PŮSOBENÍ ZDIVA S PODÉLNÝMI DUTINAMI V LOŽNÝCH SPÁRÁCH
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COMPRESSIVE BEHAVIOUR OF MASONRY WITH LONGITUDINAL HOLES IN BED JOINTS

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SOUHRN

Předmětem vyšetřování bylo chování jednovrstvých zděných stěn, tlustých 365 až 400 mm, ze svisle děrovaných cihel /364. 240.141 mm/, jak s podélnými dutinami v ložných spárách, tak i s plnými spárami, při zatížení tlakem. Bylo prokázáno, že vliv podélných dutin je značný a že je nutno k němu přihlížet při sestavování vztahů pro výpočet zděných stěn. Předkládá se též jednoduchý matematický model porušení jednovrstvé cihelné stěny při zatížení tlakem.

SUMMARY

The compressive behaviour of single wythe brick walls, from 365 to 400 mm thick, built from vertically cored bricks /364. 240.141 mm/, both with the longitudinal holes in horizontal /bed/ joints and with full joints have been studied. The effect of longitudinal holes on compressive behaviour should be considered in the design formulas of brick walls. A simple mathematical model of brick wall failure is proposed.

1. INTRODUCTION

New types of brick walls have been worked out in Czechoslovakia in order to meet recently revised requirements [1] relating the thermal insulation parameters of exterior walls. The design outside winter temperature is -15^{o} C, the obligatory exterior wall thermal resistance is $0{,}95\ m^2KW^{-1}$.

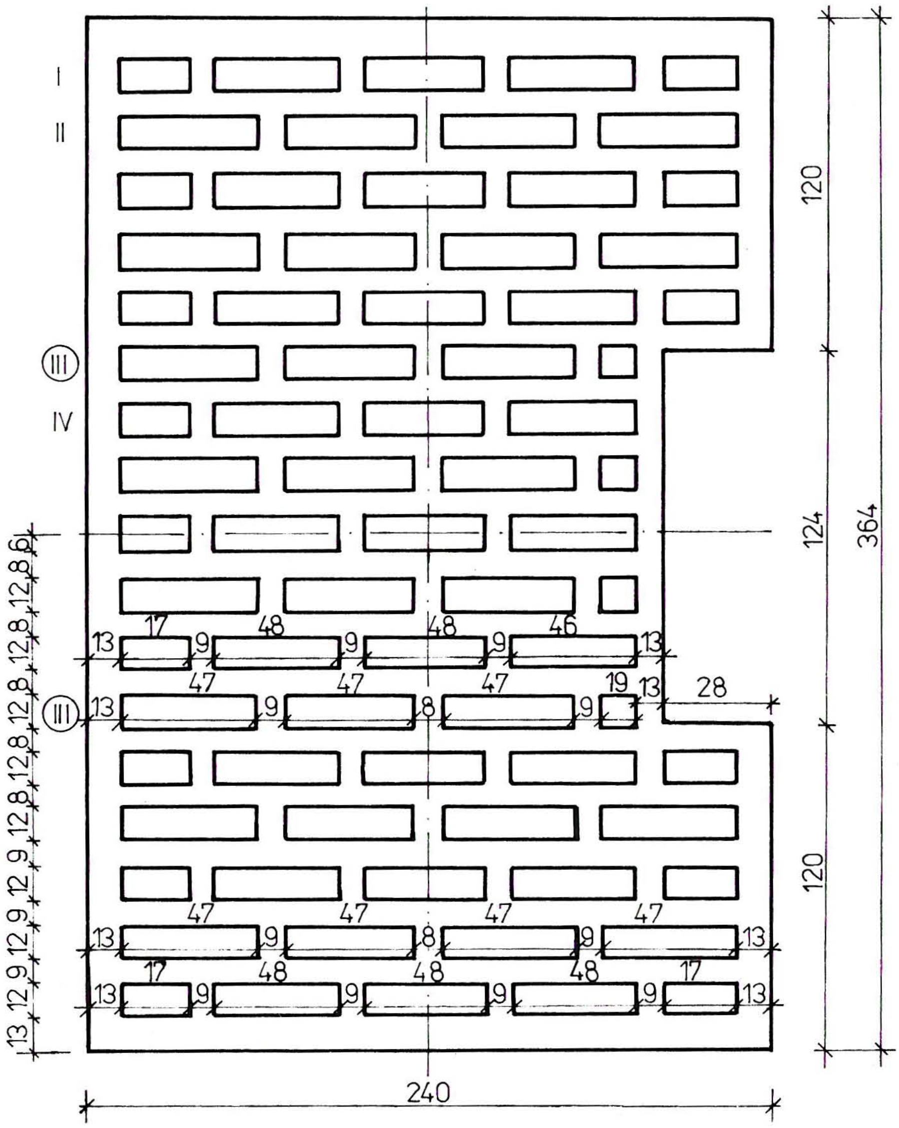

Fig 1   Brick CD-INA

Single wythe brick walls, from 365 to 400 mm thick, built from vertically cored bricks CD-INA /Fig 1/ in header bond, belong to these new structures. The term "single wythe" denotes that one brick dimension is equal to the wall thickness. The horizontal /bed/ mortar joints are provided with two longitudinal holes, 50 mm wide each, parallel to wall faces. The holes are placed closer to the exterior wall face than to the interior one /Fig 2, pillars PN/. The brick density should be $\rho = 1100\ kg\ m^{-3}$.

The bricks are laid close to each other. Due to the groove in one lateral face of each brick, vertical joints perpendicular

to wall faces are filled with mortar only in the inner part of wall.

Masonry walls with such modified joints are supposed to be loadbearing. The necessity of appropriate structural research in this field has been obvious.

2. LOADING TESTS ON MASONRY SPECIMENS

Masonry test specimens /pillars, Fig 2/ were made from the vertically cored bricks CD-INA /Fig 1/. The mean dimensions /length, width, height/ of bricks were 364.240.141 mm. The mean density of dried bricks was ρ = 1055 kgm^{-3}, the mean compressive strength was R_c^{un} = 7,60 MPa, varying from 5,52 to 9,20 MPa. The horizontal section area of solid clay material in the brick is equal to 48 600 mm^2, e.i. 58 % from the total horizontal brick area /83 900 mm^2/.

Table 1 Main test results

Test series	Eccentricity e about centre line of total section /mm/	Compressive strength of mortar R_c^{mr} /MPa/	Loadbearing capacity of pillar N_{obs} /kN/
PN-0	0	4,3	752, 630, 850
PN-1	80	3,4	556, 606, 606
PN-2	130	3,0	516, 483, 483
PL-0	0	4,1	950,1090, 694
PL-1	80	3,0	468, 606, 450
PL-2	130	3,1	256, 370, 266
PSA-0	0	3,5	575, 470, 675
PSB-0	0	3,1	420, 375, 490

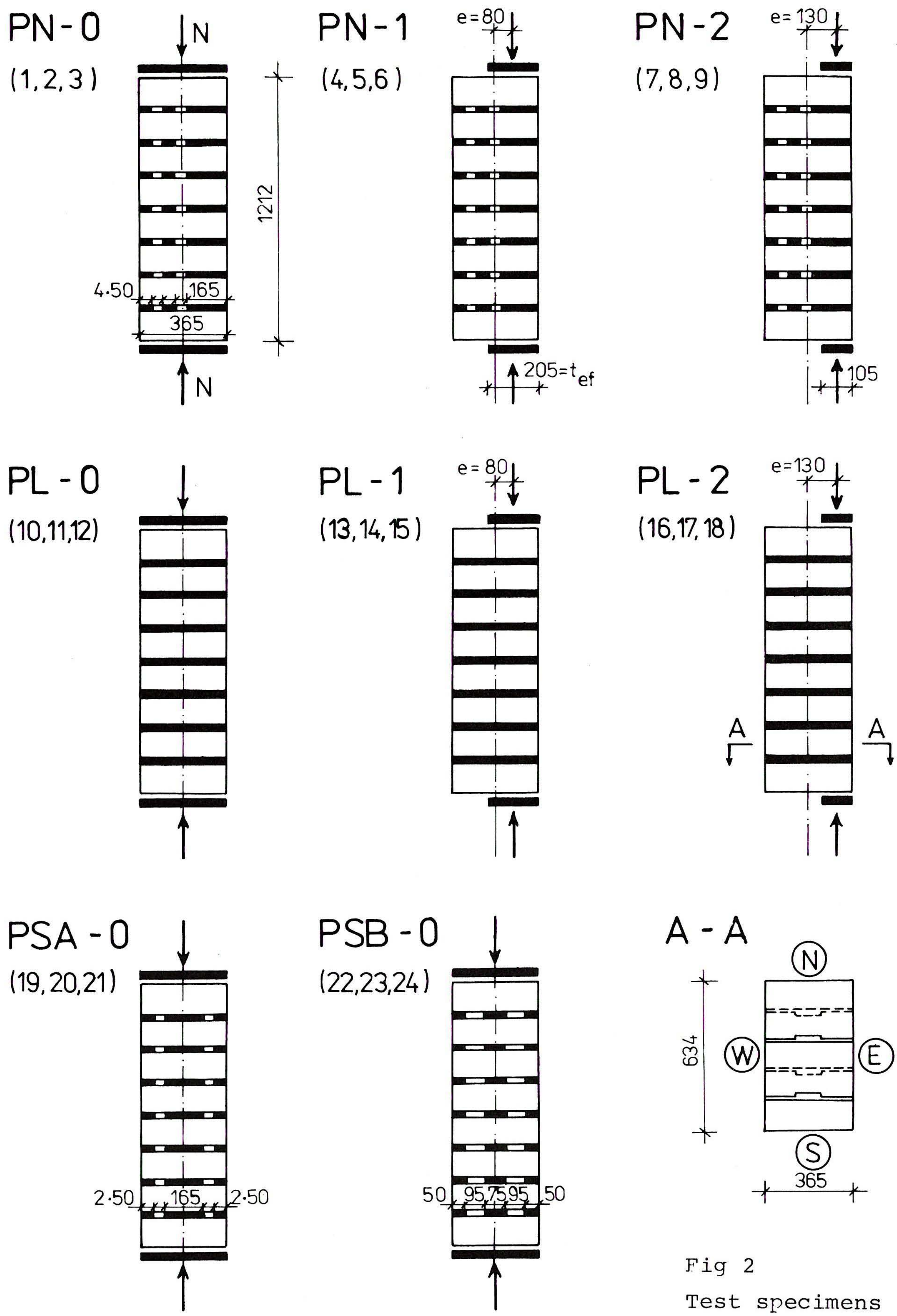

Fig 2

Test specimens

The mean compressive strength of <u>mortar</u>, used in test specimens, determined from 100 mm cubes, was $\bar{R}_c^{mr} = 3{,}44$ MPa.

All 24 masonry test <u>pillars</u> /8 series, each including 3 pillars/ were built in header bond. The nominal dimensions of pillars were 634.365.1212 mm. The pillars of the series PL-0, PL-1 and PL-2 /Fig 2/ were provided with full horizontal /bed/ mortar joints. The pillars belonging to the remaining 5 series were built with mortar joints, weakened by two longitudinal cores. The cores were arranged either symmetrically /series PSA-0 and PSB-0, where the width of each core was 50 or 95 mm, respectively/ or unsymmetrically /series PN-0, PN-1 and PN-2, where the width of earch core was 50 mm/, modelling the actual brick masonry. The figures 0; 1 and 2 in the notations of test series denote the eccentricities e of test loads /e = 0; 80 and 130 mm, respectively/ related to the centre of gravity of the total horizontal cross section area A_{tot}.

The pillars were loaded with monotonously increasing vertical compressive load N up to the loadbearing capacity N_{obs} /Table 1, Column 4/. The test equipment was provided with two horizontal cylindrical joints /on the top and in the bottom of pillar/ and with rigid steel distribution plates, the width of which was equal $t_{ef} = t_{pil} - 2e$, where t_{pil} denotes the thickness of pillar.

During the load test, the changes of the crack pattern, as well as vertical pillar strains, in the middle third part of height, were estimated carefully.

3. FAILURE PROCESS OF MASONRY UNDER MONOTONOUSLY INCREASING CONCENTRIC COMPRESSION

Experimental data obtained from the loading tests of pillars PL-0, PSA-0 and PSB-0 are an acceptable basis for studying the failure process of masonry under monotonously increasing concentric compression. The pillars differ from each other in the values of effective area A_{nt}, given by the equation

$$A_{nt} = A_{tot} - A_{hl} \qquad /1/$$

where: A_{tot} horizontal total cross section area of a pillar,
A_{hl} horizontal cross section area of holes in one mortar bed joint.

The correlation analysis [2] of the set of corresponding values $/N_{obs,i};\ k_{A,i} = A_{nt,i} : A_{tot}/$ has proved that the relation between the loadbearing capacity N_u of pillar and the ratio k_A within the interval $k_A < 0{,}48;\ 1{,}0 >$ is linear. It is possible to accept the assumption that the vertical compressive stress σ_{nt} caused by the test load N is uniformly distributed over the area A_{nt} within the entire interval $N : N_u\ < 0;\ 1 >$. Consequently, the stress σ_{nt} is determined as

$$\sigma_{nt} = N : A_{nt}. \qquad /2/$$

The compressive strength σ_u corresponds to the loadbearing capacity N_u.

It was estimated by the tests that within the investigated interval $k_A\ < 0{,}48;\ 1{,}0 >$ there is a common definite dependence of the stress σ_{nt} on the vertical compressive strain ε_y^{ms} /Fig 3/. Therefore, it is justified to characterize the failure process of masonry by means of σ_{nt}.

The failure process within the interval $\sigma_{nt} < 0;\ \sigma_u >$ should be subdivided into three sections : /a/ elasto-plastic section, /b/ crack development section and /c/ total failure section.

<u>Elasto-plastic section</u> is delimited by the stresses $\sigma_{nt} = 0$ and $\sigma_{nt}^k = k^t \sigma_u$ /where k^t is within the interval $< 0{,}42;\ 0{,}58 >$/. The stresses σ_{nt} within this section are almost uniformly distributed over the area A_{nt}. Under the stress σ_{nt}^t, the first visible cracks appear mostly on the lateral vertical faces of a pillar. The mean values of related compressive strains ε_y^{ms} are from $-0{,}250.10^{-3}$ to $-0{,}300.10^{-3}$.

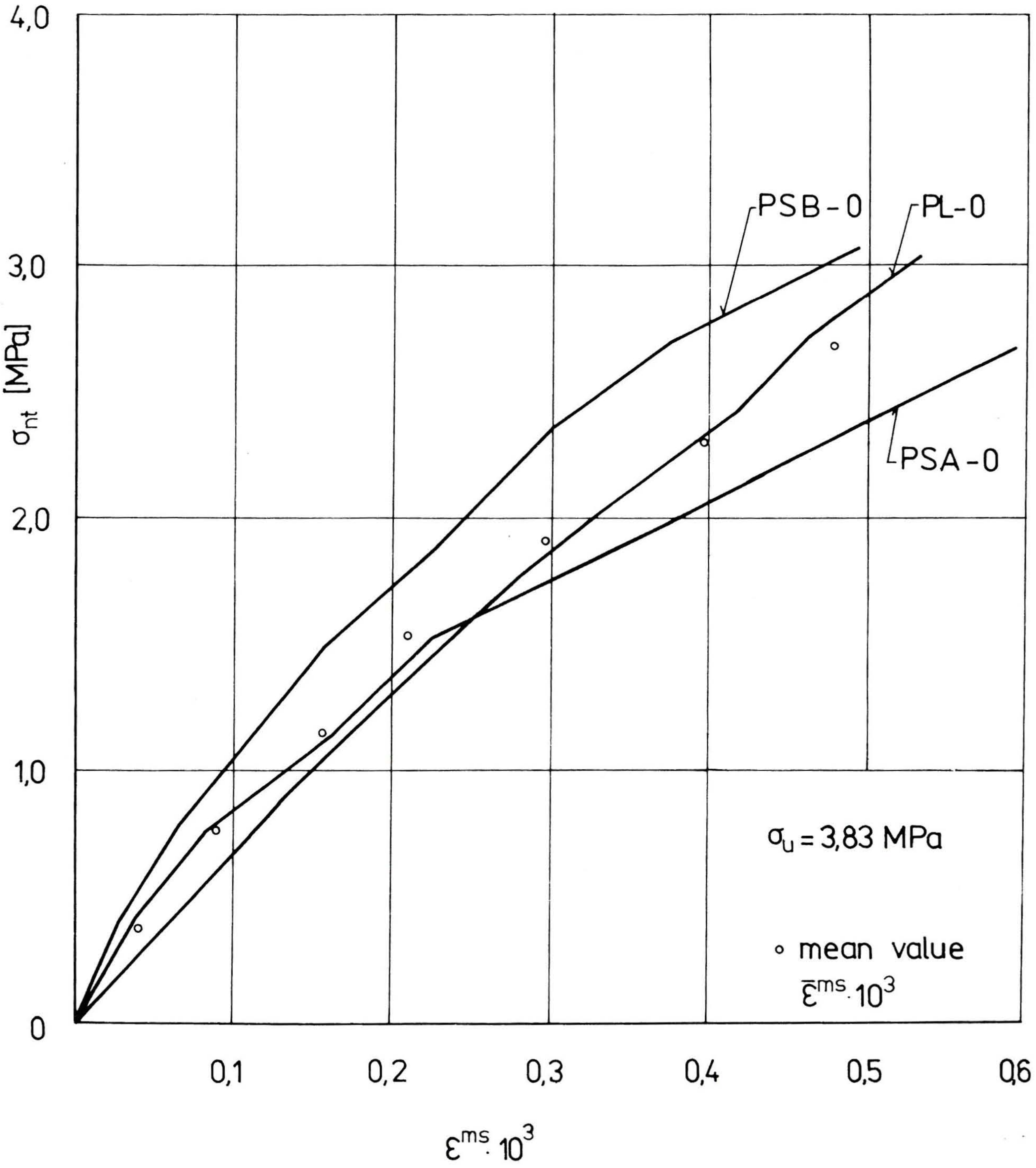

Fig 3 Stress - strain relation

<u>Crack development section</u> is within the interval $\sigma_{nt} < \sigma_{nt}^{t} ; \sigma_{nt}^{fd} \doteq 0,9\ \sigma_{u} >$. Previously developed cracks are widening and new cracks are appearing. All cracks are vertical. Most of them are 120 mm distant from east or west face of a pillar. The plane of those cracks is identical with the plane of the weakened vertical cross sections of bricks, indicated through

the encircled figures III in Fig 1 close to the borders of their part. The crack development causes the increasing ununiform distribution of vertical normal stresses.

Total failure section is within the short interval $\sigma_{nt} < \sigma_{nt}^{fd} ; \sigma_u >$. At the beginning of this section, a pillar is divided into two or three slender pillars which are progressing towards total failure very fast.

4. FAILURE PROCESS OF MASONRY UNDER MONOTONOUSLY INCREASING ECCENTRIC COMPRESSION

Pillars with full mortar joints

Failure process can be subdivided into three sections, identical with masonry under concentric compression [2,3,4] .

Elasto-plastic section is delimited by the loads $N = 0$ and N^t , when the first visible cracks appear in the vertical, coinciding with the section III in bricks /mentioned above/ in the more stressed zone of the masonry cross section. The compressive strains ε_y^{ms} in this vertical at N^t are from $-0{,}25.10^{-3}$ to $-0{,}30.10^{-3}$ /identically with the concentric compression/.

Within the crack development section, there are appearing new cracks over the whole height of the pillar. The mostly widening "main" cracks are in the less stressed zone of the masonry cross section. The total thickness of two /or three/ particular small pillars, withstanding the test load, corresponds to the width t_{ef} of loading steel plates.

Total failure section differs from the same section under concentric compression only in the value $N^{fd} \geqq 0{,}95\ N_{obs}$.

Pillars with longitudinal holes in mortat joints

Failure process is subdivided also into three sections. The position of so called main crack or cracks strongly depends on the position of longitudinal holes, irrespective of vertical sections III in bricks. Consequently, the horizontal areas of

small pillars withstanding the loads $N \geqq N^{fd}$ are either larger or smaller than the corresponding areas in pillars with full joints. This feature influences the values N_{obs}. It should be taken into account in the design formulas of masonry with longitudinal holes in mortar joints [2,3,4] .

5. MATHEMATICAL MODEL OF SINGLE WYTHE BRICK WALL FAILURE UNDER VERTICAL COMPRESSION

The proposed mathematical model of single wythe brick wall failure under vertical compression is based on the assumptions concerning both the behaviour of actual masonry specimens /paragraphs a, b, c, listed below/ and the stress-strain relations of materials used [2] .

/a/ Vertical cracks on both lateral sides of a pillar /in wall similarly, too/ start to extend over its total height, when the vertical normal stress attains the value σ_{nt}^{fd}. These cracks, called as "main", are the main characteristic of the failure. Their presence indicates that the tensile strength of bricks in the horizontal direction has been reached.

/b/ The preceeding experimental investigations showed that the horizontal distance between the capital vertical crack and the front surface of a pillar is equal to 0,25 till 0,4 multiple of the wall thickness /brick length/. This one occurs even when bricks are provided with a central hole the dimensions of which are approximately 45.70 mm. The capital crack is located in the plane that is parallel with the pillar /wall/ front surface and corresponds to the most weakened sections of bricks. In the bricks under consideration, that section is indicated by the encircled figure III.

/c/ The horizontal normal tensile stresses in the bricks consist of two components, the first one owing to the stress state of bricks without any bond to the horizontal mortar layers, the second one owing to the compatibility between bricks and mortar bed joints. The actual strain conditions can be explained

in the following way. If in masonry walls under axial compression no bond friction existed in the interfaces between bricks and mortar bed joints, the unrestrained lateral strain ε_x^{mr} of the mortar bed joints would exceed that of brick ε_x^{c}. As a consequence of the existing bond and friction, additional lateral tensile strain ε_x^{cN} in bricks and compressive strain ε_x^{mrN} in mortar bed joints are arising.

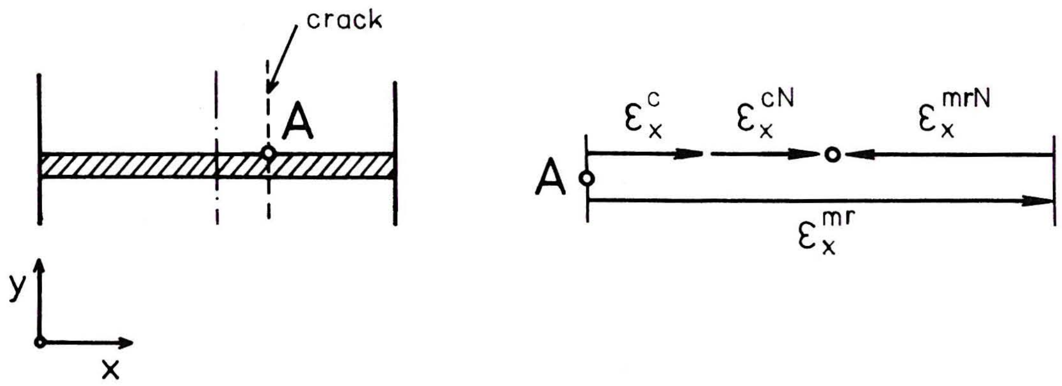

Fig 4 Compatibility condition

The compatibility condition of horizontal /lateral/ strains, based on five assumptions mentioned above, at the point A in the contact interface between brick and mortar bed joint /Fig 4/ can be written as

$$\varepsilon_x^{c} + \varepsilon_x^{cN} = \varepsilon_x^{mr} + \varepsilon_x^{mrN} \qquad /3/$$

More detailed explanation including numerical examples is presented in [2,3,4] .

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CONCLUSIONS

The effect of longitudinal holes /their section area and

position/ in bed joints on single wythe brick masonry failure mechanism is considerable. It should be taken into account in the design formulas concerning the load bearing capacity of masonry pillars and walls. The obtained experimental results have allowed to propose a simple mathematical model of brick wall failure.

REFERENCES

/1/ ČSN 73 0540 Thermo-technical properties of engineering structure and buildings. Nomenclature. Requirements and criterions /in Czech/. Czechoslovak Code. Prague 1977

/2/ Pume, D.: Mathematical model on compressive failure mechanism of brick masonry /in Czech/. Stavební výzkum, 1983,4

/3/ Pume, D.: Failure mechanism of masonry built from the new types of vertically cored bricks under eccentric compression /in Czech/. Stavební výzkum, 1983,5

/4/ Pume, D.: Compressive load bearing capacity of masonry structures built from vertically cored bricks with unsymmetrical longitudinal holes in bed joints /in Czech/, Stavební výzkum, 1983,6