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Ultimate Load Capacity of Circular Strongly Reinforced Concrete Columns

Résistance ultime de colonnes circulaires en béton fortement armé

Bruchbelastung sehr verstärkter, runder Betonsäulen

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1. INTRODUCTION

Special problems are involved about economy and safety of strongly reinforced concrete columns occurring in the design of tall buildings Although circular-bound columns are not necessarily the most economical form of column construction, the extra cost is mostly offset by the advantages arising from the extra available floor space, especially in multi-story buildings.

Experimental investigations have been carried out several years ago at the ISMES (Bergamo, Italy) on 1 : 2.5 scale models. The scale ratio of supported loads was $2.5^2 = 6.25$. Some design considerations were examined and various types of reinforcement were compared.

The aim of the research was to establish a comparison between the maximum load which may be supported by differently reinforced circular columns, designed at the base of a multi-story building, having fixed diameter and established effective length. The slenderness of the columns was relatively small (5 to 7.5).

So many variants enter into the design of a column that is not easy to decide which combination gives the most economical member. For a column having a fixed diameter (as smaller as possible) and a very high load, exceeding 5,000 tons, the proportion of the concrete, the percentage of longitudinal reinforcement, indipendent or helical binders and steel pipes filled with concrete must be taken into consideration, and only an experimental comparison may suggest the best solution.

2. OUTLINE OF TESTED SERIES OF MODELS

Our tests concerned exceptional cases of reinforcement, beyond the rules established by the Italian Code for calculating the increase in bearing capacity due to the circular binding.

Two series of 1 : 2, 5 models were tested. They were circular columns (Ø = 40 cm) with different height Length, diameter, type of concrete, shape of web reinforcement (welded circular hoop), steel reinforcement of normal specified yield point (2, 400 Kg/cm^2) were common factors for each series; whereas the percentage μ of the longitudinal bars, of section A_f, and μ_1 of the circular binders (^), of equivalent section A_s, were different (Table 1).

1st SERIES

model N°	Ø column cm	H cm	A^{Ω} cm²	An core cm²	A_f cm²	μ %	A_s cm²	μ_1 %	A_{tot} cm²	μ_{tot} %	P_r (tons) rupture (◇)	(●)	$\sigma_r = \frac{P_r}{\Omega}$ Kg cm²	A_i (*) cm²	$\frac{\varepsilon_d}{\varepsilon_l}$	(P)
1	40	300	1250	-	0	0	0	0	0	0	-	306	245	1250	0,.20	125
2	40	300	1250	706	12, 5	1	25, 0	2	37, 5	3	187, 5	350	280	2562	0, 20	125
3	40	300	1250	633	25, 0	2	12, 5	1	37, 5	3	282, 0	350	280	2187	0, 22	125
4	40	300	1250	633	62, 5	5	125, 0	10	187, 5	15	560, 0	1006	805	7812	0, 18	250
5	40	300	1250	633	125, 0	10	62, 5	5	187, 5	15	750, 0	950	750	5937	0, 14	250
6	40	300	1250	467	125, 0	10	250, 0	20	375, 0	30	970, 0	1525	1220	14375	0, 09	250
7	40	300	1250	408	250, 0	20	125, 0	10	375, 0	30	1060, 0	1406	1125	10625	0, 14	250

2nd SERIES

model N°	Ø column cm	H cm	A^{Ω} cm²	An core cm²	A_f cm²	μ %	A_s cm²	μ_1 %	A_{tot} cm²	μ_{tot} %	P_r (tons) rupture	$\sigma_r = \frac{P_r}{\Omega}$ Kg cm²	A_i (*) cm²	$\frac{\varepsilon_d}{\varepsilon_l}$	(P)
Protot.	100	500	7850	7235	209, 0	2, 7	105, 0	1, 35	314, 0	4, 0	NO FAILURE	-	-	0, 26	1500
1	40	200	1250	907	33, 9	2, 7	17, 6	1, 35	51, 5	4, 1	675	540	2550	0, 26	250
2	40	200	1250	-	22, 6	1, 8	50, 2	4, 0	72, 8	5, 8	825	660	4598	0, 60	250
3	40	200	1250	-	22, 6	1, 8	100, 4	8, 0	123, 0	9, 8	1180	944	7620	0, 60	250
1 a	40	200	1250	907	33, 9	2, 7	17, 6	1, 35	51, 5	4, 1	650	520	2550	0, 27	250
2 a	40	200	1250	-	22, 6	1, 8	50, 2	4, 0	72, 8	5, 8	780	624	4598	-	-
3 a	40	200	1250	-	22, 6	1, 8	100, 4	5, 0	123, 0	9, 8	1130	904	7620	-	-

(◇) VALUE AT INTERRUPTION OF TEST (COLUMNS H=3 m)

(●) FAILURE ON SPECIMEN OF 120 cm HEIGHT

(*) $A_i = A_n + 15\,A_f + 45\,A_s$

(^) This percentage is related to the equivalent unit weight.

1st Series

Tests were carried out on 7 circular section models, ϕ = 40 cm and 300 cm high, corresponding to a prototype ϕ 1 m and 7.5 m high.

The first column had no steel reinforcement; the others 6 were divided into three groups of two models, with total reinforcing percentage $\mu_{tot.} = \mu + \mu_1$ of 3%, 15% and 30% respectively.

In each group the first model had double μ, and μ_1 reduced by half, in relation to the second one.

The gradually increasing practically centered axial load tests were carried out in two separate stages. Stage one was interrupted when the radial displacements of the pillar became noticeable. In the second stage the height of the columns was reduced to h = 120 cm; the columns were then subjected to gradually increasing axial load up to collapse.

The tests showed a better behaviour of axial reinforcement during the first tests stage, whereas at collapse the models with circular reinforcement behaved a little better.

During the first stage axial and diametral deformations were measured; in the second stage (column 120 cm high) only measurements of diametral deformations were taken (fig. 1).

The concrete was composed of crushed limestone, with a maximum grain size of 9 mm; the cement was normal (type 500), in the proportion of 300 Kg/m^3, with the ratio W/C = 0.6 .

2nd Series

Here we had a prototype column ϕ = 100 cm and 5 m high with longitudinal reinforcement of steel (ϕ = 32 mm, μ = 2.7%) and circular binders (ϕ = 20 mm) 9 cm spaced (μ_1 = 1.35%). The column was tested with the eccentric load foreseen in design (e = 56 mm) up to the maximum of the press-machine (2,000 tons), without reaching the collapse.

Moreover three 1 : 2.5 scale models (ϕ = 40 cm, 200 cm high) were tested: the first was exactly the model of the above mentioned prototype, while in the two others the reinforcing binders were composed of mild steel tubes, 4 and 8 mm thick respectively. These three models were tested with central load.

A second group of 3 models, equal to the previous ones, was tested with eccentric load as for the prototype (e_m = 56/2.5 = 22.4 mm).

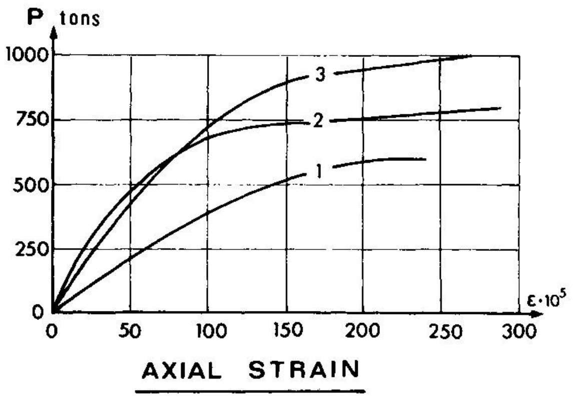
All these models were tested up to collapse. At the various load stages both horizontal and diametral deformations were measured (fig. 2).

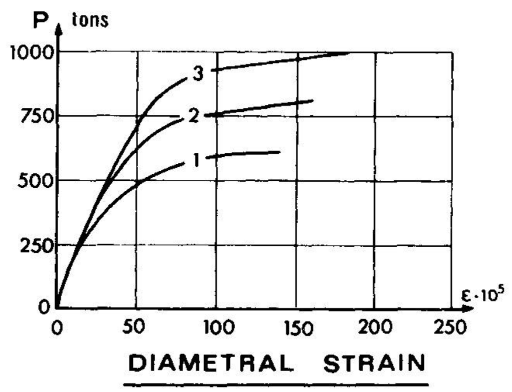
The concrete used for models was composed of quarry aggregates, with maximum grain size of 30 mm, high resistence cement (type 680) (^) in the proportion of 360 Kg/m^3; ratio W/C = 0.4 .

Some photoes give an idea of the reinforcements and of the models after the collapse.

(^) Failure 430 Kg/cm^2 at 28 days.

CENTERED LOAD





STEEL REINFORCEMENT
1 – longitudinal 30 ⌀ 12; rings ⌀ 8/3,6 cm
2 – steel pipe s = 4 mm + longitud. 20 ⌀ 12
3 – steel pipe s = 8 mm + longitud. 20 ⌀ 12

FAILURE
1 – 675 tons
2 – 825 tons
3 – 1180 tons

ECCENTRIC LOAD (e = 22,4 mm)

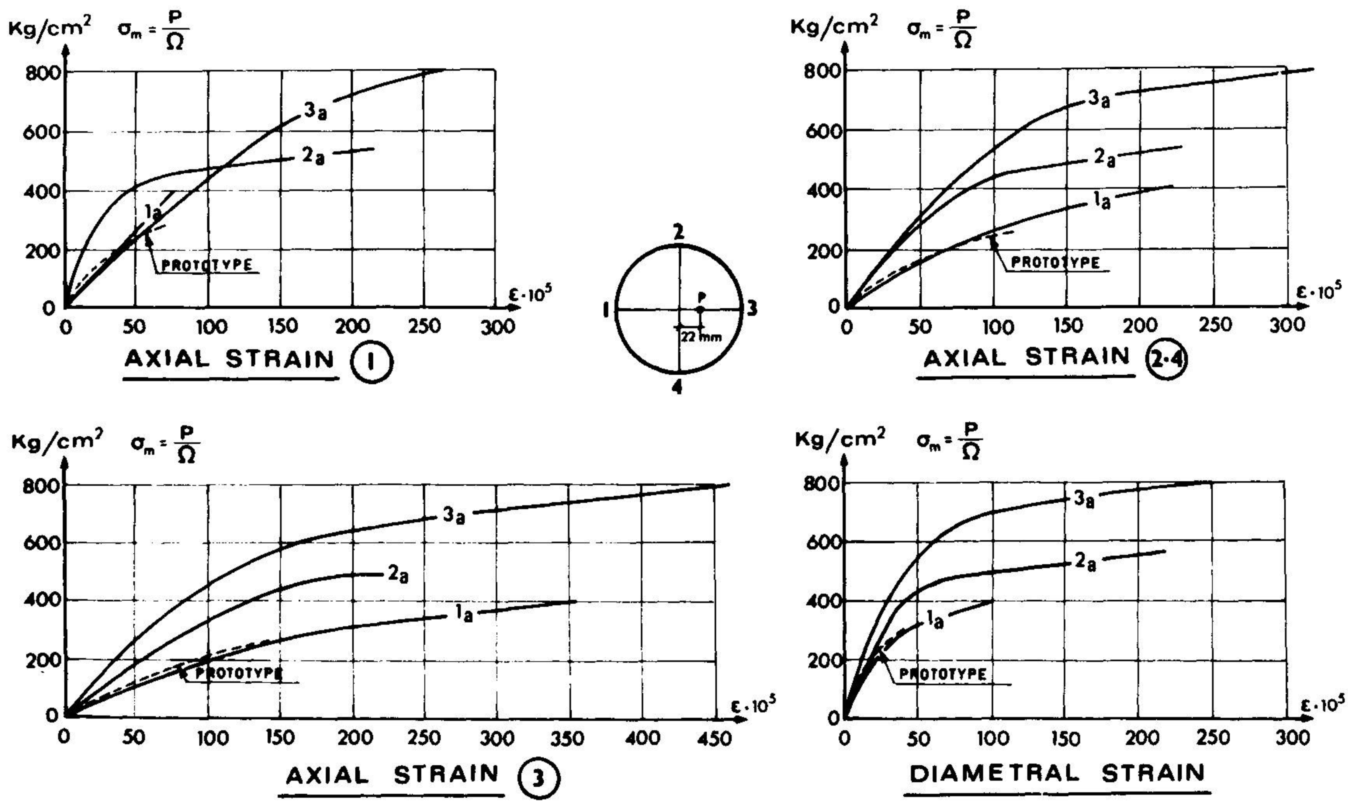
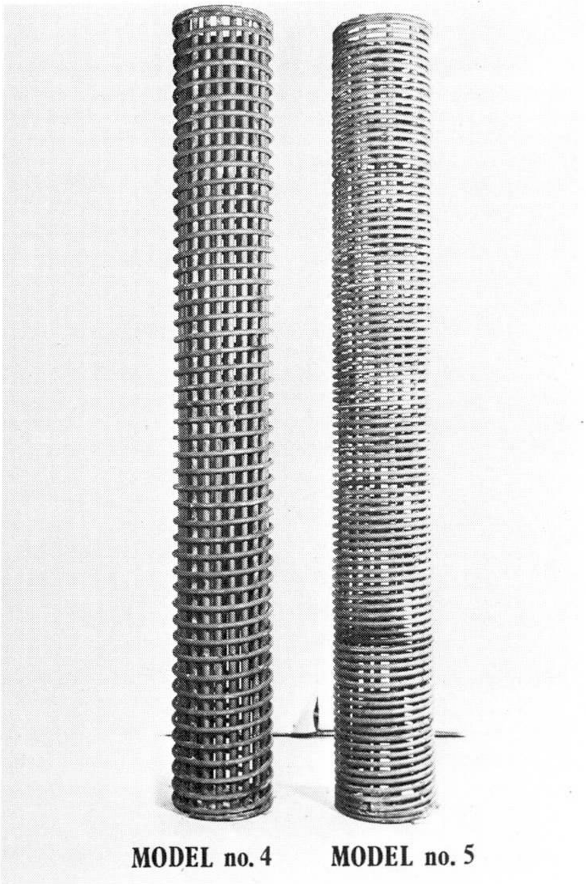


FIG. 2 - Second series



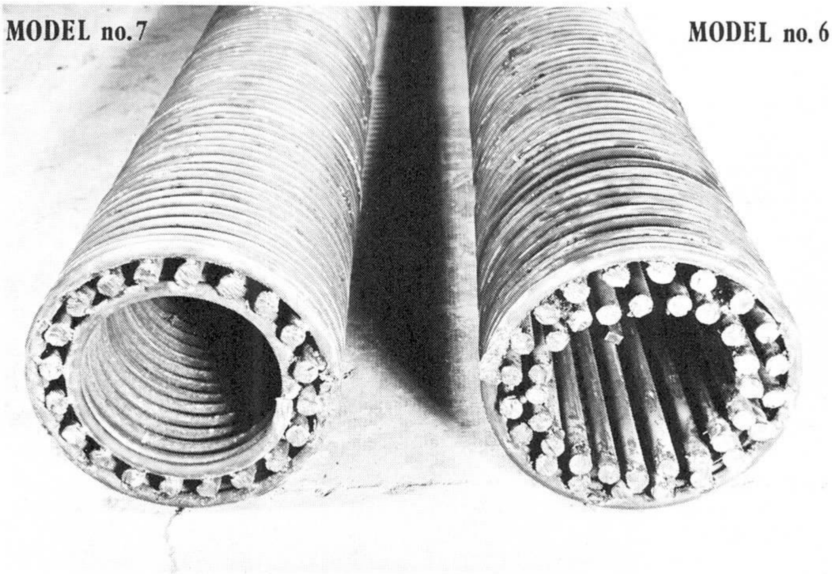
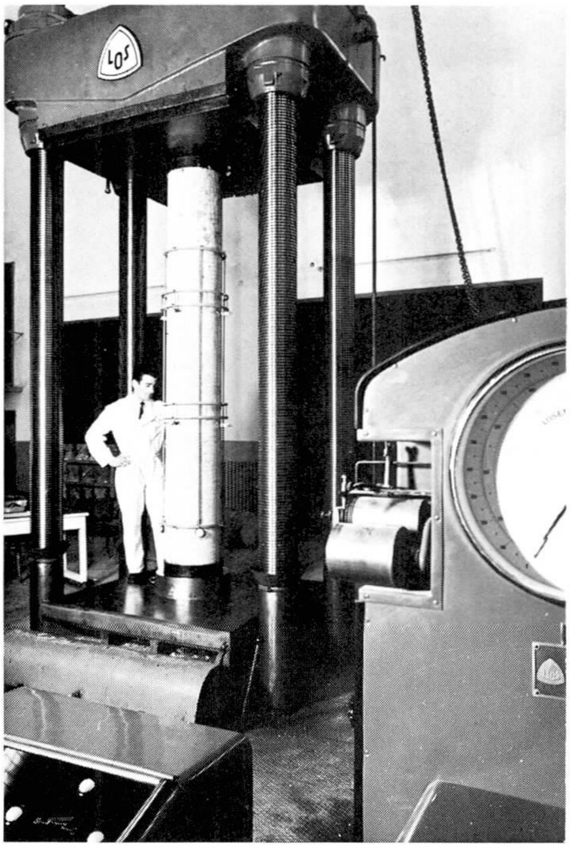


PHOTO 2 First Series:

Model no. 6 : $\mu = 10\%$, $\mu = 20\%$.
Model no. 7 : $\mu = 20\%$, $\mu = 10\%$.

PHOTO 1 First Series:

Model no. 4 : $\mu = 5\%$, $\mu = 10\%$.
Model no. 5 : $\mu = 10\%$, $\mu = 5\%$.



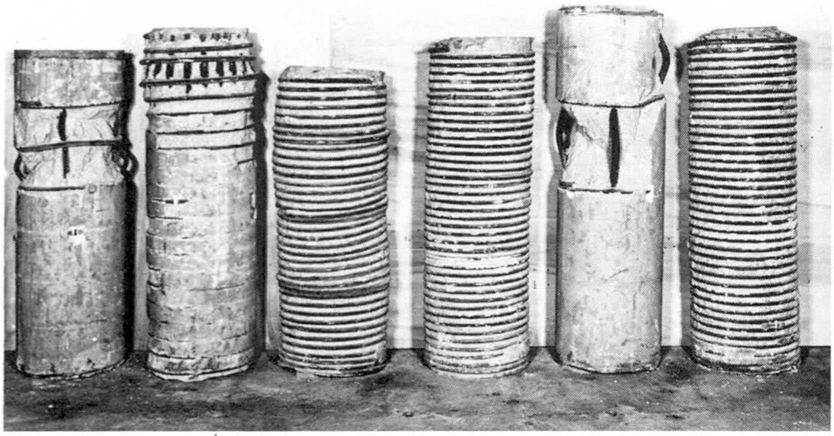


PHOTO 4 First Series:

1.20 m height models after failure tests.

PHOTO 3

Model under test; view of the apparatus for measurement of axial and diametral deformations.

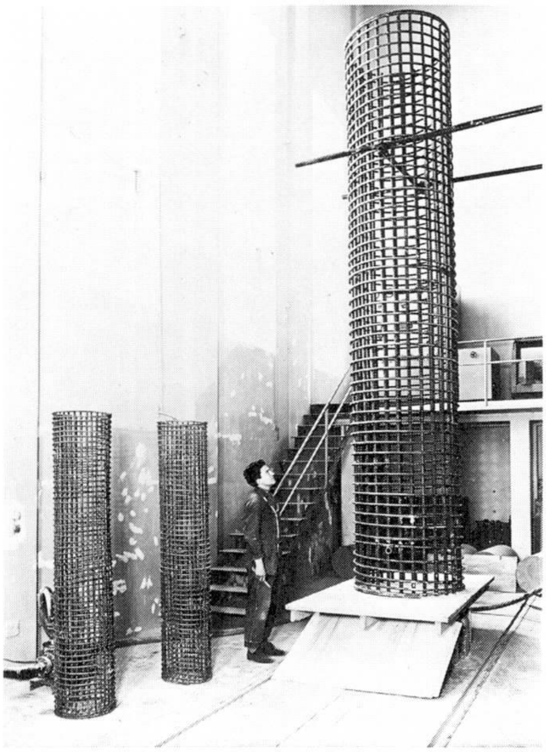


PHOTO 5 Second series:
Reinforcement of prototype pillar.

PHOTO 6 Second series:
Prototype pillar under test.

PHOTO 7 Second series: (H = 2 m):
Models after failure tests.

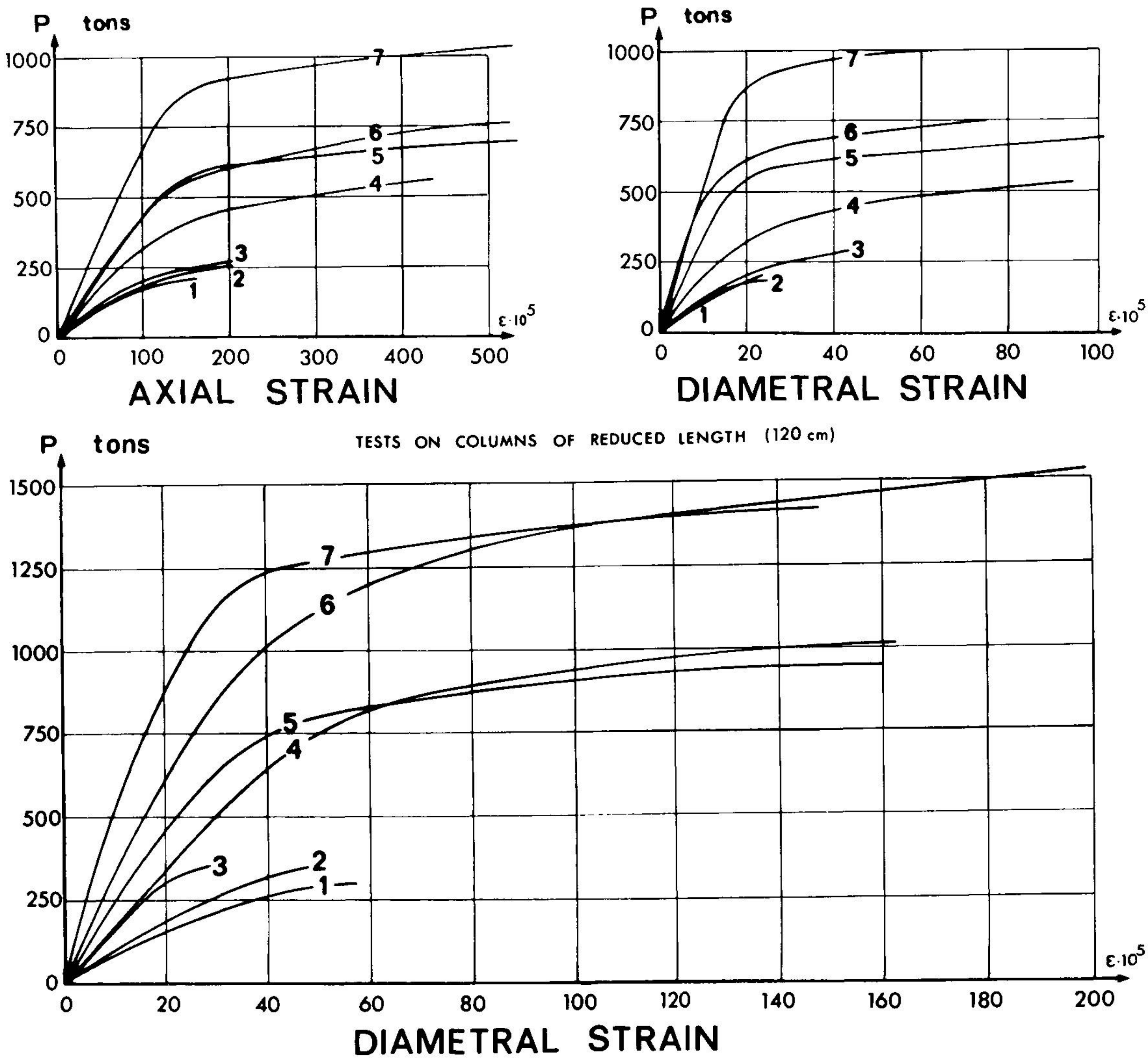


FIG. 1 - First series

3. CONCLUSIONS

The tests on large scale models of strongly reinforced concrete circular columns, having limited slenderness, may give useful indications in design stage.

The first series of tests shows the elevate ultimate capacity of strongly reinforced concrete columns. Up to the yield point, the axial reinforcement appears more useful than the binder reinforcement; at collapse the binders show greater efficiency.

In the second series, the agreement of the deflections of one prototype and the corresponding model have been established. Moreover the remarkable influence of steel pipe reinforcement has been shown.

SUMMARY

The paper deals with some tests on large scale models of strongly reinforced concrete columns having circular shape and limited slenderness. The usefulness of this type of tests in design stage is put in evidence.

RESUME

Le rapport présente quelques essais sur de grands modèles de colonnes circulaires en béton fortement armé et d'élancement limité. On met en évidence l'utilité de ce type d'essai dans la phase du projet.

ZUSAMMENFASSUNG

Der Artikel beschreibt Versuche an hochbewehrten Säulen mit kreisförmigem Querschnitt und begrenzter Schlankheit. Die Zweckmässigkeit dieser Art von Versuchen in der Entwurfsphase wird hervorgehoben.