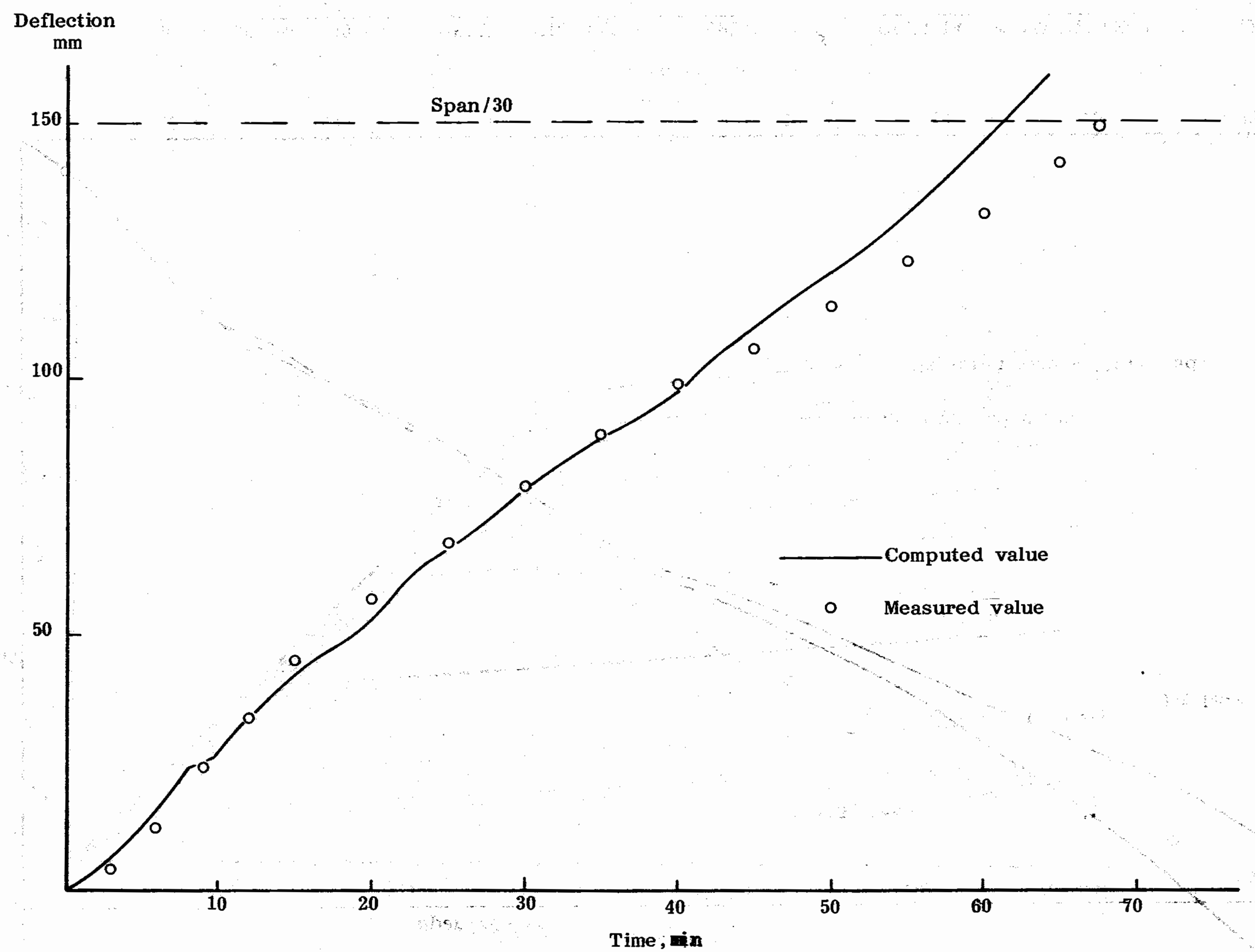


VARIATION OF STRESS-STRAIN DATA WITH TEMPERATURE FOR GRADE 43A STEEL FIG. 2

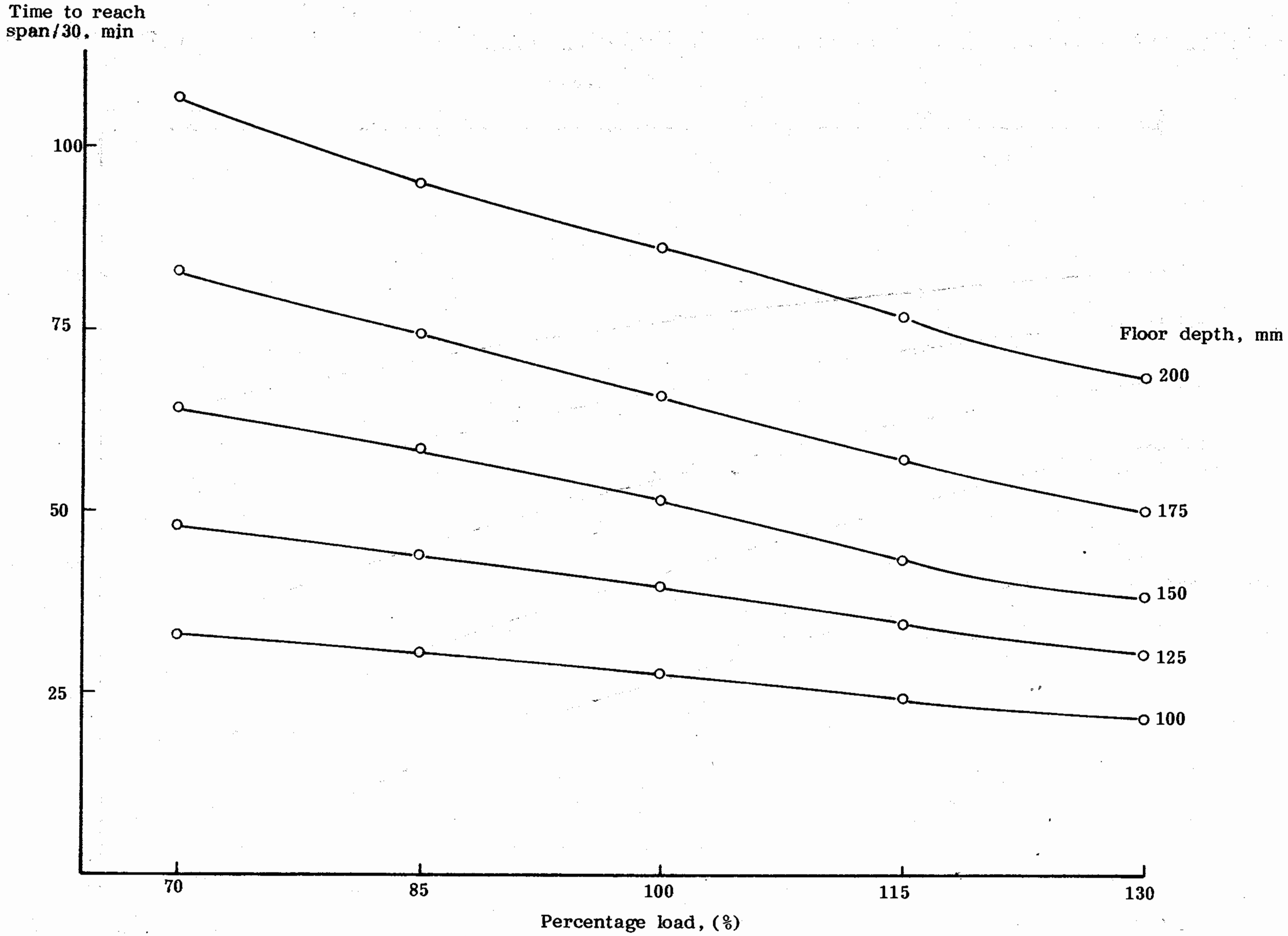


305 x 165 mm x 40 kg/m SHELF ANGLE FLOOR - DEPTH = 200 mm CENTRAL BEAM DEFLECTION

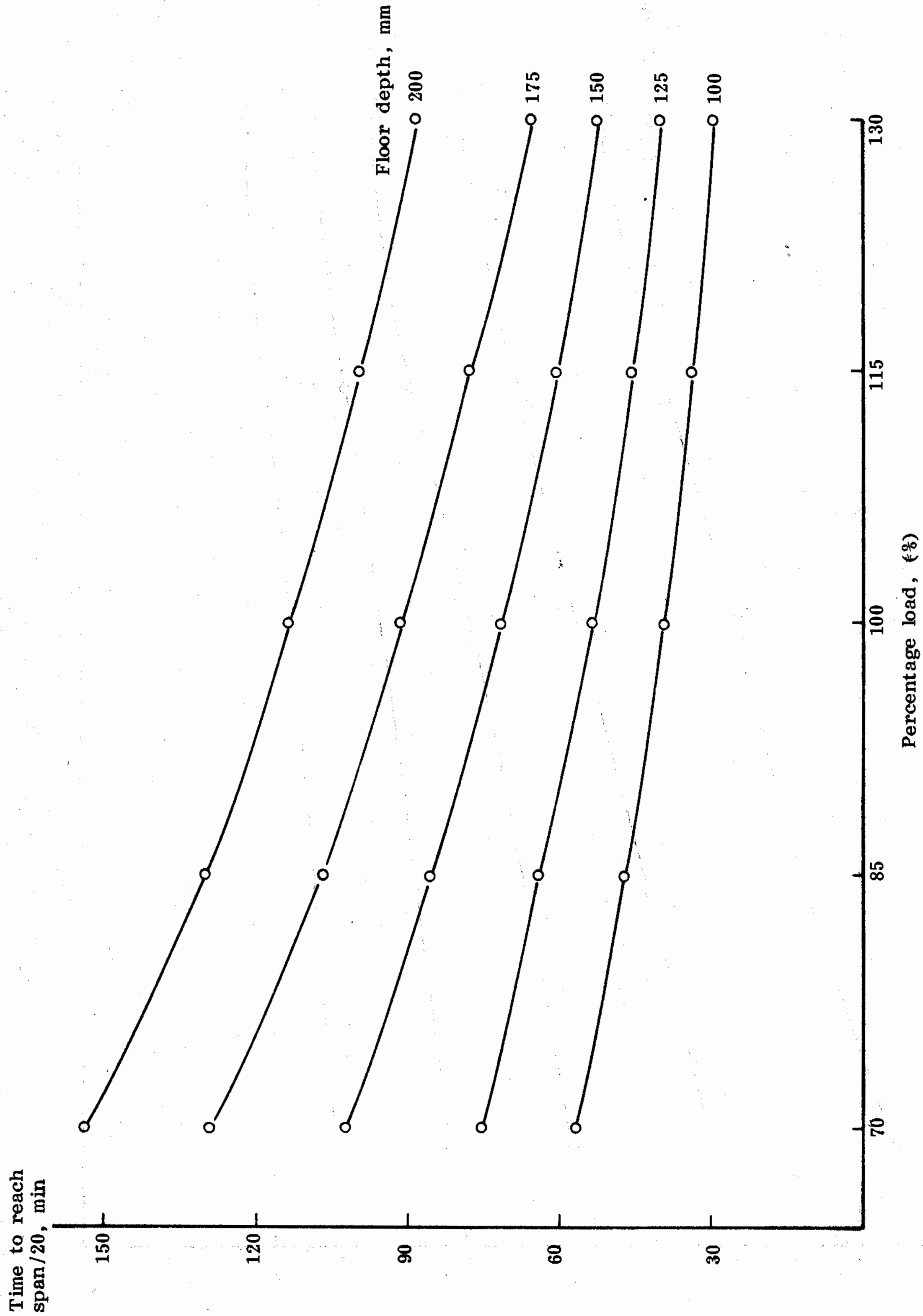
FIG. 3
(R3/2226)



406 x 178 mm x 54 kg/m SHELF ANGLE FLOOR - DEPTH = 200 mm CENTRAL BEAM DEFLECTION FIG. 4
(R3/2227)

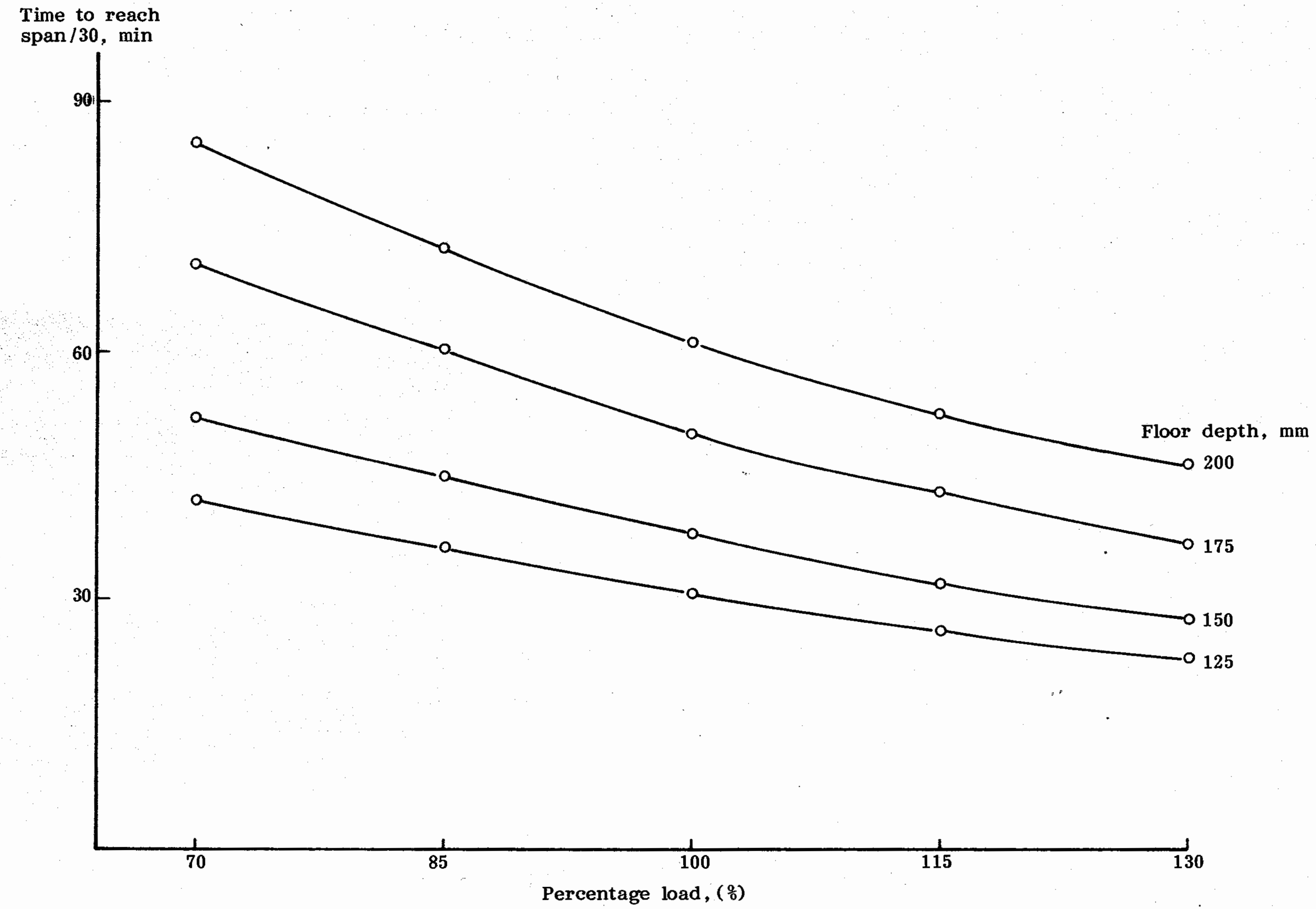


305 x 165 mm x 40 kg/m SHELF ANGLE FLOOR SYSTEMS. EFFECT OF APPLIED LOAD ON FIRE RESISTANCE TIMES FIG. 5 (R3/2228)



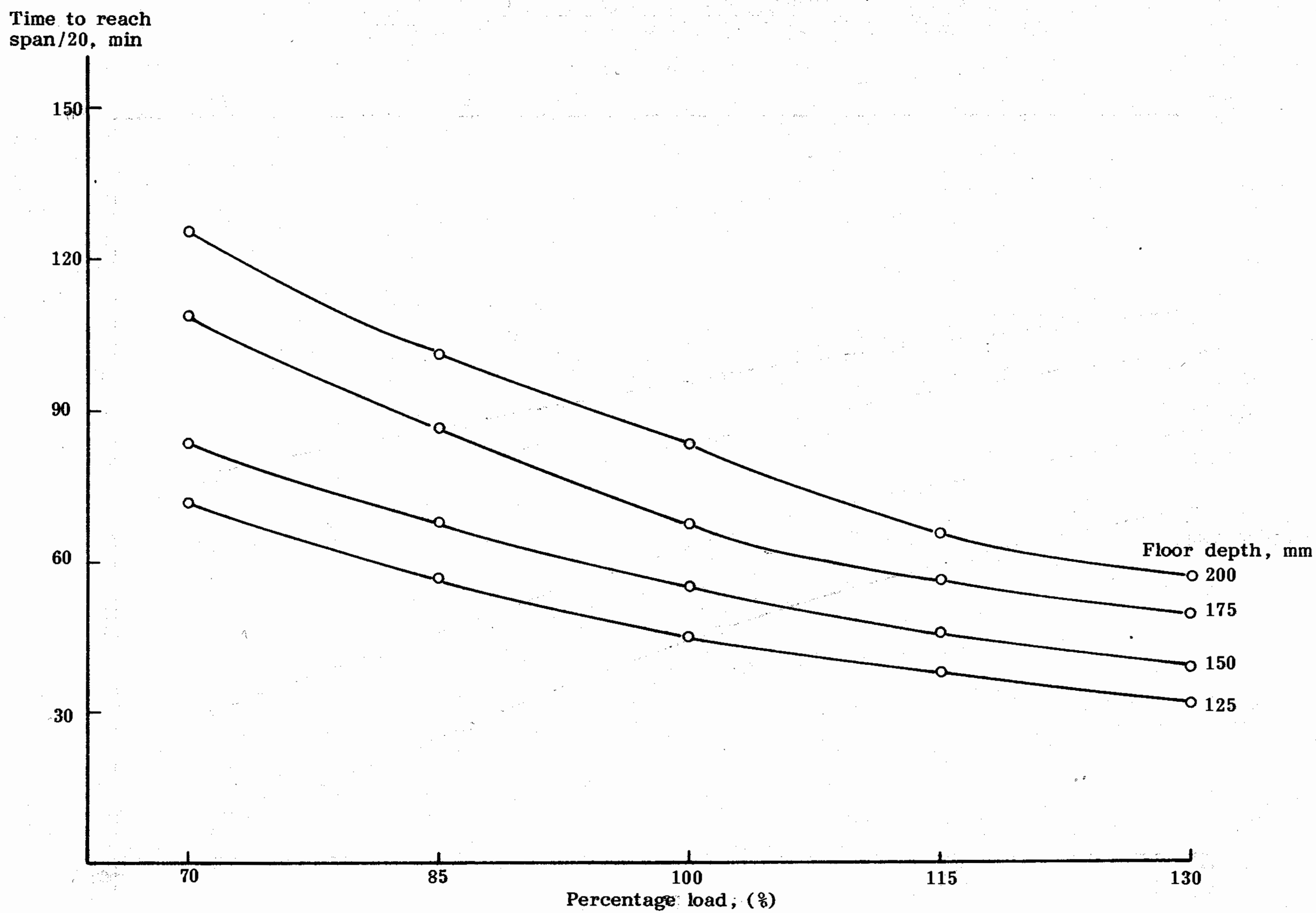
305 x 165 mm x 40 kg/m SHELF ANGLE FLOOR SYSTEMS. EFFECT OF APPLIED LOAD ON FIRE RESISTANCE TIME

FIG. 6
(R3/2229)



406 x 178 mm x 54 kg/m SHELF-ANGLE FLOOR SYSTEMS
EFFECT OF APPLIED LOAD ON FIRE RESISTANCE TIMES

FIG. 7
(R3/2230)



406 x 178 mm x 54 kg/m SHELF-ANGLE FLOOR SYSTEMS
EFFECT OF APPLIED LOAD ON FIRE RESISTANCE TIMES

FIG. 8
(R3/2231)

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