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TRANSVERSE LOAD COEFFICIENTS FOR SOME BRIDGE PIER SHAPES

by

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S U M M A R Y

Apart from the longitudinal drag, the bridge piers might experience large transverse hydrodynamic load when angled to the flow. In this paper the transverse load coefficients are studied for FIVE shapes of bridge piers, generally adopted by Indian practice, for angles of incidence between the approach flow and the longitudinal axis of the section in the range 0 to 50 degrees. In addition a pier with square ends has also been tested. The experiments were conducted in a flume in the Froude number range 0.28 to 0.49. The results are compared in order to possibly ascertain the best shape from the view point of minimum transverse load experienced.

Earlier work on this aspect in Australia indicated that the code of practice for road bridges laid down by the Indian Roads Congress might underestimate the magnitude of the transverse load on circular piers. The paper examines this aspect also for the shapes investigated and recommends a simple relation for the transverse coefficient to be adopted for any shape of the pier.

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LIST OF SYMBOLS

- V Velocity of flow
- w Maximum width of horizontal cross-section of pier
- l_c Chord length of horizontal cross-section of pier
- α Angle of incidence between approach flow and longitudinal axis of horizontal cross-section of pier
- g acceleration due to gravity
- h depth of flow
- F Froude Number ($V/\sqrt{gh}$)
- h' depth of immersion of the pier (depth of flow minus the end clearance)
- ν kinematic viscosity
- ρ mass density
- R Reynolds Number ($V \cdot l_c/\nu$)
- C_{TRANS} Transverse load coefficient

INTRODUCTION

Recent work has shown that the bridge piers might be subjected to a considerable transverse load whenever the flow approaches the river at an angle (1,2). It was also attempted to use special sections with a view to minimise these forces (3). Apelt (1) has drawn attention to the fact that though the Indian Code has taken cognisance of the transverse forces the method of calculating it for a given angle of attack results in a grave underestimation of these forces for cylindrical piers. The investigation described in this paper was undertaken to study the transverse forces on the bridge pier shapes adopted by the Indian Code and to evolve a suitable method of calculation if the design provision of the Indian Code is not adequate.

EXPERIMENTAL APPARATUS AND TECHNIQUE

The experiments were carried out in a level rectangular flume 8 m long, 40 cm wide and 50 cm deep. The flow rate was measured by a calibrated V-notch provided at the head of flume while a gate at the downstream end controlled the depth of the flow. The channel entrance was provided with usual contractions and honey-combs to provide quiet flow. The test section was located at 2.5 m from the entrance of the flume. It was ascertained by measurements that the velocity distribution was almost uniform in the approach section to the pier. The average of the velocities in the midquarter of the section was taken to be the incidence velocity on the pier.

The force on the pier was measured by a drag-balance supplied by Kempf and Remmers, West Germany. This is a one component balance working on strain gauge principle. The model pier was fixed to the balance with the axis of the pier coinciding with the axis of the balance. The bottom of the pier was adjusted to be 2 mm above the bed of the flume. The balance and the pier were then attached to a circular plate and then this system was mounted on to a support fixed to the rails on the top of the channel (Fig.1). This permitted the circular plate to rotate, along with the balance and the pier. The angle of rotation was measured on a protractor. Thus, for any angle, the axis of the pier was always coinciding with the axis of the balance and hence the drag measured by the balance gave the transverse load on the pier. The drag balance was calibrated and found to have a linear response with load. The calibration was checked at intervals.

MODEL PIER SHAPES

The shapes of the models are taken from the code of practice of the Indian Roads Congress (4). Table I shows the shapes of the piers tested and the type numbers assigned to them. Four ratios of l_c/w for each type have been studied and their subscript description is given in Table II. The models were made of seasoned wood.

TABLE I

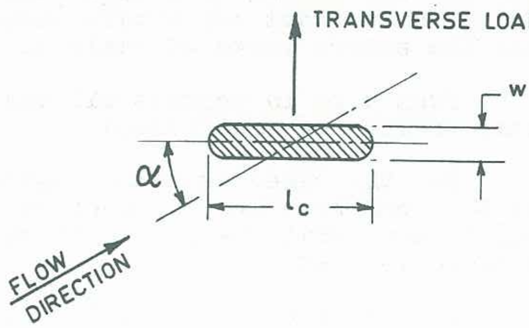
Shape and Designation of Piers Tested

Type	Shape	Description
1		Pier with semicircular cut and ease waters
2		Piers with triangular cut and ease waters. Angle 60°
3		Pier with triangular cut and ease waters. Angle 90°
4		Piers of rectangular shape
5		Piers with cut and ease waters of circular arcs cutting at 90°
6		Pier with cut and ease waters of equilateral arcs of circles

TABLE II

Variants for each type and proportions

	A	B	C	D
l_c (mm)	40	50	60	65.2
w (mm)	10	10	10	10
l_c/w	4.00	5.00	6.00	6.52
$R \times 10^{-4}$	2.229	2.787	3.344	3.634



FLOW CONDITIONS

Each type was tested for 5 flow rates corresponding to the Froude numbers: 0.293, 0.326, 0.366, 0.415 and 0.486. Studies were made for 5 angles of attack: α = 10, 20, 30, 40 and 50° which is the range generally encountered in practice. The Reynolds numbers for each l_c/w ratio based upon the chord length, l_c of the pier, has been maintained constant for the above Froude number ranges. This is achieved by keeping the velocity of flow nearly constant and by suitably adjusting the depth of flow. The Reynolds number obtained for each l_c/w ratio is also shown in Table II.

EXPERIMENTAL RESULTS

The transverse load coefficient is defined as:

$$C_{Trans} = \frac{\text{Transverse load}}{1/2 \, \rho \, V^2 \, h' \, l_c}$$

The values of C_{Trans} obtained from the experimental studies have been adjusted to infinite channel width by applying the method of blockage correction developed by Maskell (5) with the awareness of the limitation that it was derived for bluff shapes in a closed working section.

In Fig. 2 and 3 are shown two of the typical curves of C_{Trans} versus α corresponding to pier types 1A and 2B respectively. It is seen that no single shape gives the minimum force coefficient for the entire range of α. Moreover the curves do not show any uniform trend with the Froude number. It is also evident that the C_{Trans} varies considerably when the angle of attack exceeds 10°.

Also plotted in the above figures are the curves obtained on the basis of the Code of practice of the Indian Roads Congress. It should be noted that the Code has recommended two values for the constants to be used - one for the circular pier or the piers with semicircular ends and another for all other shapes. Comparison with actual experimental results show that

(a) the Code of practice gives lower values for piers with semicircular ends
(b) the Code gives over-estimated values for all other shapes and piers.

The fact that the Code gives under-estimated values for circular pier has already been pointed out by Apelt (1). Hence it is concluded that the Code needs a revision on this aspect.

In Fig.4 are drawn those curves that give maximum C_{Trans} values taking into account all the types of pier tested, all the variations of l_c/w ratio and the range of Froude numbers. An enveloping curve is then drawn and it is found that the equation of this curve can be given by

$$C_{Trans} = \frac{3}{2} \sin^{1/3} \alpha$$

This expression can therefore be used for all types of piers without any apprehension of under-estimating the transverse forces.

CONCLUSIONS

(1) For the six shapes of bridge piers studied in the present investigations it is found that not any single shape gives the minimum transverse coefficient for the entire range of angle of attack.

From 0 to 10 degrees all the shapes follow almost a single curve giving same transverse coefficient.

For the range 10 to 30 degrees type 6 D (l_c/w = 6.52 and arcs meeting at 60°) can be taken to experience minimum transverse load. It is interesting to note that the pier with square ends also experiences similar lesser transverse load.

For the range 30 to 50° type D (l_c/w = 6.52 and triangular nose at 60°) experiences minimum transverse loads.

(2) It is established that the transverse load on piers with circular ends calculated according to the IRC Code results in an underestimation of the forces, whereas for piers with other shapes, it results in a high over-estimation.

(3) Based upon the results of the present studies an enveloping curve for the transverse coefficient is evaluated. The simple relation,

$$C_{Trans} = \frac{3}{2} \sin^{1/3} \alpha$$

is recommended for any shape of pier.

(4) The present studies show the dependence for C_{Trans} on Reynolds number. Moreover, the range of Reynolds number is very large in practice in comparison with what could be obtained in flume studies. The full behaviour of C_{Trans} versus Reynolds number needs to be investigated.

REFERENCES

1. Apelt C.J. - Flow loads on Bridge Piers - Jour. I.E. Aust., Vol 37, No.7-8, July-Aug. 1965, pp 185-191

2. Apelt C.J. and Isaacs, L.T. - Bridge Piers - Hydrodynamic Coefficients. Proc. American Soc. Civil Engineers, Jour. Hydraulics Division, Vol 94, No.HY1, January, 1968, pp 17-30.

3. Apelt C.J. and Isaacs, L.T. - Hydrodynamic Force coefficients for Bluff Cylinders of Tee shapes and their relevance to Bridge Piers. Paper No.2574, presented at the Third Australasian Conference on Hydraulics and Fluid Mechanics held in Sydney, 25th to 29th November 1968.

4. Indian Roads Congress - Standard specifications and code of practice for Road bridges; Section II, Loads and stresses. New Delhi, Indian Roads Congress, 1967, p.25.

5. Maskell, E.C. - A Theory of Blockage Effects on Bluff bodies and Stalled Wings in a closed wind tunnel. Great Britain, Aeronautical Research Council Reports and Memoranda No.3400, November 1963, 22 p.

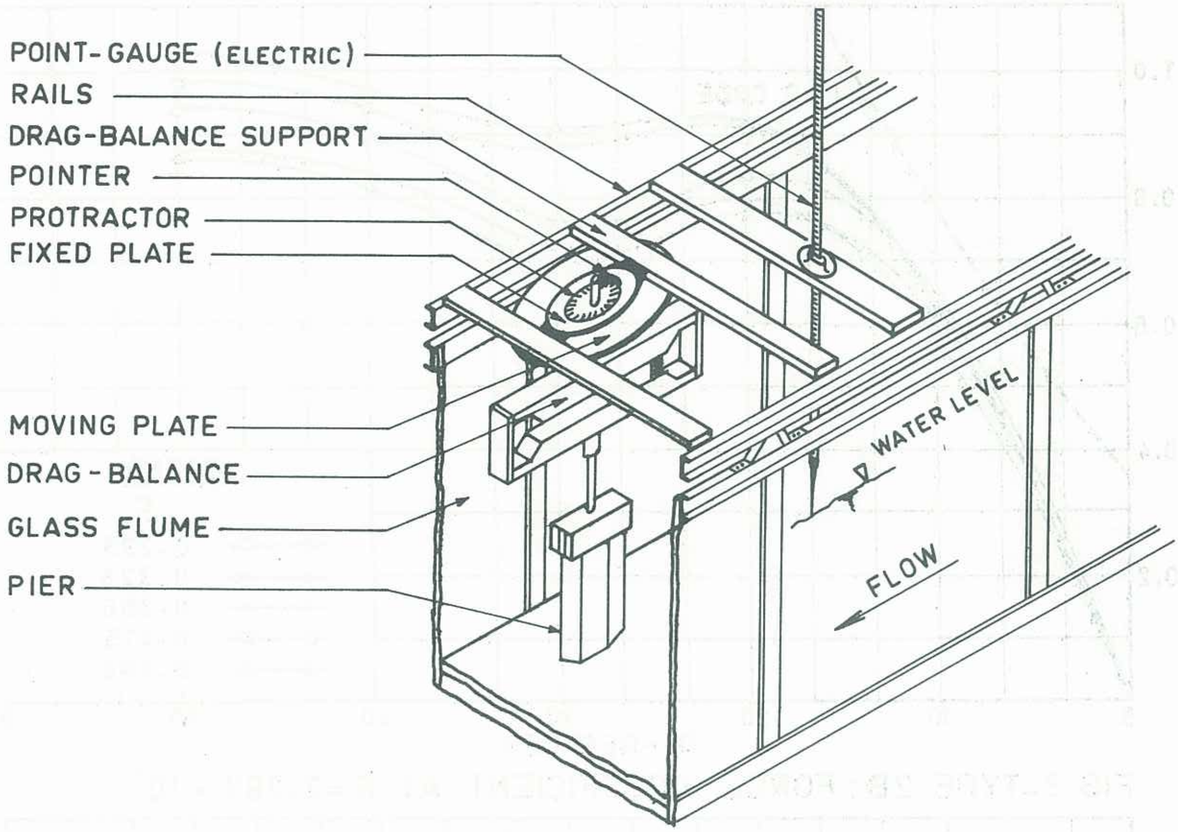


FIG.1 - FORCE MEASURING SYSTEM

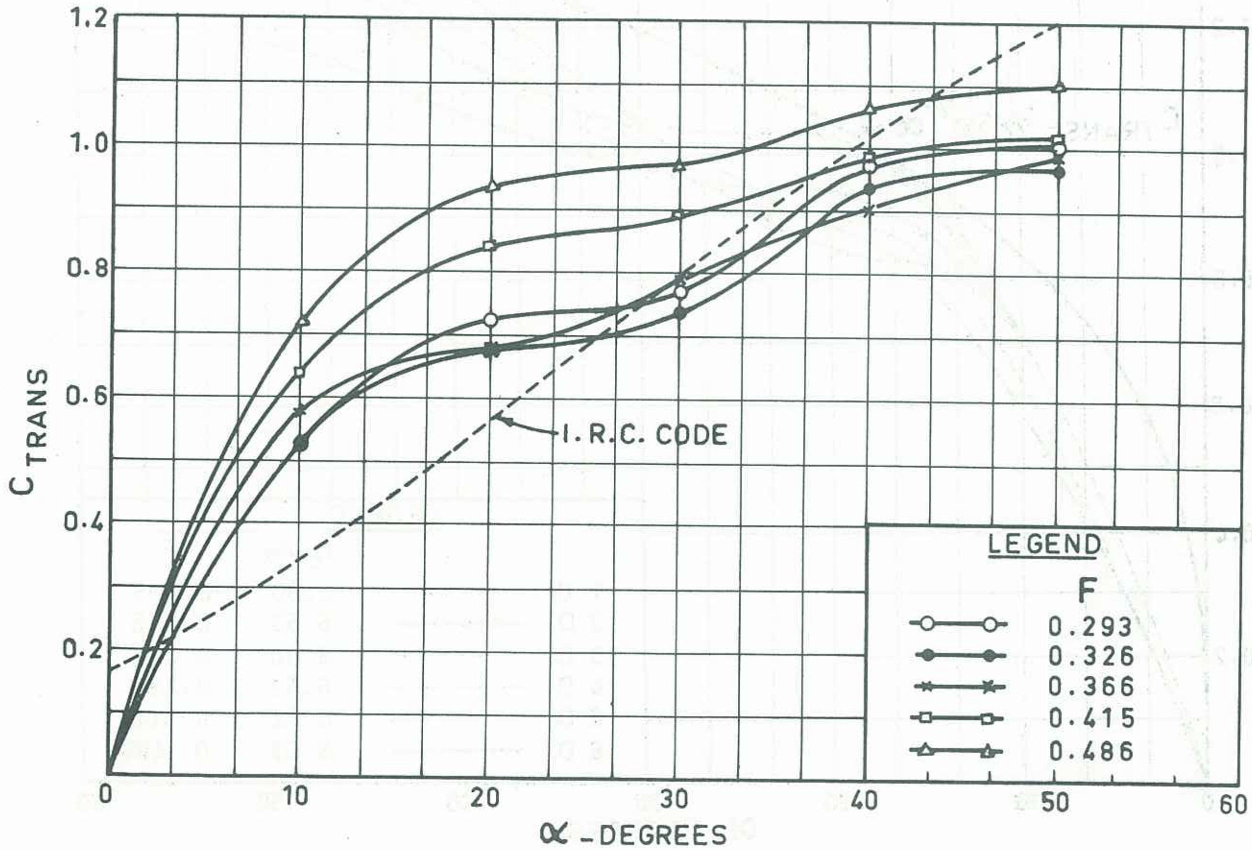


FIG 2 - TYPE 1A : FORCE COEFFICIENT AT $R = 2.229 \times 10^4$

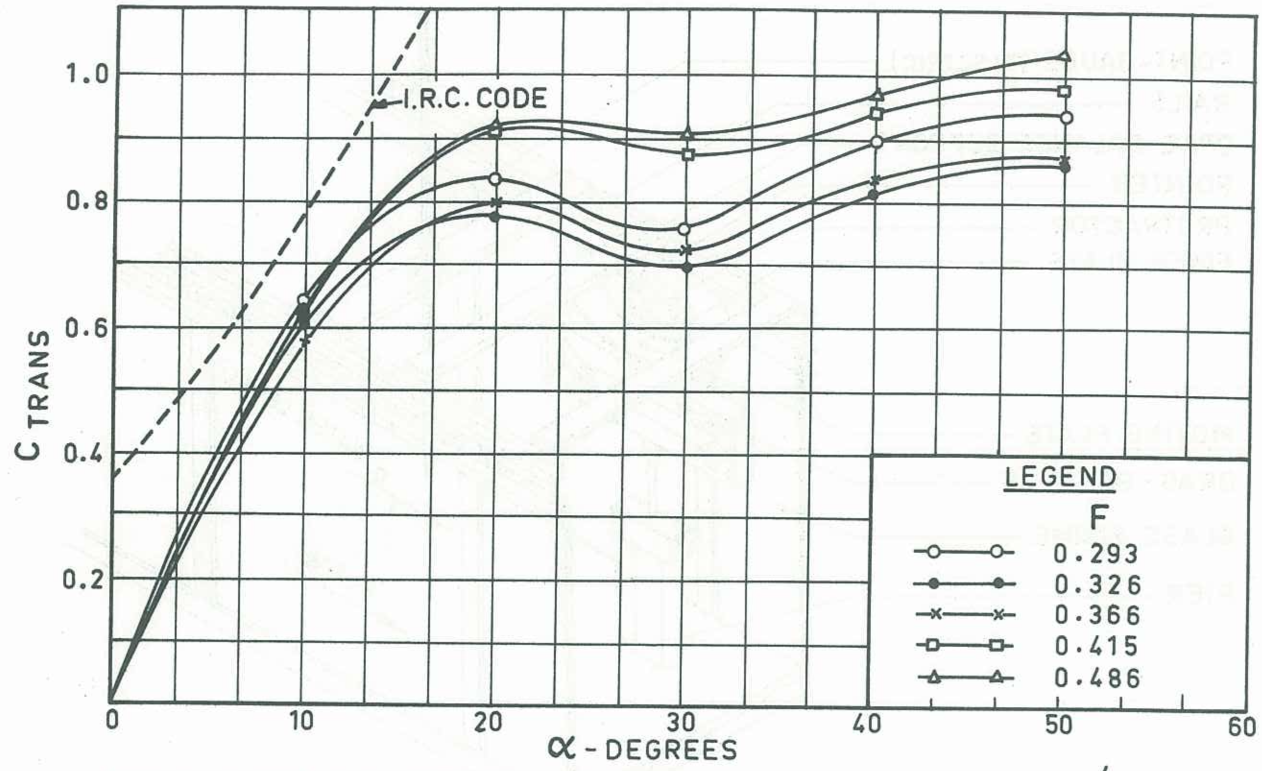


FIG 3-TYPE 2B: FORCE COEFFICIENT AT $R = 2.787 \times 10^4$

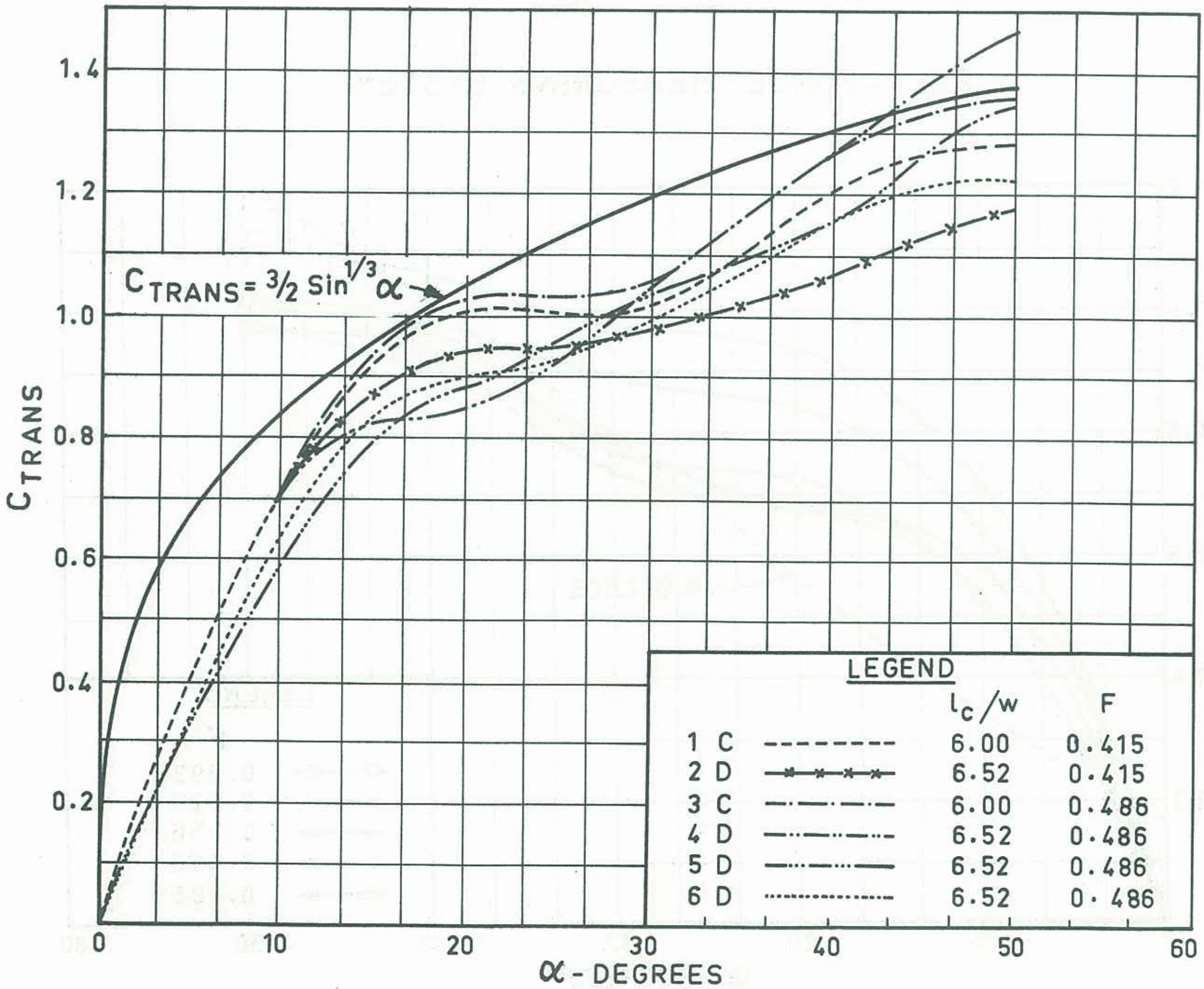


FIG. 4 - MAXIMUM FORCE COEFFICIENT CURVES