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La résistance des murs minces en béton chargés axialement sous une charge répartie

Die Festigkeit von dünnen, axial gedrückten Betonwänden unter verteilter Belastung

The strength of thin concrete walls in axial compression under distributed loading

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Introduction

The tests described in this paper are part of a research programme in progress at the Building Research Station, of the Department of Scientific and Industrial Research, to investigate, in the first instance, the strength and performance of thin concrete walls. That programme has been outlined elsewhere (1). Its purpose is to obtain experimental data on which design recommendations may be based for a more economic use of load-bearing reinforced concrete walls in multi-storey buildings.

Outline of the tests

Fourteen concrete test walls, 9 ft 0 in high and 4 in thick, were subjected to distributed axial compression in short-period tests to destruction.

An ordinary Portland cement and washed, uncrushed, natural river sand and gravel were used for the concretes, and these materials and the water were proportioned by weight to an accuracy of 0.1 %. The cement was obtained commercially and a quantity sufficient for all the tests was mixed in successive batches in a mechanical mixer in such a manner as to produce as uniform a material as possible. Representative samples were tested in the manner prescribed in B. S. S. No. 12 (2) and the cement was found to comply with the requirements of that British Standard. The aggre-

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(1) F. G. Thomas, *Structural Engineering Research at the Building Research Station (The Structural Engineer*, Vol. 26, No. 2, pp. 81-103. Institution of Structural Engineers, London, February, 1948).

(2) *B. S. S.*, No. 12. *Ordinary Portland and Rapid-Hardening Portland Cements*, British Standards Institution, London, 1947.

Reference No.		Length (ft in)	Mean storage conditions: Mean temperature (° F)	Mean storage conditions: Mean relative humidity (%)	Age at test (days)	Load at fracture (tons)	Mean crushing strength (lb/in²)
1A	1	6′ 0″	70	54	22	395	3 070
	2		69	51	15	351	2 730
	3		70	53	14	308	2 390
1B	1	6′ 0″	65	51	15	296	2 300
	2		63	54	14	> 500	> 3 890
	3		60	41		> 461	> 3 580
	4		58	50		350	2 720
1C	1	4′ 6″	63	58	14	272	2 820
	4		58	50		240	2 490
	5		59	40		287	2 980
	2	3′ 0″	62	59		165	2 570
	6		61	44		152	2 360
	3	1′ 6″	60	54		76.8	2 390
	7		64	44		80.0	2 490

TABLE 1. — *Wall Test Data : Walls 9 ft 0 in high, 4 in thick.*

gates were known to be of good quality, were dried before use and were well-graded with a maximum size of 3/4 in.

The concretes were prepared in an open-pan, paddle-type mixer in a laboratory in which the temperature and relative humidity were controlled at 64° F and 65 %. From each batch of concrete a sample was drawn to cast control specimens concurrently with a portion of the wall. These specimens consisted of 4 in cubes, 6 in $\times$ 12 in cylinders and 4 in $\times$ 4 in $\times$ 16 in beams, and the number of each type varied as the wall series proceeded but was in no case less than six for any one condition of storage. The cubes and beams were moulded in accordance with the British Standard Code of Practice (³), and the cylinders in a manner similar to that specified by the American Society for Testing Materials (⁴) with the exception that they were not capped. The walls were cast in the laboratory housing the com-

(³) British Standard Code of Practice *The Structural Use of Normal Reinforced Concrete in Buildings*, British Standards Institution, London, 1948.

(⁴) A. S. T. M. Designation C31-44 : *Making and Curing Concrete Compression and Flexure Test Specimens in the Field*, American Society for Testing Materials, Philadelphia, 1944.

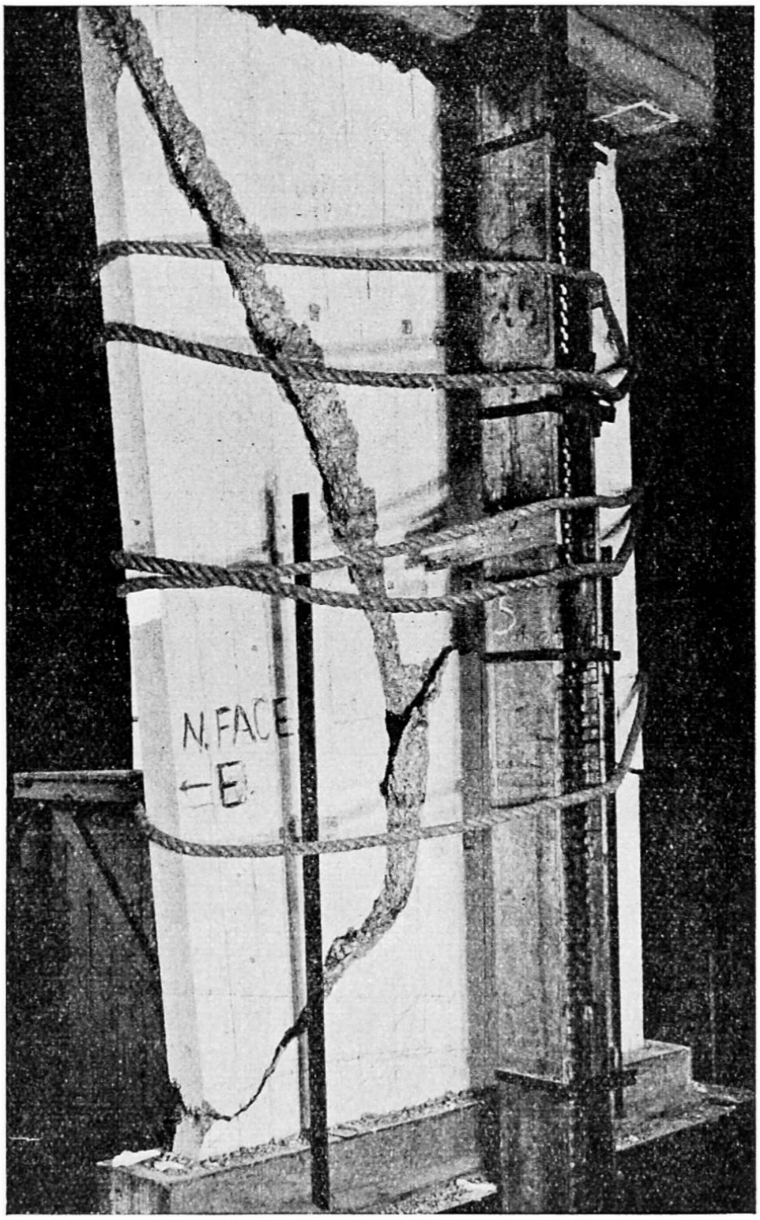

fig. 1. View of wall 1 B 4 after failure.

pression machine used in the wall tests, in one lift and on reinforced concrete pallets. The temperature and relative humidity of this testing laboratory were not controlled, but they were continuously recorded.

After casting the wall and its control specimens, damp sacking was spread over them until the wall forms were stripped or the specimens demoulded. The respective curing periods were three and two days. The walls were stored in the testing laboratory with certain of the control specimens, whilst the other specimens were stored in air at 64° F and a relative humidity of 65 %.

The walls were loaded axially in a hydraulic compression machine of 500 tons capacity. The machine was of the twin-screw type, in which the walls were compressed by a hydraulic ram against a crosshead located by the screws. The load on the ram was recorded by a pendulum-type dynamometer, and this load was distributed along the full length of the wall by two stout loading beams located between the wall and the bearing plates

Reference No.		Age at test (days)	4 in cubes				6 in × 12 in cylinders			
			Controlled storage 64° F., 65 % R. H.		Storage with wall		Controlled storage 64° F., 65 % R. H.		Storage with wall	
			N°	Crushing strength (lb/in²)	N°	Crushing strength (lb/in²)	N°	Crushing strength (lb/in²)	N°	Crushing strength (lb/in²)
1A	1	22	6	3 720			6	2 890		
	2	15	6	3 440			6	2 500		
	3	14	6	3 340			6	2 220		
1B	1	15	6	2 860			6	2 110		
	2		6	5 260			6	3 680		
	3	14	6	4 540	12	4 570			12	3 280
	4		6	4 020	12	3 190			12	2 340
1C	1		6	3 480			6	2 610		
	4		6	3 470	6	3 600			6	2 680
	5		6	3 610	12	3 720			12	2 790
	2	14	6	3 780	6	3 730			6	2 920
	6		12	3 460	12	3 280	8	3 100	8	2 760
	3		6	3 250	6	2 860			6	2 290
	7		12	3 940	12	3 460	8	2 990	8	2 770

of the machine. The top of the wall and the pallet were bedded between these loading beams using a cement mortar. In loading the wall the procedure consisted of two test runs, a preliminary run and the test run proper.

During the test run proper the overall loading rate to failure of the wall ranged from about 15 to 20 lb/in²/min through the test series. The wall test data is given in Table 1 and a view of one of the walls after failure can be seen in Figure 1.

The control specimens were weighed before they were tested at the same age as that at which the corresponding wall was tested. The cubes and beams were tested in accordance with the above-mentioned B. S. Code of Practice, but the cylinders were crushed between two sheets of 3/16 in hard plywood inserted between the cylinders and the steel platens of the testing machine. The test data obtained from the control specimens is given in Table 2.

The strengths developed by the walls and those of the cubes and cylinders are compared in Table 3.

TABLE 2. — *Control Specimens : Test Data.*

4 in × 4 in × 16 in beams				Mean density (lb/cu. ft)	
Controlled storage 64° F., 65 % R. H.		Storage with wall		Controlled storage 64° F. 65 % R. H.	Storage with wall
N°	Modulus of rupture (lb/in²)	N°	Modulus of rupture (lb/in²)		
6	530			143.5	
6	530			143.2	
6	425			143.0	
6	415			143.3	
6	500			147.2	
		6	455	144.0	142.4
		6	365	144.8	142.5
6	435			144.4	
		6	410	144.6	144.0
		6	490	143.2	142.2
		6	395	142.8	142.5
6	475	6	405	143.7	141.5
		6	360	144.4	143.0
6	430	6	395	143.2	142.6

Conclusions

The following conclusions were drawn from the tests :

(i) For 4 in walls stored under laboratory conditions of moderate temperature and humidity and of lengths not less than 4 ft 6 in, a fair average value of the wall strength (defined as the ultimate mean compressive stress) was 75 % of the mean crushing strength of 4 in cubes cast in the same concrete and stored in air at 64° F and a relative humidity of 65 % (the controlled-stored cube strength).

(ii) For walls similar in size and materials, the values of the ratio wall strength : controlled-stored cube strength did not differ from their average by more than ± 7 1/2 %

(iii) For shorter 4 in walls from 3 ft 0 in to 1 ft 6 in long there was a small reduction in the average value of the ratio wall strength : controlled-stored cube strength to a value not less than 65 %. The average value for walls of these lengths tended to approach the lower limit of the values for the longer walls.

Reference No.		Ratio $\frac{\text{wall strength}}{\text{4 in cube strength}}$ (%)		Ratio $\frac{\text{wall strength}}{\text{6 in} \times \text{12 in cylinder strength}}$ (%)	
		Controlled storage of cubes 64° F., 65 % R. H.	Same storage	Controlled storage of cylinders 64° F., 65 % R. H.	Same storage
1A	1	82.5		106.0	
	2	79.5		109.0	
	3	71.5		107.5	
1B	1	80.5		109.0	
	2	> 74.0		> 105.5	
	3	> 79.0	> 78.5		> 109.0
	4	67.5	85.0		116.0
1C	1	81.0		108.0	
	4	72.0	69.0		93.0
	5	82.5	80.0		107.0
	2	68.0	69.0		88.0
	6	68.0	72.0	76.0	85.5
	3	73.5	83.5		104.5
	7	63.0	72.0	83.5	90.0

(iv) The wall strengths were related to the crushing strengths of 6 in $\times$ 12 in cylinders stored in air at 64° F and a relative humidity of 65 %, and tested between plywood packings, in a manner consistent with a fair average value of the ratio cylinder strength : cube strength of 75 %. Thus, the walls not less than 4 ft 6 in long had strengths which compared favourably with those of controlled-stored 6 in $\times$ 12 in cylinders.

(v) For 4 in walls which were similar in other respects, no significant decrease in the ratio wall strength : cube strength was evident over a range of controlled-stored cube strengths from about 2 500 to 5 000 lb/in^2.

(vi) In no test was instability the criterion of failure of the wall. The walls crushed without appreciable bending.

Acknowledgment

The work described above has been carried out as part of the research programme of the Building Research Board of the Department of Scientific and Industrial Research, and this paper is published by permission of the Director of Building Research.

Ratio $\frac{6 \text{ in} \times 12 \text{ in cylinder strength}}{4 \text{ in cube strength}}$ (%)
Same storage
77.5
72.5
66.5
74.0
70.0
71.5
73.0
75.0
74.5
75.0
78.0
{ 89.5 / 84.0 }
80.0
{ 76.0 / 80.0 }

TABLE 3. — *Walls and Control Specimens : Proportional Strengths.*

(Ratios quoted to ± 0.25 %)

Résumé

Les résultats d'essai obtenus sur des murs en béton de 10 cm d'épaisseur chargés axialement montrent qu'en réduisant la longueur du mur de 1,80 m à 0,45 m, le rapport de sa charge de rupture moyenne par rapport à celle du cube d'essai de 10 cm de côté exécuté dans le même béton s'abaisse de 0,75 à 0,65. On n'a pas pu déterminer si ce rapport est influencé par la résistance du cube pour des tensions de 175 à 350 kg/cm². Les essais donnent une valeur moyenne constante de 0,75 pour le rapport de la charge de rupture de cylindres de 15 cm × 30 cm (essayés entre plaques de multiplex) à celle des cubes d'essai de 10 cm de côté, dans le cas où cylindres et cubes ont été conservés dans l'air ambiant. Pour tous les essais, la rupture du mur fut causée par dépassement de la tension de compression du béton. Aucune valeur sensible pour la flèche ou voilement n'est à signaler.

Zusammenfassung

Die Ergebnisse von Versuchen an 10 cm dicken, einstöckigen, axial gedrückten Betonwänden zeigen, dass bei Verkleinerung der Wandlänge von 1,50 m auf 0,45 m das Verhältnis der höchsten mittleren Druckspannung in der Wand zur mittleren Druckfestigkeit von 10 cm Würfeln aus gleichem Beton von ungefähr 0,75 auf höchstens 0,65 sinkt. Es konnte nicht festgestellt werden, dass dieses Verhältnis durch die Aenderung der Würfeldruckfestigkeit innerhalb eines Bereichs von 175 bis 350 kg/cm^2 beeinflusst wurde. Die Ergebnisse zeigten einen gleichbleibenden Durchschnittswert von 0,75 für das Verhältnis der Druckfestigkeit von 15 $\times$ 30 cm Zylindern (geprüft zwischen harten Sperrholzfassungen) zu derjenigen von 10 cm Würfeln, wenn die Zylinder und die Würfel zusammen an der Luft gelagert wurden. Bei allen Versuchen versagte die Wand durch Ueberwindung der Druckfestigkeit des Betons. Weder nennenswerte Biegung noch Knicken trat auf.

Summary

Data obtained from tests on 4 in concrete walls of single-storey height under distributed axial compression suggests that as the wall length is reduced from 6 ft 0 in to 1 ft 6 in the ratio between the ultimate mean compressive stress in the wall and the mean crushing strength of 4 in cubes of the concrete used is reduced from about 0.75 to not less than 0.65. There was no evidence to suggest that the ratio is affected by the cube strength within a range of cube strengths from about 2 500 to 5 000 lb/in^2. The data was consistent with a fair average value of 0.75 of the ratio between the crushing strengths of 6 in $\times$ 12 in cylinders (tested between hard plywood packings) and 4 in cubes, when the cylinders and cubes were stored together in air. In all the tests the wall failed by crushing of the concrete, and neither appreciable bending nor buckling occurred.