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REINFORCED CONCRETE TROUGH ROOFING.

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Introduction—General description—Roof ventilation—Jack-arching *versus* trough roofing—Reinforced brickwork roofs compared—Reinforced concrete roofs compared—Sloping roofs—Moulding—Carriage and fixing at site—Tests—Method of testing—Calculations—Tables.

Introduction.

The origin of the trough roofing about to be described may be traced to the reinforced concrete flumes put up at Sulemanki Headworks to carry irrigation water for the compounds and gardens in the station. These flumes were precast in 10-foot lengths, 1 inch thick of section 9 inches by 6 inches, and lightly reinforced. They were carried on specially designed, precast reinforced concrete supports, and were meant to carry 0·2 cusec* on a gradient of 1 in 2,500.

Mr. E. R. Foy, C. I. E. (late Chief Engineer, Sutlej Valley canals) expressed doubts as to the strength and durability of this apparently slender but neat structure, and loading tests were carried out, which gave remarkably good results, the strength being much in excess of the requirements of a light-duty irrigation duct. This suggested their use as light and cheap girders for heavy roofs. It is over two years since these flumes were put in and they stand unimpared to this day.

From this beginning was developed a new system of precast, centerless, hollow flat roofing, which is cool, fireproof, strong but light, suited to all spans, and cheaper and more comfortable than the usual types.

General Description.

The roofing consists of 16-inch by 7-inch or 16-inch by 9-inch reinforced concrete troughs, laid side by side with the troughs covered by $\frac{3}{4}$-inch slabs, precast in 3-ft. lengths, bedded in mortar. The longitudinal joints between the troughs are grouted with cement mortar, and the space above these and between the top slabs is filled with cement concrete. If it is desired to provide a flat ceiling, slabs $\frac{1}{2}$ inch by 2 feet with side projections are slid in from the ends, so as to rest on corresponding projections in the troughs (Fig. 1). Above the top slabs is a cushion of 5 inches or less of rammed earth, gobri plastered. In floors, 2 inches of cement concrete is laid over the top slabs. Underneath, the joints between the troughs and the ceiling slabs are filled with mortar and the surface is then white-washed. In roofs the slope for drainage can be given either in the earth cushion or in the troughs themselves.

For spans from 6 to 11 feet the section used is 16 inches by 7 inches, and for spans from 12 to 14 feet, 16 inches by 9 inches. For spans of 14 feet or more a combination of 16-inch by 7-inch troughs and joists

* Cusec = cubic foot per second.

is used. In this case the troughs are cast solid for 6 inches at the end, and moulded so as to fit over the bottom flange of the joist and project an inch below it. For greater security the main tensile reinforcement of the troughs is bent up through the solid end to curve over the top of the joist, (Figs. 3, 4) where it is wired to similarly bent reinforcing rods left projecting from the troughs on the other side of the joist, and encased in cement concrete. Wire netting is wrapped round the bottom flanges of each joist to give a key for cement plaster to level off the ceiling and to afford protection to the joist from fire. As will be seen from the tables the cost is very much the same whether there is only one or more joists.

Roof Ventilation.

If it is desired to provide top ventilation wire gauze is substituted for the ceiling slabs at suitable intervals round the room, with corresponding openings to the outer air. These openings are also protected by wire gauze, and their number will regulate the ventilation. This system of ventilation through the ceiling should be very effective in removing the film of hot air which more than anything else keeps a room stuffy and hot. Opinions differ as to whether the troughs should contain a dead-air cushion or air in circulation, but it is generally accepted that a dead-air cushion is distinctly more effective, both against heat and sound conduction. Circulation in hollow roofs is necessary only when they contain wood work that can rot. It is also necessary in damp basement floors to remove the moisture. In a trough roof there is no woodwork, and a dead-air cushion appears preferable.

Jack-arching versus Trough-roofing.

The advantages of a trough roof over a jack-arch are :—

(i) Including a 5-inch earth cushion, it weighs 80 to 85 lb. per square foot against 150 to 160 lb. per square foot in the case of jack-arching. This means a reduction of over three tons of load per hundred square feet of roof and therefore a considerable reduction of load on the foundations. Also, with the lighter roof, the wall sections can be thinner, resulting in a further economy in cost and reduction in foundation loads.

(ii) Its initial cost is much less. There is a saving of almost 33 per cent.

(iii) It is fire-proof. There is no exposed steel or woodwork, as in the case of larger spans, and the steel joists are encased in cement with a minimum covering of one inch.

(iv) It requires no centering and is easier and quicker to erect.

(v) It gives a flat roof without any special ceiling.

(vi) It gives a cool roof, due to the air cushion in the hollows. It is also more nearly sound-proof.



Mistri quarters at Marala.

(vii) It admits of top ventilation.

(viii) It will take punkha hooks and other roof suspensions as easily as a jack-arch, besides giving a wider choice of points.

(ix) It bears evenly all over the walls like a reinforced concrete or a reinforced brick roof and has no concentrated loads under joists, except for spans of 14 feet or over, in which case the concentrated load under a joist is not much more than for a single 5-foot span of jack-arching. This gives more freedom in arranging openings.

Reinforced Brick Roofs Compared.

To the reinforced brick roof the trough roof is superior in the following respects :—

(i) It requires no centering.

(ii) It requires little supervision on the roof itself—all supervision being concentrated in a workshop. In reinforced-brick roofs this supervision is of paramount importance.

(iii) The reinforcement in a trough roof is free from the effects of salts ; in a reinforced brick roof the salts in the brick may attack the reinforcement and cause collapse.

(iv) It is somewhat lighter.

(v) It is much cooler and admits of roof ventilation.

(vi) It is suited to all spans, whereas a reinforced brick roof is not, except by the interposition of projecting girders.

Reinforced Concrete Roofs Compared.

Compared to the ordinary type of reinforced concrete roofing, a trough roof requires no centering, has the economy and coolness of a hollow-tile T-beam design, requires less supervision on the spot and is somewhat lighter and cheaper. In point of strength it compares favourably with the T-beam type, and is very much more economical than a flat-slab design. With the analysis of rates given in an appendix, the cost and strength data can be compared for different cases.

Sloping Roofs.

The trough design is as well suited to sloping roofs as to flat roofs. In the former case the earth cushion is dispensed with, and the top and ceiling slabs can also be left out unless a hollow and cool roof is desired. As sloping roofs have to carry less heavy loads the troughs can be made of lighter and cheaper sections.

Including top and ceiling slabs the trough roof (with section reduced to suit the required strength) will weigh no more per square foot than an Allahabad-tile roof, *i.e.*, 35 to 40 lb., and without the top and ceiling slabs it will weigh from 20 to 25 lb. per square foot, which is not far from

the weight of a single Allahabad-tile roof. It requires no intermediate trusses, purlins or battens ; only a through ridge girder. The side walls have ties suitably spaced to resist the outward thrust on them.

Calculations.

In the calculations attached, no account is taken of the additional ¾ inch thickness of concrete on the top (the top slab and the filling between these slabs). This, if considered, will make the sections much stronger both in compression and tension.

Again, the calculations for the cantilever are much on the safe side. If the troughs are individually considered, the assumptions are correct, but in actual practice the top flange of one trough butts against that of another, the joint being filled with cement, and further stiffening results from the top ¾-inch concrete filling.

Thus it will be seen the cantilever action will really never develop, so that, in addition to the usual factor of safety allowed in calculations, there will be a further and considerable factor of safety when the roof is assembled—the mass roof being much stronger than the individual troughs.

Moulding.

The standard sizes of mould, 16 inches by 7 inches and 16 inches by 9 inches, should cover all spans. The length of the mould for the former should be 12 feet so as to give any length up to this, and for the latter 16 feet. Shorter lengths can be made in those long moulds.

The moulds are of deodar wood sheet-lined inside for durability. They will give long service if kept in constant use or if carefully stored.

Before the mould is fitted together, the necessary reinforcement (which has been previously bent to shape and secured in position according to the calculations given in Table I) is placed ¾-inch clear of the bottom. This allowance is essential, as anything under ¾-inch will not be sufficient for fire protection. Special attention should be given to the correct spacing of the stirrups, especially in the end quarter spans, as any defect in these may lead to sudden failure from diagonal tension. The reinforcement being fixed in position, the top of the mould is fitted and the ends secured against any concrete running out.

The inside is now lightly smeared with waste oil, and the concrete, a 1 : 2 : 4 mixture, is poured in just wet enough to run and fill up every corner. The concrete should be thoroughly tamped as each panful is poured, and when the mould is full the whole should, if possible, be vibrated to expel any air and to fill the voids. The trough should then be left in the mould for 12 to 36 hours, according to the temperature. It is generally best to allow 24 hours, after which the concrete can stand a certain amount of rough handling such as is inevitable in removing the mould. The trough, out of the mould, should be kept covered by sacking and allowed to set in air for a day, after which it should be immersed in

water, placed in damp sand or itself filled with water. It should remain thus for at least 15 days, but a month is desirable. After a month the troughs are ready for use on a roof, and can be subjected to the full loads at once.

Carriage and Fixing at Site.

Care should be taken that the troughs are not thrown on the ground from any height. They should be gently deposited. They can either be lifted to the roof in slings or slid up sloping rails, greased if necessary. They should be placed in position over all the rooms and the ceiling slabs inserted from the ends before the finishing-off is done.

Before the troughs are laid the bearing surface of the walls should be carefully levelled to give them a firm, even bedding, the bottom line of the troughs being checked by a string. This done, the joints between the ceiling slabs and the trough projections can be filled, then those between the trough tops, after which the top slabs should be bedded in mortar over the troughs, and the spaces between these slabs filled with a weak cement concrete.

The earth covering should be placed as soon as the top slabs are completed and should be kept damp for a few days. A 4 to 6-inch covering of earth should be given. This will prevent temperature cracks and add to the coolness of the room. The ceiling can then be white-washed.

Tests.

Before using on a large scale it was necessary to subject the troughs to various loading tests. This was done at Sulemanki and Marala, and included tests for bending moment, diagonal tension, shock and deflection. All the tests bore out the theoretical calculations. The deflections at working loads were well within what was permissible. The tests give the strengths of individual troughs, but when assembled in a roof the strength would be much increased. In a test of a finished roof, where 98 men were made to stand on an area of about 110 square feet (the average load per square foot was one maund), no measurable deflection could be noticed, and when the men walked off the people in the room below hardly realised it, the roof was so sound proof.

In one of the troughs the stirrups were placed, by mistake, at three times the calculated distance in the quarter spans. This trough was tested, and though it gave excellent results for deflection, when about $2\frac{1}{2}$ times the working load had been put on, it failed suddenly, although the deflection was still inconsiderable.

This sudden callapse demonstrated very clearly the danger of insufficient provision against diagonal tension. Failure by tension is less to be feared, as it is gradual and there is ample warning given by the increasing deflection. Even after the yield point of the steel has been reached it may take days before failure occurs, if no further load is added.

The first building roofed by troughs was a store at Sulemanki. One of the troughs appeared to be cracked, though the crack possibly existed before the trough was placed on the roof. The Executive Engineer subjected it to a severe test which it withstood so successfully that it was left in position. The test consisted in making as many men as could squeeze on one length jump simultaneously.

Trough roofs have since been used for the mistris, peons and beldars' quarters at Marala, as well as for the overseers' quarters at Sambrial.

It is proposed to use the same type of roof for a rest-house at Pathanki (Upper Chenab Canal) and also for a set of sub-divisional quarters.

Method of Testing.

The tests were carried out on 10 and 12-foot clear spans. The ends were placed with the necessary bearing, evenly, on specially erected end blocks. A fine piano wire was stretched clear of the trough, but close to it in the plane of its under face. The $\frac{3}{4}$-inch top slabs were then placed on the trough to give an even bearing to the test load. One-cwt. bags were then placed uniformly across, one layer at a time, and in order to prevent any indeterminate distribution of load, due to arch action, no two bags were permitted to touch. With each layer the deflection was noted both morning and evening, and again on the next morning before placing the next layer. The load at which visible hair cracks first appeared was also noted and the cracks were located. These observations were continued as more load was added, till finally the trough failed. The results of these tests are shown in an appendix.

Calculations.

Clear span = 14 ft.

Size of trough = 16″ × 9″

l = Effective span = 14·75 ft.

f_c = Permissible compressive stress in concrete = 650 lb. per sq. in.

f_s = Permissible tensile stress in steel = 16,000 lb. per sq. in.

$$n = \frac{\text{Modulus of elasticity of steel.}}{\text{Modulus of elasticity of concrete.}} = 15$$

Sectional area of trough, top slab, joints and ceiling slab = 57·75 sq. ins.

Loading per foot run of trough 16″ *wide*—

Concrete	@ 144 lb. per cub. ft.	=	58 lb.
5″ earth	@ 100 lb. per cub. ft.	=	56 lb.
Live load	@ 40 lb. per sq. ft.	=	53 lb.
w = total load per foot run of trough		=	167 lb.

Neutral Axis.

Let d = depth of centre of steel below the surface of concrete = 8″

and kd = depth of neutral axis below that surface.

$$k = n \div (f_s/f_c + n) = 0{\cdot}378$$

$$\therefore kd = 3{\cdot}024''$$

Total Compression.

In computing the total compression only the top flanges are considered as effective. The webs, top slab and fill are neglected. This is an assumption on the safe side.



Test of 16″ ×7″ trough.

Assuming the full stress of 650 lb. per sq. inch at the upper face of the flange, the stress at the under face will be :

$$f_c\ (kd - 2)/kd = 220 \text{ lb.}$$

Total Compression

$$= \frac{650 + 220}{2} \times 6{\cdot}5 \times 2 = 5{,}655 \text{ lb.}$$

Where $6{\cdot}5'' =$ sum of the mean widths of the two sections of the flange.

$jd =$ arm of resisting couple $= 7{\cdot}17''$

Moment of Resistance—M_1

$$= M_1 = \text{Total compression} \times \text{arm of couple}$$
$$= 5{,}655 \times 7{\cdot}17$$
$$= 40{,}500 \text{ inch-lb.}$$

Bending Moment—M

$M = wl^2/8 = 54{,}500$ inch-lb.

As M is greater that M_1, when the steel will be stressed to the permissible limit, the concrete will be stressed beyond it and will therefore require reinforcement on the compression side. As the concrete can resist a moment equal to M_1 the compression steel will be required to resist $M - M_1 = M_2 = 14{,}000$ inch-lb.

Let $A_s =$ Area of tension steel.

Let $A_{s1} =$ Area of compression steel required to resist M_2.

$f_s{}^1 =$ stress developed in compression steel.

Let $ad =$ distance of centre of compression steel to top surface of concrete $= \frac{3}{4}$ in.

$\therefore a = 0{\cdot}094$

$f_s{}^1 = f_s\ (k - a)/(1 - k) = 7{,}300$ lb./sq. in.

$As = M/f_s\, jd = 0{\cdot}475$ sq. in.

The area of 2 bars $\frac{7}{16}$ inch diameter plus 1 bar $\frac{1}{2}$ inch diameter equals 0·496 sq. in.

$A_{s1} = M_2/d\,(1-a) = 0{\cdot}272$ sq. in.

Use four bars $5/16''$ diam. $= 0{\cdot}306$ sq. in.

Shear.

$V = wl/2 = 1230$ lb.

Unit shear $= v = V \div$ effective sectional area

Now effective sectional area equals area of concrete below the neutral axis, but above the tensile steel plus 2/3rds area of concrete above the neutral axis = 28·1, say, 28 sq. ins.

Hence $v = 44$ lb./sq. in.

Since this is greater than 40 lb. per sq. in. permissible, stirrups are required for a distance. $x = l\ (1 - 40/44)/2 = 0{\cdot}67$ ft. $= 10$ ins.

Assuming steel to take 2/3 of the diagonal tension

Total diagonal tension $= 2/3 \left(\frac{44 + 40}{2}\right) \times 10 \times \frac{28{\cdot}1}{7{\cdot}17} = 1100$ lb.

Where $\frac{28{\cdot}1}{7{\cdot}17} = \frac{\text{Effective sectional area for shear}}{j\ d}$ = equivalent width of beam $= b$.

Tension taken by two 3/16 in. stirrups $= 2 \times 2 \times 0{\cdot}0276 \times 16000 = 1768$ lb.

These two stirrups are more than enough. Actually, however, the first two stirrups are spaced 5 inches and the remainder 6 inches up to the quarter span and 12 inches in the middle half. This number is required to keep the reinforcement in place, and also to guard against cantilever action referred to later. It is always desirable to be on the safe side in providing for diagonal tension as a failure due to it, being sudden, is most to be feared.

Bond.

$u = V/ojd = 40$ lb. sq. in.

This is safe as 80 lb./sq. in. is permissible.

Here o = Circumference of two 7/16 in. and one $\frac{1}{2}$ in. bar $= 4{\cdot}32$ sq. ins.

Projecting Cantilever.

In a finished roof, where one trough butts against the other, cantilever action will not occur. This check is made to determine the strength of a trough acting as an individual unit.

The following loads tend to break the web considered as a cantilever fixed to the bottom flange :—

A = Weight of web itself $= 7{\cdot}1$ lb.

B = Weight of top slab, earth and live load $= 49{\cdot}0$ lb.

C = Weight of top flange $= 6{\cdot}4$ lb.

D = Weight of concrete in joint, earth and live load on this part $= 11{\cdot}3$ lb.

Take moments about the neutral axis in the plane XX (Fig. 2).

$M = 7{\cdot}13 \times 0{\cdot}64 + 49 \times 2{\cdot}4 + 6{\cdot}4 \times 3{\cdot}1 + 11{\cdot}3 \times 3{\cdot}9 = 175{\cdot}9$ in.-lb.

A_s = tensile reinforcement required $= M/f_s\, jd = 0{\cdot}017$ sq. in.

3/16 inch bar, area 0·0276 sq. in. per foot as provided is more than sufficient.

Note.—$d = 1{\cdot}25 - 0{\cdot}50 = 0{\cdot}75$ in.

To determine whether the concrete at XX will be safe against crushing, it is enough to calculate the depth of a beam for a design where steel and concrete are fully stressed.

($M = \frac{1}{2} f_c\, kjb\, d^2 = 1282\, d^2$ lb./in.

$\therefore\ d = \sqrt{M/1282} = 0{\cdot}37$ ins.).

The actual value of d is 0·75 in. so that the concrete is safe in compression.

Shear.

$V = 7{\cdot}13 + 49 + 6{\cdot}4 + 11{\cdot}3 = 73.83$ lb.

$v = V/bjd = 9{\cdot}5$ lb./sq. in.

This is safe, as 40 lb./sq. in. is allowed.

TABLE I.

Data for Design of Reinforced Concrete Trough Roofs.

Clear span.	Length of one trough.	Total load per foot.	B. M.	V.	Type.	Reinforcement. Tensile.	Reinforcement. Compressive.	Reinforcement. Stirrups.	Concrete one trough.	Steel. One trough.	Steel. 100 sq. ft.	Concrete including both slabs. One trough.	Concrete including both slabs. 100 sq. ft.	Cost per sq. ft. with ceiling.
Feet.	Feet.	lb.	inch-lb.	lb.	ins.	sq. in.			lb. cwt.	lb.	lb. cwt.	c. ft. lb.	c. ft. lb.	Rs.
8	9	160	17,400	680	16 × 7	0·21 3 bars 5/16″	(*a*) 2 bars 3/16″	3/16″ diam. spacing 3″, 6″ and 12″ (*b*).	317 2·83	8	75 0·67	3·3 477	31·1 or 4,475	-/7/9
10	11	160	16,500	840	16 × 7	0·32 3 bars 3/8″	2 bars 3/16″		388 3·46	20	150 1·34	4·0 583	30·3 or 4,372	-/9/-
12	13	160	37,500	1,000	16 × 7	0·45 3 bars 7/16″	4 bars 5/16″		458 4·08	40	250 2·23	4·8 689	29·9 or 4,306	-/11/-
12	13	167	39,200	1,050	16 × 9	0·34 3 bars 3/8″	(*a*) 2 bars 3/16″		527 4·70	22	138 1·23	5·2 753	32·7 or 4,706	-/9/3
14	15·6	167	54,500	1,230	16 × 9	0·475 2 bars 7/16″ + 1 bar ½″	4 bars 5/16″		631 5·64	50	268 2·3	5·9 847	31·5 or 4,538	-/11/6

(*a*)—None required according to calculation.
(*b*)—First 2 stirrups spaced 3″, remainder 6″ in outside quarters and 12″ in middle half of span.

TABLE II.

Reinforced Concrete Trough Roofing.

Analysis of Rates:—

1. *Concrete per* 100 *cub. feet—*

	Rs.
Ballast 85 cub. feet @ Rs. 25/- per 100 cub. feet ..	21·25
Sand 42 cub. feet @ Rs. 5/- per 100 cub. feet ..	2·10
Cement 22 cub. feet @ Rs. 2/4/0 per 100 cub. feet ..	49·50
	72·85
	Rs.
	73
Labour	27
Moulds	7
Total per 100 cub. feet ..	107
2. *Reinforcement per cwt.*	14
3. *Carriage and laying per* 100 *sq. feet—*	
Carriage up to one mile .. .. Rs. 2/8/-	
Fitting for ceiling, etc. .. .. „ 3/8/-	Rs. 6.

Cost per 100 *sq. feet.*

Section.	7 inches × 16 inches.			9 inches × 16 inches.	
Span.	8 feet.	10 feet.	12 feet.	12 feet.	14 feet.
	Rs.	Rs.	Rs.	Rs.	Rs.
Concrete ..	33·3	32·4	32·0	35·0	33·7
Reinforcement ..	9·0	18·8	31·22	17·2	32·2
Fitting, carriage, etc.	6·0	6·0	6·0	6·0	6·0
Total cost ..	48·3	57·2	69·22	58·2	71·9
per 100 sq. feet ..	..	..	..	..	..
Cost per sq. ft. ..	-/7/9	-/9/-	-/11/-	-/9/3	-/11/6

Cost of ceiling (included in above).

	Rs.
Concrete 3·1 cub. feet @ Re. 1 per cub. foot	3·1
Labour of pointing, etc.	3·1
Total ..	6·2
Say ..	6/4/-

or -/1/- per sq. foot.

TABLE III.

Cost of Jack-arch Roofing at Marala.

5″ brick, 60°—arch, 1½″ concrete over crown.

Bricks and concrete in cement, 5″ earth.

	Load per 100 sq. ft.	Cost per 100 cub. ft.	Cost Per sq. ft.
	lb.	Rs.	Rs.
Lime and cement brickwork	56·4	47	0·221
Lime and cement concrete ..	54·0	44	0·198
Mud ..	40·0	1	0·004
Total ..	150·4	..	Rs. ·423 = 6·768 annas say -/7/-

Extras.—

Centering ..	..	..	.. Re. -/1/- per sq. ft.
Ceiling ..	..	..	.. ,, -/2/6
Plaster ..	..	..	.. ,, -/1/-
Total with ceiling	..	..	.. ,, -/11/- or Rs. 68·7 per 100 sq. ft.
Total with plaster	..	..	.. Re. -/9/- per sq. ft. Rs. 56·3 per 100 sq. ft.

TABLE IV.

Cost of Reinforced Concrete Trough Roofs combined with Steel Joists for Large Spans.

Size of room.	Span of trough.	Sizes of troughs.	Cost per 100 sq. ft.			Total.	Cost per sq. ft.
			Joists @ Rs. 13 per cwt.	Troughs.	Solid piece and reinforcement @ -/5/- per l. ft.		
Feet.	Feet.	Inches.	Rs.	Rs.	Rs.	Rs.	Rs.
8 × 10	8	7 × 16	..	48	..	48	-/7/9
10 × 12	10	7 × 16	..	57	..	57	-/9/-
12 × 14	12	7 × 16	..	69	..	69	-/11/-
12 × 14	12	9 × 16	..	58	..	58	-/9/3
14 × 16	14	9 × 16	..	72	..	72	-/11/6
14 × 16	8	7 × 16	29	48	5/-	82	-/13/-
16 × 18	9	7 × 16	23·1	48	5/10/-	86	-/13/9
18 × 20	10	7 × 16	28·6	57	6/4/-	92	-/14/9
,,	7	7 × 16	45	48	12/5/-	106	1/1/-
20 × 22	11	9 × 16	31·3	58	7/-	96	-/15/3
,,	7·75	7 × 16	45	48	14/-	107	1/1/-

TABLE V.

Cost of Jack-arch Roofs.

Dimensions of room.	Area.	Clear span.	Size of joist.	Weight per foot run.	No. of joists.	Weight per sq. ft.			Cost of 100 sq. ft. of roofing.					
						Joists.	Roofing material.	Total.	Joists.	Roofing material.	Plaster.	Ceiling.	Total.	Total minu cost of ceiling.
Feet.	Sq. ft.	Feet.	Inches.	lb.		lb.	lbs.	lb.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.
8×10	80	8	6×3	12	1	1·3	150·4	152	16·3	50	6	10	83	73
10×12	120	10	7×4	16	2	2·9	,,	153	34·0	,,	,,	,,	100	90
12×14	168	12	8×4	18	2	2·8	,,	153	32·5	,,	,,	,,	99	89
14×16	224	14	9×4	21	3	4·4	,,	155	50·6	,,	,,	,,	117	107
16×18	288	16	10×5	30	3	4·5	,,	155	58·5	,,	,,	,,	125	115
18×20	360	18	10×5	30	4	7·3	,,	158	77·4	,,	,,	,,	143	133
20×22	440	20	12×5	32	4	8·7	,,	159	74·2	,,	,,	,,	140	130

TABLE VI.

Weights and Cost of Trough Roofs and of Jack-arch Roofs compared.

Size of room.	Clear span.	Jack-arch roofs.				R. C. trough roofs with ceiling.			Saving in trough over jack-arch roofs.			Remarks.
		Load including joist.		*Cost per 100 sq. ft.*		*Dead Load.*		Cost per 100 sq. ft.	Load per 100 sq. ft.	Cost per 100 sq. ft. jack-arches with ceiling.	Cost per 100 sq. ft. jack-arches without ceiling.	
		Per sq. ft.	Per 100 sq. ft.	With ceiling.	Without ceiling.	Per sq. ft.	Per 100 sq. ft.					
Feet.	Feet.	lb.	Cwt.	Rs.	Rs.	lb.	Cwt.	Rs.	Cwt.	Rs.	Rs.	
8×10	8	152	135·6	82	72	80	71·4	48	64·2	34	24	
10×12	10	153	136·5	100	90	80	71·4	57	65·1	43	33	Generally speaking the *cost* of trough roofs is ⅔rds that of jack-arch roofs and the dead load is approximately half.
12×14	12	153	136·5	99	89	85	75·9	58	60·6	41	31	
14×16	14	155	136·5	117	107	85	75·9	72	62·3	45	35	
16×18	16	155	138·2	125	115	83	74	86	64·2	39	29	
18×20	18	158	141	143	133	83	74	92	67	51	41	
20×22	20	159	141·8	140	130	88	78·5	96	63·3	44	34	

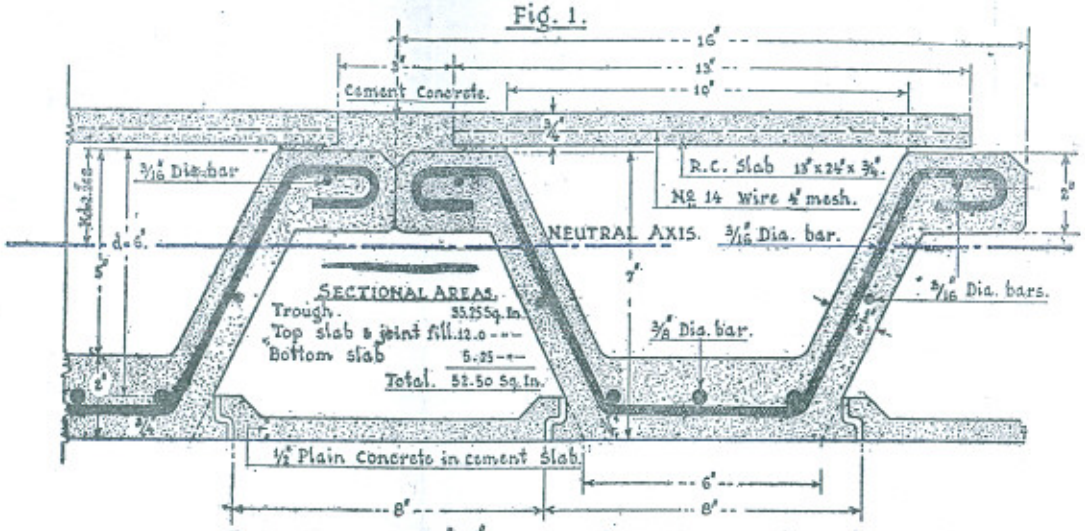
NOTE.—Necessary allowance has been made for plastering under jack-arches. Working load over roof not included.

REINFORCED CONCRETE TROUGH ROOFING.

Figs. 1 & 2. Scale in Inches.



Fig. 1.



R.C. TROUGH 16"x7" FOR 10-FOOT CLEAR SPAN.

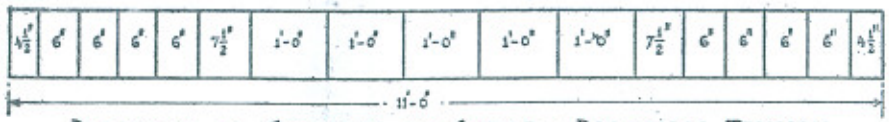
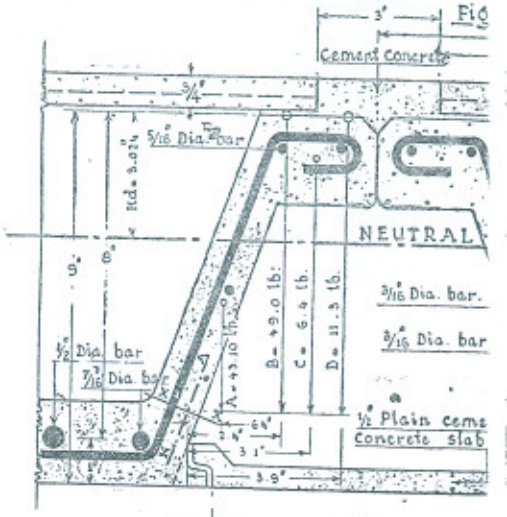


DIAGRAM OF STIRRUPS FOR SHEAR & DIAGONAL TENSION.

Proc. P.E. Congress Vol. XVI - 1928.



R.C. TROUGH 16"x9" FOR 1



DIAGRAM OF STIRRUPS FOR S

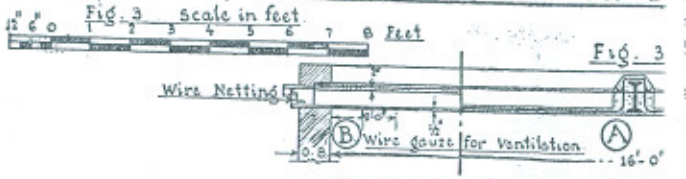


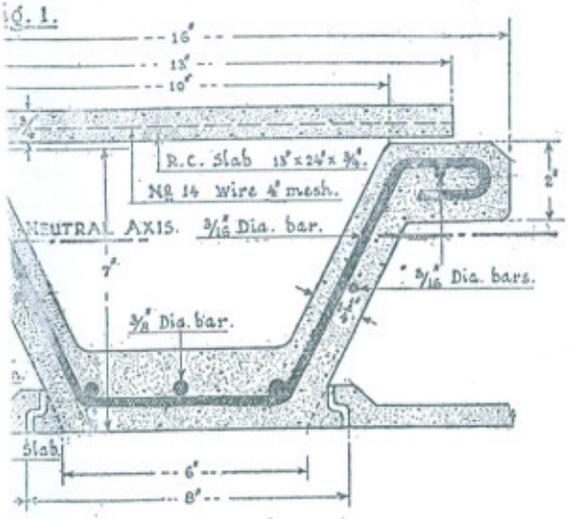
Fig. 3

COMBINED ROOF OF R.S.

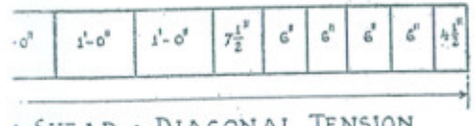
E TROUGH ROOFING.

le in Inches.
7 8 9 10 11 12 Inches.

ig. 1.

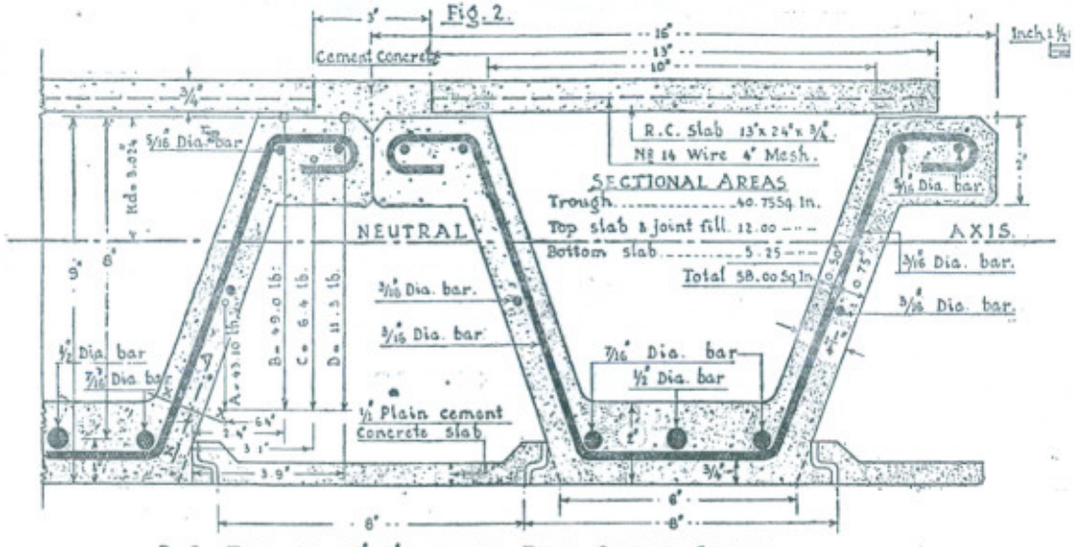


2 10-FOOT CLEAR SPAN.



2 SHEAR & DIAGONAL TENSION.

Fig. 2.



R.C. TROUGH 16'x9' FOR 14-FOOT CLEAR SPAN.

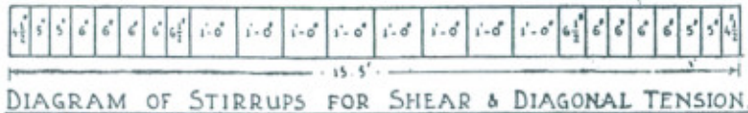
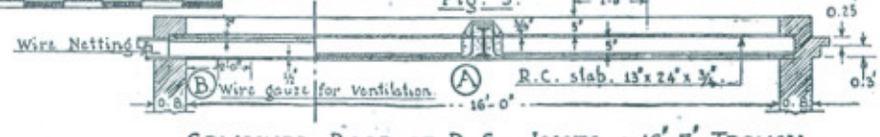


DIAGRAM OF STIRRUPS FOR SHEAR & DIAGONAL TENSION.

Fig. 3 scale in feet.



Fig. 3.



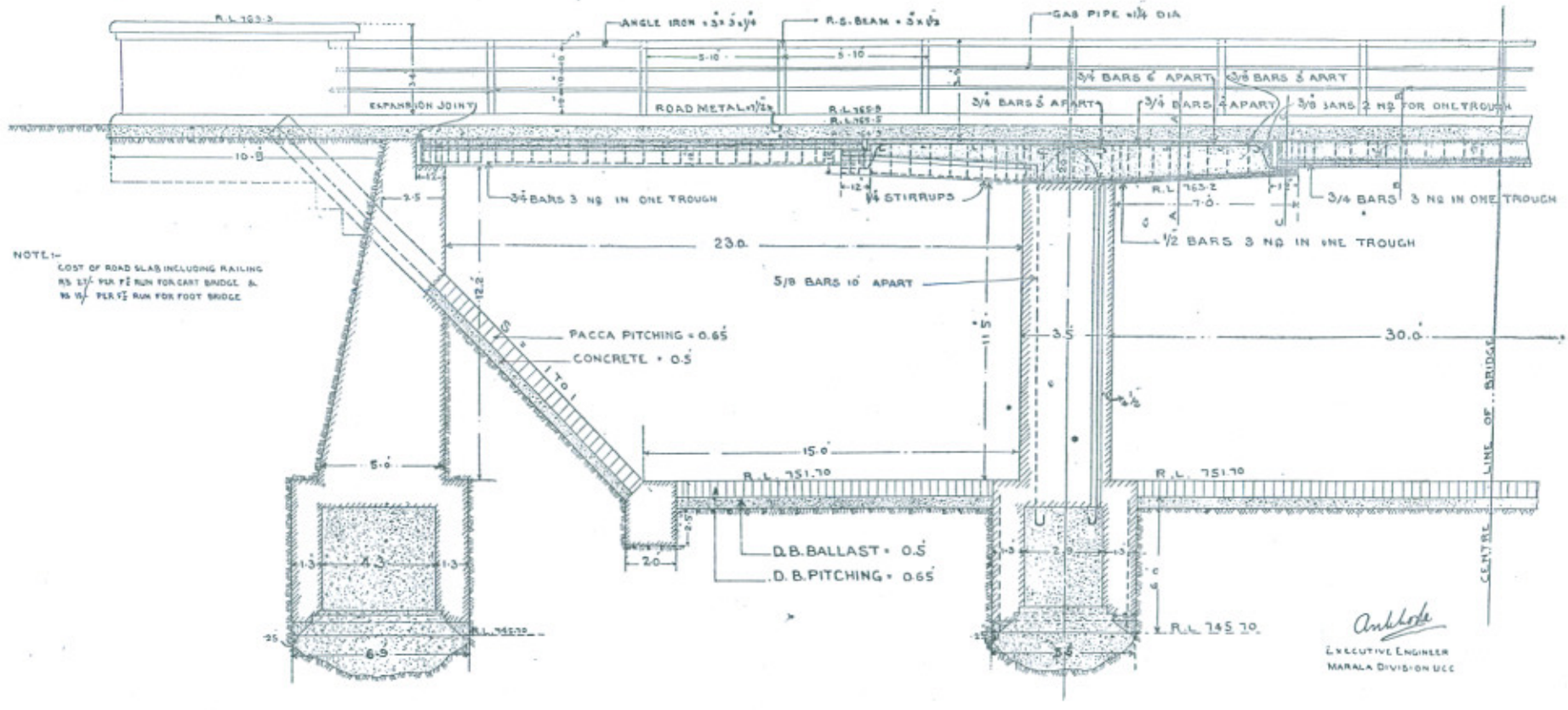
COMBINED ROOF OF R.S. JOISTS & 16'x7' TROUGH.

·25

Wire Ga

A.N. KHOSLA.

R C TROUGH BRIDGE 30 FT. CLEAR SPAN



NOTE:-
COST OF ROAD SLAB INCLUDING RAILING
RS 17/- PER FT RUN FOR CART BRIDGE &
RS 15/- PER FT RUN FOR FOOT BRIDGE

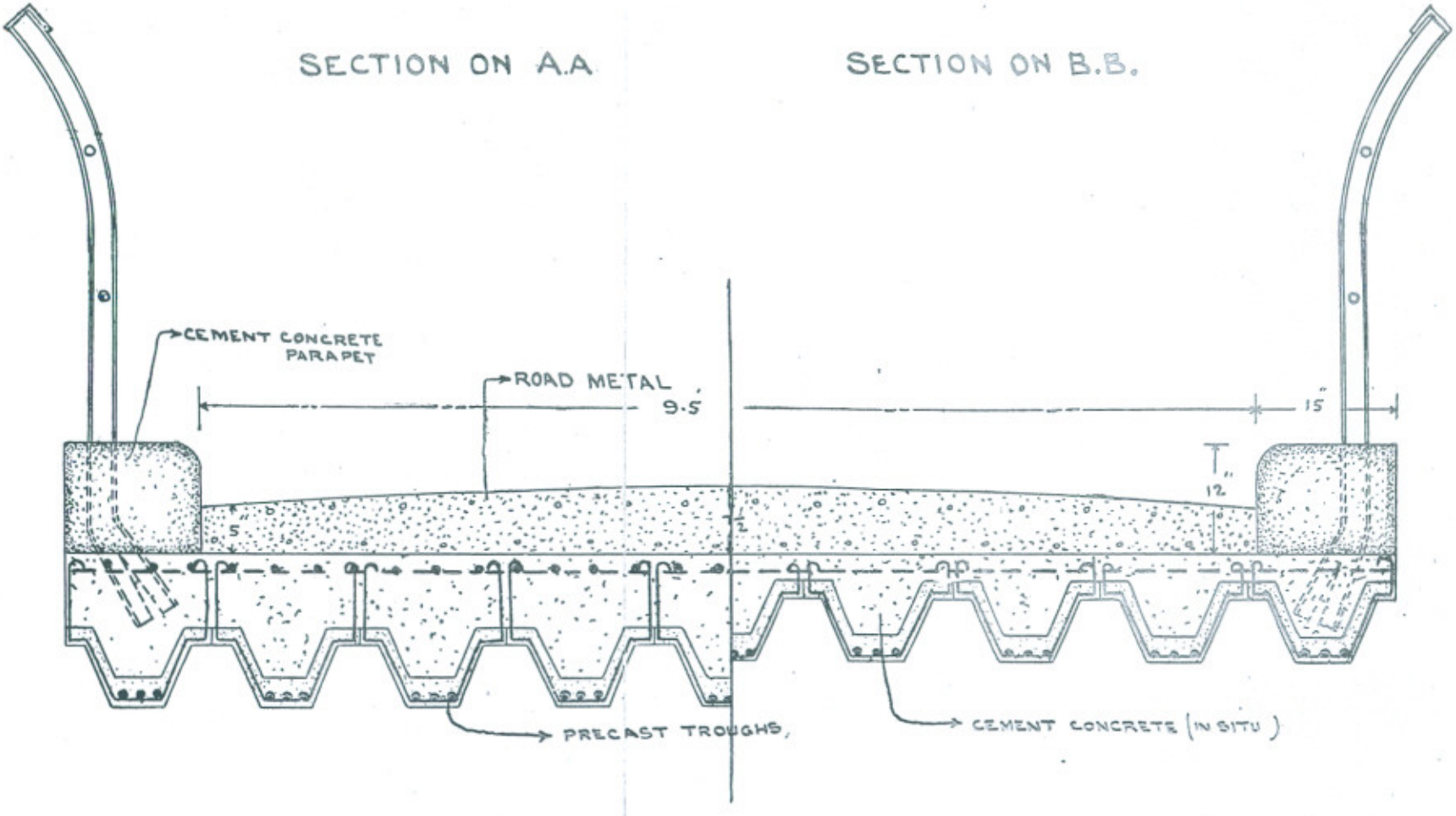
EXECUTIVE ENGINEER
MARALA DIVISION UCC

MARALA DIVISION U.C.C.

R.C TROUGH BRIDGE = 30FT SPAN

SECTION ON A.A

SECTION ON B.B.

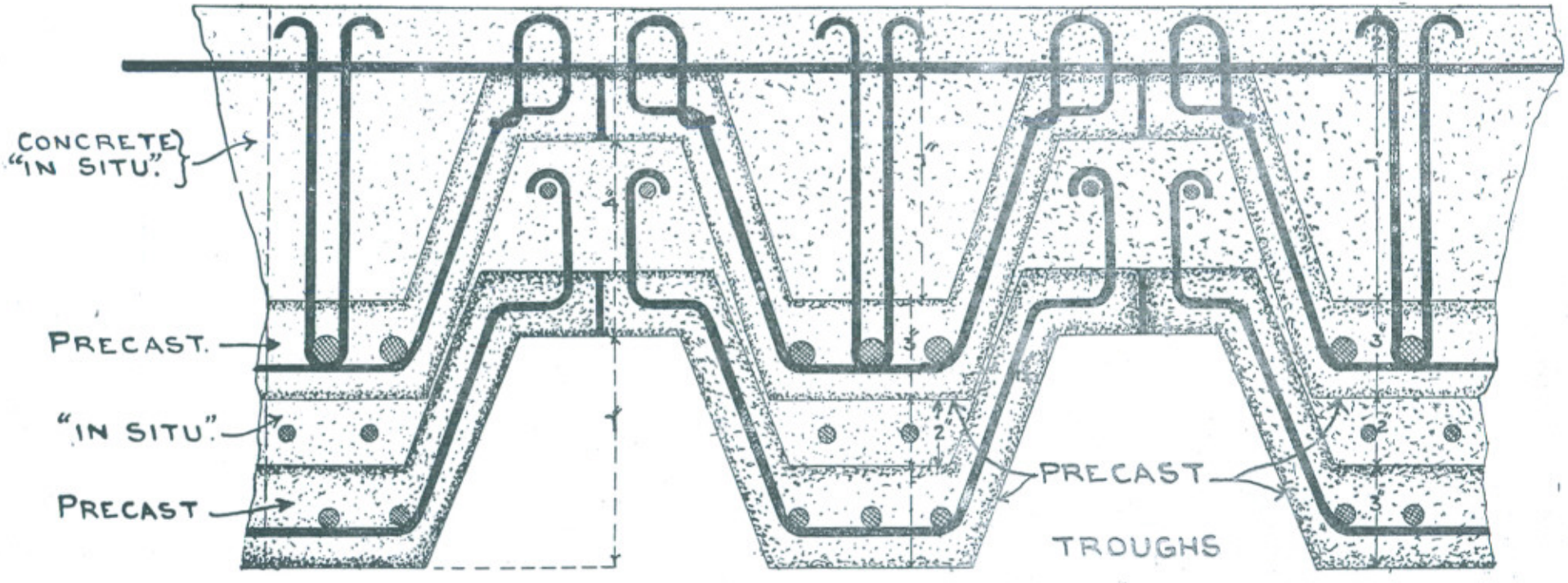


EXECUTIVE ENGINEER
MARALA DIVISION U.C.C.

MARALA DIVISION U.C.C.

R.C. TROUGH BRIDGE 30ft SPAN

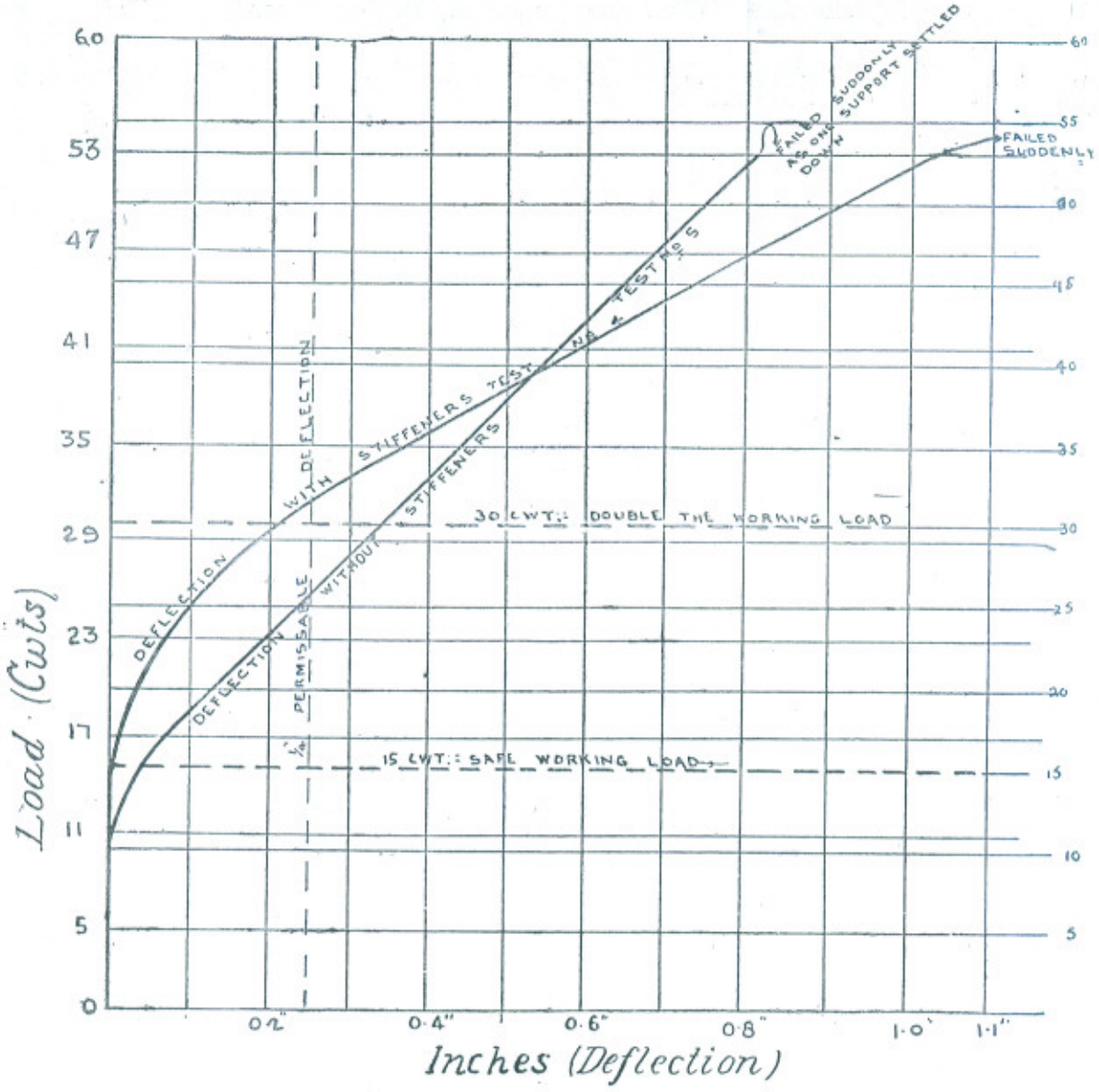
SECTION ON C.C.



Ambrose

EXECUTIVE ENGINEER

MARALA DIVISION U.C.C.



Ankhola

EXECUTIVE ENGINEER

MARALA DIVISION U. CHENAB CANAL

DISCUSSION.

MR. A. N. KHOSLA, Joint-Author, in his introductory remarks stated that the great feature of the trough is that all unnecessary concrete is dispensed with beyond the absolute minimum that is required for giving cover to the reinforcing steel or for giving stiffness or for strength in compression. The concrete of the trough, including the top and bottom slabs, gives a total thickness of from 3″ to 3½″ but the strength is that of a girder 7″ to 9″ deep according to the depth of the trough. This trough roof is the lightest flat roof possible and as such is eminently suited for buildings in water logged or threatened areas where too much load on the foundations is highly undesirable. He added that the other advantages had been dealt with in the paper.

The rates given in the paper are those at Marala and could be varied to suit different localities. The cost of moulds might be approximately taken as Rs. 6/- a running foot. Thus a 14′ mould would cost about Rs. 84/- including the galvanized iron sheet lining.

A number of tests were made on the troughs after sending in the paper and a statement of these as sent to the Honorary Secretary but it was too late to be printed. The tests generally bear out the calculations. The largest span tested was 16′ clear. It was designed to take 24 cwts. as normal working load and it stood with a load of 82 cwts. The deflection became great and the load was removed as the elastic limit had apparently passed.

(A curve of deflections for a 10′ trough was shown on a tracing exhibited by Mr. Khosla).

The factors of safety obtained in the various tests ranged from 3 to 3¾. The photograph opposite page 90 showed the test of a 10′ clear span trough which was meant to stand 15 cwts. only but which actually stood 59 cwts. before it broke, thus giving a factor of safety of almost 4.

Since writing the paper, the trough roofs on the Pathanke Rest House (Nokhar Sub-Division) had been completed and appeared to be a satisfactory job. The maximum span in this rest house is 14′.

The Joint-Author went on to say that a recent development of the trough is its use on road bridges of all descriptions. A bridge of 3 spans of 12′ clear designed for a 15 ton road roller is under construction in the Upper Chenab Circle and quite a number of other trough bridges are under consideration. He showed a typical 15 ton road roller bridge section and pointed out that it would be noticed that the trough is pre-cast and the full thickness is obtained by adding 1 : 2 : 4 concrete at site. The pre-cast work and the work at site, are held together by stirrups spaced at suitable intervals, and also by a layer of cement grout which is put on the pre-cast work before fresh concrete is laid on. It would be noticed that there is no centering whatsoever

and that, whereas the full thickness of compression concrete is secured, half of the unnecessary concrete below the neutral axes is dispensed with, resulting in lightness and economy. The cost of the completed trough roadway slab would be about R. 1/8/- to 1/12/- a square foot.

The Joint-Author explained that for long span bridges another design had been worked out for a cart bridge where 30′ spans are covered by pre-cast troughs without any centering the necessary section being obtained at each site by putting on fresh concrete tied to the pre-cast work by stirrups worked out to take the stresses. The roadway which is 9·5′ clear between the wheel guards would cost on the average Rs. 26/- a running foot or about Rs. 800/- to 900/- for each span of 30 ft. A comparison of these figures with those given in Mr. Fane's paper would show how much saving could be effected by the elimination of shuttering. A parapet or a through girder type bridge is apparently much more costly than this plain trough type and more difficult to erect. More particularly in a foot bridge, the quantities of materials and the cost involved in the parapet girders are more than that of the actual road slab they are meant to carry. The reduction in loads is obtained by the trough design without sacrificing the effective depths. The middle 18′ troughs are freely supported over the 7′ cantilevers projecting either side of each pier. The 18′ slab has 12″ overall depth for purposes of strength but only 8″ for weight.

The cantilevers vary from 16″ at the end to 20″ at the supports, the net thickness being only $12\frac{1}{2}$″ and $15\frac{1}{2}$″. The design had been worked out on the basis of the standard loading for cart bridges.

Mr. Kanwar Sain, Joint-Author in his introductory remarks stated that the idea of reinforced concrete trough roofing really came from the iron troughing plates used as flooring in the combined road and railway bridge at Suleimanke. The few tests carried out on the reinforced concrete flumes were quite encouraging. The final form as discussed in the paper, was the result of subsequent tests and of a detailed study of the defects noticed during these tests. The theoretical work regarding the actual compression area of concrete and the reinforcement required for various spans for various loads were evolved later. At first it was considered doubtful whether the trough shape with thin webs could be dealt with as a beam, but the exhaustive tests made by him at Suleimanke and by Mr. Khosla at Marala substantially corroborated the theoretical calculations. He thought it a pity that these tests were sent late and therefore do not appear with the paper. He felt sure that a study of these tests would convince the most sceptical of the reliability of this form of construction. Several roofs, with and without ceilings, were constructed at Suleimanke. Later the roofs of a cook house and of outhouses were constructed in Sechanwala Sub-Division of the Western Bar Division and on a larger scale in Merala Division using these pre-cast troughs on spans of 6, 8, 10, 12 and 14 ft.

He explained that the trough shape as the most economical in the use of concrete, would be apparent from the fact that every part of it, top compression flanges, the webs and the bottom steel protecting thickness, serve as a roof-covering, thus giving a maximum covering capacity for the same quantity of concrete. It could be readily shown that the T-shape could not compare with the trough-shape for covering capacity, using the same quantity of concrete.

In the paper before the Congress the trough form of construction is considered only as a type of roof for houses. He believed it had a much wider scope of utility. For closure works this type would be especially useful. There was no trouble with expansion joints as experienced by Mr. Fane.

Referring to Mr. Nicholson's remarks on Mr. Fane's paper, regarding future increase of load, he pointed out that troughs have a special advantage. After 5 or 6 years when load might increase, these troughs could be easily removed and replaced by heavier sections, the lighter sections being used on third class roads. It would be unjustifiable to invest more capital now in anticipation of heavier loads on some future date. At present putting ordinary reinforced concrete slabs for bridges over distributaries is a troublesome business for the S. D. O. He knew the arrangement and the carriage of centering to be a difficult business and that the placing of reinforcement in its proper position needs careful supervision. With this pre-cast trough type of construction a few moulds or even one, might do for small jobs, and trough making could be started on the same day as the concreting of the founds. Once shown how to do it, it is difficult to make an error in placing the reinforcement. Another important point is to keep the concrete wet. This is easy to do, as the trough will hold a fair quantity of water, which will last for several days. By the time the abutments are built up the troughs are also ready for roofing the span. He thought trough construction would be useful for hollow walls and should prove efficacious in excluding heat or cold owing to the enclosed layer of air. The authors had, however, not yet tried it in this form.

A sketch of the mould and of the cast iron block used for bending the stirrups would have been a useful addition to the paper and he regretted its omission. The sketches have been supplied to be printed in the book. He wished to add a word about actual costs. As far as labour is concerned, he thought the rates given in Table II in the paper would generally hold for every place in the Punjab but the cost of materials, especially the cost of stone ballast, might be high enough to make the cost of this type of roofing equal to that of jack arching.

Substitution of pacca brick ballast in place of stone ballast might result in comparative cheapness but, as yet, enough is not known about the strength of brick ballast concrete. In the calculations given in the paper for the strength of the trough, 650 lbs. was taken as the safe

permissible working compressive stress in concrete for concretes having an ultimate compressive stress of at least 2,000 lbs. per square inch at an age of 28 days, thus giving a factor of safety equal to three. Experiments carried out by Mr. A. G. C. Fane on 1 : 2 : 4 concretes, using brick ballast and kankar as coarse aggregates give an ultimate mean compression stress of about 2,500 lbs. per square inch. Mr. Fane has actually adopted a working stress of 500 lbs. per square inch for 1 : 2 : 4 kankar concretes in his designs. During March 1926, some 6" cube blocks of 1 cement 2 pacca brick surkhi and 4 pacca brick ballast (not Jhama) were sent from Suleimanki to the Government Test House. The minimum of the reported ultimate compression strength at an age of 2 months' was 2,754 lbs. Assuming that concrete at 2 months' age is about 25% stronger than that at one month, the minimum ultimates strength of these tested blocks comes out to be 2,200 lbs. per square inch, which is more than a 2,000 lbs. limit.

In order to stick to 650 lbs. as the safe working stress in case of brick ballast, so that the same section of reinforced concrete trough might be retained owing to considerations of weight, it might be possible to achieve this by making the mix slightly richer than 1 : 2 : 4.

The December 1927 issue of *Concrete* gives the following useful information about the strength of brick ballasts :—

Mix.		
1 cement ..		
1 sand ..		Comp. strength at 28 days 4,000 lbs. per square inch.
2 crushed brick ballast ($\frac{1}{4}$" to $\frac{1}{2}$" size) ..		
1 cement ..		
1 brick surkhi ..		4,400 lbs. at 28 days.
2 crushed brick ($\frac{1}{4}$" to $\frac{1}{2}$" size ..		

He did not say that these values might be accepted as they are, but it would be worth while for some one who has the facilities at hand to study by means of experiments the strength of brick concretes for various proportions.

He wished to say a word about the permisssible tensile stress of steel as taken in the design. 16,000 lbs. per sq. inch was allowed for British Steel or Tata's tested steel, complying with B. E. S. A. specifications. But in the market, sections generally available below $\frac{1}{2}$" diameter are continental. Ultimate tensile stress for continental steel is generally 24/28 tons against 28/33 tons for British Standard steel per square inch. Taking a factor of safety of four in each case, the permissible working stress in British steel comes to 16,000 lbs. which for continental steel is 13,500 lbs. per square inch. But sections of continental steel are generally lighter and are accepted by the Indian Stores Department subject to a maximum variation of 10 per cent. below standard British weights. Making an allowance for this, a safe tensile value with four as the factor of safety works out as 12,000 lbs. per square inch. If

continental steel be used the sections of reinforcement would need to be slightly altered from what has been shown in the diagrams attached to the paper.

He thanked Mr. Nicholson, Mr. Montagu and Mr. B. P. Varma without whose kind help and encouragement it would have been almost impossible to carry out the experiments with troughs as to their ultimate strength or to use them on buildings in place of jack arching in order to expose this type of roof to the test of time.

MR. A. G. C. FANE, pointed out that apparently the method of loading with filled bags gave an arch effect. (Mr. Khosla explained that the bags were in separate rows and Mr. Fane withdrew this criticism). He thought the difficulty of carriage of these large pre-cast troughs would be great.

MR. AJIT SINGH referred to the fact that in using these troughs specialized construction would be necessary wherever works were taking place. He also thought there would be considerable difficulty in raising the troughs into position.

MR. W. S. DORMAN observed that one of the severe tests described in the paper consisted in making as many men as could be squeezed on to one length jump simultaneously. He asked what would have happened to the men had the test failed !

MR. H. W. NICHOLSON, referring to the difficulty of transport of the troughs said it was better one or two should break on the way than fail in the work afterwards. He wondered if it would be impossible to devise some method of mixing concrete in vacuum in order to remove air voids and so increase permissible stress.

MR. R. P. HADOW pointed out that an objection to jack arch roof construction as used in the Irrigation Branch rest houses was that it caused echo. He did not know if Mr. Khosla has used the trough system over similar spans in similar rest houses. If so, Mr. Khosla might tell the meeting if his method of construction entirely obviated echo. If it did, it was a very good point.

Mr. B. M. SULLIVAN said it appeared that Mr. Khosla had taken up a method of construction with many good points. The jack arch was ugly and caused echo. This had in many places been displaced by reinforced brick roofs. In its turn this method, though it possessed advantages lacking in jack arck construction, had been found unsatisfactory largely due to the difficulty of supervision, with consequent leakage of water to the rods. This caused rusting and risk of failure. The advantages of the trough construction appeared to be that the beams could be made on the ground and the work easily supervised, centering was not needed, the cost was no more than other methods and the air cushions should give a cool roof. He doubted if the bars had enough cover in all cases.

COLONEL B. C. BATTYE congratulated the author and said that he was convinced that the investigations were a move in the right direction. The omission of the need for centering and concentration of manufacture under conditions permitting of proper supervision, were both features of great importance, especially in the view of the likelihood of the early employment of water cement ratio methods of proportioning concrete.

With regard to the proposed use of troughing for bridge flooring and heavy loads, he pointed out that the stirrups left in the pre-cas trough would have to be very carefully calculated to meet the shearing stresses between the new and the old work.

A practical point that the author should bear in mind was that the ends and corners of the pre-cast beams should be protected so as to prevent them being damaged in transport.

MR. KHOSLA, Joint-Author, in replying said that the question of carriage had been raised by almost every speaker. He emphasised the advantage of moulding the troughs at site. He had carried the beams a maximum distance of one mile but had experienced no difficulty from breakage. Referring to Mr. Hadow's remark he said he had not lived in the rest house he had built but would investigate the question of echo. With regard to Colonel Battye's remarks he stated that he had referred to various American books from which it appeared that if a layer of neat cement was placed between old and new concrete about 80 per cent. strength resulted. In the calculations he submitted in comparison with Mr. Fane's figures of cost he had ignored the strength of this layer of neat cement and had calculated the stirrups for the full bond stress. He would note Colonel Battye's advice regarding the protection of the ends and corners of the beams. Regarding Mr. Dorman's remarks the Executive Engineer who carried out the test, on enquiry, stated that he had taken sufficient precautions against accident to men by putting up scaffolding.

He thanked Mr. Murphy, without whose help and encouragement, the trial of this type of construction, on any large scale would have been impossible. He also thanked Mr. Nicholson who in the earlier stage had been a source of help, encouragement and new ideas to him.

APPENDIX.

TESTS OF TROUGHS.

Out of the large number of tests carried out by authors a few typical ones are only given below—

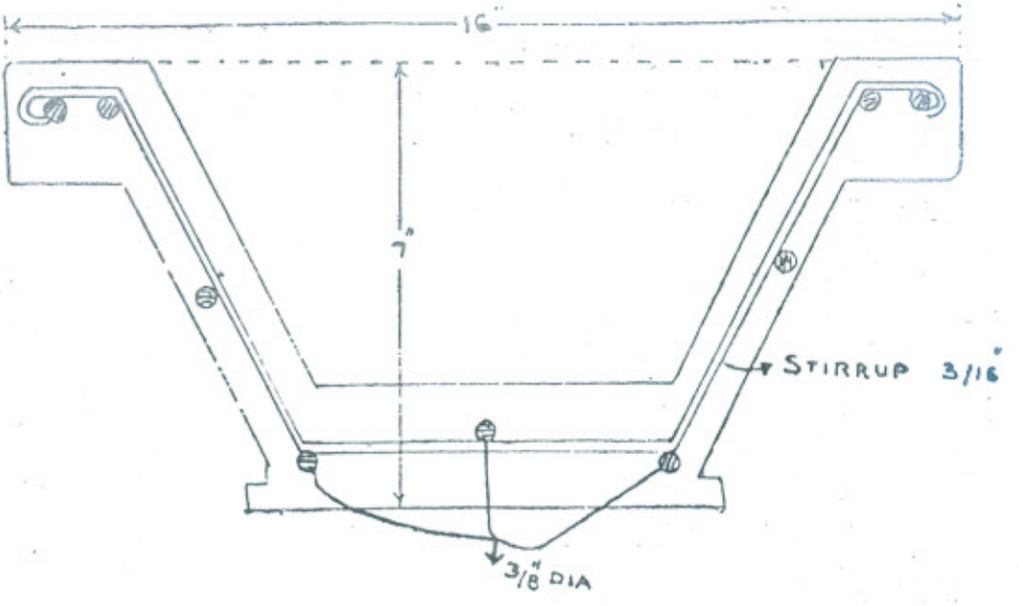
TEST No. 1.

At Suleimanke by Mr. Kanwar Sain.

Dimensions 16″ × 7″ × 9·2′ long.

Mixture $\frac{1}{\text{cement}} : \frac{2}{\text{pacca brick surkhi}} : \frac{4}{\text{pacca brick ballast.}}$

Manufactured on 16th November 1926, tested 11th January 1927.



PART I.

¾″ slabs were placed on the top of trough and the loading started with bricks in layers, each layer consisted of 36 bricks.

The loading was continued in quick succession and deflections noted. At 16 layers the deflection was 10/32″ and there were just slight hair cracks.

Total superimposed load.. =4,576 lbs.
Load of trough and slabs.. = 350 ,,

Total .. = 4,926 lbs. say 44 cwt.

Area covered by load .. $= \frac{16}{12} \times 8 = 10{\cdot}7$ s. ft.

Load per square feet .. = 442 lbs.

PART II.

The bricks were now removed, and 20 maunds iron was placed in the middle.

When the load was removed, the trough came back its normal condition in both cases, there being just a slight deflection of the order of 1/32″ which may be considered a permanent set.

PART III.

The same trough was again loaded with 50 cement bags each weighing one cwt. with a deflection at the middle of 22/32″.

The load was removed and the deflection at the middle was found to be 3/8″ permanent set.

PART IV.

A heavy iron (weight not noted) was dropped from 5′ height in the middle of the trough and repeated, on the fourth repetition, the top flanges crushed and the trough failed by the sides opening out by cantie ver action.

TEST No. 2.

At Suleimanke by Mr. Kanwar Sain.

Section of the trough and reinforcement as in Test No. 1 except that the stirrups were 1/4″ dia. one feet apart.

The compression rods were also 1/4″ dia. instead of 5/16″ of Test No. 1.

Clear span .. = 8′
Overall length .. = 9·5′

Mixture $\frac{1}{\text{Wah cement.}} : \frac{2}{\text{Sand.}} : \frac{4}{\text{Rupar stone ballast (machine crushed).}}$

The load was done with one cwt. cement bags in quick succession up to 56 bags giving a deflection of 3/4″.

TEST No. 3.

By Mr. Kanwar Sain at Suleimanke, dated 24th January 1927.

(Age not given).

Size 16″ × 8″ × 11·5′

Clear Span = 10.′

Mixture $\frac{1}{\text{Wah cement.}} : \frac{2}{\text{Sand.}} : \frac{4}{\text{Brick Ballast.}}$

The trough was loaded with cement bags and deflection noted for various superimposed loads, (weight of trough plus slabs may be taken at 5 cwts.). There was a minus 1/8″ initial deflection with no load, *i. e.* with load of trough only.

Dated 24th January 1927.

Total load cwt.	5	19	26	33	40	47	54	61	70
Deflection inches.	1/8	1/8	6/32	10/32	14/32	16/32	25/32	26/32	28/32
Remarks ..	..	..	..	..	..	..	..	..	hair cracks appeared at ends.

This load was put on at 3 p.m. on 24th January 1927, and left over night.

Test was renewed at 4 p.m., on 25th January 1927, and the deflection had increased to $1\frac{1}{16}$″.

More load was added. Dated 25th January 1927.

Total load ..	70	74	77
Deflection ..	$1\frac{1}{16}$″	$1\frac{1}{4}$″	2″ and went in increasing to 3″.
Remarks ..	..	cracks slightly progressed.	A good many appreciable cracks appeared in the middle and two of these travelled up to the top showing that the elastic limit had passed.

RESULTS OF TEST No. 3.

Load per feet run $= \frac{77}{10} = 7{\cdot}7$ cwt. or 862 lbs.

Load per square foot $= \frac{12}{16} \times 7{\cdot}7 = 5{\cdot}8$ cwt. or 650 lbs.

Tensile strength developed in tension steel before elastic limit was reached, is calculated below :—

fs = strength of steel at elastic limit.

$$= \frac{M}{As\ Jd} = \frac{77 \times 112 \times 10{\cdot}5 \times 12/8}{0{\cdot}588 \times 0{\cdot}8757} = 37{,}730 \text{ lbs.}$$

Factor of safety $= \frac{37{,}730 \text{ lbs.}}{16{,}000} = 2{\cdot}3$ in tension.

TEST No. 4.

At Marala from 16th October 1927 to 23rd October 1927.

Trough 16″ × 7″ × 11 ft.

Mixture $= \frac{1}{\text{Wah cement.}} : \frac{2}{\text{Marala sand.}} : \frac{4}{\text{Sangla ballast.}}$

(Note.—The Sangla ballast if used unwashed has too much clay. It is also brittle.)

Reinforcement :—Standard as given in calculations except that 2 No. 3/16″ bars were used in each one of the compression flanges instead of one Tension reinforcement 3 No. × 3/8″ bars.

Stirrups 3/16″ bars as shown in drawings.

Date of manufacture, 20th September 1927.

Age on the first day of the test, 25 days.

The trough was kept filled with water or damp sand all these days.

DECEMBER.

Date ..	16	17	18	19	20	21	22	23	24
Load ..	11	17	23	29	35	41	47	53	55
Deflection ..	..	..	..	·185	·571	·665	·813	1·032	..
Remarks ..	..	..	..	..	Hair-cracks first noticed although they existed before.	Hair-cracks.	Hair-cracks.	4 cracks widened at middle.	Failed.

The working load for the calculations is 160 lbs. per ft. or $\frac{160 \times 10{\cdot}5}{112}$

$= 15$ cwts.

Breaking load $= 55$ cwts.

Factor of safety $= \frac{55}{15} = 3{\cdot}67.$

The stress developed in tensile steel therefore amounts to 16,000 × 3·67 = 58,720 lbs. per square inch.

TEST No. 5.

Marala.

Conditions exactly as per test 4 except that the ballast was from some other quarry.

Date of manufacture, 27th October 1927.

Date of starting, 23rd November 1927.

Kept wet or covered with wet sand and air cured afterwards for one day.

Date ..	23	24	25	26	27	28	29	30
Load ..	11	17	23	29	35	41	47	53
Deflection ..	0	1/16	3/16	5/16	7/16	9/16	11/16	13/16
Remarks ..	..	..	..	..	..	..	..	Failed by disturbance of the supports.

This test gives almost the same results as test 4 and therefore the same factor of safety.

NOTE.—The section of the tensile bars was tested and it was found that all the three bars had been reduced in section 6′ from one end and 5′ from the other at the position of a stirrup, where failure occurred.

TEST No. 6.

Marala.

A doubt having been raised as to whether the factures of the test 4 and 5 were due to failure of tension reinforcement or due to the failure cantilever reinforcement (stirrup) it was decided to put in wooden stiffeners on top.

This trough was manufactured on 1st November 1927, and tested on 1st December 1927. It was water cured for 28 days and air cured for 2 days.

The loading was done in quick succession up to 8 layers of cement bags that is a total load of 53 cwts. (including load of trough itself), and then allowed to stand for sometime. Only hair cracks appeared and the deflection approached that of test No. 5 at the same load.

Then the ninth layer was put on and a few minutes after application of the load the trough failed apparently by tension, having stood a total load of 59 cwts. giving a facture of safety of almost 4.

The compression reinforcement in this case is one 3/16″ diameter bar in either compression flange, as against two 3/16″ bars in each flange in the troughs of tests 4 and 5. This trough is in accordance with the standard reinforcement given in table No. 1.

The deflection curves of tests 4 and 5 are plotted on plate No. Taking a permissible deflection of one five hundredth of the span under working loads, it comes to ¼″ for a 10 feet span. The working loads in these cases being 15 cwts. for each trough, it will be noticed that the deflections are much below the permissible.

TEST No. 7.

Trough 18′×16″×10″ clear span 16′.
Date of manufacture, 14th November 1927.
Date of testing, 28th December 1927.

Total load sustained up to elastic limit of steel was 81 cwts. without breaking of trough, against a normal load of 24 cwts.