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Autor(en): **Freeman, Ralph Anthony**

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Innovative Cable Erection System for Cable-Stayed Bridges

Système novateur pour montage des fils des ponts haubanés
Neuartiges Seilmontagesystem für Schrägseilbrücken

Ralph Anthony FREEMAN
Civil Engineer
3F Engineering Consultants
Bangkok, Thailand



Anthony Freeman, born 1946, received his Engineering Science degree at Oxford University, England. With wide experience in steel bridge construction, he now runs his own consulting practice specializing in construction methods and systems, in Bangkok and in London.

SUMMARY

The Second Hooghly River Bridge in Calcutta, now nearing completion, will have a cable-stayed main span of 457 metres, one of the longest in the world. The parallel wire Hi-Am cables are currently being rapidly erected using an innovative scheme and equipment, which are described in the article. The core of the system is a set of 600 tonne capacity hydraulic strand jacks and pumps which was made in Bangkok: it is being used both for pulling in and final stressing in one continuous operation. The Contractor's team of Indian engineers is carrying out the work without foreign supervisors.

RÉSUMÉ

Le pont "Second Hooghly River Bridge" à Calcutta, actuellement en voie d'achèvement, est un pont haubané de 457 mètres de portée centrale, une des plus longues du monde. Les câbles à fils parallèles Hi-Am sont actuellement rapidement mis en place grâce à une méthode et un matériel novateurs qui sont décrits dans l'article. La base de cette méthode est un jeu de vérins de précontrainte et pompes hydrauliques de 600 tonnes de capacité, fabriqués à Bangkok. Ces vérins sont utilisés pour le tirage et la mise en tension des câbles en une seule opération continue. Les travaux sont dirigés par une équipe d'ingénieurs indiens.

ZUSAMMENFASSUNG

Die Second-Hooghly-River-Brücke in Kalkutta, Indien, wird bald fertiggestellt. Mit 457 Metern wird ihre Stützweite eine der längsten der Welt sein. Die Montage der Paralleldrahtseile Typ Hi-Am erfolgt unter Benutzung eines neuartigen Systems und mit Geräten die im Artikel dargestellt werden. Mittelpunkt des Systems sind litzenziehende Hydraulikpressen und Pumpen, die in Bangkok hergestellt wurden und 600 Tonnen Ziehkraft aufweisen: Sie werden für alle Phasen des Einziehens und Spannens ohne Unterbrechung eingesetzt. Die Arbeit erfolgt ohne ausländische Überwachung.



1. INTRODUCTION

The Second Hooghly River Bridge in Calcutta, India, has a cable stayed main span of 457 metres, currently one of the longest in the world. Articles describing the Bridge design and other aspects of its construction can be found elsewhere in this Publication and in [1].

At the time of publication of this article erection of the main cable stayed river span is being completed with admirable speed despite severe delays during construction of the earlier elements.

The steelwork and concrete slab elements of the deck are constructed using methods and equipment which were employed for the sidespans over the Calcutta and Howrah shores; only cable erection is a new operation for the crews building the Main River Span.

The cable erection scheme and the equipment for it were conceived, developed, and designed in detail by 3F Engineering Consultants, Bangkok, who were appointed after an international competition. The system was designed to be as "contractor-friendly" and rapid in use as possible.

The remarkable rate of erection being achieved at the time of publication by the all Indian crews indicates that the aim was achieved. No 3F supervision has been necessary other than three advisory visits. The rate of main span erection is especially remarkable in view of the comparison with the rate achieved on the side spans.

2. HISTORY

2.1 Bidding

The Contractor, Braithwaite Burn & Jessop Co Ltd (BBJ), invited international tenders for the design of an erection and stressing scheme for the bridge's main support cables in 1988. 3F Engineering Consultants, who won the contract, had been newly formed in Bangkok by key members of the team which had been responsible for the successful rapid completion of Bangkok's 450 metre span Rama IX cable stayed bridge. [2],[3].

3F's brief was subsequently extended to include the development and design of schemes for erection and stressing of Temporary Cables (used to secure the pylons during construction) and of the permanent Holding Down Cables which counteract uplift in the bridge's end supports.

3F's Contract was awarded in May 1988. After an intensive development effort in consultation with all parties, 3F's concept proposals were approved in August 1988 by BBJ, the Hooghly River Bridge Commissioners and their Engineer, Schlaich Bergermann and Partners of Stuttgart (the Bridge's Designers). The design phase was completed in April 1989.

The original intention to send Thai supervisors from the Rama IX Bridge team was subsequently cancelled by mutual agreement because of changed circumstances. 3F's detailed Method Statements and Drawings coupled with a limited number of visits proved anyway sufficient for BBJ's experienced team to carry out the operations quickly and effectively. Cable Erection work on site commenced in July 1991.

2.2 Hydraulic Strand pulling Stressing Equipment

Procurement of the novel stressing jacks from international suppliers was the subject of a later international tender based on 3F's outline design and performance specification, but no

suitable offer was received. 3F's proposal to carry out the detailed design and to arrange for the manufacture of the equipment in Thailand was then accepted, and the work was entrusted to Vemac Co Ltd of Bangkok after a further round of bidding. The equipment was ordered in January 1990 and arrived on site in Calcutta one year later.

3. THE PROBLEM

The cables of many cable stayed bridges are arranged for stressing at the deck end as was the case at Rama IX Bridge. Hooghly bridge's final design has the cable stressing anchorage zone in a tulip shaped chamber at the pylon head.

This arrangement permits an economic open deck cross section with simple deck cable anchorage details, but it poses an interesting challenge for the cable erection system designer: the stressing chamber is restricted in size and access to the individual anchorages within it is difficult; both the stressing and the pulling-in equipment have to be fitted into and mounted on the relatively small space available at the pylon head, and the means of bringing them there have to be provided.

If all these problems can be solved, however, the advantages for the permanent structure of keeping the deck simple with all the complications concentrated in the relatively small pylon head zone can actually benefit the construction contractor also.

4. CONCEPT

Earlier feasibility studies by others had considered pulling-in and stressing as two separate operations requiring different sets of equipment. 3F considered that an essential requirement of the scheme must be the elimination of the need for such time consuming and potentially dangerous equipment changes in mid-operation.

At the heart of the scheme were the 600 tonne capacity strand pulling Jack and Pump sets, designed to operate at three widely different speeds. Conventional winch powered Hoists were to be used for the first stage of lifting after which the Hoist and the Jack pulling pilot strands would work together.

4.1 Use of Strand

Stay cables are normally pulled in by winches and finally tensioned by jacks working on a series of coupled screwed rods. This system, used for instance at the Rama IX Bridge, had also been proposed for Hooghly. The cable sockets were provided with threads suitable for screwing in 5 1/2" screwed rods.

Bundles of prestressing strands have become commonplace in recent years for heavy lifting operations. Use of strand as the main pulling/stressing element at Hooghly made it possible to achieve the aim of carrying out pulling-in and stressing in one continuous operation. It also eliminated the need to handle and change heavy screwed rods and equipment high above the bridge deck and in and around the difficult environment of the pylon head.

Detailed investigations at the concept stage confirmed that with the use of high strength alloy steels it was feasible to connect sufficient strands to the female thread provided in the cable sockets.



4.2 Hydraulic Jacks and Pumps

No suitable standard jacking equipment was available which could meet the requirements as well as fit in the confined space of the anchorage/stressing chamber of the pylon heads. BBJ was also anxious not to be dependent on any one equipment supplier.

3F therefore made the basic design of the Jacks, Strand Anchors and Stools, (Fig. 3) for the purpose, together with a performance specification for the Hydraulic Pumps and System.

The arrangement using four standard 150 tonne rams between heavy steel slabs was adopted instead of the alternative and more common hollow ram jacks for the following reasons:

- shorter overall length suitable for the restricted space available;
- two rams can be disconnected to double the high speed for pulling in operations where the load is low;
- the strands are visible and accessible between the anchorages within the Jack;
- use of standard 150 tonne rams increases the range of possible manufacturers and is more appropriate for such a special requirement.

4.3 Main Hoist

The first phase of cable erection required a fast method of lifting, for which the Main Hoist was developed. The Hoist is used to lift the upper cable socket beside the cable plane until it is just above the previously erected cable at which point the Jack is connected and Hoist and Jack work together. The upper sheave block runs on a trolley which allows the cable socket to be moved back into the cable plane as it approaches the pylon.

5. EQUIPMENT MANUFACTURED IN THAILAND

3F carried out the detailed design of the Jacks and Strand Pulling Equipment for Vemac and checked and supervised their hydraulic system design. A large screwed rod and nut were also produced for stressing the Holding Down Cables. All the equipment was tested at Vemac's works under 3F supervision to check both for correct operation of the grips and release mechanisms and also to test for strength. Some of the tests were witnessed by BBJ's Technical Adviser.

5.1 Hydraulic Jacks and Stools and Strand pulling equipment

5.1.1 The Jacks are equipped with electrically operated hydraulic valves and equipment (not shown in Fig. 3) mounted between two of the cylinders which allow smooth remote control. A single manual valve allows two of the cylinders to be disconnected for double high speed operation.

5.1.2 The Stools are designed to transfer the Jack load to the permanent Cable Bearers with sufficient space between the legs to allow the permanent Bearer Bars and shims to be handled into position after the cable is fully stressed. The stools are not required for the lower cables where removable Jack Bearers are provided in the permanent Pylon Head design.



5.1.3 The Strand Pulling Equipment consists of Adaptors and Rings and Jack Anchor Blocks designed for standard CCL type XL three segment wedge grips. Six types of Adaptor and two types of Ring allow 30 or 52 standard 15mm strands to be connected to the six different sizes of cable socket. The large Rings in which 38 strands are anchored are provided with strengthening clamps to control grip bursting: both Rings and Clamps were extensively tested before despatch of the equipment from Thailand.

5.1.4 The Jack Anchors are provided with a release system consisting of tubes which are pushed up against the underside of the grips by a screw operated release plate. This system has to be used at the end of stressing and also if for any reason a pulling-in and stressing operation has to be reversed.

5.2 Pumps and Remote Control Boxes

5.2.1 The high and low pressure pumps are mounted at each end of the electric drive motor shaft and valves and pressure sensors are provided to allow both automatic and manual selection of speed. The Pumps are self contained in weatherproof steel boxes, and are normally positioned on the stagings outside the Pylon Head Stressing Chamber where they can easily be checked and maintained. Hoses and cables are passed into the Jack in the stressing chamber through an unused cable port.

5.2.2 The control box is connected by cables to a socket mounted on the Jack's valve and equipment panel. The control box is equipped with push button controls and warning lamps and with a digital pressure gauge the sensor of which is fitted in the Jack pressure line.

6 EQUIPMENT MANUFACTURED IN INDIA

Whilst most of the locally manufactured equipment was made by BBJ's own workshops, the winches and sheaves of the main hoist were the subject of a tender which was won by Sureka Engineering Ltd of Calcutta.

6.1 Main Hoist

6.1.1 The Main Hoists use Sureka 5 tonne winches arranged to give hoisting capacity of up to 30 tonnes through up to 6 falls on two triple sheave blocks. The upper hoist blocks are arranged on runway beams allowing them to be positioned 650 mm out of the cable plane during the first phase of cable erection.

6.1.2 Two sets of Main Hoist equipment are provided on each pylon, arranged so that the winch operator can easily see the cable he is lifting throughout its journey. The reeved-up blocks are moved by the Tower Crane from the Backspan to the Mainspan side of each Pylon Head ready for each new cable.

6.2 Tower Crane

6.2.1 The 2 tonne lifting capacity Tower Cranes were designed to lift all items of cable erection equipment from deck level to the pylon heads. They are equipped with 1 tonne capacity electric Tirak winches with Cable Reelers manufactured by Secalt in Luxembourg: no conventional winch was available which could be fitted in the confined space available.



6.2.2 Slewing and trolley movements are carried out by hand. The slewing bearings are PTFE rings bearing on machined stainless steel runners welded to the tubular crane columns.

6.2.3 The cranes are designed to be dismantled manually and stowed in and on the pylon head. Special clamps are provided to secure the main boom section on top and the tubular columns retract into one of the cells of the Pylon Head structure. All the other parts can be stowed in another of the cells. This will allow the crane to be brought back into service for any maintenance work in future so that restressing or cable replacement operations will be possible.

6.3 Stagings and Auxiliary Hoist

6.3.1 Stagings are provided for safety and security at the pylon head: Staging Units A give access to the Main Hoist upper block and to the screw which operates the lateral travel trolley. Staging Units B give safe access over the stressing chambers and to the ladders down the inside walls; one of their longitudinal beams also serves as a runway for a 6 tonne capacity trolley hoist which is used for moving the Jack/Stool set from cable to cable.

6.3.2 Also mounted on Staging Unit B is the Auxiliary Hoist consisting of another Tirak winch and Cable Reeler. The 9.5mm wire rope from this hoist is passed down over a pulley, through the centre of the Jack, over a further pulley, and its end clamped off to the strand bundle near the cable socket. This Hoist is used during the lifting phase to pull the strand bundle ahead of the Cable Socket until the pilot strands can be secured by riggers on the stagings and fed through the Jack. Use of identical winches for the Tower Crane and Auxiliary Hoist allowed flexibility of maintenance and application of these two partially interchangeable equipment items.

6.3.3 In addition to the stagings designed by 3F, the bolting stagings around the whole Pylon Head were retained to give access during Cable Erection. These are omitted from Fig. 1 for clarity.

6.4 Saddles

Saddles are provided to ensure that curvature of the ends of the cables during erection operations are limited to 2.5 metre radius.

6.4.1 Bottom saddles. These were devised to fit easily to the permanent deck cable anchors in such a way that their attitude was automatically correct with no need for adjustment. Additional special bottom saddles were required and provided for the sets of five closely spaced backstay cables connected to the deck above the holding-down piers.

6.4.3 Cable Saddles. These saddles were provided with yokes for lifting with the Main Hoist block and with special prongs which engaged the Pylon Head steelwork in such a way as to ensure correct alignment after the lifting and first pulling-in phase. They were able to accommodate any of the six sizes of cable and socket by the use of plywood packings for the smaller sizes.



7 TYPICAL OPERATION

7.1 Preparation

7.1.1 At deck level. The cable is unreeled and grouted with polyurethane filler and pulled up the bridge on special support rollers. When the live (stressing) end reaches the pylon it is loaded into the Cable Saddle. The strand Adapter/Ring set complete with strand bundle is screwed into the cable socket, and the Main Hoist lower block and Auxiliary Hoist wire rope are attached. The Bottom Saddle is fitted to the correct cable anchor.

7.1.2 At the Pylon Head. The Jack/Stool assembly is moved and set in position and the bearer bars are prepared in readiness. The strand bundle is lowered to the deck with the Auxiliary Hoist, and the Cable Saddle is lowered to the deck on the Main Hoist.

7.2 Erection.

7.2.1 First Lifting Phase. The loaded Cable Saddle with handlines attached is lifted with the strand bundle kept ahead by the Auxiliary Hoist. When the bottom socket reaches its deck anchor, lifting is suspended while the cable is placed over the Bottom Saddle and the bottom socket is set. In the case of main span cables the Cable Saddle is first lifted as high as possible to allow the cable dead end to be manoeuvred through the pylon at deck level. The cable is then lowered again and the dead end pulled up the main span deck to its anchorage and set. Lifting is then resumed until the Cable Saddle reaches just above the line of the previously erected cable.

7.2.2 Second Lifting Phase (Pulling in Phase). The pilot strands have by this stage in the lifting been fed into the pylon and through the Jack, and the Jack set on double-high speed. (Two rams disconnected). The Jack and Main Hoist, working together, are now used to move the Saddle along the Final Cable Axis until the Saddle reaches the pylon. During this stage the load on the Jack steadily increases while the Main Hoist load reduces. When it reaches the pylon, the position of the saddle is fixed using a combination of the special centralising prongs engaging the pylon steelwork, adjustment of the Main Hoist, and a pair of chain blocks.

7.2.3 Final phase (pulling the socket into the pylon and stressing). Setting the saddle can be accomplished with little interruption of the continued cycling of the Jack, which now pulls the socket out of the saddle into the pylon, the cable itself sliding over the curved part of the saddle.

As the socket passes into the pylon, minor adjustments of the saddle attitude are easily made by the team on the staging responding to their good view of the clearances round the socket: they simply use the Main Hoist and the Chain Blocks.

As the load builds up, the Jack speed is reduced in two stages, first by reconnecting the two disabled rams, and later by changing from the low to high pressure pump. As soon as the socket anchor Ring emerges from between the cable bearers, the strengthening Clamps are fitted. As soon as the socket itself emerges, permanent shims are used to "follow up" for security, until finally the bearer bars and permanent precalculated shims are fitted.

Before the final stroke of the Jack is taken, the lower Jack Anchor's grip release system is activated. The Digital Pressure Gauge readout is used to check the load at the calculated final shim height, and after the figures are accepted, the final shim is fitted and the Jack released.



7.3 Moving to the next cable.

The complete strand bundle is now turned anticlockwise together with the Jack Anchors to unscrew the strand Anchor from the socket. The Jack/Stool assembly, complete with strand bundle is now moved using the Trolley Chain Hoist and set in the next position on the opposite side of the pylon head. With the upper Anchor Block grips also released, the strand bundle is now pulled down out of the Jack and lowered to the deck using the auxiliary hoist.

8. SPECIAL OPERATIONS

8.1 Temporary Cables

Separate procedures and equipment which are not covered in this article were used for erection and stressing of the relatively small Temporary Cables.

8.2 Holding Down Cables

The Holding Down Cables were stressed in a special procedure using the Jacks and Stools and a large Threaded Rod in place of the strands. (In the event a substitute jack consisting of eight 100 tonne rams was used for programme reasons.)

8.3 Early Stay Cables

8.3.1 The first four stay cables at each pylon head were erected by a simpler procedure without the use of the Cable Saddle.

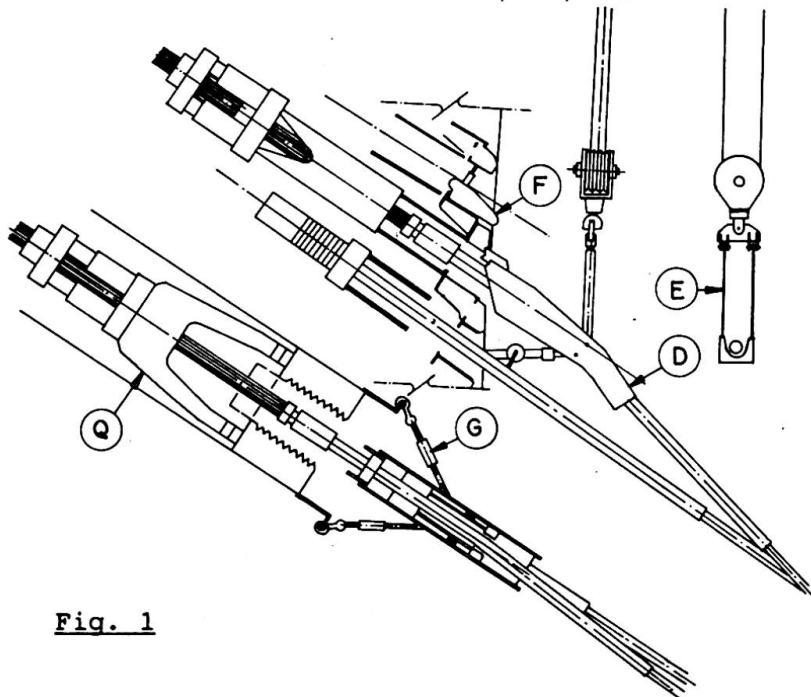
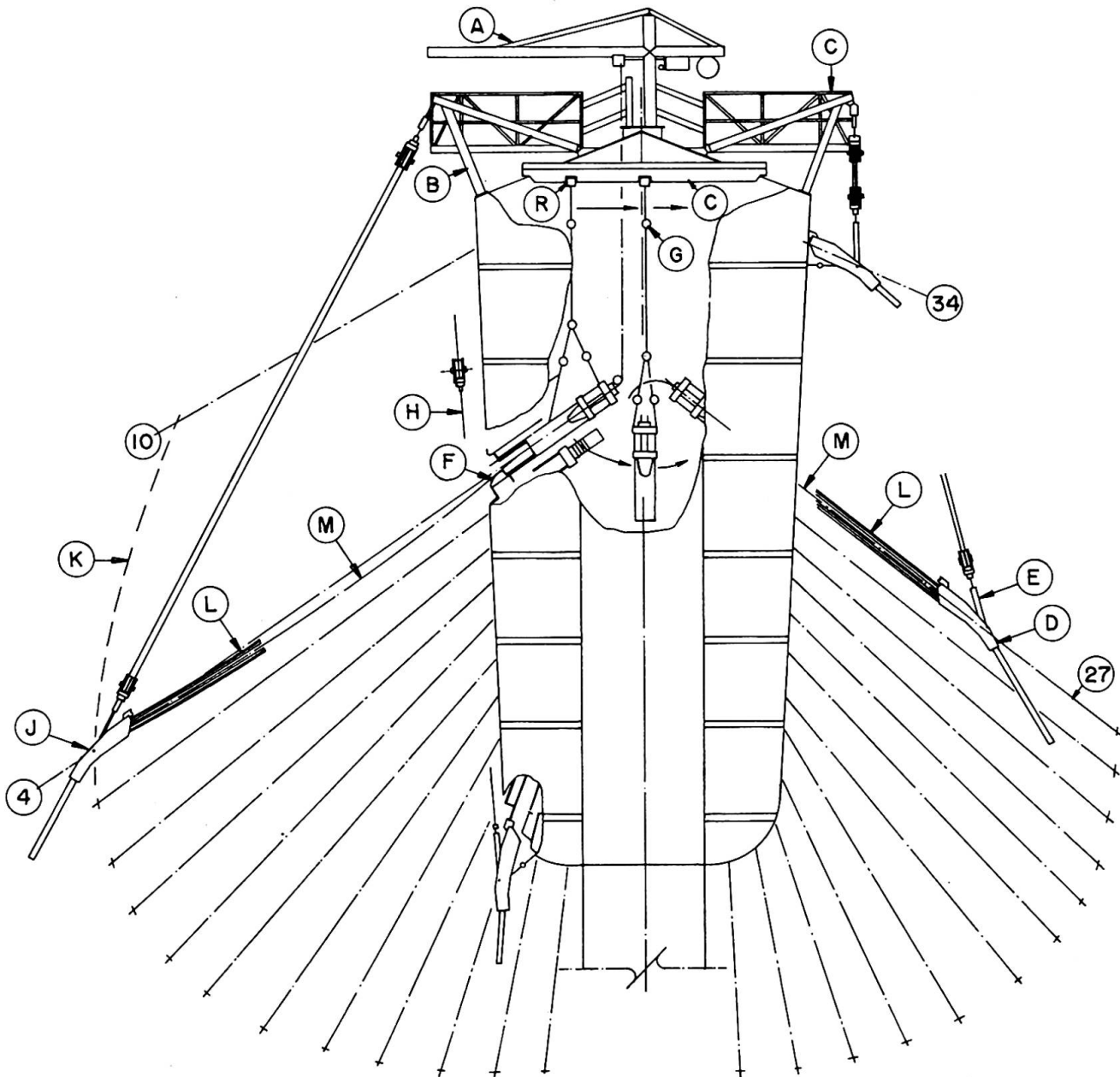
8.3.2 The next 10 cables in each pylon head use the procedure in section 7 but with the Jack resting on its own removable "jack bearer" built into the pylon. The jack bearers were provided in the permanent steelwork because of the close proximity of the bottom cable bearers to each other.

9. CONCLUSION

An innovative integrated cable erection and stressing system has been developed and successfully used to such advantage that a dramatic acceleration of the rate of erection of the Second Hooghly River Bridge during construction of the Main Span is being facilitated.

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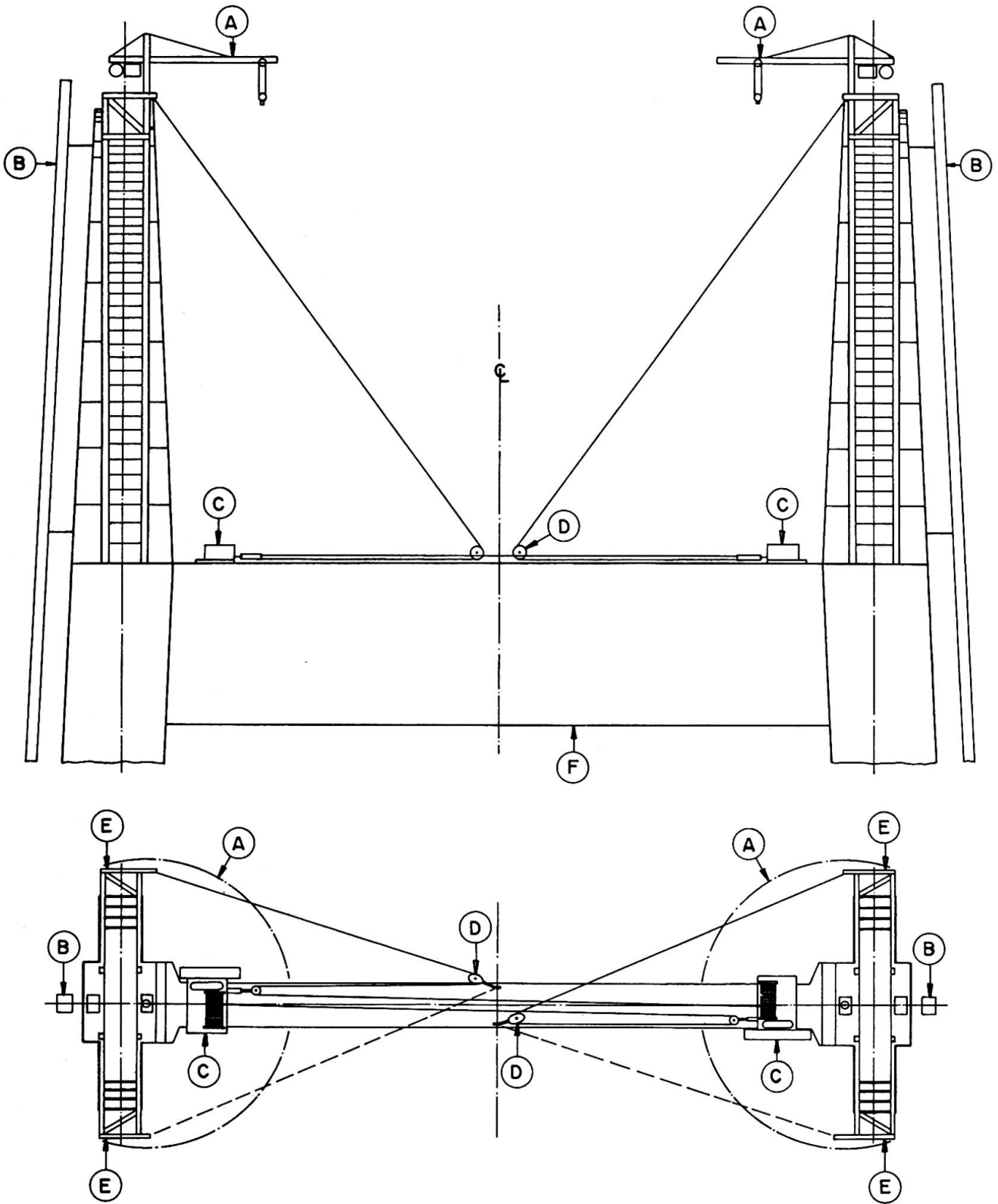
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- A Tower Crane
- B Main Hoist
- C Stagings
- D Cable Saddle
- E Saddle Yoke
- F Strand Saddle
- G Chain Block
- H 10t Sling
- J Start of Phase 2
- K Locus of J
- L Strand Bundle
- M Pilot Strands
- P 600T Jack
- Q Stool
- R Trolley Hoist

Arrangement at Pylon Head

Fig. 1



A Tower Crane
 B Personnel Hoist

C 5 Tonne Winch
 D 10 Tonne Pulley

E Trolley Runway
 F Portal Beam

Fig. 2. Arrangement of Main Hoist at Pylon Head

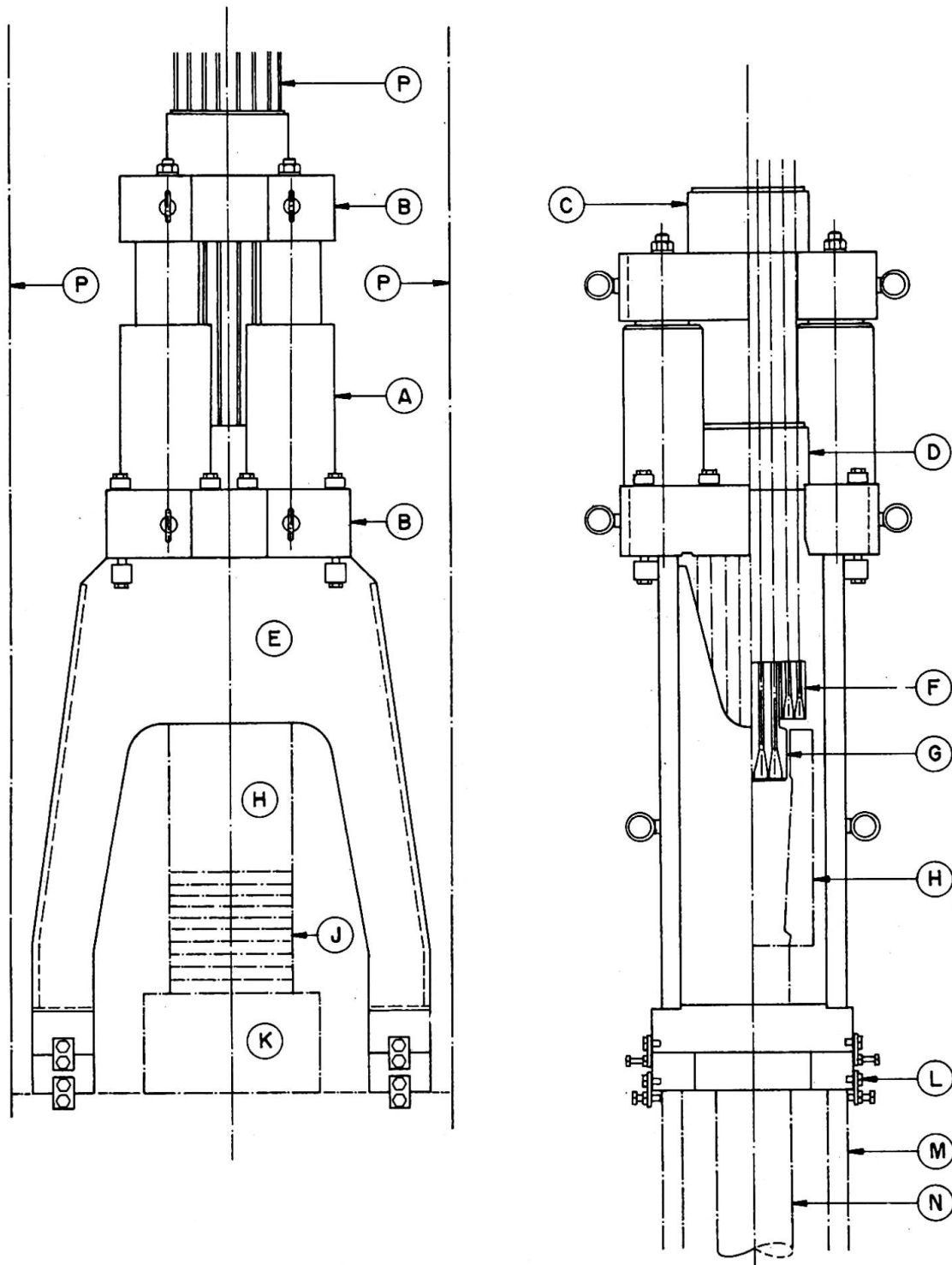


Fig. 3 3F/Vemac 600 Tonne Cable Stressing System - Jack and Stool

- | | | |
|---------------------|----------------|------------------------------|
| A 150 tonne Ram | F Ring | L Spacers |
| B Steel Slab | G Adapter | M Cable Bearer |
| C Upper Jack Anchor | H Cable Socket | N Cable |
| D Lower jack Anchor | J Shims | P Walls of Stressing Chamber |
| E Stool | K Bearer Bars | |

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