Behaviour of concrete in-filled tubular columns

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Comportement des colonnes mixtes formées de tubes remplis de béton

Verhalten von betongefüllten Stahlhohlprofilstützen

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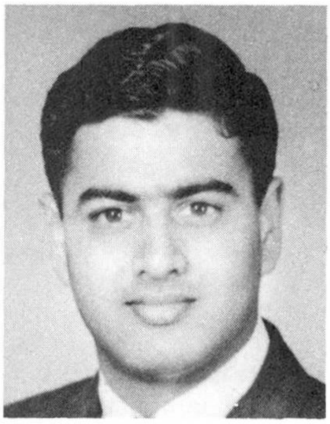

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SUMMARY
Concrete in-filled tubular columns represent a class of structure where the best properties of steel and concrete are used to their maximum advantage. Aspects governing strength and behaviour over the entire range of loading have been studied and capacity interaction diagrams proposed based on the stress strain relationship for the constituent material properties.

RÉSUMÉ
Les colonnes mixtes formées de tubes remplis de béton représentent le type d'élément structurel utilisant au mieux les caractéristiques de l'acier et du béton. Les phénomènes gouvernant leur comportement et leur résistance face aux différentes sollicitations possibles sont étudiés et des diagrammes d'interactions basés sur les relations contrainte-dilatation des matériaux constitutifs sont donnés.

ZUSAMMENFASSUNG
Betongefüllte Stahlhohlprofilstützen stellen ein Bauelement dar, bei dem die besten Eigenschaften von Stahl und Beton am vorteilhaftesten kombiniert werden. Aspekte, welche die Festigkeit und das Verhalten über den ganzen Belastungsbereich beeinflussen, wurden studiert, und ein Tragfähigkeitsinteraktionsdiagramm wird aufgrund des Spannung-Dehnungs-Verhältnisses der beteiligten Materialien vorgeschlagen.

Concrete in-filled tubular columns represent a class of structure where the best properties of steel and concrete are used to their maximum advantage. The following aspects governing the strength and behaviour have been studied. (1)

1. Confining action in circular and square CITC.
2. Triaxial effects on the core and biaxial effects on the shell.
3. Presence of lateral strain compatibility and complete interaction of core and the shell, over entire range of loading.
4. Effect of method of loading and a study of connections.
5. Factors governing the service and the ultimate load behaviour.

The test programme included -

In the first phase, 150 mm dia circular and square tubes of 300 mm to 1200 mm lengths were tested to develop a stress strain relationship for core and shell and to study items 1 to 3 above. 6 Nos. circular short specimens of CITC have been tested to verify the validity of the proposed load-strain relationship.

In the second phase, CITC, of lengths 1200 mm, 1840 mm and 2500 mm have been tested for both axial and eccentric loaded conditions and to study the connection details and transfer of load from horizontal (beams and slabs) to vertical member (CITC).

A total of 12 specimens were tested for axially loaded condition, out of which 8 were for the study of connections. 13 specimens were tested for eccentrically loaded condition. In addition, 8 specimens were tested to study the presence of bond at the concrete steel interface. 6 specimens were tested to study the effect of k, the lateral load enhancement factor with slenderness ratio.

Table I and II summarises the results of eccentrically and axially loaded sections. Fig. 1 shows a specimen under test.

Stress strain relationship of the constituent materials of the CITC was studied to prepare an equivalent stress strain relationship for the laterally confined core of concrete and biaxially stressed steel shell (overcoming the difficulty of defining the areas of cross section and ratios of module of the constituent materials) that would be applicable for the entire range of loading, taking into account progressively increasing degree of confinement applied continuously over the length of the specimen.

The following additional factors affecting stress strain relationship have been studied.

1. Effect of lateral load enhancement factor with reference to slenderness.
2. Effect of variation of Poisson's ratio of concrete with stress level and its effect on bond between core and shell.
3. Percentage load carried by shell and core over the entire range of loading, which reverses from service load to ultimate load requiring different load factors are to be applied to service load and ultimate load stages. (Fig. 2)

As opposed to reinforced concrete columns and concrete encased steel columns, in the CITC, lateral strain compatibility and composite action is absent upto a load level, $\frac{P}{P_Y} = 0.50$. Consequently, the core of CITC is laterally confined at advanced stages of loading only and at the earlier stages of loading it is under a uniaxial stage of stress. Thus for a realistic representation of actual behaviour under progressively increasing loads, different stress-strain relationship are to be employed to represent service stage and ultimate stage behaviour . Based on all the foregoing, a stress strain relationship is proposed. (1) (2)

Based on the study of connections (beam to column and flat slab to column) on the strength and behaviour, it is concluded that methods of transferring load from horizontal members (beam or slabs) to vertical members (CITC) affect the strength and behaviour of CITC as also the load-strain behaviour of constituent material. Flat slab to column type of connection , particularly when the connection is such, where the shell and core are loaded together or where the core alone is loaded (Fig. 3) is an effective connection detail, where the enhanced strength of the concrete core, is best exploited. Beam to column type of connection where shell alone is loaded first, does not lend itself for a proper exploitation of CITC. In fact this type of connection is unsafe andnot reliable.

Capacity interaction formulae for square and circular CITC, for service and ultimate load stages, based on the true stress strain curves for CITC, and taking into account percentage of load shared by the core and the shell of different stages of loading, have been developed. A typical interaction diagram for circular and square CITC is shown in Fig. 4 and 5. Effect of wall thickness, diameter and strength of concrete mix have also been studied in this investigation.

On the study of the square and circular CITC, the strength and behaviour of square and circular CITC are governed by different parameters. The confinement effect of a circular shell is far higher than the square one, all the more so, if beam to column type of bracketted connections are employed, i.e., when the connection transfers the force to the shell of the column. CITC shows large enhancement of load carrying capacity and can sustain large strains and deformations. This reserve of strength and deformation makes CITC, asideal structural element in certain special conditions, as in a seismic design. This study has indicated that for effective exploitation of CITC, high strength tubes are to be employed. In the ranges tested, i.e., relatively short specimen of $\frac{L}{d}<12$ and small eccentricity $\frac{e}{d}<0.2$, the failure load is even more than one and a half times the failure load calculated employing uniaxial stress strain relationship for steel and concrete.

A design method to take into account the enhanced strength is proposed in this study. A design method has also been developed as a part of this study.

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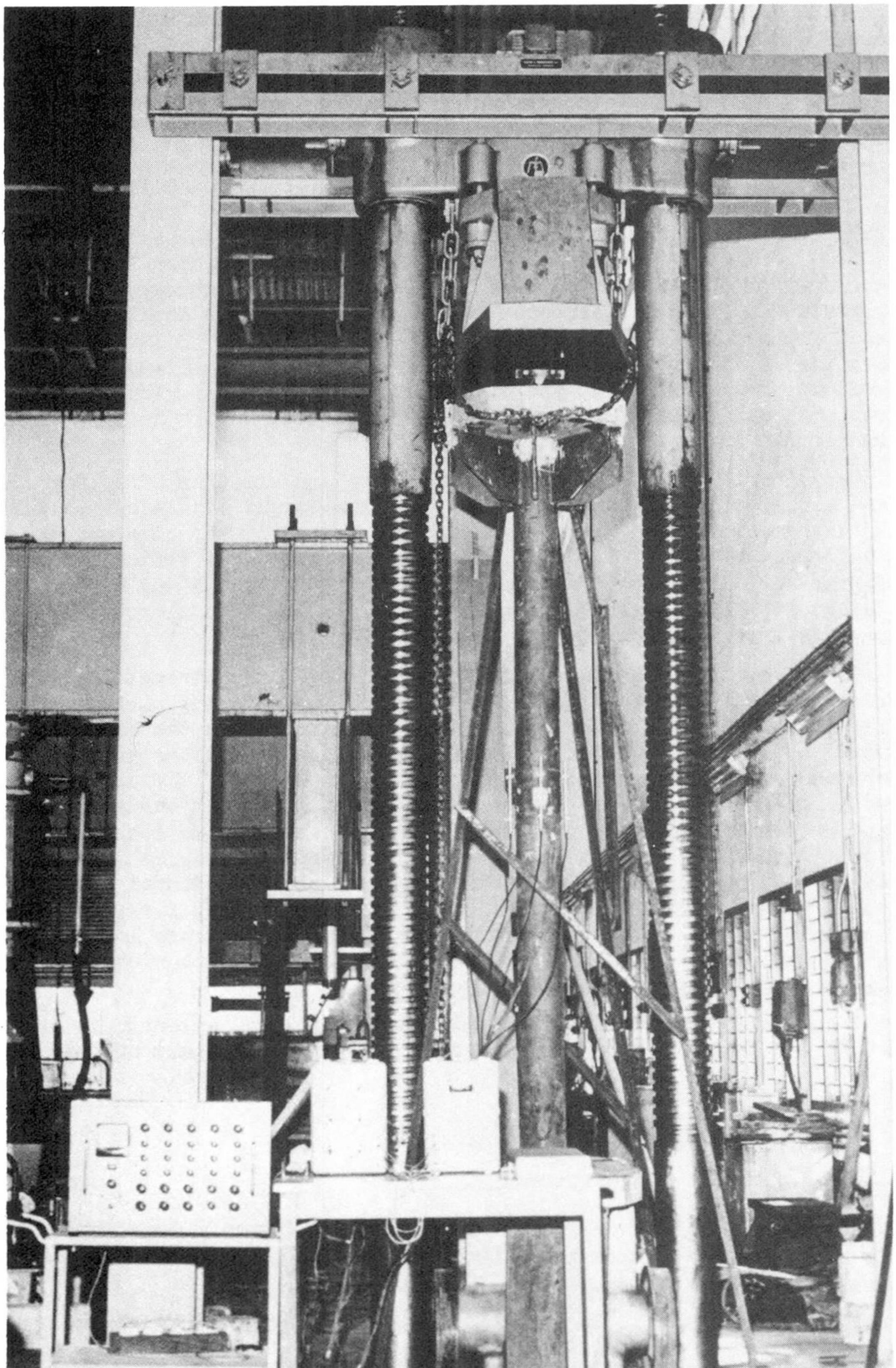

Fig:1

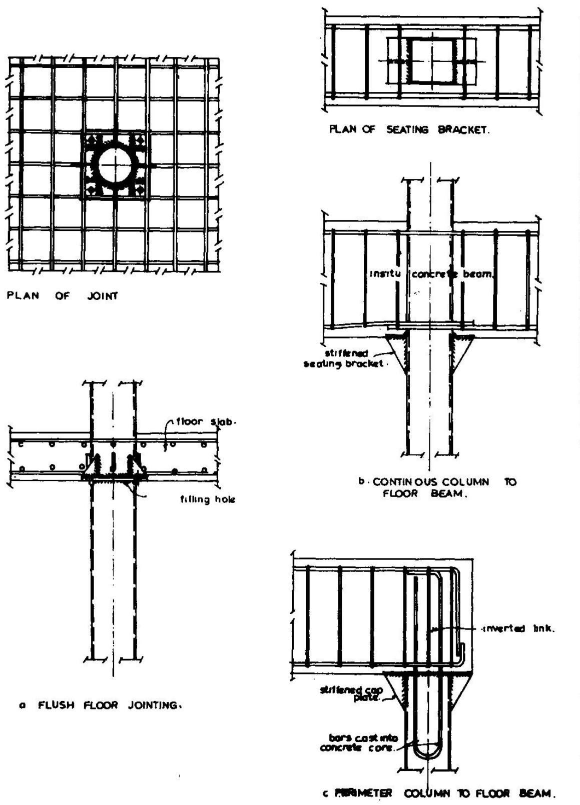

FIG: 3 TYPICAL CONNECTIONS. COLUMNS TO CONCRETE FLOOR CONSTRUCTION

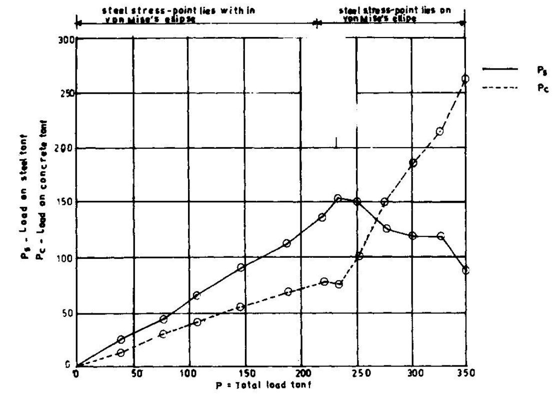

Fig: 2(a) TYPICAL DIAGRAM SHOWING LOAD SHARED BY STEEL AND CONCRETE OVER ENTIRE RANGE OF LOADING (BASED ON SEN.22)

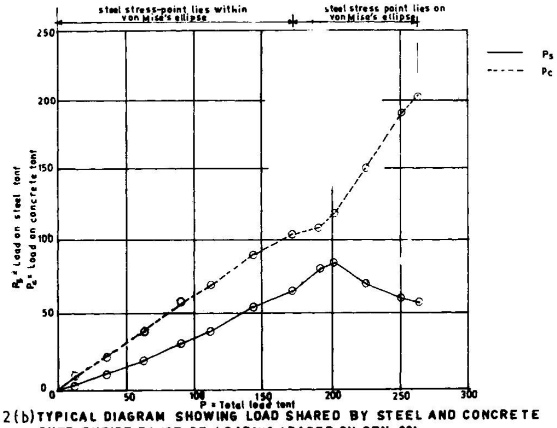

Fig: 2(b) TYPICAL DIAGRAM SHOWING LOAD SHARED BY STEEL AND CONCRETE OVER ENTIRE RANGE OF LOADING (BASED ON SEN. 22)

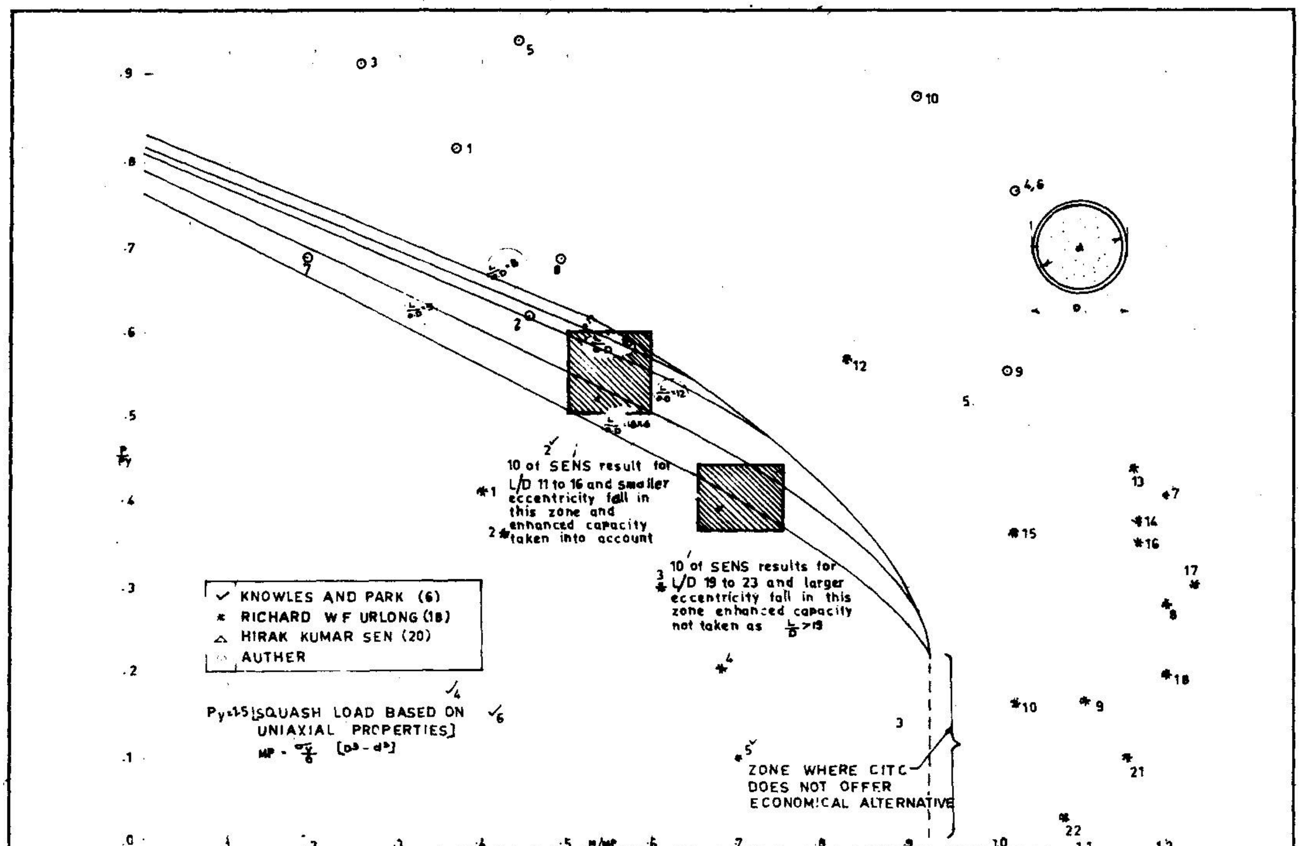

Fig: 4. INTERACTION DIAGRAM FOR CIRCLUR CITC ULTIMATE LOAD STAGE

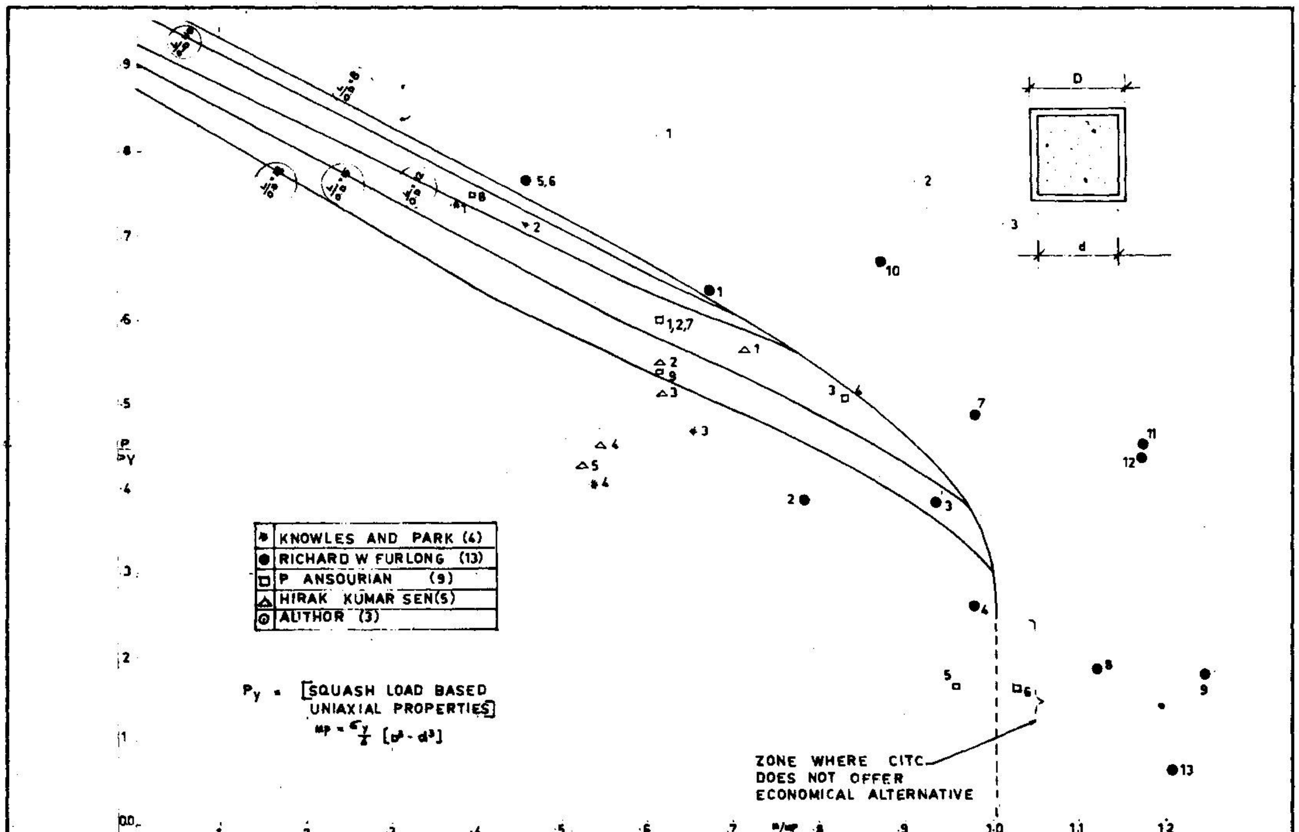

Fig 5. INTERACTION DIAGRAM FOR SQUARE CITC ULTIMATE LOAD STAGE

TABLE I

TEST RESULTS OF AXIALLY LOADED SPECIMEN TO STUDY THE INFLUENCE OF METHOD OF LOADING.

DESCRIPTION : 15 cm, nominal dia. or 15 cm. square x 6 mm wall thickness x 122 cm long tube infilled concrete corresponding to a 15 cm cylinder strength of 300 kg/cm^2

Brief Description of Loading.	Failure load (Tonne)	Observations at Failure.
Infilled circular tube core only loaded.	185	Formation of Luder Lines and spalling of mill scales and kind at mid-height.
Infilled circular tubes both shell and core loaded.	200	Luder lines with spalling of mill scales and kink at mid-height.
Infilled circular tube, bracketed arrangement beam to column type connection-shell loaded.	110	Bulges at top and local buckling.
Hollow circular tube.	90	Bulges at top and local buckling.
Infilled circular tube, shell only loaded.	85	Bulges at top and local buckling.
Infilled circular tube flat slab to column connection core and shell loaded.	205	Formation of Luder lines, bending with kink at mid-height.
Square tubes - core only loaded.	200	Cracks formation at the welds
Square tubes - both core and shell loaded.	240	Cracks at the welds.
Infilled square tube-bracketed arrangement, 'Beam to Column' type connection - shell loaded.	120	Bulges at top and local buckling.
Hollow square tube.	75	Bulges at top and local buckling.
Infilled square tube, shell only loaded.	88	Bulges at top and local buckling.
Infilled square tube - flat slab to column type connection - core and shell loaded.	250	Formation of Luder lines and bending with kink at mid-height.

TABLE II

TEST RESULTS OF ECCENTRICALLY LOADED CIRCULAR AND SQUARE CITC.

DESCRIPTION :

(1) 15 cm. nominal dia. x 6 mm wall thickness Circular CITC. 122 cm. long.
(2) Do Do 184 cm. long.
(3) Do Do 250 cm. long.
(4) 15 cm. x 15 cm. x 6 mm square CITC. 122 cm. long.

Concrete mix of the infill corresponds to 15 cm. cylinder strength of 200 kg/cm.^{2}

S.No.	Brief Description.	Length in cm.	Eccentrically applied in load in cm.	Observed failure load in tonnes.	
1.	Circular CITC Core only loaded.	184	1.0	118.0	Core only loaded with loading head-bearing through 5 cm. thick close fitting loading head.
	Do	184	1.6	98.0	
	Do	122	0.6	133.0	
2.	Circular CITC Core and shell loaded.	122	1.0	140.0	Concrete face finished smooth.
	Do	122	3.0	120.0	
	Do	250	0.6	100.0	
3.	Circular CITC beam to column type bracketed connection shell only loaded.	122	1.5	100.0	Shell only loaded through stiffened bracket.
	Do	250	4.0	80.0	
4.	Circular CITC- Flat slab to column type connection Core and shell loaded together.	122	2.0	127.0	
5.	Square CITC- Core and shell loaded.	122	2.5	112.0	Concrete face finished smooth.
6.	Square CITC beam to column type bracketed connection shell only loaded.	122	4.0	105.0	
	Do	122	5.0	95.0	
	Enhanced Failure load of Circular CITC (under axial load).			145.35	tonnes.
	Failure load of Square CITC (under axial load).			134.00	"
	Moment capacity of circular CITC.			306.78	" cm.
	Moment capacity of square CITC.			459.00	" cm.