"Materials of Construction," 1st Edit., a diagram (Fig. 545) is given illustrating some tests on the adhesion of P.C. mortar to iron bolts one inch in diameter. Judging from this diagram, the adhesive strength for 1 to 2 P.C. mortar one month old should be about 270lbs. per sq. inch. In Prof. Hatt's experiments on adhesion, the following average results were obtained:—

$\frac{7}{16}$ in. bolts in 6 in. cubes of 1-2-4 concrete = 636 lbs. per sq. in.
$\frac{5}{8}$ " " " " " 756 " "

Three tests were made in each series, the age of the concrete being thirty-two and thirty-five days.

The adhesion may be increased by using flat bars instead of circular rods, as the proportion of surface to area is so much greater in the latter case. It might here be remarked that many American engineers do not wholly rely on the chemical adhesion between the iron or steel and the concrete, but provide some mechanical connection between the two substances.

IV. Various Systems of Construction.

Monier.

This is the earliest form of steel-concrete construction, and has been fully described in Mr. Bradfield's interesting paper already referred to.

In this system a network of iron or steel rods is embedded in the concrete at a short distance from the tension surface. When the structure is subjected to stresses caused by bending which may take place in opposite directions, as in the case of arches or fixed beams, two networks should be employed, these being at short distances from the upper and under surfaces respectively. The material used for the body of Monier structures consists of 3 to 1 P.C. mortar or fine concrete.

Owing to the superior advantages in strength and economy of concrete of the composition, say, 1 P.C., 2 sand, and 4 broken stone over 3 to 1 P.C. mortar, and the difficulty experienced in manipulating and embedding a flexible network of rods when the concrete contains broken stone and gravel, the Monier has been largely superseded by the Melan or some other system, in which the metal isused in comparatively large masses in conjunction with concrete mixed with a coarse aggregate.

Melan.

This system consists of rolled steel girders or riveted girders embedded in the concrete at intervals of about 3ft. The girders are spliced together over the piers, and securely anchored at the abutments. One of the most usual proportions of concrete in modern practice is 1 P.C. to 2 sand and 4 broken stone. The system was invented in the year 1892 by Joseph Melan, of Austria-Hungary.

A number of careful experiments, which were carried out on Melan arches by the Austrian Society of Civil Engineers and Architects, yielded very satisfactory results.

In the Melan System the metal in the webs of the girders is not used to great advantage in increasing the moment of inertia of the section, and there is some loss of economy through this cause. It must be borne in mind, however, that the webs serve to bond the concrete in a vertical direction, and the girders, taken by themselves, provide considerable resistance, which might save a structure from sudden destruction even if the concrete, through defective mixing or any other cause, failed to perform the functions assigned to it.

When rolled steel girders are employed in Melan arch construction the system is subject to certain disadvantages. At the crown of the arch the girders may occupy nearly the whole depth, the flanges being close to the intrados and extrados respectfully, but at the springing line, owing to the much greater thickness of the arch, the girders, if centrally placed, would only slightly assist the concrete in bearing the tensile stresses caused by bending. If the rolled girders, instead of being central, were brought nearer to one surface, additional metal would be required at the other surface to afford sufficient resistance to bending moments in a contrary direction.

It will be noticed that when built girders are substituted for rolled ones, this objection does not apply, as the depth may be varied to suit the depth of the arch ring, as long as the girders are not made so deep that they become flimsy and difficult to handle.

Thacher System

This system is the invention of Mr. Edwin Thacher, M. Am. Soc. C.E., and has been fully described by him in an article[1] published in the *Engineering News*, which is a valuable contribution to the literature of steel-concrete construction.

The Thacher system combines in itself some of the best features of both the Monier and the Melan systems, and during the last few years has been largely employed in the construction of arches in the United States.

The metal is used in the form of flat bars, spaced about 3ft. centre to centre, and embedded in the concrete at short distances from the upper and lower surfaces of the section. The proportion of the concrete is 1 P.C. to 2 sand and 4 broken stone or gravel, not more than $1\frac{1}{4}$ inch in diameter, for which Mr. Thacher recommends a working stress of 50lbs. per square inch.

Mr. Thacher, in common with other American engineers, considers that the adhesion of concrete to steel should not be entirely relied on, and specifies that rivets with large heads should be driven in the bars at intervals, so as to form a mechanical connection between the metal and concrete. He also considers that the steel should be capable of taking the entire bending moment, without passing its elastic limit, and that it should have a flange area of not less than $\frac{1}{150}$ of the total area of the arch at the crown.

The use of concrete with coarse aggregate, in place of 1 to 3 mortar, affords considerable economy over the Monier system, although perhaps the absence of the more perfect bond provided by the network might be considered as a disadvantage. The flat bars can be easily bent, and can be placed so as to follow the contours of the intrados and extrados, and thus the main defect of the Melan system is obviated.

1. *Eng. News*, Sept. 21st, 1899.

The following specification for Portland cement concrete, as used by the firm of Keepers and Thacher, is quoted in Mr. Edwin Thacher's paper :—

"The concrete shall be composed of clean hard broken stone, or gravel, with irregular surface; clean, sharp sand, and cement, mixed in the proportions hereafter specified. Whenever the amount of work to be done is sufficient to justify it, approved mixing machines shall be used. The ingredients shall be placed in the machine in a dry state, and in the volumes specified, and be thoroughly mixed, after which clean water shall be added and the mixing continued until the mixture is thorough and the mass uniform. No more water shall be used than the concrete will bear without quaking in ramming. The mixture must be done as rapidly as possible and the batch deposited in the work without delay.

"If the mixing is done by hand, the cement and sand shall first be thoroughly mixed dry in the proportions specified. The stone previously drenched with water shall then be deposited on this mixture, clean water shall be added and the mass be thoroughly mixed and turned over until each stone is covered with mortar, and the batch shall be deposited without delay, and be thoroughly rammed until all voids are filled.

"The grades of concrete to be used are as follows: For the arches between skewbacks—1 part Portland cement, 2 parts sand, and 4 parts broken stone, or gravel, that will pass through a $1\frac{1}{4}$in. ring; for the foundations, abutments, piers and spandrels—1 part Portland cement, 4 parts sand, and 8 parts broken stone, or gravel, that will pass through a 2in. ring."

Mr. Thacher considers that it would be possible to economically build steel concrete arches with spans up to 500 or 600 feet.

Expanded Metal.

Expanded metal has been used with great success in combination with concrete, principally for small span arches and flooring slabs. It is manufactured from sheets of low carbon steel of special quality, having an ultimate tensile strength of about 25 tons per sq. in., with an elastic limit of $13\frac{1}{2}$ tons per sq. in., and an elongation of 25 per cent., measured on a length of ten inches. The sheets are cut with toothed cutters in series of slits arranged in lines, the width of the strand being the distance between the lines of slits. The slits overlap one another in adjacent lines, and are formed into meshes by extending the sheets laterally in a direction making an angle with them of 90deg. or less.

In several recent papers[1] on steel concrete construction attention is drawn to the great advantages to be derived from the use of expanded metal in conjunction with concrete. It ensures a more uniform distribution of stress, and avoids any shearing action such as would take place in the concrete with metal bars embedded at intervals. By the nature of its structure, it affords an almost perfect mechanical connection with the concrete. It is also said to be more economical than the use of metal in the form of rods or bars.

1. "Steel Concrete Construction," G. Hill, Proc. Am. Soc. C.E., March, 1898; "The Use of Expanded Metal in Concrete," A. T. Walmisley, M. Inst. C.E., *The Builder*, Sept. 15th, 1900.

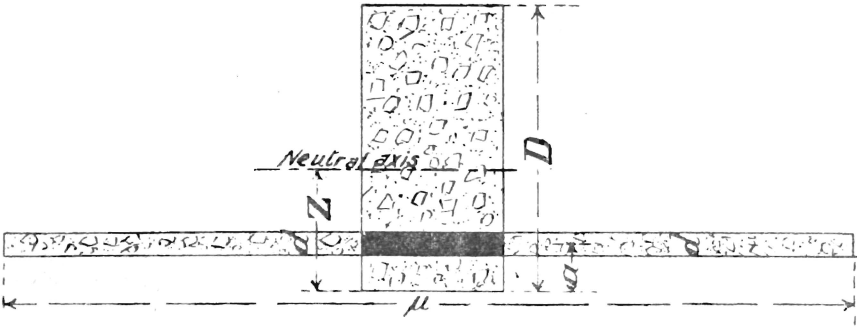


Fig. 1.

Fig. 2.

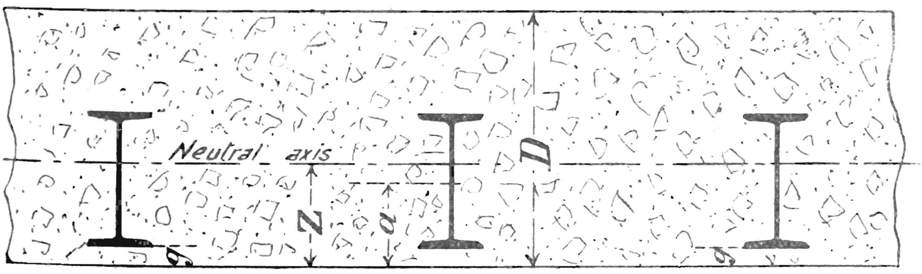
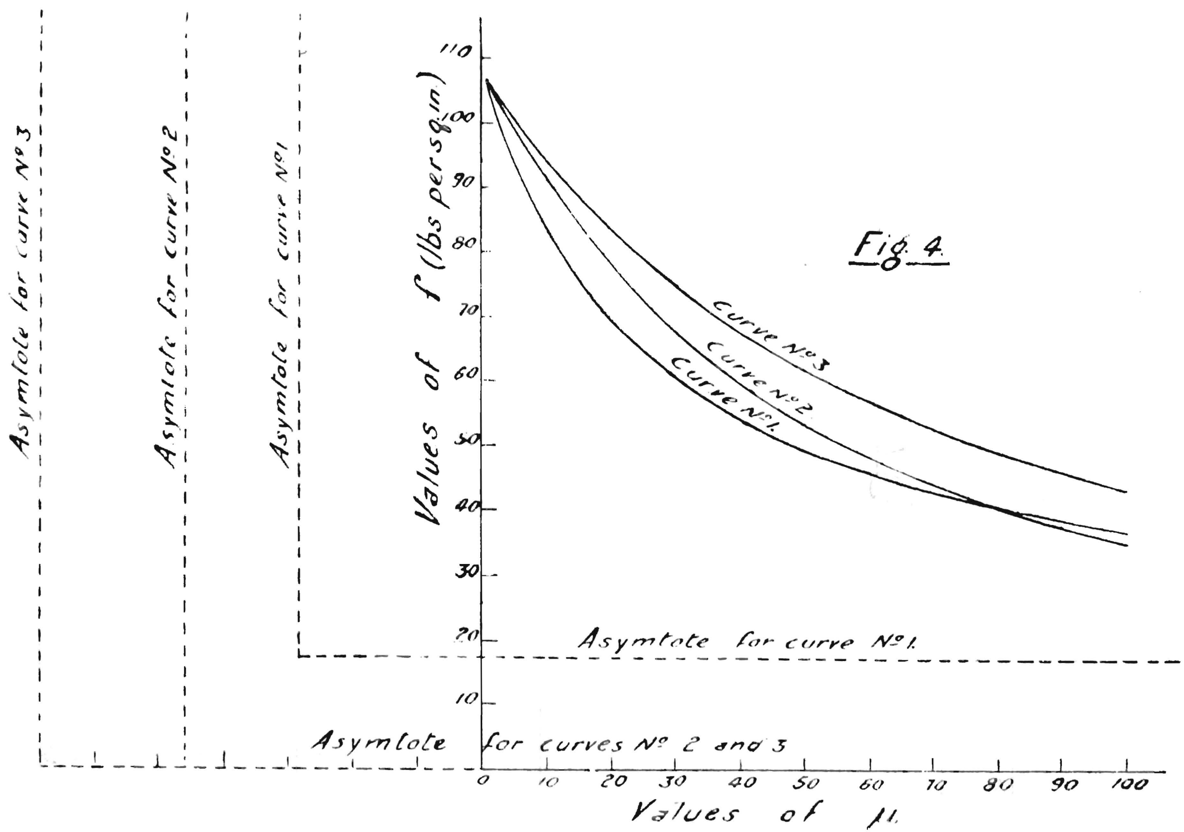


Fig. 3.

Fig. 4.



Asymtote for curve No 3
Asymtote for curve No 2
Asymtote for curve No 1
Values of f (lbs per sq. in.)
110
100
90
80
70
60
50
40
30
20
10
Curve No 3
Curve No 2
Curve No 1.
Asymtote for curve No 1.
Asymtote for curves No 2 and 3
0
10
20
30
40
50
60
70
80
90
100
Values of μ.

In Mr. Walmisley's paper, a table is given showing the stock sizes of expanded metal. By a reference to this table it will be seen that the size giving the maximum area per unit of section across the mesh is that in which the width of the mesh is 3 inches, and the strands $\frac{3}{8}$in. x $\frac{3}{16}$in. The area per lineal foot is therefore

$$4(\tfrac{3}{8} \times \tfrac{3}{16}) = \cdot 281 \text{ sq. ins.}^{1},$$

which is equivalent to a layer of rods $\frac{3}{8}$in. diameter, spaced 4in. apart, centre to centre.

It may here be remarked that in all forms of steel-concrete construction it is necessary that the metal should be cleaned as thoroughly as possible from any oil, paint, or rust, &c., adhering to it, particularly where it is not provided with projections such as rivets or bolts. This will give full play to the chemical action which takes place between the surface of the iron or steel and the cement in the concrete, and will ensure that the adhesion will attain a maximum value.

American Practice. Concluding Remarks.

As an illustration of modern practice in steel-concrete bridge construction, particulars and dimensions of a number of highway bridges which have been designed by American engineers in recent years, are given in Table III. It will be noticed that, on the whole, the height of the rise is considerably less than is usually allowed in the case of voussoir arches, and for this reason steel-concrete bridges offer great advantages in situations where headway is of not much importance, and where steep gradients in the approaches would be unavoidable if the arches were constructed of ordinary masonry.

Steel-concrete bridges are free from vibration and noise, and according to Mr. Thacher, their cost is about the same as that of steel bridges, and considerably less than the cost of stone bridges.

In addition to arched bridges, many other applications have been found for steel-concrete construction. It has been successfully employed for vaulted roofs for service reservoirs, flooring slabs and arches, retaining walls, &c., and has various other uses, many of which have been described in Mr. Bradfield's paper on Monier construction.

Although, perhaps, it is not suited to withstand the sudden loading and impact caused by railway traffic, steel-concrete construction will doubtless find increasing application in the future, wherever bridges of moderate span and elegant appearance are required. In addition to its other advantages, this form of construction combines great strength and durability with low cost of maintenance, and is in harmony with that modern tendency of engineering practice, which is leading in many cases to the erection of structures of a more permanent character than can be ensured with the use of iron or steel alone.

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1. It is assumed in this example, which is given n Mr. Walmisley's paper, that the lateral extension of the slit is equal to the shortest axis of the mesh, which could only be the case if the sheets were extended at right angles to the direction of the slits.

TABLE I.

SUMMARY OF PROF. HATT'S TESTS OF STONE-CONCRETE BEAMS.

Span = 80 inches. Section of Beams = 8 in. x 8 in.

Composition of Concrete—1 P.C., 2 sand, 4 broken limestone, 1 in. gauge and under. All beams loaded at centre.

Test No.	Age in Days.	Area of Steel Bars.	Distance of Steel Bars from under surface—in.	[1]Load at first crack—lbs.	Deflection at first crack —inches.	[2]Value of "f" at first crack— lbs. per sq. in.	[1]Load producing total failure—lbs.	Deflection at Failure— inches.
1	28	none.	......	......	......	310	2,640	0·003
2	28	none.	......	......	......	287	2,440	0·014
3	25	1 per cent.	2	5,240	0·140	333	5,740	0·163
4	28	1 ,, ,,	2	5,240	0·136	333	6,490	0·186
5	25	2 ,, ,,	2	5,990	0·109	316	10,490	0·278
6	27	2 ,, ,,	2	6,740	0·133	356	10,490	0·278
7	25	1 ,, ,,	1	7,490	0·138	296	7,740	0·145
8	23	1 ,, ,,	1	6,740	0·150	266	7,540	0·177
9	27	2 ,, ,,	1	10,240	0·174	281	12,240	0·247
10	25	2 ,, ,,	1	10,240	0·158	281	12,040	0·208
11	30	1 ,, ,,	$1\frac{1}{2}$	4,240	0·087	210	6,740	0·176
12	30	1 ,, ,,	$1\frac{1}{2}$	5,740	0·138	285	6,640	0·170

1. One-half weight of beam added.
2. Computed by Author:—Value of μ assumed = 100.
   ,, F ,, = 2.

Average value of f, tests Nos. 1 and 2 = 298 lbs. per sq. in.
,, ,, ,, f, ,, ,, 3 to 12 = 296 ,, ,,

TABLE II.

TENSILE STRENGTH AND MODULUS OF RUPTURE OF PORTLAND CEMENT CONCRETE, AND 1 TO 3 MORTAR.

Composition.	Age in Days.	Size of Test Piece.	Tensile Strength. lbs. per sq. in.	Mod. of Rup. lbs. per sq. in.	Authority.	Remarks.
Body of Arch— 1 P.C., 3 sand, 2 broken stone, 3 gravel	80	75·4ft. span arch	290	..	Austrian experiments at Puckersdorf.	Comp. of concrete for intrados, 1 P.C., 1 sand, ½ stone, ½ gravel " " extrados, 1 P.C., 2 sand, 1½ stone, 1½ gravel
1 P.C., 3 drift sand, 6 broken limestone	30	6in. x 6in. bars, 18in. span	..	486	Messrs. Hawley and Krahl, *Eng. News*, June 7th, 1900.	Mean of two tests.
1 P.C. to 5 crushed granite, not greater than 1¼in. gauge	28	not stated	319	..	Edward Sandeman, P.I.C.E., vol. CXLVI, [p. 7.	Average value. Tests for Plymouth W.W.
1 P.C., 3 sand, 6 broken trap rock	30	12in. x 8in. section, 11ft. span	..	533	L. C. Wason, Proc. Am. Soc. C.E., Aug. 1901.	1 test only.
Concrete. Composition not stated	not stated	not stated	350	..	Value assumed by W. Beer, P.I.C.E., vol. CXXXIII.	Founded on Austrian, German and French experiments.
1 P.C., 2 sand, 4 broken lime stone, 1 in. gauge and smaller	26 to 35	4 in. x 4 in.	311	..	W. Kendrick Hatt, *Eng. News*, July 17th, 1902.	Average of four tests.
1 P.C., 2·1 sand, 5·6 broken sandstone	570	10in. x 10in. bars 4ft. span	..	538	Table XXXVII. p. 608 Johnson's "Materials of Construction."	Mean of two tests from Report of Chief Engineers of U.S. Army, 1895.
1 P.C., 8 sand and stone	not stated	12in. x 12in. 3ft. span	..	454	Experiments by John Kyle, Colombo H.W., *Eng. News*, Aug. 3rd, 1900.	Lowest value, 9 tests.
1 P.C., 2 sand, 4 broken limestone, 1½in. and 2in. gauge	30	area, 10 sq. in.	180	..	W. H. Henby, Journal of the Association of Eng. Societies, Sept., 1900.	
1 P.C., 3 sand, 6 broken limestone, 1½in. and 2in. gauge	30	" " " "	110	..	Do.	
1 to 3 Portland Cement mortar	28	......	202	..	A. F. Bruce, P.I.C.E., vol. CXIII.	Average of a large number of tests.
Do.	30	......	232	..	Tests by Sewerage Dept., N.S. Wales.	Average of 13 English brands.
Do.	30	......	308	..	Do.	Average of 5 German brands.
Do.	28	......	220	..	Edwin Thacher's Specifications, *Eng. News*, Sept. 21st, 1899.	
Do.	28	......	307	..	L. C. Wason, Proc. Am. Soc. C.E., Aug., 1901.	Average 17 tests.
Do.	28	......	262	..	D. B. Butler, P.I.C.E., vol. CXXXII, p. 346.	Average 4 English brands.
Do.	28	......	213	..	Ira O. Baker, "Treatise on Masonary Construction," 9th Ed. p. 78f.	French Specifications.

TABLE III.

PARTICULARS OF STEEL-CONCRETE ARCH BRIDGES.

Locality.	Particulars of Longest Span.							Name of Designer.	Reference.
	Span in Feet and Inches.	Rise in Feet and Inches.	Ratio, Rise to Span.	Thickness at at Crown, in Feet and Inches.	Thickness at Springing, in Feet and Inches.	Composition of Concrete.	Particulars of Steel Embedded in Concrete.		
Five-span bridge, Topeka, Kansas, U.S.A.	125ft. 0in.	19ft. 0in.	0·15	2ft. 0in.	6ft. 6in.	1 P.C., 2 sand, 4 broken stone, ½in. to 1in. gauge	Steel lattice girders, 18in. deep at crown and 26in. at springing, spaced 3ft., c. to c.	Messrs. Keepers and Thacher.	*Eng. News*, April 2nd, 1896.
Three-span bridge over Passaic R., Paterson, N.J., U.S.A.	89ft. 0in.	9ft. 6in.	0·11	1ft. 3in.	5ft. 6in.	1 P.C., 2 sand, 4 broken stone, ¼in. to 1in. gauge	10in. rolled steel girders, 25lbs. per ft., placed centrally in concrete, 3ft. c. to c.	Mr. Edwin Thacher.	*Eng. News*, March 16th, 1899.
Single arch bridge, Oconomowoc, Wisconsin, U.S.A.	21ft. 0in.	6ft. 8in.	0·32	0ft. 5in.*	1ft. 6in.	1 P.C., 3 sand, 4 crushed limestone, ¾in. gauge	One layer expanded metal, 16 g. 2¼in. mesh, near intrados	Mr. Charles F. Hall.	*Eng. News*, October 19th, 1899.
Bridges connecting mainland with Green Is., and Green Is. with Goat Is., at Niagara Falls (six spans in all)	110ft. 0in.	11ft. 6in.	0·10	3ft. 4in.	6ft. 4in.	1 P.C., 2 sand, 4 broken stone or gravel, between ¼in. and 1¼in. guage.	Layers of 6in. x ⅜in. steel bars (with rivets); bars spaced 3ft., c. to c., and 3in. from intrados and extrados respectively	Messrs. Keepers and Thacher.	*Eng. News*, December 6th, 1900.
Two bridges of three equal spans each, Fall Creek, Indianapolis, U.S.A.	74ft. 0in.	9ft. 6in.	0·13	1ft. 4in.	1ft. 9in. at 10ft. from springing then increases rapidly to abutment.	1 P.C., 2 sand, 4 gravel.	10in. rolled steel girders, 25lbs. per ft., spaced 3ft., c. to c.	Melan Arch Construction Co., New York.	*Eng. News*, April 11th, 1901.
Three-span bridge over Jacaguas R., Porto Rico	120ft. 0in.	12ft. 0in.	0·10	2ft. 4in.	6ft. 0in.	1 P.C., 2 sand, 4 broken stone, 1¼in. guage, including dust.	Layers of 4in. x ¾in. bars (with rivets); bars spaced 3ft., 2in., c. to c.	Mr. Edwin Thacher.	*Eng. News*, August 1st, 1901.
Single arch bridge over Rock Creek, Zoological Park, Washington, D.C., U.S.A.	80ft. 0in.	14ft. 0in.	0·17	1ft. 6in.	5ft. 0in.	1 P.C., 2 sand, 4 broken stone, 2½in. guage.	Steel lattice girders, 14in. deep at crown and 2ft. at springing, spaced 12in., c. to c.	Melan Arch Construction Co., New York.	*Eng. News*, October 31st 1901.
Two-span bridge, Bangor, Maine, U.S.A.	46ft. 8in.	8ft. 7in.	0·18	0ft. 11in.	2ft. 6in.	1 P.C., 2 sand, 4 gravel of size 2½in. to pea.	¾in. square cold-twisted steel bars, spaced 14in., c. to c., and 2in. from intrados and extrados respectively	Designed by Aberthaw Construction Co. of Boston, on the Ransome Patent.	*Eng. News*, March 20th, 1902.
Eight-span Y bridge, Zanesville, O., U.S.A.	122ft. 0in.	11ft. 6in.	0·09	2ft. 6in.	7ft. 0in.	1 P.C., 2 sand, 4 broken stone.	Steel bars about 5in. x ⅜in. (with rivets); bars spaced 3ft. apart, and 2in. from intrados and extrados respectively	Designed by Mr. E. J. Landor on the Thacher Patent.	*Eng. News*, March 27th, 1902.

* Reinforced by three concrete ribs 4in. thick and 2ft. wide at intrados.