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REINFORCED CONCRETE CONSTRUCTIONS.

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The first application of metal to reinforce concrete or mortar appears to be due to Monier, in France in 1868. Monier embedded wire nets in concrete, or rather mortar, and he is said to have designed and constructed the first reinforced concrete arched bridge in which a wire netting was arranged near the intrados; afterwards two wire nettings were used in similar works, one near the intrados, and the other near the extrados.

Many structures have been built in Europe and America in which steel or iron reinforcements are used in those portions of the mortar or concrete in which tensile stresses occur, and various names have been proposed to denote this comparatively new form of construction. In France "Beton Arme," and in Germany "Beton und Eisen" denote these constructions. In Great Britain and America "Ferro-Concrete," "Steel-Concrete," "Concrete-Steel," "Armoured Concrete," and "Reinforced Concrete" refer to the same class of constructions. In this paper the term "Reinforced Concrete" will be used to denote all such constructions.

A history of the progress and development of Reinforced Concrete Structures will not be attempted, but it may be noted that from 1868 to 1904 many forms were developed besides the Monier, including the Wunch system, characterised by two series of reinforcements of rolled sections, one horizontal and the other vertical; the Melan system, consisting of straight or curved rolled beams, or built arched latticed girders embedded in concrete. In 1894 Dr. Fritz von Emperger, of Austria, introduced the Melan system into America (*), and since then a very large number of works have been executed, including bridges, buildings, and almost every kind of construction where plain concrete was formerly used. The form of reinforcement consists of round, flat, or square bars, twisted square bars, corrugated bars, expanded metal, etc., associated with which may be mentioned the names of Ransome, Thacher, Johnson, Kann, and others.

Experimental and mathematical investigations have been undertaken by Professors K. Hatt, Talbot, Turneaure, and others. In France M. Hennebique is identified with an enormous number of reinforced concrete constructions, building from 1900 to 1903 about 330 bridges, besides a great variety of other works. The names of M. Rabut, M. Harel de la Noe are also associated with numerous large works of this class, but the chief investigator in connection with the theory of the design of reinforced concrete structures is M. A. Considere (†) who has done more than anyone else to establish a rational system of calculations in connection with the design of structures, and has also introduced some important improvements in constructions of this class. In Holland, Austria, and Germany the subject

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† Inspecteur General des Ponts et Chaussees.

has been developed both scientifically and practically, and it is receiving considerable attention in Great Britain.

The applications of reinforced concrete are very numerous, and they are rapidly increasing. This construction is superseding steel alone, timber, stone, and brick in a great variety of cases; it has been successfully used in foundations, also in tall buildings and chimneys, various kinds of bridges for road and railway traffic, reservoir dams and retaining walls, sewers and channels of all kinds, tunnels, piles, etc.

The essential features of reinforced concrete construction is that the concrete or mortar should adhere to the metal reinforcements under all circumstances, and this has been abundantly demonstrated. The adhesion to steel rods is shown in Tables I. and II.

Table I.—ADHESIVE STRENGTH OF CONCRETE TO STEEL.

A. Bars with natural skin on. Hardened in air.

Number.	Composition— Cement	Builders' Sand.	¾ Nepean Shivers	Water per cent	Age in Days.	Surface area of bars imbedded sq. in.	Total Load Pounds	Adhesion Pounds per sq. in.
I.	1	3	–	12	45	11·78	2550	216·5
II.	1	3	–	12	45	11·78	2600	221·0
III.	1	2	2	10	45	11·78	2175	184·5
IV.	1	2	2	10	45	11·78	2000	170·0
B. Bars cleaned with emery paper before embedding. Hardened in air.								
I.	1	3	–	12·5	45	11·78	1400	118·0
II.	1	3	–	12·5	45	11·78	850	72·0
III.	1	2	2	10	44	11·78	1820	154·0
IV.	1	2	2	10	44	11·78	1825	155·0
C. Bars cleaned with emery paper before embedding. Hardened in water.								
I.	1	3	–	12	45	11·78	1820	154·0
II.	1	3	–	12	45	11·78	2255	191·0
III.	1	2	2	10	45	11·78	2410	204·0
IV.	1	2	2	10	45	11·78	2250	191·0

TABLE II.—RESULTS OF TESTS ON THE UNION BETWEEN CONCRETE AND STEEL.

The following Table, published by the St. Louis Expanded Metal Fireproofing Co., has been arranged from the original Table in "Beton Eisen," reprinted from the "Railroad Gazette, September 18th, 1903:—

No. of Test.	Type of Rod. Inch.	Size of Concrete Block.	Length of Rod embedded in concrete	Breaking Load.	Minimum area of cross-section of rod	Shearing stress in lbs per sq. in. of net section.	Stress on Rod in lbs. per sq. inch of net section.	
		Inches.	Inches	Pounds.	Sq. inch			
1	Ransome, ½	6 x 6	12	12,100	0.25	504	48,400	Concrete split longitudinally.
4	,, ½	8 x 8	12	8,300	0.25	346	33,200	Rod slipped at 8,000, dropped to 6,000, rose again to 8,300, where concrete split. Rod pulled through 3 inches.
13	Thacher, ½	6 x 6	12	4,850	0.18	270	26,900	Rod slipped, concrete split.
22	Johnson, ½	6 x 6	12	12,200	0.14	678	87,200	Concrete split.
2	Ransome, ½	6 x 6	16	8,100	0 25	253	32,400	Concrete split longitudinally.
5	,, ½	8 x 8	16	14,000	0.25	438	56,000	Rod slipped at 12,000, dropped to 8,000, rose again to 14,400. where concrete split. Rod pulled through 5in.
14	Thacher, ½	6 x 6	16	8,200	0.18	340	45.500	Rod slipped at 8,100, concrete split.
23	Johnson, ½	6 x 6	16	13,120	0.14	545	93,700	Concrete split.
3	Ransome, ½	6 x 6	26	16,800	0.25	323	67,200	Concrete crushed on end.
6	,, ½	8 x 8	26	15,000	0.25	288	60,000	Rod slipped at 15,000, rod pulled through max. stress 14,000. Rod pulled through 11½ in.
15	Thacher, ½	6 x 6	26	10,550	0.18	272	58,600	Rod broke.
24	Johnson, ½	6 x 6	26	13,750	0.14	354	98 400	Rod broke.
7	Ransome, ¾	8 x 8	20	25,900	0.56	431	46,300	Rod slipped at 18,000, concrete split.
16	Thacher, ¾	8 x 8	20	21,150	0.39	478	53,000	Rod slipped at 19,050, concrete split.
25	Johns·n, ¾	8 x 8	20	27,600	0.31	619	89 100	Concrete split.
8	Ransome, ¾	8 x 8	24	31,900	0 56	443	57,000	Rod Slipped at 14,000, concrete split.

TABLE II—(Continued).

No. of Test.	Type of Rod. Inch.	Size of Concrete Block.	Length of Rod embedded in concrete.	Breaking Load.	Minimum area of cross-section of rod	Shearing stress in lbs. per sq. in. of net section.	Stress on Rod in lbs. per sq. inch of net section.	
17	Thacher, 3/4	8 x 8	24	18,300	0.39	344	45,900	Concrete split.
26	Johnson, 3/4	8 x 8	24	25,000	0.31	467	80,600	Concrete split.
31	3/4 round	8 x 8	24	15 300	0.44	271	38,400	Rod slipped.
34	3/4 square	8 x 8	24	19,700	0.56	274	35,200	Rod slipped.
37	1 1/8 x 1/2	8 x 8	24	12,400	0.56	159	22,100	Rod slipped.
40	1 1/2 x 3/8	8 x 8	24	20,300	0.56	226	36,300	Rod slipped.
43	2 1/4 x 1/4	8 x 8	24	5,000	0 56	42	8,930	Rod slipped (Specimen injured).
32	3/4 round	8 x 8	31	18,600	0.44	255	42,200	Rod slipped.
35	3/4 square	8 x 8	31	22,600	0.56	243	40.400	Rod slipped.
38	1 1/8 x 1/2	8 x 8	31	20,300	0 56	201	36,200	Rod slipped.
41	1 1/2 x 3/8	8 x 8	31	21,700	0 56	188	38,800	Rod slipped.
44	2 1/4 x 1/4	8 x 8	31	25,500	0.56	165	45,500	Rod slipped.
9	Ransome, 3/4	8 x 8	36	36,600	0.56	339	63,500	Concrete split.
18	Thacher, 3/4	8 x 8	36	23,700	0.39	297	59,400	Rod broke.
27	Johnson, 3/4	8 x 8	36	28,000	0.31	483	90,500	Concrete split.
33	3/4 round	8 x 8	36	18,600	0.44	219	42,200	Rod slipped.
36	3/4 square	8 x 8	36	23,900	0.56	221	42,700	Rod slipped.
39	1 1/8 x 1/2	8 x 8	36	21,700	0.56	185	38,700	Rod slipped.
42	1 1/2 x 3/8	8 x 8	36	22,130	0.56	164	39,500	Rod slipped.
45	2 1/4 x 1/4	8 x 8	36	26,100	0.56	145	46,600	Rod slipped.

It is also essential that the reinforcement should not corrode, and numerous examples could be given which prove that good concrete or mortar made from Portland cement is one of the best materials for the protection of iron or steel. Newbury found that in a concrete retaining wall containing metal reinforcement in Berlin, after 11 years the rods were free from corrosion and the adhesion perfect. Bouscaren found the links of a Roebling suspension bridge embedded in concrete free from rust, and perfectly preserved, after twenty years. Professor C. L. Norton found that sheet steel and rods embedded in concrete bricks enclosed in tin boxes with unprotected steel, and exposed for three weeks. One portion was exposed to steam, air, and carbon dioxide, and another was left on the table in the testing room. He arrived at the following conclusions, after making a number of experiments:—

(1) Neat cement is a perfect protection.

(2) Concrete should be dense, without voids or cracks, and be mixed wet.

(3) The corrosion found in cinder concrete is mainly due to iron oxide in the cinders and not to sulphur.

(4) Cinder concrete, if free from voids and well rammed, is about as effective as stone concrete.

(5) It is important that the steel be clean when embedded in the concrete.

(6) It is essential that the steel be coated with cement before embedding in concrete. The unprotected pieces of steel were found to consist of more rust than steel.

Again, Prof. Norton embedded steel in concrete, clean, and in all stages of corrosion, using both wet and dry mixtures, exposed to moisture, carbon dioxide, and sulphurous gases. Some were treated in tanks supplied intermittently with steam, hot water, moist air, dry air, and continuously with carbon dioxide for from one to three months. Under this treatment, the unprotected steel vanished into streaks of rust, but protected by an inch or more of sound concrete the steel was absolutely unchanged.

Cement paint is coming into use as a protective coat to steel bridges, roofs, etc. (*)

Breuillie, in France, experimented with concrete slabs subjected to a pressure of water. Steel wires were embedded at different depths in the slabs, and they were subjected for six days to intermittent water pressure of from 39.4 to 50 feet. The water penetrated every part of the slabs. The slabs were then left exposed to the air, and the conditions of the metal tested from time to time, and always found in perfect condition. He observed that the metal was dull after contact with the concrete; that adhesion was destroyed where the water had penetrated; that bars having a slight layer of rust when embedded were free from rust in 15 or 20 days; that water after passing through the slabs contained less mortar salts than before; that under pressure of 50 feet adhesion was destroyed, but the bars did not rust. He concludes that salt is formed by the action of the cement on iron, which is dissolved by water.

Messrs. McIntyre and True (†) found, after exhaustive experiments, that under pressures of from 20 to 80 lbs. per sq. inch for two hours, all concrete containing from

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* Eng. Record, vol. xlvi., p. 280, also Report No. 9 Insurance, En Station, Boston.

(†) Engineering News, Vol. xlvii., p. 517.

30 to 45 per cent. of 1 to 1 mortar was impermeable; some specimens containing 40 to 45 per cent. of 1 to 2 mortar, and some of 1-2-4 and 1-2½-4, were also impermeable under a pressure of 80 lbs. per sq. in. They recommend 1-2-4 or 1-2½-4 concrete for moderate pressures. Feret found that the permeability diminished as the proportions of cement increased, it also diminished rapidly with time, that the concrete mixed wet gave better results, and that the proportion of the sand grains of medium size should be small, and that of the coarse and fine grains about equal to each other.

Professor Baker gives the following formula for making mortar water-tight:—1 per cent. by weight of alum is added to the dry cement and sand, and 1 per cent. of potash soap (ordinary soft soap is good) is dissolved in the water used for mixing.

THERMAL EXPANSION IN CONCRETE.

It is also essential that the co-efficient of linear expansion in reinforced concrete members should be about the same both for the concrete and the steel reinforcement. Carefully conducted laboratory experiments and general experience with reinforced concrete have shown that the co-efficients of expansion for the concrete or the steel do not differ much from each other. Professor Burr gives the results of very careful experiments made at the Columbia University by Professor Hallock on one bar of concrete consisting of 1 of Portland cement, 3 of sand, and 5 of gravel, also one bar of mortar consisting of 1 of Portland cement and 2 of sand. The bars were 4 inches by 4 inches in cross section, and about 3 feet long, the tests being made at the age of about 5½ years. The co-efficients of linear expansion for each degree Fahr. found in these investigations were as follows:—

For	1-3-5 Concrete	0.00000655
„	1-2 Mortar.	0.00000561

The co-efficient of expansion of such iron and steel as are used in reinforced concrete structures, according to the Watertown Tests, U.S.A., is about 0.0000066.

FIRE PROTECTION.

Reinforced concrete appears to be far superior to terra cotta and hollow tiles in its fire-resisting properties. Comparative tests in Germany, and the experience of some large fires in America, have proved beyond doubt the advantages of reinforced concrete construction for fire-proof buildings.

The composition of the concrete used in France, according to Considere, is 300 kg. of cement to a total volume of 1.2 cub. m. of sand and gravel mixed, and it is assumed that, after losses at the mixing pans and after ramming, there is 1 cub. m. of concrete measured in place. In submarine works the proportion of cement is increased to 500 or 550 kg. per cub. m. measured in place. In British units 506 lbs. of cement to 1.2 cub. yds. of aggregate would make 1 cub. yard of concrete in place, which would be increased for marine work from 843 to 928 lbs. of cement to 1 cub. yard measured in place. Assuming that a cask of Portland cement weighs 375 lbs. net, 1.35 of a cask would correspond with 506 lbs. Sufficient water must be used to render the concrete moist enough to flow between the reinforcing members and coat them with cement, but at the same time is able to stand ramming.

The cheapest quality of steel having a strength of

57,000 to 64,000 lbs. per sq. inch, and an elongation of 20 to 26 per cent. is generally used.

TENSION TESTS OF REINFORCED MORTAR AND CONCRETE.

The strength of reinforced concrete or mortar when subjected to tensile stress is governed by the adhesive strength of the mortar to the metal reinforcement. In all the experiments made by the author the specimen fractured at the change of section close to the heads of the specimen held by the clips, the concrete or mortar sliding longitudinally by overcoming the adhesion to the metal rods. It will be observed that the shackles are so designed that the tensile stress developed is uniformly distributed over the area of the cross section under test, which is 100 x 100 mm. (4 x 4 ins.); the length over which the elongations were measured is also 100 mm. (4 ins.). The shackles are held in a horizontal plane by means of four springs suspending the shackles at four points. The springs enable the specimen to be adjusted to a horizontal plane, a spirit level being laid on the test piece. A double set of Marten's Mirror Extensometers is attached to the specimen, one on each side, and the elongations and loads producing them are recorded in the usual way.

Tables III. and IV. give the results of experiments on mortar, specimens 24 hours in air, the rest of the time in water.

TABLE III.
TENSION TESTS OF MORTAR WITHOUT REINFORCEMENT.

Composition.	Age in months.	Total Load in thousands of lbs.	Tensile Stress, lbs. per square inch.	Extension in 0.0004" on 4 inches.	Coefficient of Elasticity in millions of lbs. square inch.	Breaking Load in lbs square inch.
1 Cement to 3 washed River Sand, passed through a sieve of 400, and caught on a sieve of 900 meshes per square inch.	12	1.00	62	0.10	3.125	281
		2.15	134	0.50	2.062	
		3.55	222	1.00	1.906	
		4.22	262	1.30	1.781	
	6	0.80	50	0.10	1.875	281
		1 94	121	0.50	1.800	
		3.23	201	1.00	1.703	
		4.50	381	1.80	1.385	
	3	0.78	4×	0,10	1.718	219
		1.75	109	0.50	1·562	
		2 80	175	1.00	1.437	
		2.05	184	1.10	1.393	
1 Cem't to 2 of Sand	12	0.90	56	0.10	2.500	319
		2.35	147	0.50	2.312	
		3.88	242	1.00	2.110	
		5.10	319	1.60	1.797	
	3	0.78	48	0.10	1,718	296
		1.80	112	0.50	1.625	
		2.05	128	0.60	1.613	
1 Cem't to 4 of Sand	6	0.80	50	0.10	1.875	187
		1.66	104	0.50	1.450	
		2.80	175	1.00	1.437	
	3	0.83	51	0.10	2.031	187
		1.66	104	0.50	1.450	
		2.40	150	1.00	1.187	
		2.50	156	1.10	1.137	
	2	0.70	44	0.10	1.250	142
		1.53	95	0.50	1.281	
		1.67	104	0.60	1.218	

TABLE IV.

TENSION TESTS OF MORTAR REINFORCED WITH BESSEMER STEEL RODS.

Composition.	Age in months.	Total Load in thousands of lbs.	Tensile Stress, lbs. per square inch.	Extension in 0.0004" on 4 inches	Coefficient of Elasticity in millions, lbs. per square in.	Breaking Load in lbs. per sq. inch.
1 Cem't to 3 of Sand	1	0.91	57	0.10	2 575	234
4 Steel rods ½" dia.		2.05	128	0.50	1.935	
		3.12	195	1.00	1.637	
		3.57	223	1.20	1.597	
do.	1	1.07	67	0.10	3,575	285
		2.24	140	0.50	2.175	
		3.47	217	1.00	1.857	
		4.05	253	1.20	1.847	
1 Cem't to 3 of Sand	1	1.09	68	0.10	3.675	575
5 Steel rods ½" dia.		3.10	194	0.50	3.255	
		5.55	347	1.00	3 157	
		8.59	537	1.60	3.161	
1 Cem't to 3 of Sand	1	0.88	55	0.10	2.375	218
1 Steel rod ½" dia.		1.92	120	0.50	1.775	
		2.96	185	1.00	1.537	
		3.52	220	1.60	1.117	
1 Cem't to 3 of Sand	3	0.80	50	0.10	1.875	301
4 rods ½" diameter		2.40	150	0.50	2.375	
		3.63	227	1.00	1.958	
		4.46	279	1.40	1.770	
1 Cem't to 3 of Sand	3	1.04	65	0.10	3.375	516
5 rods ½" diameter		3.09	193	0.50	3.235	
		5.28	330	1.00	2.988	
		7.70	481	1.60	2.811	
1 Cem't to 3 of Sand	3	1.12	70	0.10	3,875	281
1 rod ½" diameter		2.37	148	0.50	2.335	
		4.30	269	1.00	2.379	