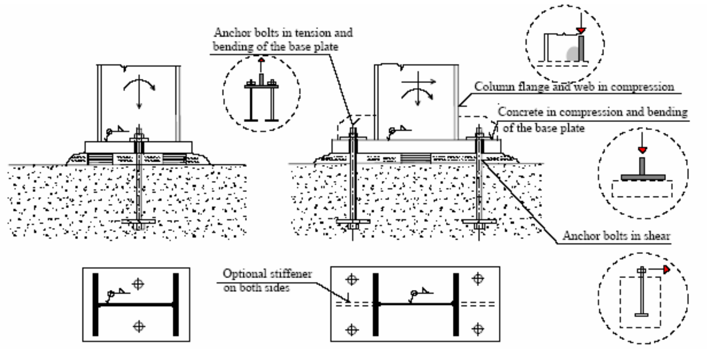


Ligações Semi-Rígidas – Placa de Base

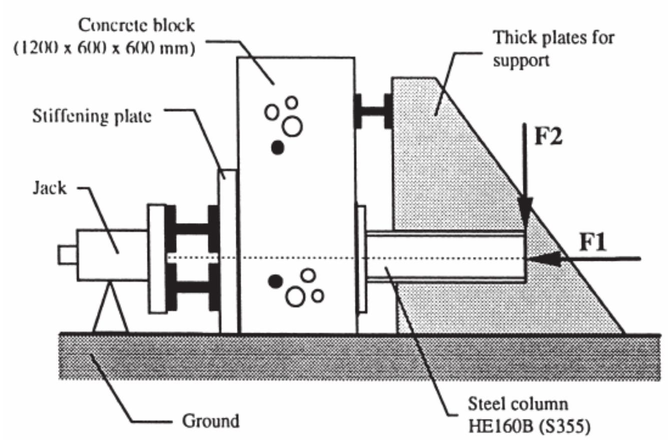
Programa de Pós-Graduação em Engenharia Civil
PGECIV - Mestrado Acadêmico
Faculdade de Engenharia – FEN/UERJ
Disciplina: Projeto Estrutural I
Professor: Luciano Rodrigues Ornelas de Lima

1. Introdução

- The semi-rigid behaviour of column bases influences the structural frame response and in particular:
  - ✓ the frame lateral deflections and the global frame stability in unbraced frames;
  - ✓ the column stability in braced frames.
- Taking this semi-rigid effect into account leads to significant cost savings linked to the reduction of the man power necessary to realise rigid column bases (less stiffening) or to the reduction of the column and/or beam size in the case of pinned column bases

2. Ensaios Experimentais

- Twelve experimental tests on column bases have been recently carried out in Liège.



2. Ensaios Experimentais

- The compressive force F1 → two jacks acting on the rear face of the concrete block
- Similar concrete blocks (slightly reinforced) are used for all the tests: 1200 mm high for a 600 x 600 mm square base. All the blocks were concreted at the same time in order to ensure that their mechanical behaviour is as homogeneous as possible
- To prevent any movement of the block, an efficient support against the moment created by force F2 is formed by two large thick steel plates placed on each side of the column profile

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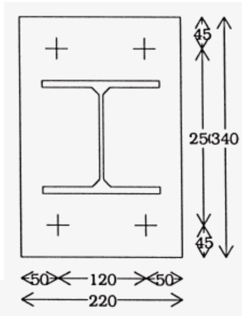
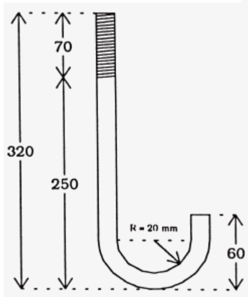
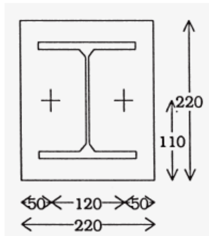
2. Ensaios Experimentais

- Two types of test configurations are considered, with four and two anchor bolts respectively
- In the first case, the column base is nearly rigid, while in the second it is usually modelled as pinned
- steel column profile: HE160B (S355)
- two different thicknesses are used for base-plates: 15 mm and 30 mm (S235)
- Anchor bolts: M20 10.9







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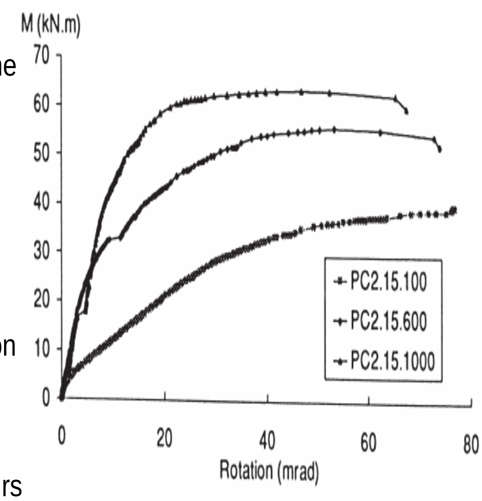
2. Ensaios Experimentais

Table 1
Nomenclature of the tests

Name	Anchor bolts	Plate thickness (mm)	Normal force (kN)
PC2.15.100	2	15	100
PC2.15.600	2	15	600
PC2.15.1000	2	15	1000
PC2.30.100	2	30	100
PC2.30.600	2	30	600
PC2.30.1000	2	30	1000
PC4.15.100	4	15	100
PC4.15.400	4	15	400
PC4.15.1000	4	15	1000
PC4.30.100	4	30	100
PC4.30.400	4	30	400
PC4.30.1000	4	30	1000

3. Resultados – PC2.15

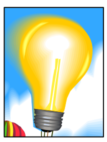
- Two anchor bolts, 15 mm plate thickness
- It has to be noted that the higher the force in the column, the higher the bending moment resistance of the column base
- The initial stiffness → quite similar for the three tests (first loading steps)
- In fact, the stiffness changes significantly as soon as a separation is observed between the plate and the concrete in the tensile zone
- the lower the initial compressive force → the more quickly this occurs

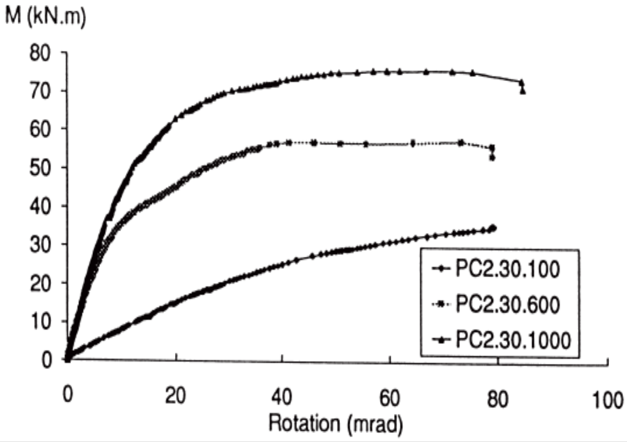


3. Resultados – PC2.30

- Two anchor bolts, 30 mm plate thickness
- Unlike the previous figure it shows that the initial stiffness of test PC2.30.100 is much lower than that of the two other tests PC2.30 → concrete process problems

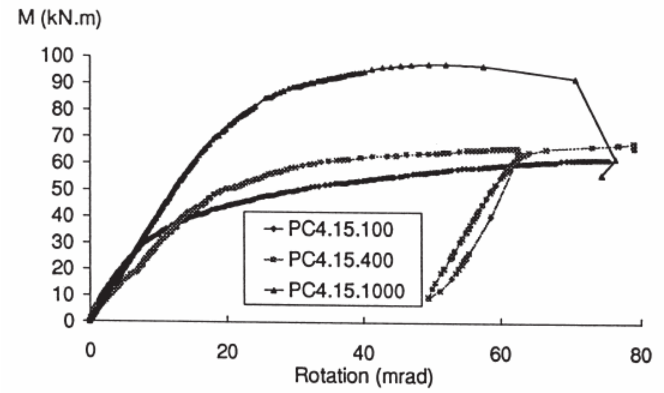
pinned???





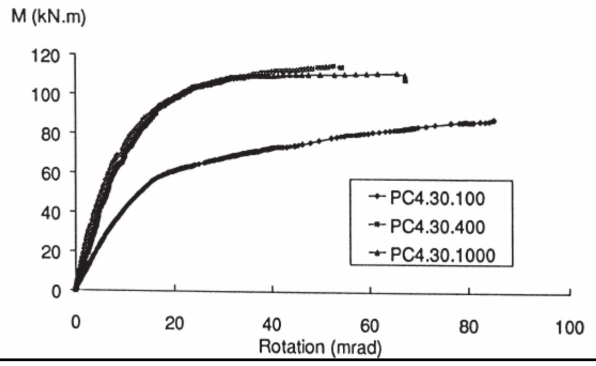
3. Resultados – PC4.15

- Four anchor bolts, 15 mm plate thickness
- The significant difference in strength between test PC4.15.1000 and the two other tests PC4.15 has to be pointed out. This may be explained by the fact that the anchor bolts in tension are activated much later when the compressive force in the column is high



3. Resultados – PC4.30

- Four anchor bolts, 30 mm plate thickness
- Unlike the three previous figures, it has to be noted that test PC4.30.1000 does not exhibit a higher strength than test PC4.30.400. In fact, this is due to the yielding, at the end of the test, of the end section of the steel HE160B profile. In addition, local plate buckling is also observed in the column flange subjected to the higher compressive stresses.



3. Resultados

Table 2
Ultimate resistaces and collapse modes of the experimental tests

Name	$M_{Ru,\ test}$ (kN.m)	Collapse mode
PC2.15.100	40	Failure of anchor bolts
PC2.15.600	56	Failure of anchor bolts
PC2.15.1000	63	Crushing of the concrete
PC2.30.100	35	Failure of anchor bolts
PC2.30.600	57	Failure of anchor bolts
PC2.30.1000	75	Failure of anchor bolts
PC4.15.100	62	Yielding of the plate
PC4.15.400	68	Collapse of the plate and of anchor bolts
PC4.15.1000	97	Yielding of the plate
PC4.30.100	86	Tearing of the anchor bolts
PC4.30.400	117	Tearing of the anchor bolts
PC4.30.1000	110	Yielding and local buckling of HEB160

4. Modelo Mecânico

- Component Method
- Experimental observations
  - ✓ the contact between the plate and the concrete → complex
  - ✓ the bond between the anchor bolts and the concrete quickly disappear
  - ✓ under the column flanges in compression, the plate deforms significantly in bending
  - ✓ the pressure under the plate is non uniform, even under axial compression
  - ✓ in the compression zone, the extended part of the plate has not to be disregarded as it prevents crushing in the concrete
  - ✓ plastic line is observed in the extended part during the test

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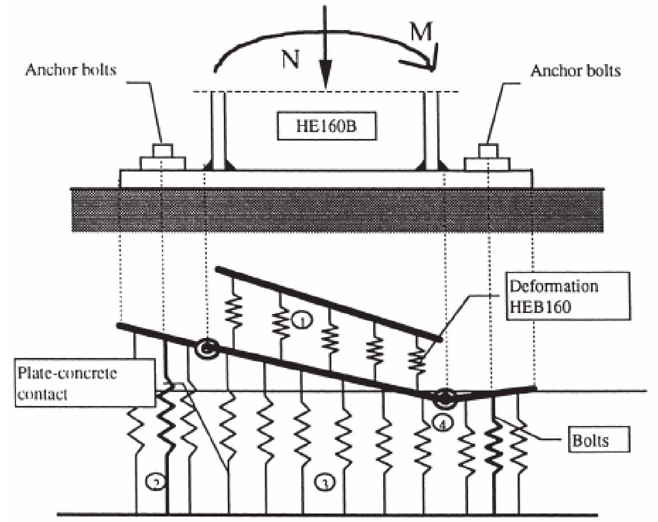
4. Modelo Mecânico

- Extensional springs (tension or compression)



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4. Modelo Mecânico

- Behaviour of the individual components
- Concrete

The plate-concrete contact is a very complex phenomenon, because the contact zone varies with the eccentricity of the compressive forces as well as with the flexibility of the plate, directly linked to its thickness.

The concept of equivalent rigid plate described in Annex L of Eurocode 3 [2] is followed. The behaviour law adopted for concrete is the classical parabolic-rectangular law. The concrete plate contact is modelled by a finite number of springs; each of them corresponds to a small part of the contact zone. A hundred of such springs leads to a good level of accuracy.

4. Modelo Mecânico

- Behaviour of the individual components
- Anchor bolts and plate in tension

The local response of the anchor bolts in tension and of the plate depends on the thickness of the plate and on the position of the bolt rows: **inside or outside the flange.**

EUROCODE 3 is used for the determination of the behaviour curve of these components. For some tests with thick base plates, it has been assumed that **no prying effect occurs** between the concrete and the edge of the end-plate in the tension zone. This assumption is justified as follows: the anchor bolts have a very high deformability; therefore the resulting relative displacement between the plate and the concrete is significant, sufficiently to be considered as higher than that due to the flexural deformation of the plate.

4. Modelo Mecânico

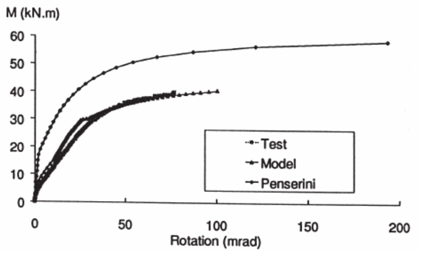
- Behaviour of the individual components
- Plate in compression

In the compression zone, the plate also deforms. Tests have shown that this deformation is very local and can be assimilated to a plastic hinge. This one is modelled through the use of a spring in bending characterized by an elastic-plastic law in the compression zone. This spring is infinitely rigid in the tension zone, the deformation of the base-plate being covered then by that of the ‘anchor bolts and plate in tension’ component.

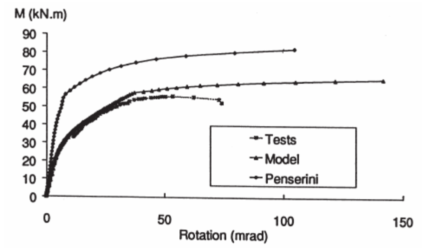
- The steel profile

Because of the high normal forces in the column, this one might partially yield. An elastic-plastic behaviour law is adopted for the related springs. The possible plate buckling of the column flanges and/or web in compression is not yet covered by the model.

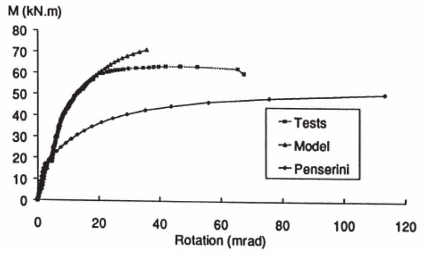
5. Comparações com Testes



PC2.15.100



PC2.15.600



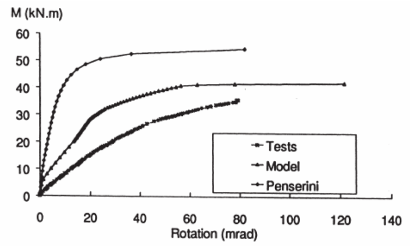
PC2.15.1000

- **Curves M x ϕ → good agreement**
- **two anchor bolts, the theoretical curves obtained using the <u>PENSERINI model</u> → the agreement between the latter and the experimental tests is far from being convincing**

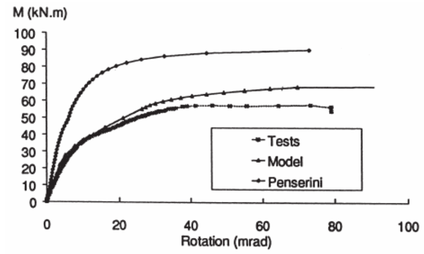
5. Comparações com Testes

- <u>Ultimate load difference</u> → the great complexity of the behaviour when the different components of the column base are close to collapse:
  - ✓ concrete is a material whose mechanical properties can vary considerably, according to the quality of the compaction. Furthermore, the crushing of the concrete under local forces is not an easy phenomenon to model;
  - ✓ the anchorage of the bolts in the concrete is aleatory. In fact, contrary to what was expected, the anchorage of the bolts by the concrete was not sufficient enough to prevent a relative overall movement between the bolt and its support. Fortunately, these movements only occurred in the case of very high tension forces at the end of the test, and thus only altered the ultimate load.
  - ✓ the displacements at the end of the test become quite significant, which leads to geometry changes which are not correctly taken into account in the mechanical model.

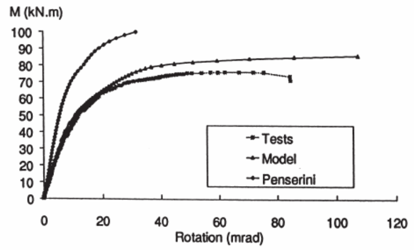
5. Comparações com Testes



PC2.30.100

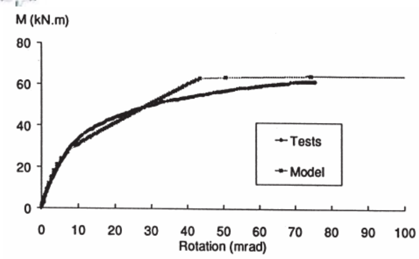


PC2.30.600

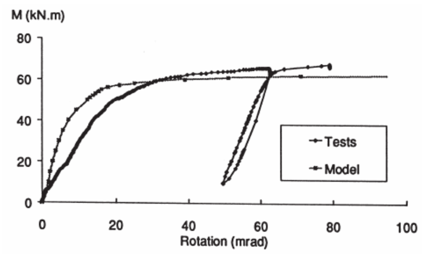


PC2.30.1000

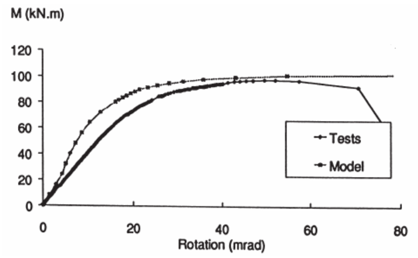
5. Comparações com Testes



PC4.15.100



PC4.15.400



PC4.15.1000

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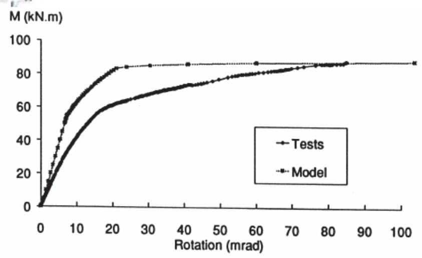
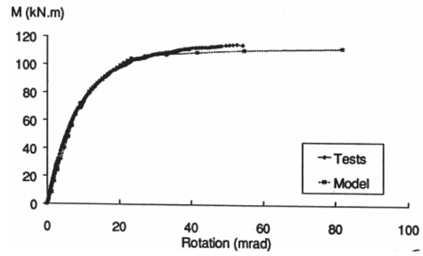
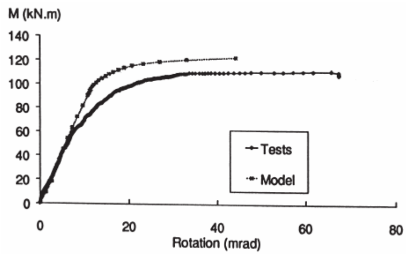
5. Comparações com Testes



PC4.30.100



PC4.30.400



PC4.30.1000

- **PC4.30.400 (Fig. 20) → excellent results**
- **PC4.30.100 → same problem as test PC2.30.100, i.e. an actual stiffness for the concrete lower than the theoretical prediction**
- **PC4.30.1000 seems to be well described by the mechanical model when the moment is lower than half its ultimate value.**

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6. Eurocode 3

- The rotational stiffness S_j of a column base for normal force in combination with bending moment may be determined with table 6.12 where the contribution of the concrete portion just under the column web (T-stub 2 of figure 6.20) to the rotational stiffness is omitted
- The tension stiffness coefficient $k_{T,l}$ of the left side of the joint should be taken as the sum of the stiffness coefficients k_{15} and k_{16} acting on the left side of the joint, see table 6.11
- The tension stiffness coefficient $k_{T,r}$ of the right side of the joint should be taken as the sum of the stiffness coefficients k_{15} (base plate in bending) and k_{16} (anchor bolt in tension) acting on the right side of the joint, see table 6.11
- The compressive stiffness coefficient $k_{C,l}$ of the left side of the joint should be taken as the stiffness coefficient k_{13} (concrete in compression) acting on the left side of the joint, see table 6.11

6. Eurocode 3

- The compressive stiffness coefficient $k_{C,r}$ of the right side of the joint should be taken as the stiffness coefficient k_{13} acting on the right side of the joint, see table 6.11
- For the calculation of $z_{T,l}$, $z_{C,l}$, $z_{T,r}$, $z_{C,r}$ see 6.2.6.1

Loading	Lever arm z	Rotational stiffness $S_{j,ini}$	
Left side in tension Right side in compression	$z = z_{T,l} + z_{C,r}$	$N_{Sd} > 0$ and $e > z_{T,l}$	$N_{Sd} \leq 0$ and $e \leq -z_{C,r}$
		$\frac{E\,z^2}{\mu\,(1/k_{T,l} + 1/k_{C,r})}\;\frac{e}{e+e_k}$	where $e_k = \frac{z_{C,r}\,k_{C,r} - z_{T,l}\,k_{T,l}}{k_{T,l} + k_{C,r}}$
Left side in tension Right side in tension	$z = z_{T,l} + z_{T,r}$	$N_{Sd} > 0$ and $0 < e < z_{T,l}$	$N_{Sd} > 0$ and $-z_{T,r} < e \leq 0$
		$\frac{E\,z^2}{\mu\,(1/k_{T,l} + 1/k_{T,r})}\;\frac{e}{e+e_k}$	where $e_k = \frac{z_{T,r}\,k_{T,r} - z_{T,l}\,k_{T,l}}{k_{T,l} + k_{T,r}}$

6. Eurocode 3

Loading	Lever arm z	Rotational stiffness $S_{j,ini}$	
Left side in compression Right side in tension	$z = z_{C,l} + z_{T,r}$	$N_{Sd} > 0$ and $e \leq -z_{T,r}$	$N_{Sd} \leq 0$ and $e > z_{C,l}$
		$\frac{E\,z^2}{\mu\,(1/k_{C,l} + 1/k_{T,r})}\;\frac{e}{e+e_k}$	where $e_k = \frac{z_{T,r}\,k_{T,r} - z_{C,l}\,k_{C,l}}{k_{C,l} + k_{T,r}}$
Left side in compression Right side in compression	$z = z_{C,l} + z_{C,r}$	$N_{Sd} \leq 0$ and $0 < e < z_{C,l}$	$N_{Sd} \leq 0$ and $-z_{C,r} < e \leq 0$
		$\frac{E\,z^2}{\mu\,(1/k_{C,l} + 1/k_{C,r})}\;\frac{e}{e+e_k}$	where $e_k = \frac{z_{C,r}\,k_{C,r} - z_{C,l}\,k_{C,l}}{k_{C,l} + k_{C,r}}$
$M_{Sd} > 0$ is clockwise, $N_{Sd} > 0$ is tension, μ see 6.3.1(6). $e = \frac{M_{Sd}}{N_{Sd}} = \frac{M_{Rd}}{N_{Rd}}$			

6. Eurocode 3

- Artigo J. P. Jaspart:
  - ✓Página da CAPES: www.capes.gov.br
  - ✓ entrar em periódicos e depois, na letra J – Journal of Constructional Steel Research – volume 48 (1998) – páginas 89-106
  - ✓ Application of the component method to column bases - J.P. Jaspart and D. Vandegansb
- Material ECCS:

  http://openlink.br.inter.net/lucianolima/baseplates_ECCS.pdf