THE MYSTERY OF MOVEMENT JOINTS IN VENEER WALLS

D.R.W. Martens[1] A.T. Vermeltfoort[2]

ABSTRACT

In the Netherlands, a tendency is recognised to make more and more movement joints in veneer walls. Consequently, these walls act like rigid elements in which all deformation concentrates in the movement joints. In surrounding countries (e.g. Belgium) the spacing of vertical and horizontal movement joints is much larger. Questions that arise are: how much movement joints are needed to prevent cracking, and when cracks occur which crack width is acceptable?

The paper describes different crack-causing parameters, some explorative studies and several research items. An inventory of cracking in facades was made, as well as literature surveys concerning the shrinkage and temperature deformation of masonry walls [Vermeltfoort & Martens]. In order to determine the most critical areas in a veneer wall, the stress distribution in facades with and without movement joints was numerically simulated with the finite element program DIANA.

Based on the explorative studies, three proposals for fundamental research at PhD level are presented to study: a) the masonry stiffness aspects such as: how to make a soft mortar and the effect of open perpend joints, b) the execution aspects like stress distribution in and around lintels during building and c) the architectural aspects such as: detailing of walls, the use movement joints and crack-control.
PhD candidates are invited to reflect.

Key words: veneer wall, movement joint, cracking parameter

---

[1]) Professor and [2]) Ass. prof. Eindhoven University of Technology, Dep. of Structural Design, BKO, P.O. Box 513, Postvak 7, 5600 MB Eindhoven. The Netherlands.

INTRODUCTION

Outer walls of buildings have been built in masonry since centuries [Peirs]. After World War I, in the northern part of Europe, cavity walls were developed in order to prevent water transmission through the outer walls. More recently, veneer walls are considered as a protective skin that has to withstand all the climatic influences. Nevertheless, much attention is paid to the aesthetic quality of the wall. Consequently, cracking of the masonry must be prevented. In order to fulfil this requirement, movement joints became increasingly popular by consultants of facade engineering, (fig. 1).

Architects, owners and contractors are less enthusiastic about movement joints. Although different types of movement joints can be used (Figure 2, Figure 3) [CUR71], [KNB 99], they seldom have a positive influence on the appearance of the masonry wall,

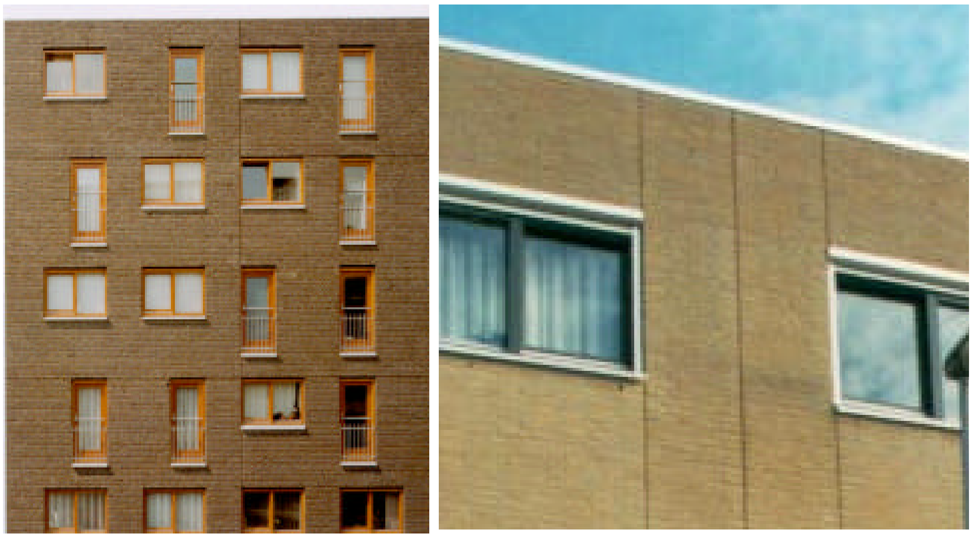


Figure 1 Small spacing of movement joints in modern masonry

they are expensive, they have a negative influence on the structural coherence of the veneer wall and they have to be maintained. Due to these conflicting interests, there is a need for a better understanding of crack development in veneer walls. Nowadays, the rules, which are used to determine the spacing of movement joints, are not based on fundamental scientific research. The backgrounds of the rules are more or less a mystery [Vermeltfoort & Martens].

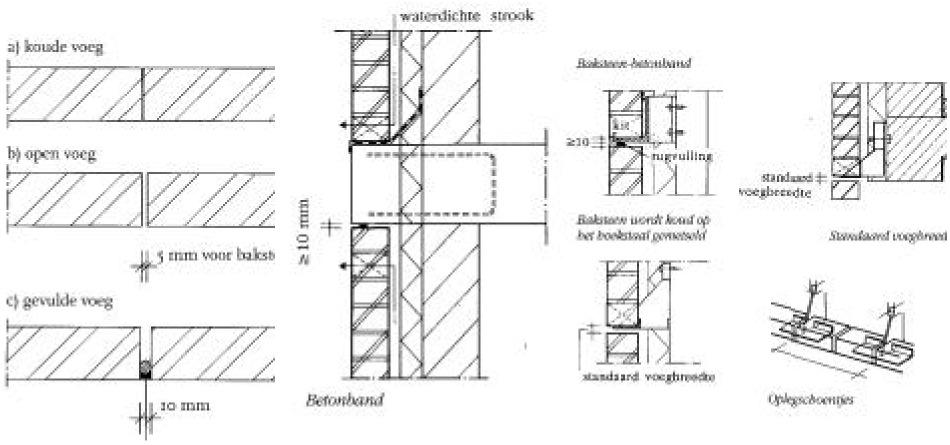


Figure 2 Sections of different types of vertical and horizontal movement joints [CUR71]

To reveal this mystery, a lot of questions have to be answered:

- How many movement joints do we really need to prevent cracking?
- Is there no other way to tackle the problem of cracking of masonry?
- What are the aesthetic and structural consequences of movement joints in veneer walls?
- Which scientifically funded design rules can be applied, or do we still have to rely on empirical formulas?

Which criteria are used as guidelines: limitation of crack width or prevention of cracks?

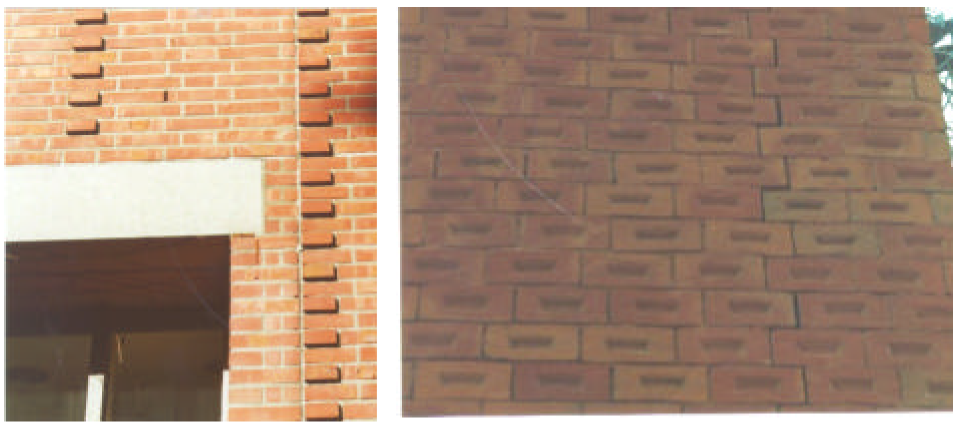


Figure 3 Two types of movement joints

CRACK CAUSING PARAMETERS

Cracks arise at places where the tensile stresses exceed the tensile strength of the masonry. [Sutherland 96] presents a detailed table of causes and remedies. In general, tensile stresses in masonry structures may result form two types of actions:

a) Direct actions: external forces like gravity forces, wind loading, and ground pressure, and
b) Indirect actions: imposed deformation

The indirect actions can be caused by:

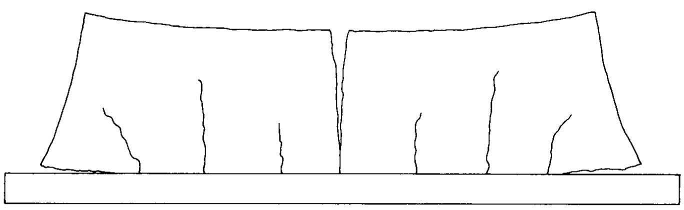
- environmental changes (temperature, humidity)
- settlements of the foundation
- deformation of supporting structural elements such as beams and walls

It is important to notice that most actions vary as a function of time.

As long as the structure is allowed to deform freely, no stresses will occur due to an imposed deformation, and the tensile stresses introduced by the external forces can be estimated using the well-known theory of elasticity. On the contrary, in the case of restrained deformation, the time-dependent non-linear behaviour of masonry influences the value and the distribution of the tensile stresses. For such structures, no general accepted calculation method exists. Therefore, this paper will focus on the phenomenon of restrained deformation as crack causing parameter. In the following parts, different types of restraints will be considered.

Restraints at the bottom of the wall

Every wall has to be built on a foundation or a supporting structural element (beam, brackets or floor). Depending on the stiffness of the supporting element, the deformation of the wall will be restrained both in vertical and horizontal direction.
If the wall is built on a rigid foundation, there will be a restraint of the horizontal deformation since the thermal deformation of the foundation will be smaller than the thermal extension or shortening of the wall (Figure 4). Due to shrinkage, the wall will tend to shorten while the length of the foundation will be constant. As has been demonstrated earlier in literature, this will lead to important horizontal tensile stresses and cracks at the bottom of the wall. Various authors presented a relationship between the crack-free length and shrinkage-strain, [CUR171], [Pluijm 00], Figure 5. The introduction of a damp proof course with a limited friction coefficient may reduce the restraint of the wall. [Ibrahim] and [McGinley] studied friction properties of DPC's.



c.

Figure 4 Tensile stresses and cracks in a wall built on a rigid foundation, due to shrinkage of the masonry [CUR171 chap. 6].

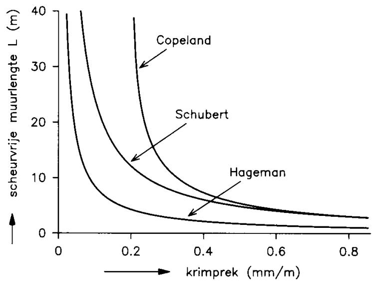


Figure 5 Crack-free length versus shrinkage-strain [CUR171]

When numerically modelled it is always assumed that shrinkage occurs instantly, Figure 6. In practice, this is never the case since a wall can not be built at once. Shrinkage or temperature changes will take some time. These phenomena in combination with the influence of stress relaxation have not been taken into account very often yet. More research is needed to evaluate the time effects of shrinkage, creep and relaxation.

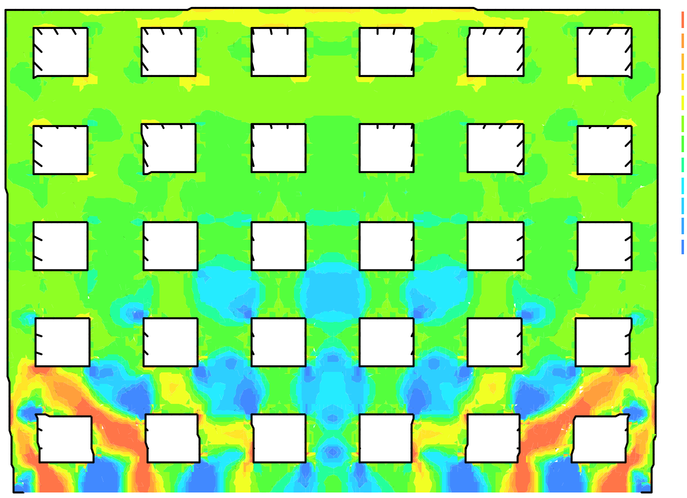


Figure 6 Tensile and compressive stresses in a veneer wall with openings.

Restraints at the vertical edges of the wall

At the corners of (larger) buildings, the horizontal deformation of the edge of a veneer wall will be restrained due to the stiffness of the perpendicular wall and the presence of the wall ties in the corner. In the case of sunshine on one of the walls, a different thermal extension of the walls will occur. In numerical simulations of this phenomenon by [Pluijm 2000], it was assumed that the connection between the two walls was rigid. As a result, important tensile stresses were found, as demonstrated in Figure 7, left. In practice, the corner connection is not as rigid as assumed which will reduce the tensile stresses. More research is needed to evaluate the influence of the stiffness of the corner wall connections on the stress distribution in veneer walls under imposed actions. The result may be the omission of the aesthetically unacceptable movement joint in the corner, Figure 7 right.

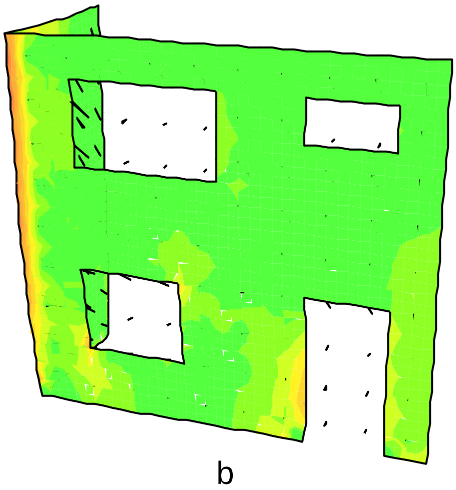


Figure 7 Stress distribution and deformations at a masonry corner according to linear elastic numerical simulation, [Pluijm 2000] and movement joint at corner

<u>Restraints at the top of the wall</u>

If the top of the wall is connected to a floor or a roof structure made of another material, the different thermal and moisture movements of both materials can lead to horizontal tensile stresses and vertical cracks. In Figure 8 an example of this phenomenon is presented.

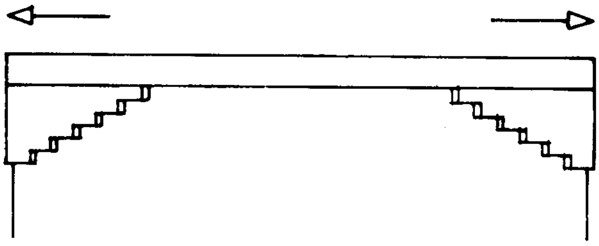


Figure 8 Tensile cracks in a wall due to restraint at the top of the wall.

<u>Restraints and discontinuities in the middle part of the wall</u>

Not only at the edges but also in the middle part of the wall, some deformation restraints may occur. Veneer walls are always connected via wall ties to the load-bearing inner wall-leaf. The deformation of the veneer wall is mostly different from the deformation of the inner wall-leaf. The latter is protected against influences of environmental, temperature and humidity changes while it is loaded in vertical direction by self-weight and various floor loads. The differential deformations between inner and outer wall leafs may not exceed the deformation limits for the wall ties. For this reason, horizontal movement joints are recommended for higher walls

If the veneer wall is made of a combination of materials with different coefficients of

thermal expansion (e.g. a combination of clay bricks and concrete blocks or a combination of clay brick masonry and steel or concrete lintels), a temperature or moisture change will cause an interaction between the expanding or shrinking materials which will result in tensile or compressive stresses. A similar situation is encountered in the case of a sudden variation in the thickness of a wall. The stress level in both parts will be different, which will introduce a mutual deformation restraint. The same effect occurs at openings in the wall. Due to a reduction of the vertical section of the wall, the horizontal stresses above and below an opening will be higher than in the wall sections besides the opening.
A stiff connection between the veneer wall and the inner wall-leaf always forms a deformation restraint. Such connections may occur when window frames are fixed both to the inner and the outer wall leaf. A same obstruction appears when a lintel or a sill is connected to the load-bearing inner-wall leaf.
In Figure 1 different zones in masonry veneer walls which are susceptible for crack formation are indicated.

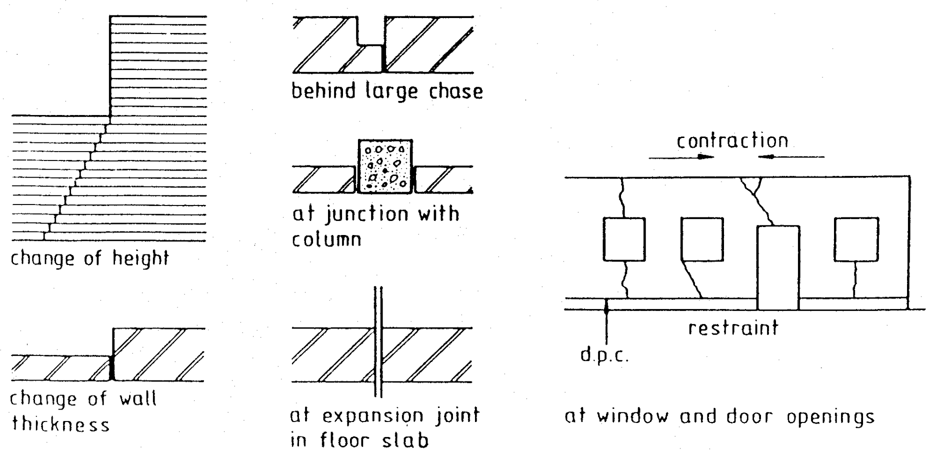


Figure 1 Preferred locations of masonry movement joints are located at zones in masonry veneer walls that are susceptible for crack formation [Beck & Curtin]

RESEARCH ITEMS

Based on the explorative studies mentioned above and in [Vermeltfoort & Martens], the following three proposals for fundamental research are presented to study:
a) the masonry stiffness aspects such as: how to make a soft mortar and the effect of open perpend joints),
b) the execution aspects like stress dis tribution in and around lintels during building and
c) the architectural aspects such as: detailing of walls, the use movement joints and crack-control.

Influence of masonry stiffness

The stress distribution in restrained structures under imposed deformations is primarily influenced by combination of masonry stiffness and restraint stiffness. The stiffness of the masonry is determined by the mechanical properties of the bricks and the mortar. The properties of both the bricks and mortars did change over the last decades. Consequences for unit stiffness were not so severe, but variation in quality became smaller due to modern production techniques, while the quality, and in particular the stiffness, of the mortar strongly increased. In ancient buildings lime mortars were used while more recent cement mortars are preferred. In literature, it is described that older buildings did not suffer from cracking thanks to the use of lime mortars [Zijl]. This statement has not been verified thoroughly until now. What's the real stiffness of masonry made with lime mortars or with cement mortars? Undoubtedly, a lower stiffness must be favourable for the crack behaviour of veneer walls, but how can we reduce this stiffness in combination with a high durability of the joints, and adequate bond strength at acceptable costs? It is a real challenge to develop a mortar, which satisfies these requirements.

The stiffness and consequently the occurring tensile stresses do not only determine crack formation in a masonry wall. The tensile strength of the masonry, which is determined, by the tensile strength of the bricks and/or the bond strength of the mortar, also plays an important rol+e. In the case of masonry with thin layer mortar, the stiffness of the masonry is almost the same as the stiffness of the bricks, which results in relative high tensile stresses. On the other hand, the tensile strength of this type of masonry is much higher than the tensile strength of traditional masonry. Is this a favourable situation ? Using thin layer mortars, the filling of the perpend joints is labour intensive. Studies were made to evaluate the physical aspects of open perpend joints [Ven], but what is the influence of open perpend joints compared with filled joints on wall stiffness ?

Moreover, various time-dependent effects have not yet been investigated. Information about shrinkage and creep of masonry under compressive loading is available [Pluijm 99], [Vermeltfoort & Martens] but the time-dependent behaviour of masonry under shear loading, under tensile forces parallel to the bed joints or under combined vertical and horizontal loading remains a mystery.
Relaxation effects will anyway influence the stress development in restrained walls under imposed deformation. It should also be kept in mind that these imposed deformations are time-dependent actions (daily and seasonal fluctuations) and that these imposed deformations are not uniformly distributed over the thickness and the height of the wall. For instance, sunshine on the outer face of a veneer wall will result in a temperature gradient over the thickness of the wall dependent on the rate of insulation in the cavity [CUR80]. Due to heat transmission via the foundation, the temperature of the veneer wall at the bottom will always be lower than the temperature at the top of the wall. As a result, the geometry of the wall, i.e. the thickness and the height, will affect the stress distribution. A same effect appears due to moisture movement in a veneer wall. Another long-term phenomenon is the development of differential settlements of foundations.
Interaction between all the time-dependent and geometrical effects will undoubtedly diminish the tensile stresses in veneer walls. Numerical and experimental research into this interaction is absolutely needed.

Influence of execution

Execution. The building of a masonry veneer wall differs from the construction of concrete walls. A concrete wall is built in a relative short time by pouring concrete into a mould. From that moment on, shrinkage of the whole wall will start. Masonry walls are built in a short time, usually brick by brick. In most cases, it lasts two or three days before a wall with a height of 2,5 to 3 m is finished. This means that shrinkage of the masonry wall will occur in different stages. After the first day of building, the bottom part of the wall will shrink over night and the next days fresh masonry will be made on 'partially' hardened and shrunk masonry. As a result hardening and shrinkage of the different parts of the wall will not be the same. Moreover, in some countries pointing of the masonry takes place a long period after building of the wall. In this case, before pointing, little cracks may occur in the joints (the weakest zones) which will be disguised by the pointing.
It can be concluded that there must be an influence of this typical way of building on the stress distribution in masonry veneer walls. That means that the theoretical models, which are applicable for concrete walls, are not valid for masonry veneer walls.

Lintels. In the case of openings in a wall the lintel will introduce an extra complication. Lintels can be made of steel that will not shrink (but has a higher thermal expansion coefficient than clay brick masonry) or concrete that will shrink more or less dependent on its age.
Recently, at Eindhoven University of Technology, an experimental research program was started to evaluate the influence of the phased building method on the deformation and stress distribution around a window opening in clay brick veneer walls with prefabricated concrete lintels. Tests are also needed to thoroughly investigate the stress and strain evolution due to shrinkage and creep in complete masonry veneer walls with various brick and mortar types in comparison with small sized specimens [Vermeltfoort & Martens], [Pluijm 99], [Pluijm & Vermeltfoort].

Execution rules. Another aspect that has to be dealt with concerns execution rules for the construction of veneer walls. Since imposed deformation is an important cause of crack formation in veneer walls, it is recommended to try to reduce the impact of this parameter. In many cases, simple precautions during execution may be sufficient to diminish the imposed deformation due to shrinkage, temperature and moisture changes of the wall. The use of older, dry concrete bricks, the covering of fresh masonry with a plastic sheet and postponing the pointing of the wall for at least 6 months after building are simple actions that may reduce the crack risk considerably.

Architectural aspects

In the design of large masonry buildings attention should be paid to the restrained deformation of the different building elements. In some cases movement joints will absolutely be necessary to reduce the risk for crack formation, but in most situations an adequate architectural design is sufficient to realize beautiful masonry buildings without (visible) movement joints. In the building represented in Figure 10 recesses in the wall and wall high windows were introduced as hidden movement joints and masonry arches were used to span large window openings. The implementation of these simple design principles has led to a building without any movement joint in the masonry.

Figure 10 Example of recessed walls, wall high windows and arches

Detailing of walls. Architectural detailing is an important factor that affects the restraint of masonry veneer walls. Lintels which are connected to the load-bearing inner leaf of the cavity wall, will restrain the deformation of the veneer wall and if the windows are fixed to both cavity wall-leafs a similar effect will occur. Essential is to remind that the connection between the inner and outer leaf of a cavity wall should be avoided as much as possible.

Crack control. Prevention of cracks was the basic principle in recent studies e.g. [CUR71], [CUR80]. However, an important aspect of the problem of cracking of veneer walls concerns the definition of acceptable damage. The question is: Are small cracks allowable or must cracks absolutely be avoided ?

If small cracks are accepted, the crack width limits have to be determined. On esthetical grounds a maximum acceptable crack width is difficult to give. It depends on the personal experiences and eyesight of the observer and the visibility of the wall. For walls that are seen quite often from a close distance, noticeable cracks should be avoided. The acceptability of a crack depends on the function of the building and the prominence of the crack. How easily a crack is noticed depends on crack location, the level of lighting, the wall colour and the wall finish. Cracks at the junction of the wall and a slab and cracks in joints of face brick walls are not obvious, particularly if the joints are raked. However, cracks in walls that are rendered and finished to a smooth surface and painted in a light colour are much more noticeable. Until now, information about this item is very scarce. In [Meier p84] a linear relationship between the distance of the observer and the crack-width was established depending on the desired ‘quality’ level of the masonry (Figure 11).

More research is needed to determine general accepted limits, which can be incorporated in international standards like Eurocode 6. If these limits are established, a method for the calculation of the crack width has to be developed. At Eindhoven University of Technology an experimental and theoretical research program is going on in order to develop design rules for reinforced masonry [Martens 00, 01]. In the case of unreinforced masonry the calculation of the crack width is less feasible due to the large scatter in the material properties and due to the lack of quality control on the execution of the masonry. If veneer walls are prefabricated, cracks could easier be controlled.

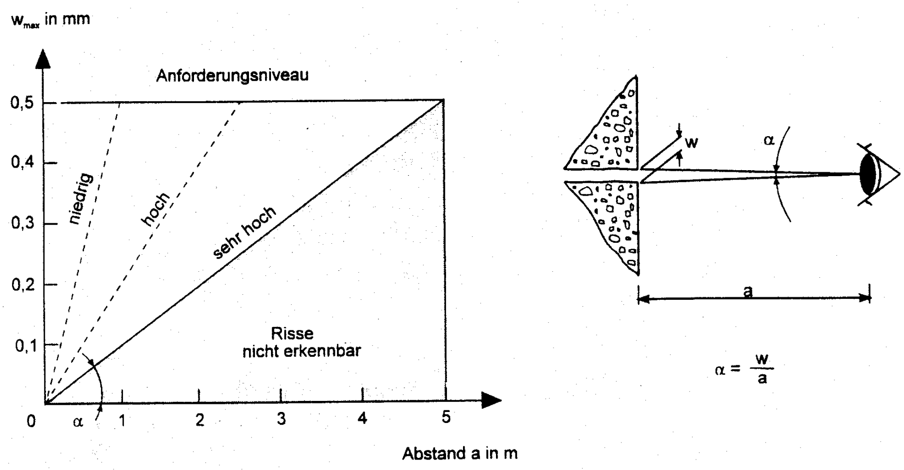


Figure 11 Acceptable crack width versus distance of the observer [Meyer]

If cracks have to be avoided, the most reliable solution is prestressing of the masonry. In this case, the pre-stresses have to exceed the maximum value of the tensile stresses which ever can occur in the veneer wall. For unreinforced masonry walls, the introduction of movement joints may diminish the risk of cracking considerably but prevention of cracks can not be guaranteed.

CONCLUSIONS

Since cracking of masonry is considered to be unacceptable especially in the Netherlands, consultants of facade engineering promote the use of movement joints. The rules which determine the spacing of the movement joints are primarily empirical and consequently often a mystery. This situation is not desirable for architects, owners and contractors since movement joints disturb the appearance of the facade, they are expensive and they need regular maintenance. Only fundamental research can bring these two conflicting opinions closer together and solve the mystery.

An inventory of the behaviour of existing buildings, various experimental tests and more advanced time-dependent analytical and numerical calculations are needed, in combination with requirements for acceptable crack widths.

At Eindhoven University of Technology some aspects are being investigated recently but more efforts are necessary to achieve the final goal. PhD candidates are invited to reflect but also other research institutes are invited for co-operation.

ACKNOWLEDGEMENTS

The financial support of ‘De Cornelus Lely Stichting’ en ‘De Stichting Stapelbouw’ (the Dutch Masonry Foundation) is gratefully acknowledged. Participating in ‘De Stichting Stapelbouw’ are the clay brick, calcium silicate, concrete and aerated concrete units industries and the mortar manufacturers.

REFERENCES

Beck, J.K. and Curtin, W.G., 1989, Some aspects of buildability of concrete blockwork, Brit. Mas. Soc. Proc. No 3, pp. 35..40

CUR71, Aanbeveling 71, 2000, Constructieve aspecten bij ontwerp, berekening en detaillering van gevels in metselwerk, CUR Gouda, with back ground reports.

CUR 1999, Details voor metselwerkconstructies. CUR Gouda

CUR80, Aanbeveling 80, 2001, Beheersing van scheurvorming in steenconstructies, CUR Gouda, including back ground reports.

CUR 171, see [Rots]

Ibrahim K.S. and Suter G.T., 1994, Shear behaviour of flashing materials in brick-mortar joints, 10th IBMaC, Calgary, Canada, pp. 1121..1129.

KNB, 1999, Bouwfysische en bouwtechnische dilataties in baksteengevels, KNB brochure, De Steeg, The Netherlands.

Martens, D.R.W., 2000, Time-dependent behaviour of pre-stressed masonry, 12th IBMaC, Madrid, Spain, pp. 1157..1167.

Martens, D.R.W., 2001, Scheurwijdte bepaling bij trekproeven op gewapend metselwerk en lijmwerk, Technische Universiteit Eindhoven.

Meyer, U., 1996, Zur Riszbreitenbeschraenkung durch Lagerfugenbewehrung in Mauerwerkbauteilen, Aachen, ISBN 3-86073-134-1.

McGinley W.M. and Borchelt, J.G., 1991, Influence of materials o the friction developed at the base of clay brick walls, 9th IBMaC, Berlin, pp 292..300.

McGinley W.M. and Borchelt, J.G., 1990, Friction at supports of clay brick walls 5th North Am. Mas. Conf. 1990 pp 1053..1066.

Pluijm, R. Van der, & Vermeltfoort, A.T., 1998, Influence of the type of mortar joint on the time dependent behaviour of masonry, 8th Can. Mas. Symp. Jasper, Canada, pp. 517..528

Peirs, G.,1999, Movement joints in Europe: A new disease, Mas. Int. Vol. 12 No 3 pp 79..80.

Peirs, G., 1993, Continental cavity walls are (Sometimes) different, Brit. Mas. Soc. Proc. No 5, pp. 11..13.

Pluijm, R. Van der, 1999, Korteduur- en langeduurgedrag van Baksteen Metselwerk, TNO Rapport.

Pluijm, R. Van der, 2000, Numerieke simulaties van het gedrag van gevels onder invloed van temperatuurverandering, TNO 2000-CON-BM-R3015-3

Pluijm, R. Van der, 2000, Beheersing van scheurvorming in steenconstructies, TNO background report for [CUR80]

Rots, J.G. (ed), 1997, An experimental/numerical basis for practical design rules. (based on CUR Report 171, 1994) A.A. Balkema / Rotterdam, ISBN 90 5410 680 8

Suter G.T. and Ibrahim, K.S., 1992, Shear resistance of damp-proof-course materials in brick-mortar joints, 6th Can. Mas. Symp., Saskatoon, pp. 119.1-12.

Sutherland, R.J.M., 1996, All masonry moves: When does it matter ?, Masonry International Vol. 9, No 3, pp 78..83.

Sutherland, R.J.M., 1989, Masonry as a Decorative Wrapping, Masonry (3) Workmanship in Masonry Construction, Proc. Brit. Mas. Soc. 1989, pp 1..3.

Ven, P.J.C.E. van de, 1999, Vochtdoorslag bij gelijmde baksteenconstructies met open stootvoegen, Masters Thesis, Technische Universiteit Eindhoven.

Vermeltfoort, A.T., en Martens, D.R.W., 2001, Meer of minder dilatatievoegen in buitenspouwbladen ? Stand van zaken Jas of Harnas, rapport TUE/CCO/21.xx.
Zijl, G van, 2000, Computational modelling of masonry creep and shrinkage, Thesis, TU Delft

ADDITIONAL LITERATURE

Workmanship in masonry construction, 1989, Brit. Mas. Soc. Proc. No 3.
The cavitywall controversy, 1993, Brit. Mas. Soc. Proc. No 5.
Callebaut, K., Viaene, W. and Van Balen, K. Production of historic lime mortars: evidences from old mortar analyses and laboratory tests, 12th IBMaC, 2000, pp. 363..372.
Cook, G.K. Hinks, A.J. 1992, Appraising building defects: perpectives on stability and hygrothermal performance, Longman scientific and Technical
Howell, J. 1996, Cavity walls: the science of structural revolutions, 7th North Am. Mas. Conf. 1996 pp 33..42