THE EFFECT OF BEAM TO COLUMN CONNECTION IN A RC PORTAL FRAME

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Rakenteiden Mekaniikka, Vol. 26
No 2 1993, ss. 35 - 50

SUMMARY

A full scale rc (reinforced concrete) portal frame has been built in order to study the effect of beam to column connection on deflection and supporting moment of a column in practice. Five different connection types were used in tests: the aim was to find out the difference between a hinged connection and a connection with a bearing pad. Another aim was to find out a connection type which is more rigid than a connection with a full size bearing pad: two examples of new connections are shown.

The results of hinge- and bearing pad-connections are esitimated with a calculation method, which has been proposed and used in references (Lindberg 1987, Keronen 1984, Keronen 1991). This method takes into account the effect of a bearing pad in a beam to column connection on the deflection of a frame and the moment surface of a column.

The results show that beam to column connection type has a significant effect on deflection and supporting moment of a column. The hinge-connection caused clearly - eaven 4.3 times - greater deflection and supporting moment than a connection with a full size bearing pad. However, the least deflections were found for new connection types.

On grounds of this research it is important to take into account the beam to column connection type in constructing columns in a rc portal frame. Also it is important - as the final aim of this research is - to develope the rules for effective length factor of this kind of columns.

INTRODUCTION

In Finland one-storied industrial and commercial buildings and storehouses are often constructed of prefabricated rc portal frame structures. Stability is usually achieved by cantilever action of columns. At least one column in a frame is cantilevered; others can be pin ended.

In beam to column connection there is an elastomeric bearing pad in order to prevent peak stresses on the contact surfaces and cracks due to the different rotation of a column and a beam.

It is generally assumed that the beam to column connection behaves as an ideal hinge. However, a bearing pad allows a movement of the reaction of the beam as a result of different rotations between the beam and the column. The movement of the action point causes a moment that may be opposite sign compared to common practice. The action point of the reaction of the beam varies due to the horizontal load.

PROPERTIES OF THE BEARING PAD

The movement of the reaction of the beam depends on the size and the elasticity of the bearing pad. Also the smoothness of the contact surfaces, time and temperature have an effect on the movement. Equal shape factors (= the relationship between loaded and unloaded surface) do not necessarily quarantee that the compression properties for bearing pads are similar. Thinner bearing pad usually behaves stiffer.

In compression tests (Keronen 1984) bearing pads were loaded between two concrete blocks of size $200 \cdot 200 \cdot 200\ \mathrm{mm}^3$ (smooth steel mold). The compressive strain of a bearing pad was measured using Demec -pins that were attaced in the concrete cubes. Two pairs of pins were used in order to eliminate the compression strain of concrete.

Elastic properties were examined for bearing pads $150 \cdot 150\ \mathrm{mm}^2$ (70° IRH). The thicknesses were 3, 4, 5, 6 and 8 mm (shape factor $k = 12.5 \ldots 4.7$) and the compressive stress 0.4...12.0 MPa (with loading speed 0.4 MPa/min). Every pad was loaded quickly up to 12 - 13 MPa and unloaded several times before tests.

For the thickness of 8 mm, the modulus of elasticity was 110...220 MPa. For other thicknesses this value varied between 100...280 MPa being at its most for 5 ja 6 mm pads by compressive stress 10 MPa.

The bearing pads (also 70° IRH) used in this research were tested. The modulus of elasticity was 37 - 82 MPa (under stress 1.8 - 7.1 MPa) for size 150·150·8 mm^3 (hole ϕ 34 in the middle and a cutting: $k = 3.3$) and 50 - 126 MPa (4.1 - 16.4 MPa) for size 65·150·8 mm^3 ($k = 2.8$); corresponding loading speeds were 6 and 2 MPa/min. These values were measured during 5. compression cycle (0 -> max. load -> 0) between smooth concrete blocks 200·200·200 mm^3.

In first loading tests the pads were between the blocks all the time from the preciding fast loading-unloadings to the end of the test. The aim was to represent the effect of wind load. In second tests the aim was to simulate the portal frame in loading tests: in these tests the pads were released from the connection between every vertical loading. There were no preciding loadings before measurements. So in bearing pad loading tests there were any preciding loadings before measured loading cycles. This means that the region of low modulus of elasticity in the beginning of the tests is included in second loading measurements, but is pressed away in first tests. This is the obvious reason - in addition to the different shape factors - for different test results in these two tests.

The modulus of elasticity in computer calculations was 60 MPa, as in earlier studies.

In figure 1 the rotation difference ω between beam end and column top is shown as a function of the eccentricity e/d. The reaction of the beam is $N = 500$ kN, the area of the bearing pad is 350·350 mm^2, the modulus of elasticity $E = 60$ MPa and the thickness t 5 and 10 mm. Values are typical for the calculations concerning a rc portal frame. One can see that the eccentricity e/a grows intensively with small values of the rotation ω. This leads to a quick increase of the moments in beam to column connection.

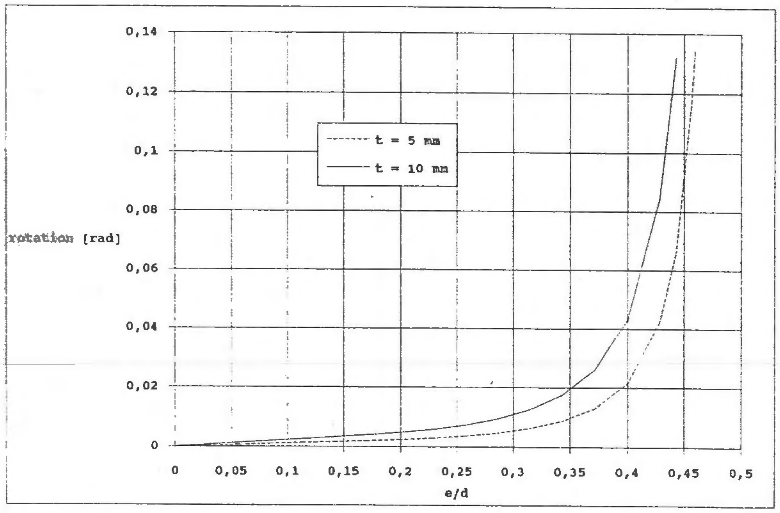

Fig. 1. Relationship between the eccentricity e/d and the rotation difference ω.

STRUCTURE OF THE TEST FRAME

A full scale precast concrete portal frame was constructed for loading tests. The frame consists of precast columns and a beam. The columns are supported rigidly by a steel beam HE 320 A that is fastened to the floor (fig. 2).

The size of the columns is 180·180 mm^2 and length 3300 mm. So, the slenderness λ is 140 (L_0 = 2.2·L). There is one reinforcementbar of ϕ12 mm in each corner of the column cross-section. The ties are ϕ6 k 150.

The rc beam is very rigid compared with the columns: cross-section is 280·600 mm^2 and length 1300 mm.

Strength of concrete was 45 MPa, strength grade of reinforcement A500HW and steel at least Fe 510 C.

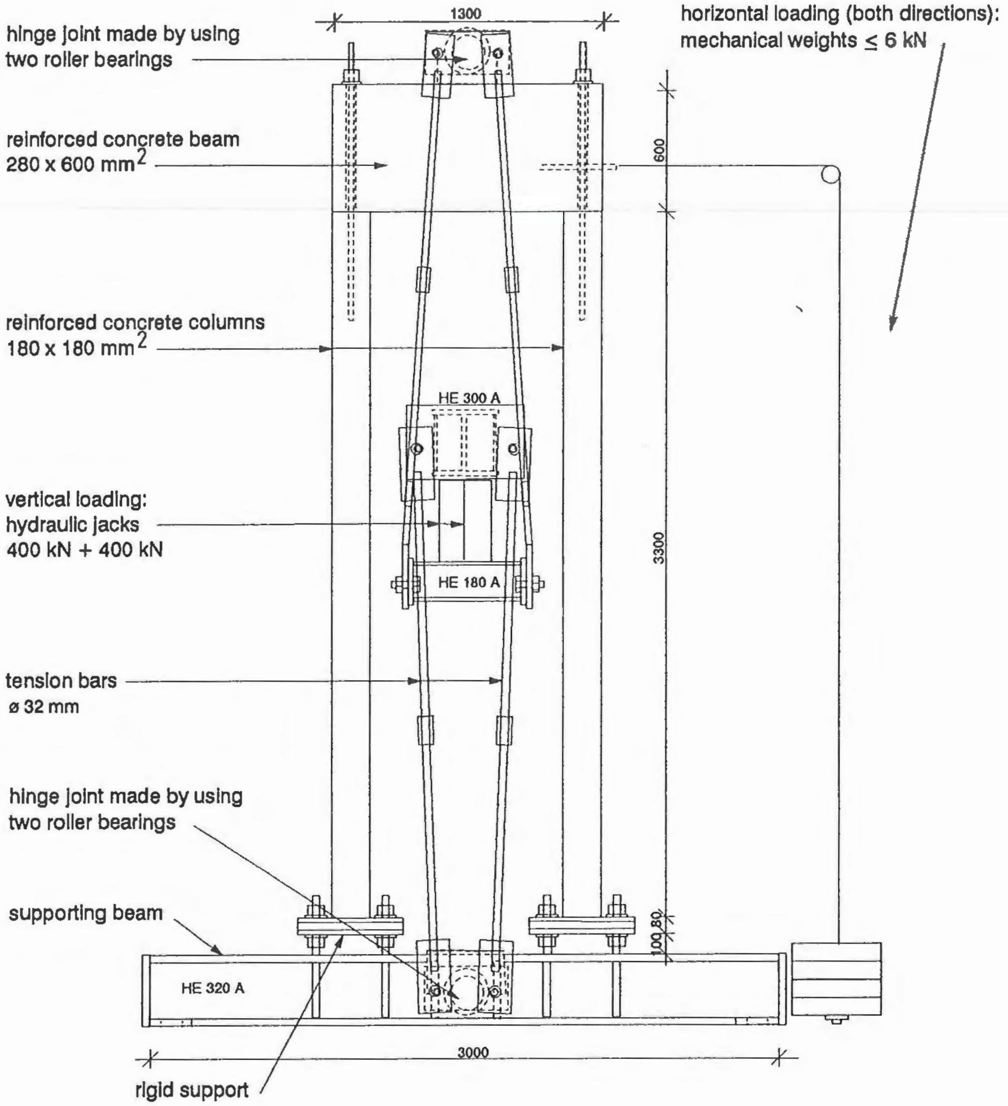

Fig. 2. Rc portal frame.

BEAM TO COLUMN CONNECTIONS

In the tests there were five connection types: 1) a bearing pad which covers whole supporting area (150·150·8 mm^3), 2) a bearing pad which covers only half of the supporting area (65·150·8 mm^3), 3) a hinge, 4) a steel component and 5) a steel component with a pretensioned bar (fig. 3). In every connection the transfer of the lateral force was ensured by a reinforcement bar ϕ 16.

Connection type 1 corresponds a situation where the column top supports only one beam end. In second type the column top is prepared to support two beam ends; pads are placed symmetrically in the frame. These connections are common in portal frame structures.

Connection 3 corresponds common idealisation in calculations. Type 4 is a new idea how to make a connection more rigid. In last type this connection is pretensioned with a reinforcement bar ϕ 16 (stress 300 MPa). The maximum exentricity in steel component connections is 60 mm.

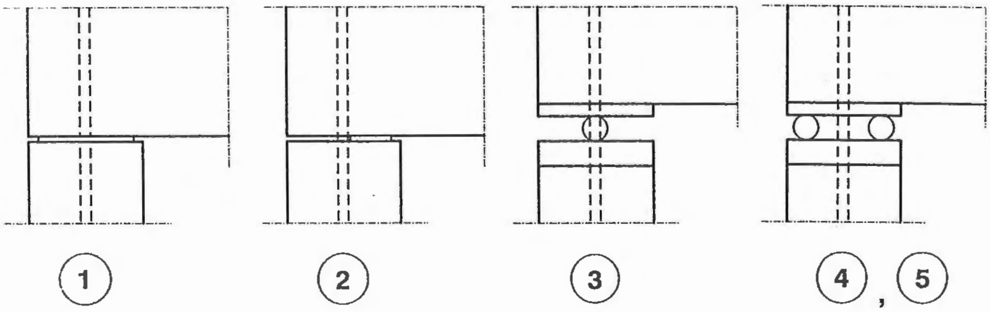

Fig. 3. Beam to column connections.

LOADING SYSTEM

The vertical load was arranged with two hydraulic jacks of 400 kN. The jacks were located between two short HE-beams in the middle of the frame. The beams were connected to the frame by tension bars of ϕ32 mm.

The frame was loaded by vertical loadings N = 37, 70, 102, 135, 167, 265, 292 kN for one column. These loadings corresponds mean compression 1.1 - 9.0 MPa.

Horizontal loading was arranged with mechanical weights. Tension wire was fastened to the end of the beam. Two wires were used: the frame was loaded symmetrically on both directions to minimize the permanent deflection. There were 1 - 4 cycles for one vertical loading.

In tests horizontal loads were $H \leq 6$ kN for whole frame. The maximum value depends on the vertical loading and the beam to column connection type. The horizontal effect from vertical loading system is subtracted from final horizontal loading.

Proposed loadings are from first cycle and the horizontal loading is always to same direction.

TEST RESULTS

Deflection

The deflection of the frame depends strongly on the connection type between the beam and the column. The full size bearing pad has same kind of effect on the rigidity of the frame as in tests with a steelframe (Keronen 1984): a frame with full size bearing pads is clearly more rigid than a frame with hinge connections; and the more vertical loading the larger is this difference (fig. 4 - 7).

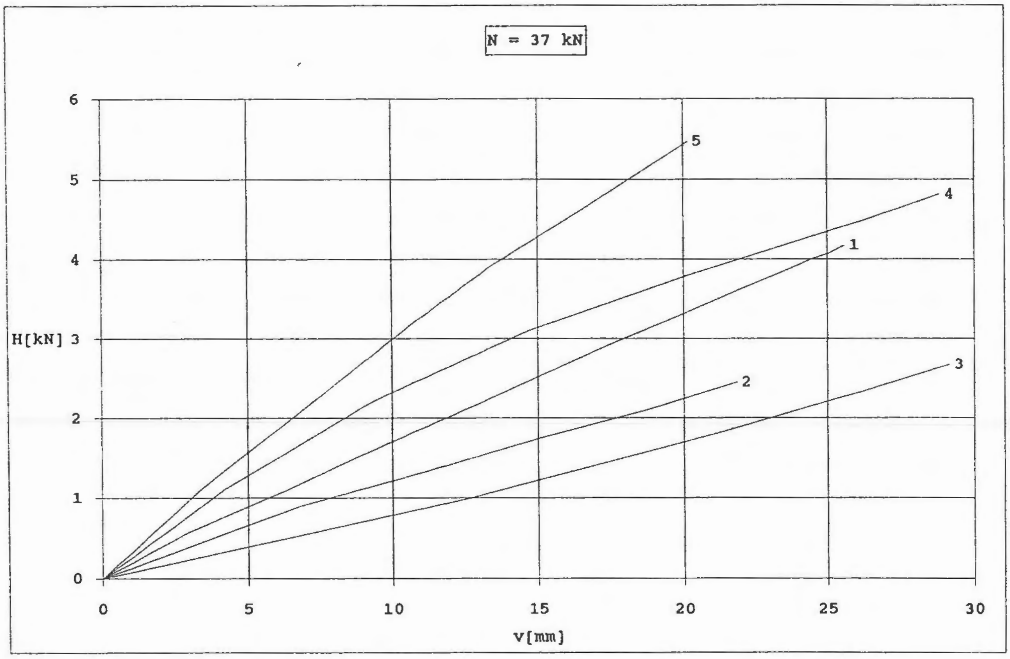

Fig. 4. The deflection of the frame, when N = 37 kN. Numbers refer to the connection type.

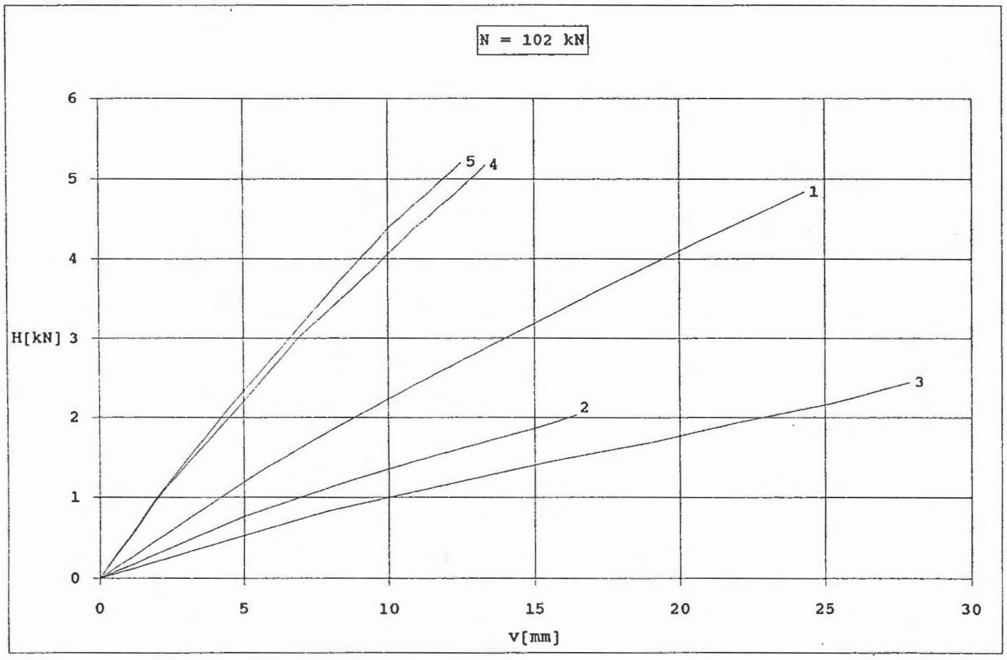

Fig. 5. The deflection of the frame, when N = 102 kN/column.

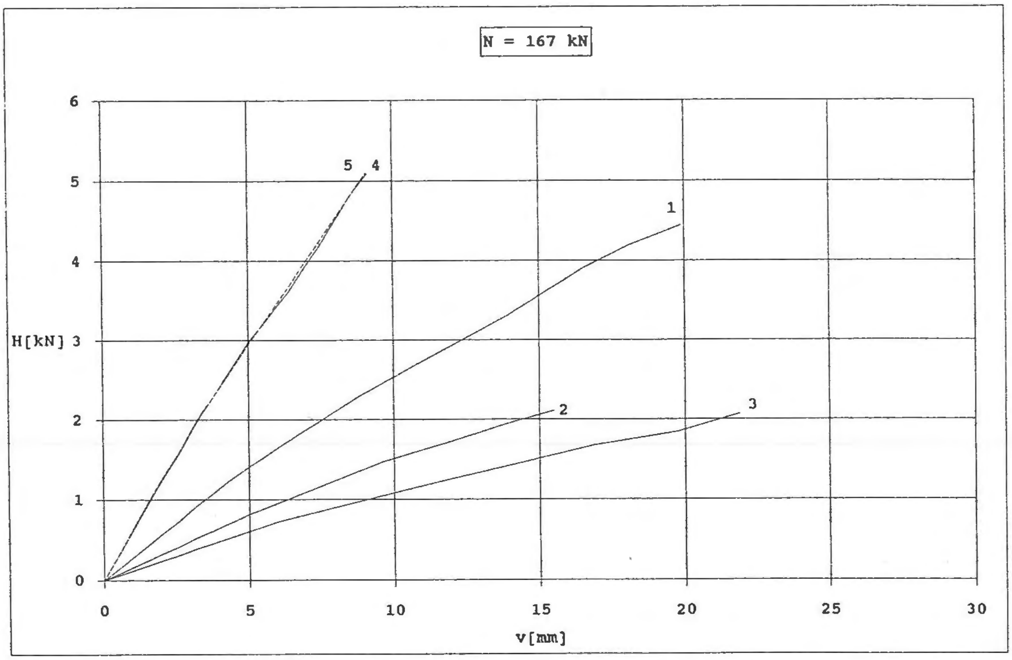

Fig. 6. The deflection of the frame, when N = 167 kN/column.

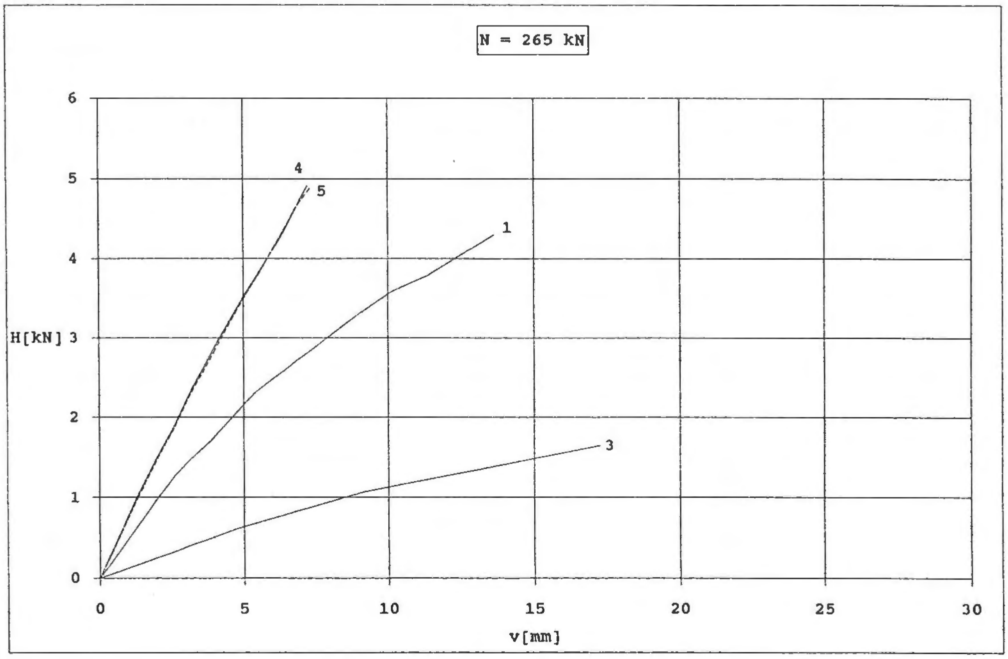

Fig. 7. The deflection of the frame, when N = 265 kN/column.

For example, when vertical loading N is 102 kN and horizontal loading H is 2 kN, the relative deflection with hinged connection is 2.6, and when N is 167 kN respectively 2.8 compared with the deflection with bearing pad connection. Under vertical loading 267 kN and horizontal loading 1 kN the relation is 4.3.

Also the half size bearing pad connection effects smaller deflection than the hinged one although the difference is now slighter: the corresponding relative deflections are now 1.4 (N = 102 kN, H = 2 kN) and 1.5 (N = 167 kN). The deflections are in these cases 1.8 - 1.9 times larger compared with deflections with full size pads.

The effect of the location of the hinge was also studied. There were no difference between the deflections either the hinge was situated centricly or eccentricly (e = 42 mm symmetrically).

The frame with connections 4 or 5 is most rigid under every loading situation. Pretensioned connection effects clearly smallest deflection when pretension force is at least 0.5 · N. For smaller values this effect becomes insignificant. The minimum pretension force was the same for a steel component connection with eccentricity e = 45 mm instead of 60 mm.

The steel component connection reduces deflections 49 - 57 % (N = 102 - 167 kN, H = 2 kN) compared with deflections with full size bearing pad and respectively 80 - 85 % compared with hinged connection. For shorter eccentricity (e = 45 mm) respective figures are 43 - 46 % and 76 - 81%.

With every connection type the deflection of the frame was the less the more the vertical loading was. Vertical loading effects most to deflections with steel components and least to deflections with hinges.

Typical deflection figures after loading cycles show (fig. 8 and 9), that there is clearly more dissipated energy in tests with bearing pad than hinge connections. These figures located symmetrically in regard to origo; deflection without horizontal loading was normally 1 - 4 mm.

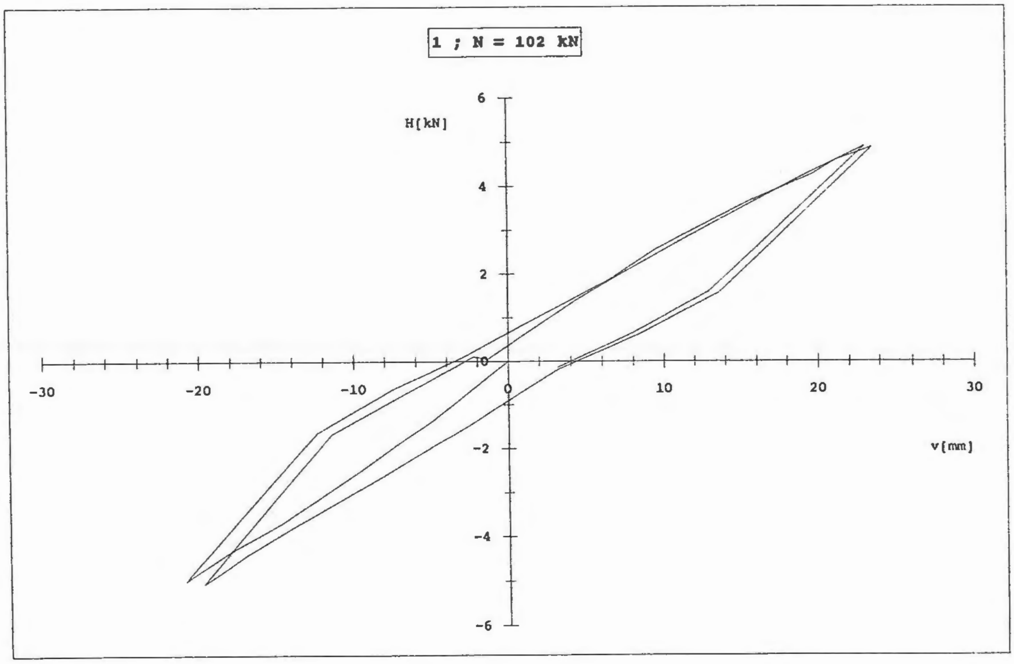

Fig. 8. Typical loading cycles for connection 1.

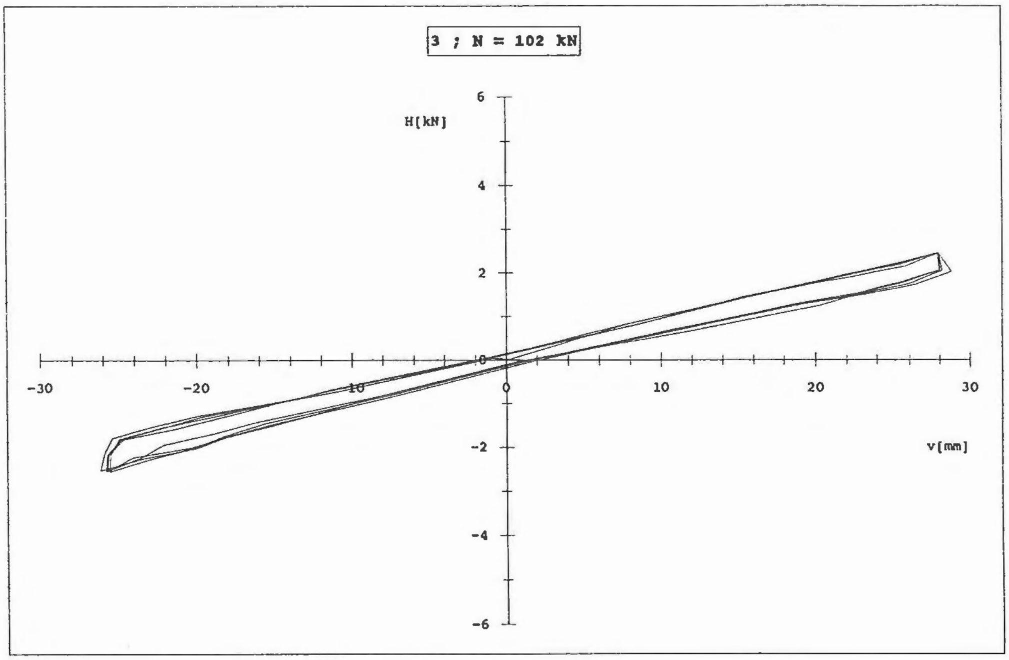

Fig. 9. Typical loading cycles for connection 3.

Supporting moment

Also the supporting moment of the column depends on the connection type. In figure 10 supporting moments are counted up (= supporting moment of the frame).

The results are similar to deflection figures: the relative supporting moment with hinged connection is 2.0 (N = 102 kN, H is 2 kN) and 2.1 (N = 167 kN) times greater than with full size bearing pad connection. Relations are here smaller than with deflections because the effect of vertical loading to supporting moment is slighter compared with horizontal loading.

The respective relative supporting moment relation between hinged and half size bearing pad connection is here 1.3 (N = 102 kN and 167 kN, H = 2 kN). The supporting moments are in these cases 1.6 times greater compared with full size pads.

The steel component connection reduces supporting moments 31 - 38 % (N = 102 - 167 kN, H = 2 kN) compared with full size bearing pad frame and respectively 65 - 71 % compared with hinged connection. For shorter eccentricity respective values are 27 - 29 % and 63 - 67%.

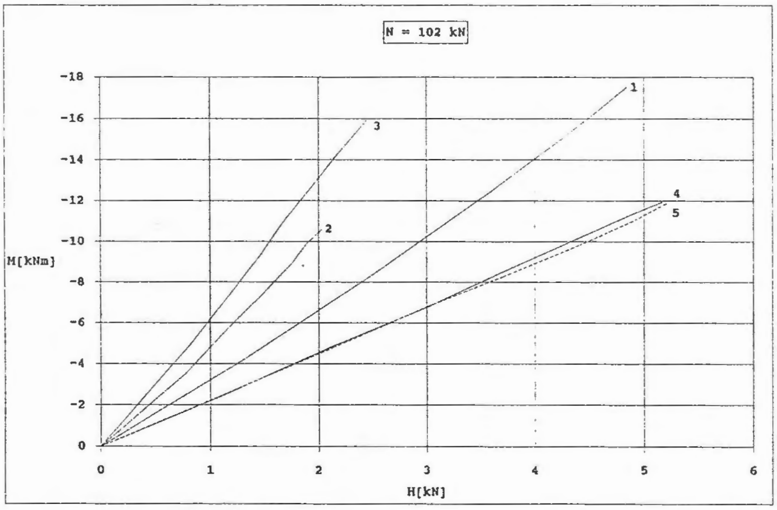

Fig. 10. The sum of the supporting moments of the columns in a frame, when N = 102 kN/column.

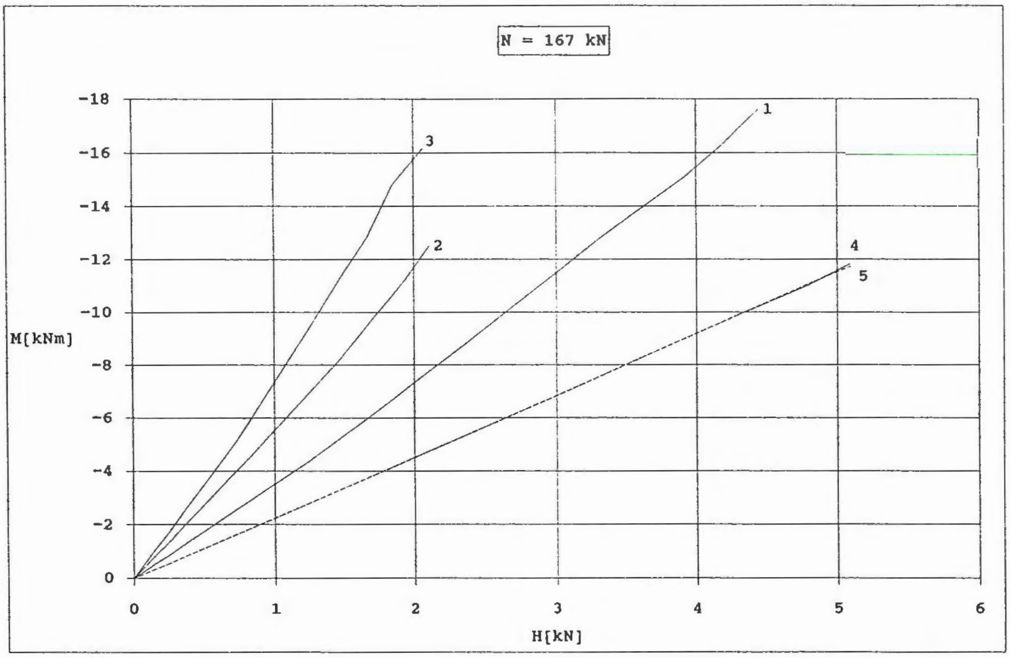

Fig. 11. The sum of the supporting moments of the columns in a frame, when N = 167 kN/column.

Theoretical calculations

The deflections according to the analysing method are represented in figure 12 and the supporting moments in figure 13.

Before these loadingtests the columns were cracked as result of shrinkage and earlier loadings. Therefore the rigidity of the column is taken here from the tests. As can be seen, the effect of connection to the deflection and supporting moment is similiar also in theoretical calculations.

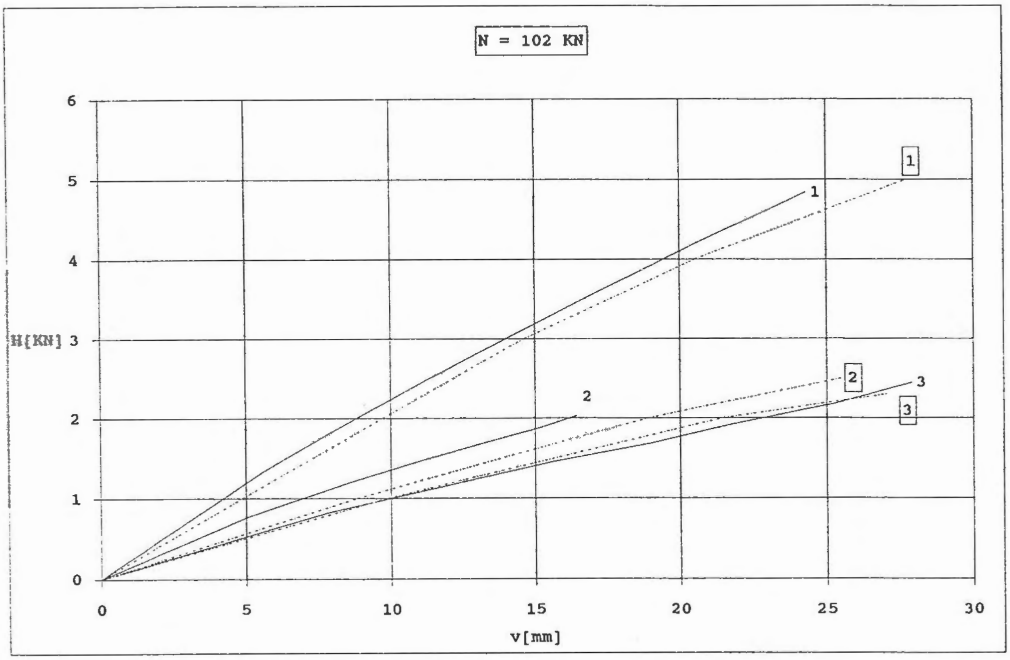

Fig. 12. Deflection in tests (solid line) and according to the analysing method (dashed line).

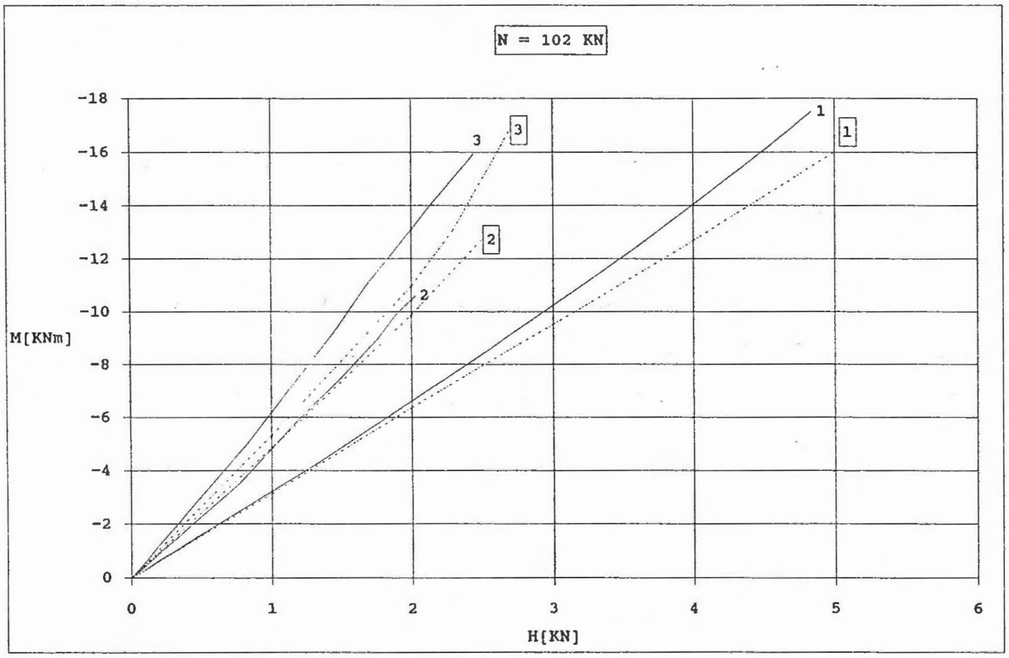

Fig. 13. Supporting moment in tests (solid line) and according to the analysing method (dashed line).

CONCLUSIONS

Tests with the rc portal frame show that the effect of the connection between a beam and a column is significant to the rigidity and the supporting moment of the frame. The full size bearing pad connection reduces deflections over 60 % and supporting moment about 50 % compared with respective values with hinged connection (N = 102 - 167 kN, H = 2 kN).

Also tests show that the bearing pad should be full size type: the type where the column top is prepared to support two beam ends reduces respective deflections about 30 % and supporting moment over 20 %.

New steel component connections proved to be worth of developement: deflections reduced over 80 % and supporting moment over 60 % compared with hinged connection. The result does not seem to be sensitive for eccentricity.

It is quite obvious that the connection type should be taken into account in dimensioning a cantilever column.

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