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Influence of Ashlar Inclusions on Behaviour of Masonry Walls

Influence des pierres de taille sur le comportement des murs en maçonnerie

Einfluss der Quadersteineinschlüsse auf das Mauerwerksverhalten

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SUMMARY

The behaviour of masonry facade walls can be strongly affected by the inclusions of ashlar pieces as ornate of doors, windows and corners and also on cornices. Their omission in the assessment may lead to errors on the unsafe side. In this paper a study using finite element analysis for a particular case illustrating this effect is shown.

RÉSUMÉ

Le comportement des murs en maçonnerie peut être fortement influencé par la présence de pierres de taille disposées comme ornement de portes, de fenêtres, d'angles ou de corniches. Il faut tenir compte de cette particularité dans l'évaluation de la résistance, car elle a en général un effet négatif. Un cas particulier, étudié à l'aide d'une analyse par éléments finis, est présenté dans cet article.

ZUSAMMENFASSUNG

Das Mauerwerksverhalten wird stark beeinflusst durch Quadersteineinschlüsse, die als Ornamente von Türen, Fenstern, Ecken oder Erkern dienen. Werden sie bei der Abschätzung des Verhaltens vernachlässigt, können daraus Fehler zur unsicheren Seite hin entstehen. Der Artikel beschreibt eine mittels der Finiten-Elemente-Methode analysierte Fallstudie.

1. INTRODUCTION

The internal performances of an ancient building's masonry walls are usualy not considered in detail when studies on structure rehabilitation are tackled by the Engineer. The Technician is not hardly enticed to carry out sophisticated analysis about actual behaviour of those elements due to their massive character.

For normal uses, assessing masonry walls as performed by an homogeneous, isotropic material, not taking into account the intrinsic complexity of their composition, may be used as a sufficiently precise approximation; particularly when vertical loads are predominant and compression stresses are high enough to ensure that friction forces will be developed in such a way that relative displacements between adjacent blocks and even between blocks and filling mortar will be restricted.

Classical redesign assumes the wall as a two-dimensional, linear-elastic member. Development of discharge arches on lintels is always taken into account, but the actual ability of the structure to develop internal vaults is very rarely considered, excepting, if even, on sandwich walls. Redesign is often made by calculating the mean stress along the wall, assuming that peak stresses are dissipated by the considerably high creep of the masonry. The presence of rigid element on lintels, cornices, corner and jambs, is neglected, and those elements are seen as just decorative pieces with no real influence on the general structural behaviour of the wall.

During the previous studies to the restoration of the Moorish Palace of "La Aljafería" (Saragossa), we noticed that this simplificating hypothesis could sometimes be on the unsafe side. The feeling that substituting a specific material by another of lower performance, on the assessment of the wall, should provide, in any case, a more unfavorable solution, pays no attention to the compatibility of their deformations. This may come to the point of not detecting concentration of stresses high enough to accelerate the collapse of the element.

In this particular case, the main tower of La Aljafería's Palace had the dungeon and ground levels build on sandwich walls, with two ashlar external leaves, about 80 cm thick, and an internal filler on massive rough masonry, with a plaster-based mortar matrix, about 2,0 m thick, which were the only layer of the four upper levels.

The huge difference of deformability and creep between both materials produced a considerably high channelling of loads towards the ashlar shell, having the masonry layers immediate to the top of the ashlar layers very high action effects, which surpassed their resistance capacity. Also the horizontal stresses generated by Poisson effect and plastification of the mortar produced a pressure on the internal face of the ashlar shell that favoured their inestability.

These effects were seen on a finite elements analysis of the cross-section of the wall. This result has made us rethink the convenience of detailed studying of the influence of rigid noble elements of facades in global wall behaviour.

2. MODELLING THE TOWER

This calculating model belongs to the Nordwest tower of Nuevo Baztán Palace, which stands in a village 30 kms away from Madrid, designed as an industrial town during early XVIII century for providing with ammonition, spirits and other various intendence to the royal army of Marie Louise of Savoia, Regent of Spain.

The set of buildings constituted by the Palace, the inevitable church, wine-presses, workshops and market surrounding a huge central square, besides worker lodgings, was designed by J.B. Churriguera, one of the best Spanish baroque architects. The Palace, thought as a "hunting hut" for the Lord and his Court, is a two-storey building with two towers in the corner of the North facade and an extra false tower in the corner of the west facade adjacent to the church.

Building's walls are made out of calcareous stone masonry with lime mortar. The corners, jambs, lintels and cornices are made out of ashlar of much better quality calcareous blocks. The modelized tower has a square section, 6,57 m long and walls of 1,50 m thick in ground, and two upper floors, lighting the wall in the last storey. Two of its facades are exterior ones in all their height while the other two are interior ones in their first two stories.

The thickness of the ashlar pieces that form the jambs, lintels and cornices of the exterior facades is only about 40 cm, been indented with the masonry that performs the wall. The higher body of the tower is also made by ashlar. The scarce entity of ashlar pieces in the lower floors was inviting to a classic manual calculus, but the experience with the Aljafería's Tower enticed us to use a more sophisticated model, introducing these elements with their greater relative rigidity.

Assessment was made modelling the tower with a total of nearly 4.000 knots and 3.000 brick elements, varying in size from 30 x 30 x 15 cm^3 to 100 x 70 x 90 cm^3, what is nearly elemental block level. The cover was represented with shell elements, and the floor loads were supposed punctual, located in the knots, affecting each knot with the load of the according floor surface. Two different types of foundation, rigid and elastic (springs) has been taken into account.

The early results of this study were exposed in the 1st International Conference of Rehabilitation of the Architectural Heritage and Buildings of Tenerife, on July '92. Further analysis taking into account different relationship between deformability modulus and also seismic forces are to be shown now.

3. RESULTS

a) Effect of inclusion of rigid zones

Figures Nº 1 and 2 show the stress levels in facade layer in both foundation hypothesis. In these graphics it is clearly appreciated the effect of development of inner discharge vaults among ashlar pieces. As it can be seen, wall compressions, far for having an uniform distribution from top to bottom, show a widely irregular stress distribution. The effect is better seen when they are confronted with similar sections in which the material is assumed to be homogeneous (Fig. 3) or with a lower relationship between deformation modulus (Fig 4). Also, it's shown how the closest masonry to the ashlar, is overloaded due to the reception of discharging arches.

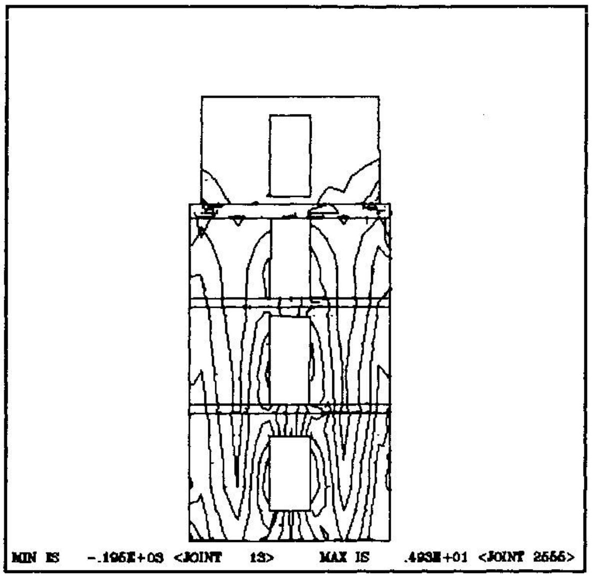

Fig 1 . STRESSES ON FACADES RIGID FOUNDATION

The effect is also notable in the response of the structure to seismic actions. In fig 5 and 6 can also be seen the considerable difference existing in stress distribution along the structure whether we consider it as built with homogeneous materials and in the case in which we consider the existence of rigid inclusions on corners and around the holes.

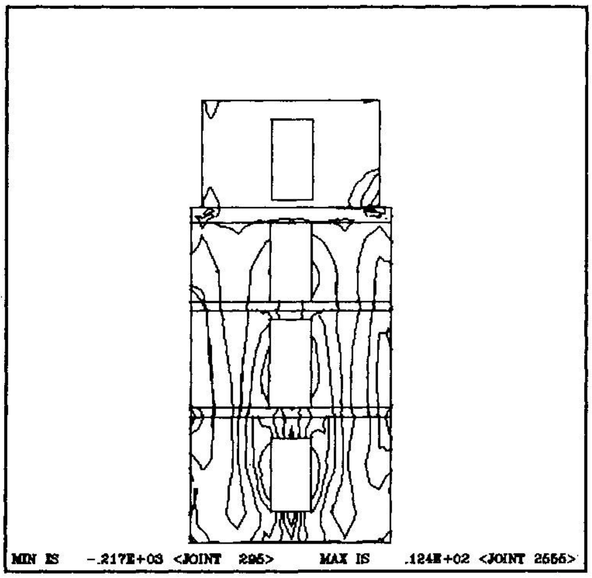

Fig. 2 STRESSES ON FACADES ELASTIC FOUNDATION

In the whereabouts of the base, the stress distribution is strongly conditioned by the rigidity of foundation, but this effect is very quickly disipated with height due to the great efficiency of discharging vaults. This comes to the point that as near as in the first floor level, stress distribution is nearly undistinguishable between both hypothesis.(Fig 7,8)

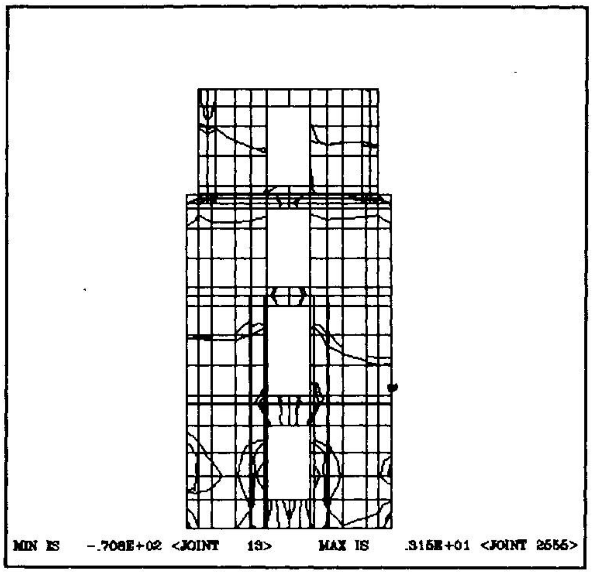

Fig. 3 STRESSES AT FIRST FACADES
HOMOGENEOUS MATERIAL

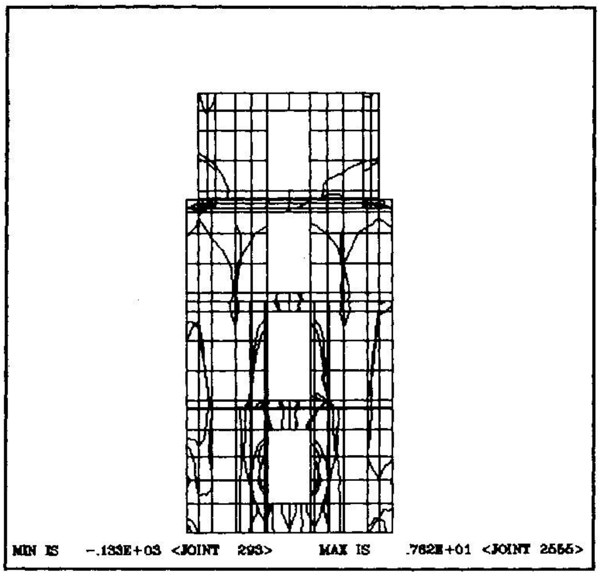

Fig. 4 STRESSES AT FACADES
SLIGHTLY DIFFERENT MATERIALS

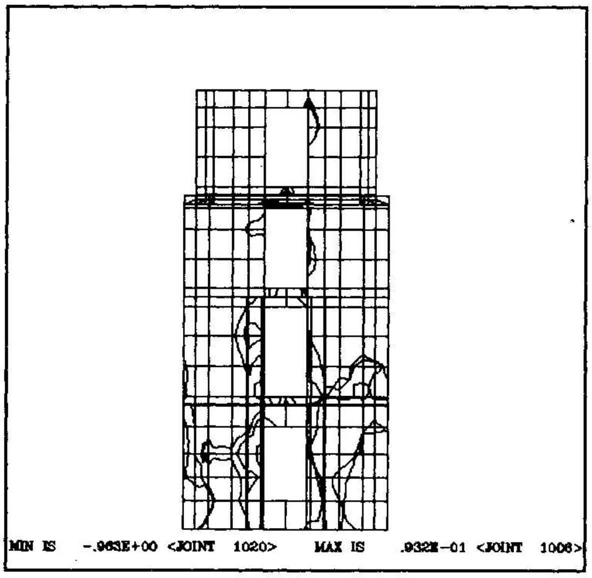

Fig. 5 STRESSES DUE TO SISMIC ACTIONS
HOMOGENEOUS MATERIAL

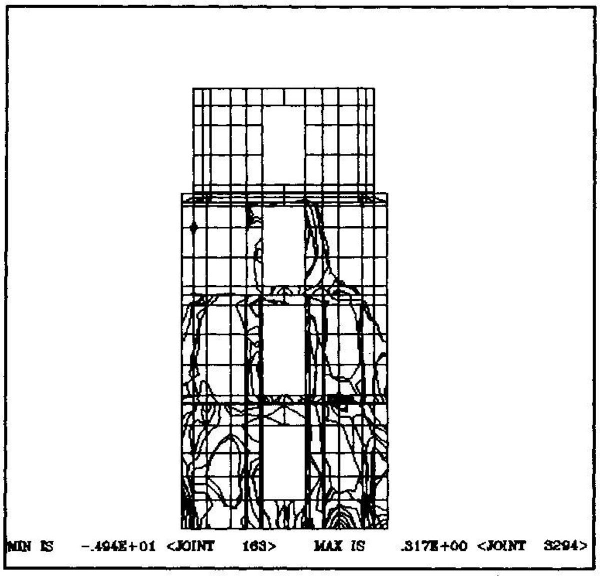

Fig. 6 STRESSES DUE TO SISMIC ACTIONS
HETEROGENEOUS MATERIAL

An early and easy approximation to the evaluation of this effect can be done by simple substitution of the area of the ashlar elements by masonry elements whose area should be multiplied by the relationship between deformation modulus. Fig 9 and 10 show that this procedure is on the safe side on the evaluation of the action effects as well as in ashlar zones as in the mass of the masonry (zones far away from the rigid zones). The calculus, nevertheless is hardly on the unsafe side in masonry layers in contact with the ashlar pieces, being in the safe side as soon as an intermediate stress between the one that stands the ashlar, and the calculated stress in the masonry according to this simplified method is adopted for this zone.

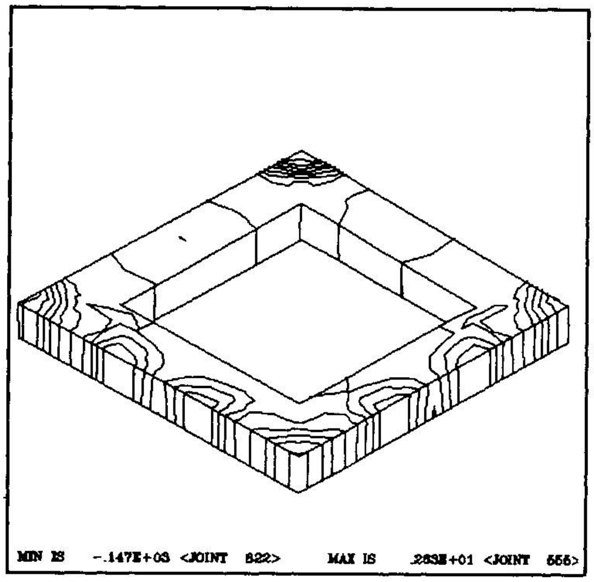

Fig. 7 STRESSES AT FIRST FLOOR LEVEL RIGID FOUNDATION

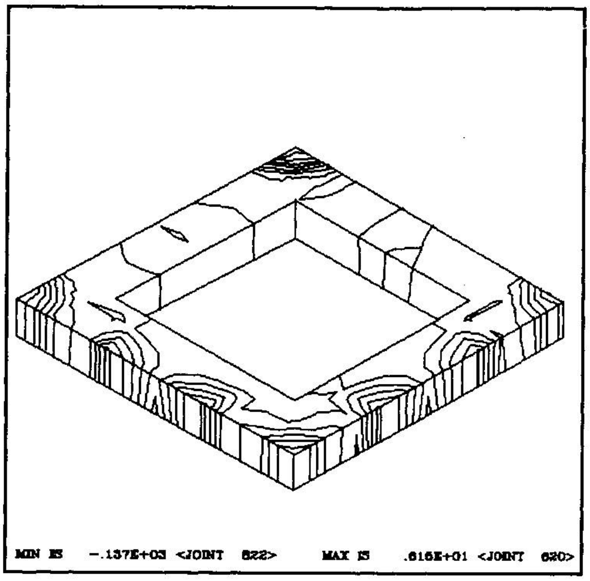

Fig. 8 STRESSES AT FIRST FLOOR LEVEL ELASTIC FOUNDATION

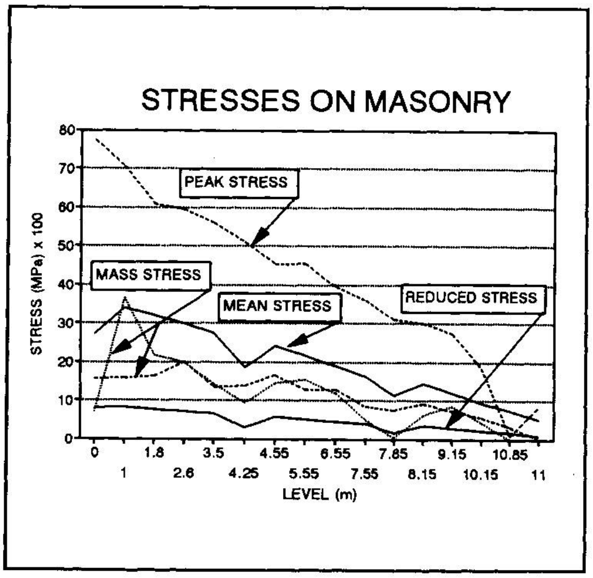

Fig. 9 ACTUAL STRESSES ON MASONRY RELATED TO CLASSIC METHODS

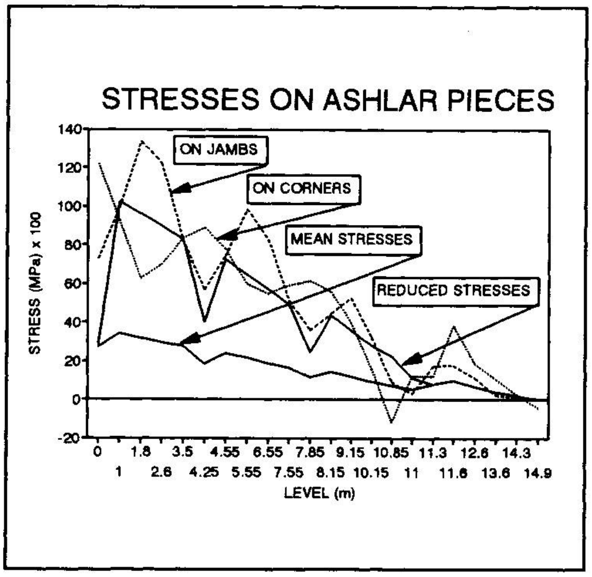

Fig. 10 ACTUAL STRESSES ON ASHLAR RELATED TO CLASSIC METHODS

A more accurate procedure requires a very fine net on the modelling of the wall in the neighbourhood of the ashlar pieces, due to the lack of accuracy that introduces the own finite element method in the determination of stress peaks in the proximity of a discontinuity. This takes a huge effort in modelling and interpretation of results, and the use of powerful calculus computers, which are not within reach of normal projecting offices, so the greater precision achieved is not rentable for normal cases. Furthermore only with the use of programmes that allow the consideration of non-linearity of the stress-strain diagrams and the plastic range is this greater precision turned into a greater accuracy and thus in a better reflection of the actual behaviour.

8. CONCLUSIONS

- The behaviour of a building's walls, when their thickness is considerable, is conditioned by the development of discharging vaults instead of traditional discharging arches. If no 3-D assessment is carried out, significant but punctual errors are given on the unsafe side.

- The existence of ornates, tops, lintels and corners of ashlar included in the wall produce a high channelling of stresses, discharging the mass of the masonry and overloading the layers in contact with the rigid zones.

- The classic assessment methods are not sufficient to carry out an accurate aproximation to the actual stresses. Nevertheless a more precise order of magnitude of its value may be achieved by determining the fraction of the load that the rigid pieces recieve by the traditional method of analysis of equivalent areas and by adopting a mean tension between the corresponding value of the rigid pieces and the one corresponding to remainder of the wall section.

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