

# Defects in Masonry Walls

## Guidance on Cracking: Identification, Prevention and Repair



**International Council  
for Research and Innovation  
in Building and Construction**



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CIB W023 – Wall Structures

# **Defects in Masonry Walls.**

## **Guidance on Cracking: Identification, Prevention and Repair**

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## Presentation

Over the past decade the CIB Commission W023- Wall Structures has engaged in the preparation of documents covering specific aspects of the construction of building wall structures. To this end, a strategy of setting up working groups taking care of different issues was designed.

Currently, the following working groups are acting within the Commission: WG1- Serviceability of Masonry Walls, WG2- Preparation of Codes on Masonry, WG3- Large Panel Buildings, WG4- Historic Masonry Buildings, WG5- Reinforced and Prestressed Masonry, WG6- Seismic Design of Masonry Structures, and WG7- Complex Shaped Masonry.

As a result of these actions, in 2006 a book was prepared by the Commission and published by the publisher Taylor and Francis, entitled “Enclosure Masonry Wall Systems Worldwide”, presenting the typical masonry wall enclosures in twelve countries, representing different continents.

Later, in 2010, was published the “Guide on Structural Rehabilitation of Heritage Buildings” which constitutes CIB Publication 335, with guidance for dealing with interventions of rehabilitation of heritage buildings, with a special emphasis on the assessment of the structural safety.

Now, in 2014, the Commission concluded the preparation of the document entitled “Defects in Masonry Buildings. Guidance on Cracking: Identification, Prevention and Repair”, focusing on preventing cracking defects in masonry walls.

Other publishing projects are underway: a publication entitled “Reinforced and Prestressed Masonry”, covering all essential aspects of these specific types of masonry, and a document entitled “Complex Shaped Masonry”, dedicated to the specific aspects of the design of masonry elements of complex shape. It is expected to have these documents finalised in the coming years.

The document “Defects in Masonry Buildings. Guidance on Cracking”, is focused on emphasizing the importance of ensuring the proper serviceability behaviour of masonry walls, in order to avoid defects, especially cracks, through: identifying the most common types of cracking associated with the behaviour in service of masonry walls; presentation of some strategies for crack repairs; presentation of some recommendations and guidance to prevent and repair cracks in masonry walls; and, identifying research needs, in order to improve the existing recommendations.

This document was developed under the coordination of Hipólito Sousa, Convenor of WG1, by a Panel of Authors, members of CIB Commission W023 and other experts with recognised curricula. Contributions were also received from other experts around the world, with knowledge of the situation in their countries. Thanks are due to all of them.

I hope that this publication will be fruitful and contribute to the development and the progress in the quality of masonry, i.e. to perform masonry walls without defects, specially, cracking.

After 18 years as the Coordinator, I am proud of the achievements made by the CIB Commission W023 during this period.

I take the opportunity to thank the members of the Commission throughout this period for their cooperation in the Commission activities. I also thank the CIB Secretariat, in particular the Secretary-General Wim Bakens, for the cooperation and constant encouragement, and the confidence expressed by the CIB Programme Committee, notably by awarding the CIB PC Commendation 2006.

November 2014

**S. Pompeu Santos**

Coordinator of CIB Commission W023

## **Preface**

CIB Commission W023 - Structural Walls is fundamentally concerned with masonry, mainly with Codes, Historic Buildings and Seismic Design.

Important concerns have been raised, particularly about the serviceability behaviour of masonry walls, structural or infilling, since it has been realised that there is a need to pay more attention to these aspects, recognising their relation with defects on masonry walls.

A working group: WG1- Serviceability of Masonry Walls was created in 2011 within the Commission with the mission to prepare a guide focused on avoiding cracking defects in masonry walls.

Considering the diversity of masonry uses, this guide was intended to be a concise document, to have general interest and to complement the guidance in structural codes. The objective is not to deal with the diagnosis of masonry defects, or with the defects associated with seismic or ancient buildings, but to help technicians with its identification, prevention and repair.

The document was prepared by a Panel of Authors, members of CIB Commission W023 and other experts, under the Coordination of Hipólito Sousa, also Convenor of WG1.

The authors are: Ercio Thomaz (Brazil), Hipólito Sousa (Portugal), Humberto Roman (Brazil), John Morton (UK), José M. Silva (Portugal), Márcio Corrêa (Brazil), Oscar Pfeffermann (Belgium), Paulo B. Lourenço (Portugal), Romeu S. Vicente (Portugal) and Rui Sousa (Portugal).

Information about the masonry practices in their countries was also provided by the following experts: Barry Haseltine (UK), Dirk Martens (Netherlands), Erhard Gunkler (Germany), Jan Kubica (Poland), Oliver Dupont (France), Roberto Capozucca (Italy) and Tor-Ulf Weck (Finland). A revision of the English language of the document was made by John Morton (UK) and Barry Haseltine (UK).

The document was approved in general at the Commission meeting in Antwerp (Belgium) in October 2014. It was subsequently subjected to minor adjustments and brought to the attention of all members of the Commission and then published by the CIB Secretariat.

To all those who have contributed selflessly to the preparation of this publication I express my sincere thanks.

I sincerely hope that this document is an unpretentious but interesting contribution for the growing knowledge in the masonry field.

November 2014

**Hipólito Sousa**

Coordinator of the Panel of Authors



## **1- Introduction 1,2,3,4**

### **1.1- MOTIVATION**

In recent years, CIB Commission W023- Wall Structures has been involved in the preparation of background documents for design standards, building codes and recommendations for masonry structures. Working groups were created in order to develop specific aspects related to masonry behaviour, such as: Serviceability of Masonry Walls, Preparation of Codes on Masonry, Historic Masonry Buildings, Reinforced and Prestressed Masonry, Seismic Design of Masonry Structures or Complex Shaped Masonry.

In this respect the present work has been developed by a working group dealing with the serviceability behaviour of masonry walls, since the need to give more attention to these aspects and their relation with defects in masonry walls was identified.

The concept of defects is quite subjective, because in building construction there is still a strong component of manual work, where workmanship is very important.

This document is concerned with defects that are not simple, minor aesthetic, imperceptible or unavoidable failures, but with failures that could be considered to compromise the building behaviour and might result in a claim being made. Nowadays masonry is still used in important structural and non-structural elements.

In many situations, as is usual in northern European countries, masonry is commonly the structure in load-bearing masonry buildings. In other applications, such as is usual in southern European countries, masonry is mainly used for infill walls in buildings with reinforced concrete frames.



Figure 1.1 - Example of masonry wall with cracking

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<sup>2</sup> Ercio Thomaz - Brazil

<sup>3</sup> Márcio Corrêa - Brazil

<sup>4</sup> Humberto Roman – Brazil

Theoretically the infilling walls have no relevant mechanical behaviour, but in practice these walls have structural importance since some transference of loading can occur due to building structure/wall interactions. These interactions, as well as other effects like dimensional changes of the walls, due to thermal or moisture movements or foundation settlement, can lead to several different defects in masonry walls in serviceability states, such as cracking, one of the most important (Figure 1.1).

On the other hand, apart from the structural role, or not, of masonry walls, these cracking defects can affect other important functional walls requirements.

According to Grimm [1.1], cracks are the first cause of three occurrences, as shown in Figure 1.2. Besides the implications in Figure 1.2 there is also significant damage to acoustic insulation, durability and the fire resistance of masonry.

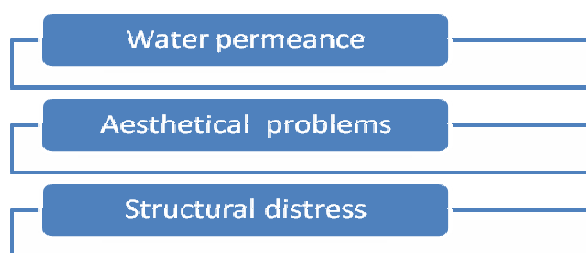


Figure 1.2 - Problems related to cracks in masonry [1.1]

Moreover, despite the general quality improvement expected from the profusion of codes and standards, in recent years some building masonry cracking defects are still being reported with high frequency in different countries. These defects incur costs and can involve litigation between different parties involved in the construction process. In terms of liability, which party is responsible is a relevant question.

In fact, although building construction is an industrial activity, we know that buildings are still prototypes and in some areas, like masonry, the relationship between traditional technologies and local materials is relevant and important, so different practices evolve in different areas.

Therefore, these aspects justify that more attention should be paid to design in order to avoid or minimise defects associated to the serviceability behaviour on masonry walls, whether structural or non-structural.

As underlined by Thomaz [1.2], crack prevention deals with any things such as those shown in Figure 1.3.

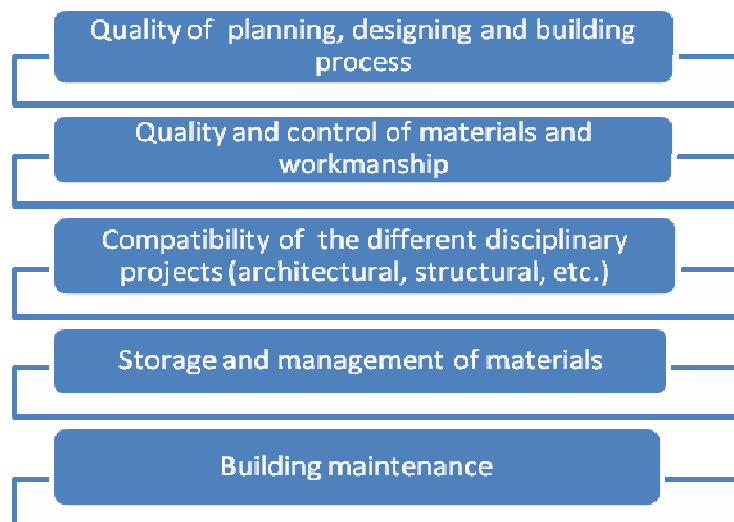


Figure 1.3 - Crack prevention [1.2]

## 1.2- MAIN OBJECTIVES

Considering the motivation and the diversity of masonry solutions, this guide aims to be a document which will be of general interest and will complement the guidance in structural codes.

The objective is not to deal with the diagnosis of masonry defects, named by several authors as “building pathology” [1.3], or with the defects associated with seismicity, where a lot of research and methods are already available. Also this document is not intended to be used for historic or ancient buildings.

So, focused on actual masonry buildings worldwide where there is information, the main objectives of this guide are:

- to underline the importance of assuring good serviceability behaviour of structural or infilling masonry walls so as to avoid defects, mainly cracking;
- to identify the most common types of masonry cracking associated with the serviceability behaviour of masonry walls in buildings;
- to present some strategies for crack repairs;
- to give some recommendations and guidance to both prevent and repair cracking in enclosure and partition masonry walls;
- to identify some needs for research in this area and to formulate better recommendations.

## 1.3- ORGANIZATION

The guide is organized in five chapters. Each chapter was prepared with the contribution of several authors, as acknowledged.

The current Chapter 1 is intended to give a better understanding of the scope, main objectives and organization of the guide.



Chapter 2 is intended to give an overview of masonry construction techniques in different countries, to discuss the general causes of buildings defects and the methodology of analysis, with a focus on masonry cracking identification.

Chapter 3 is dedicated to masonry serviceability improvement. After a short review of code guidance, special reference is made to movement and joint detailing and permissible deviation and tolerances, and also to cracking prevention criteria of masonry partition walls. This chapter presents also the specific problem of cladding cracking in UK and Ireland, and the Brazilian code recommendations to prevent cracking in structural masonry.

Chapter 4 deals with the presentation of repair strategies for cracking in masonry walls, including some Brazilian repair techniques.

In Chapter 5 brief conclusions are presented, with general remarks together with some guidance on helping to prevent cracking. In addition, some research needs are given.

## **References**

- [1.1] GRIMM, C. (1997) - "Masonry Cracks: Cause, Prevention and Repair", Masonry International, 10(3), pp. 66-76.
- [1.2] THOMAZ, E. (1998) - "Prevention and Repair of Masonry Cracks", Journal of Construction Technology, 37, pp. 48-52.
- [1.3] CIB (2013) - "A State-of-the-Art Report on Building Pathology", V. P. Freitas (ed), CIB W086, FEUP, LFC (ISBN 978-90-6363-082-9).

## 2- Specifics of Masonry Walls and Identification of Defects <sup>1,2</sup>

### 2.1- BUILDING MASONRY SOLUTIONS

There is a large variety of masonry wall solutions (Fig.s 2.1 to 2.3) which depends mainly on locally available materials, climate conditions, building technologies and housing traditions, amongst others. Nowadays masonry can be used in buildings in different situations, but actually mainly as structural vertical support walls, or as a non-structural infilling component within a steel or concrete framed structure. In both cases, in building construction, masonry can form the enclosure or the partitions. In those two functions the requirements and the behaviour expected from the masonry are very different, and in both the design and construction phase these differences will always be present.



(a)



(b)

Fig. 2.1 - Some examples of different types of masonry in Africa: (a) Urban buildings in masonry at Maghreb; (b) Popular rural masonry houses in north Mozambique.

<sup>1</sup> Hipólito Sousa – Portugal

<sup>2</sup> Rui Sousa – Portugal

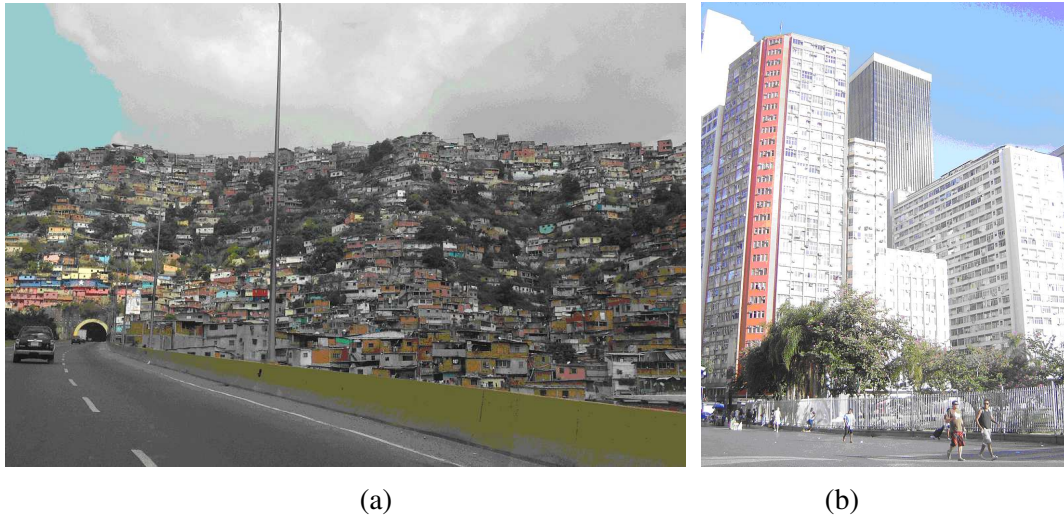


Fig. 2.2 - Examples of different types of masonry in South America: (a) Urban poor quality housing in Venezuelan “favelas” and (b) Modern urban buildings in Brazil



Fig. 2.3 - Examples of different types of masonry in Europe [Photos (a), (c) and (d) taken from 2.1]

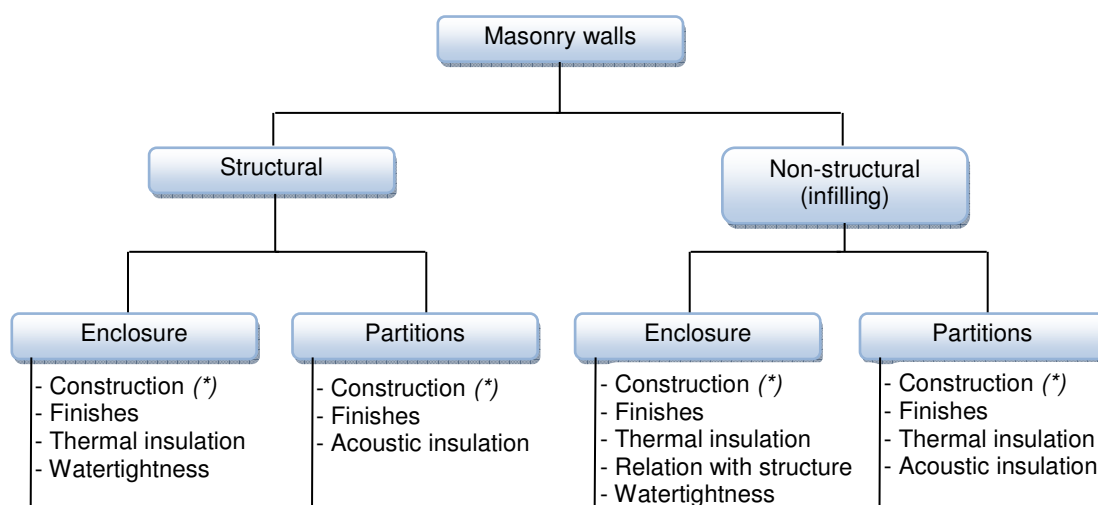
In view of variations in the previous photographs it is important to give a general overview of the most common masonry solutions and materials used worldwide, to

understand better the influence of such solutions in the masonry behaviour and how these practices can be related to the causes of cracking in masonry walls.

Nowadays, in the majority of countries masonry is not as common a structural building solution as it was in the past. Nevertheless, structural masonry is more used in many Central European Countries (e.g., Belgium, France, Germany and Netherlands), especially in low rise buildings of one or two storeys. It is also used in many countries around the world.

Forming the building enclosure in masonry is a very common solution worldwide: single leaf or cavity walls are both frequently used. In Europe perhaps clay bricks or blocks (perforated either vertically or horizontally) are the most common units used laid in general purpose mortar laid in normal joints or in thin joints (thin layer mortar). Other units, such as concrete blocks and bricks, are also widely used. In virtually all developed countries there are requirements for the building's thermal performance which generally result in the use of thermal insulation layer/s. The general use of ancillary components is not present in all countries.

In frequent cases the same materials and similar solutions can be used in structural or non-structural enclosure masonry. Masonry partition walls are constructed with different materials, but normally when the wall is only infilling, the wall is usually slender and lighter.



(\*) Type of construction, includes materials, arrangement and cavities

Figure 2.4 - Aspects associated to masonry wall solutions

Tables 2.1, 2.2 and 2.3 give an overview of the most common solutions used for masonry and masonry materials nowadays. Traditional and ancient masonry solutions are not analysed. Most of information is about Europe and the information is given by country. When considering the worldwide (non-European) countries, only the Brazilian situation is presented. These tables are based on existing references [2.2] and contributions of experts from different countries. All information is presented for a range of solutions for non-structural (enclosure and partitions walls) and structural masonry (internal/external walls).



Table 2.1 - Non-structural masonry: Solutions and materials for enclosure walls

Region	Countries	Building structure			Type of masonry Walls			Masonry materials															
								Units					Mortars			Ancillary			Thermal insulation layer				
		Reinforced Concrete	Steel	Timber	Single leaf	Cavity	Veneer	Clay		Concrete			Calcium Silicate	General Purpose	Thin layer	Light-weight	Wall Ties	Joint reinforcement	Lintels	Exterior	Cavity	Interior	No insulation or large units
								Dense	Light-weight	Dense	Light-weight	Auto.Aerated											
South Europe	Greece	F	R	R	R	F	R	R	F	R	R	R	R	F	R	R	NF	R	R	R	F	R	R
	Italy	F	NF	NF	NF	F	R	F	F	R	NF	R	R	F	NF	R	R	NF	F	F	F	R	NF
	Portugal	F	R	R	F	F	R	NF	F	NF	R	R	R	F	R	R	R	R	NF	NF	F	R	NF
	Spain	F	R	R	F	F	R	NF	F	NF	R	R	R	F	R	R	R	R	NF	NF	F	R	NF
Central Europe	Belgium	F	NF	NF	NF	F	F	NF	F	NF	F	F	F	F	F	R	F	F	F	NF	F	NF	NF
	France	F	R	NF	F	NF	F	NF	F	F	NF	NF	R	F	F	R	NF	R	F	NF	NF	F	NF
	Germany	F	R	R	F	F	R	NF <sup>1</sup>	F	NF <sup>1</sup>	F	NF	F	F	NF	NF	F	NF	F	F	F	R	R
	Netherlands	F	NF	NF	NF	F	NF	F	R	NF	R	R	R	F	NF	R	F	R	F	NF	F	R	R
	Poland	F	R	R	F	F	NF	NF	F	R	NF	F	NF	NF	F	R	F	NF	F	F	NF	R	R
North. Europe	Finland	F	R	F	R	R	F	F	R	R	R	R	R	F	R	R	F	NF	NF	R	F	F	R
	UK	F	F	F	R	F	R	F	R	NF	NF	NF	F	F	R	R	F	NF	F	NF	F	NF	R
Brazil		F	F	R	F	R	NF	R	F	R	F	NF	NF	F	R	R	NF	NF	NF	R	R	R	F

1- If exterior thermal insulation layers are mounted on the wall

Contributions of experts F- Frequent F U- Used, but not frequent NF R- Not used/ Rare R  
 Existing references [2.2] F- Frequent F U- Used, but not frequent NF R- Not used/ Rare R Unknown information U

Table 2.2 - Non-structural masonry: Solutions and materials for partition walls

Region	Countries	Building structure			Type of masonry		Masonry materials											
		Reinforced Concrete	Steel	Timber	Single leaf	Cavity	Units					Mortars			Ancillary			
							Clay		Concrete			Calcium Silicate	General Purpose	Thin layer	Light-weight	Wall Ties	Joint reinforcement	Lintels
							Dense	Light-weight	Dense	Light-weight	Auto.Aerated							
South Europe	Greece	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
	Italy	F	NF	NF	F	NF	NF	F	R	NF	NF	R	F	NF	R	R	NF	F
	Portugal	F	R	R	F	NF	R	F	F	R	R	R	F	R	R	R	R	R
	Spain	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
Central Europe	Belgium	F	R	R	NF	F	NF	F	NF	F	F	F	F	F	R	F	F	F
	France	F	R	R	F	R	NF	F	NF	R	F	R	F	F	R	R	R	R
	Germany	NF	R	NF	F	R	R	F	R	NF	F	F	NF	F	R	F	R	NF
	Netherlands	F	F	NF	F	NF	R	R	R	R	R	F	F	F	R	R	R	F
	Poland	F	R	R	F	NF	NF	F	R	NF	F	NF	R	F	R	NF	NF	F
North. Europe	Finland	F	R	R	NF	R	F	R	R	R	R	NF	F	NF	R	R	R	R
	UK	F	F	F	F	R	R	R	F	F	F	F	F	NF	R	R	NF	NF
Brazil		F	F	R	F	R	NF	F	R	F	NF	NF	F	R	R	R	NF	F

Contributions of experts F- Frequent F U- Used, but not frequent NF R- Not used/ Rare R  
 Existing references [2.2] F- Frequent F U- Used, but not frequent NF R- Not used/ Rare R Unknown information U

Table 2.3 - Structural masonry: Solutions and materials for external and internal walls

Region	Countries	Masonry walls					Masonry materials															
		Structural			Type		Units						Mortars			Ancillary			Thermal insulation layer			
		Unreinforced	Reinforced	Confined	Single	Cavity	Clay		Concrete			Calcium Silicate	General Purpose	Thin layer	Light-weight	Wall Ties	Joint reinforcement	Lintels	Exterior	Cavity	Interior	No insulation or large units
							Dense	Light-weight	Dense	Light-weight	Auto.Aerated											
South Europe	Greece	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	Italy	F	NF	NF	F	F	F	F	NF	NF	R	R	F	NF	R	NF	NF	F	F	F	NF	NF
	Portugal	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	Spain	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
Central Europe	Belgium	R	F	R	NF	F	NF	F	NF	F	F	F	F	F	R	F	F	F	NF	F	R	R
	France	F	R	R	F	NF	NF	F	F	NF	NF	R	F	F	R	NF	R	F	NF	NF	F	NF
	Germany	F	NF	F	F	F	NF <sup>1</sup>	F	NF <sup>1</sup>	NF	NF	F	F	NF	NF	F	NF	F	F	NF	R	R
	Netherl.	F	R	R	F	F	R	NF	NF	R	R	F	F	F	R	F	NF	F	R	NF	R	R
	Poland	F	NF	R	F	NF	NF	F	R	NF	F	NF	F	F	R	NF	NF	F	F	NF	R	R
North. Europe	Finland	R	NF	R	R	R	R	F	R	NF	R	F	NF	R	R	R	NF	R	F <sup>2</sup>	NF	R	
	UK	F	R	R	NF	F	F	R	R	NF	NF	NF	F	R	R	F	R	F	R	F	R	R
Brazil		F	F	R	R	R	F	R	F	R	NF	F	R	R	R	NF	F	R	R	R	R	F

1- If exterior thermal insulation layers are mounted on external walls; 2- Insulation often built in the concrete units;

Contributions of experts

F- Frequent

F

U- Used, but not frequent

NF

R- Not used/ Rare

R

Existing references [2.2]

F- Frequent

F

U- Used, but not frequent

NF

R- Not used/ Rare

R

Unknown information

U

## 2.2- DEFECTS IN MASONRY WALLS

### 2.2.1- General aspects

Problems with the behaviour of buildings normally appear through the occurrence of defects.

The behaviour of buildings is quite complex and involves aspects of material science that sometimes are not well understood yet. Also, masonry is a subject which is not taught in depth during Engineering and Architecture University courses. These aspects increase the difficulty in accurately identifying defects in buildings elements and determining the cause. In general terms, the main causes of defects are associated with human and natural causes (Table 2.4).

Table 2.4 - General causes of defects in buildings [2.3]

Causes	Type	Agent
Human actions	Design	Improper calculation methods and errors, insufficient technical information and level of detailing, improper design assessment (loads, local conditions, compatibility between different functionally aspects...)
	Execution	Use of bad quality materials, inadequately qualified and experienced personnel, inadequate execution control of construction works, bad interpretation of the project
	Utilization	No, or inadequate, maintenance procedures, changes in the utilization, excessive loading...
	Disasters	Fire, explosion, impact, ...
Natural actions	Physical	Wind and rain effects, snow, creep, thermal/moisture movements, ...
	Chemical	Oxidation, carbonation, acid rain, salts...
	Biological	Vegetation (roots, fungus,...), animals (warms, insects,...)
	Disasters	Seismic, cyclone, avalanche, flood, volcanic eruption, ...)

Some studies point out that the most common cause of defects is associated with mistakes in the design process and with inadequate execution of construction works. The quality of building materials and the absence or maintenance quality are less frequently considered as the cause.

In the particular case of masonry walls, the defects are mainly caused by incompatibility between the different functional demands, inadequate construction detailing and / or inadequate execution of construction works. Moreover, the use of new architectural trends (Figure 2.5) and the use of new materials whose behaviour may not be fully understood can also increase the potential of buildings exhibiting defects.



Figure 2.5 - Example of architectural language with some aspects like shape and colour that increase the risk of defects

In addition to knowing the cause, it is also important to distinguish whether the defect is structural or non-structural.

Structural defects affect the mechanical behaviour of the construction element. These elements may perform other functions (e.g. structural walls can also perform acoustic and thermal insulation, water-tightness and fire resistance functions). Moreover, structural defects can also affect non-structural elements, therefore it is important to understand and consider the interaction between these two types of element to prevent the defects.

In general terms, the most common masonry structural defects are:

- cracking due to the settlement of foundations, excessive loading and deformations (shear and flexural) and other effects (creep, shrinkage and thermal);
- local crushing due to high compressive loads;
- corrosion of metallic elements or chemical reactions.

And the most common masonry non-structural defects are:

- undesired changes in the physical properties of the materials due to the presence of water/humidity (from the soil, construction works, precipitation, condensation, hygroscopicity, accidental causes, ...) thus affecting the durability, aesthetics and the environmental conditions of the buildings or building elements;
- cracking in non-structural elements (e.g. partition walls and applied rendering systems) due to the interaction with structural elements, thus making this defect associated with the structural ones;
- ageing and degradation of the materials, in particular rendering systems, due to continuous exposure in the environment, inadequate use or absence of maintenance procedures;
- inadequate behaviour in other aspects (non-structural safety, environment comfort conditions, energy consumption).



When defects have occurred, repair solutions and strategies are very important. A proper analysis to correctly identify the defect and determine the cause of its occurring must be performed. Only then can a repair solution be advocated.

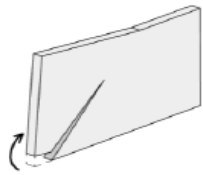
Given the complexity and diversity of defects, the existence of different constructive elements and possible interactions between them, the existence of many specific repair solutions is implied. Moreover the effectiveness of the repair solutions requires a sound knowledge about such problems.

Some methods developed to organize information about defects are referenced by different authors and can be very useful tools to summarise information and help in analysis and decision making. Normally, each analysis, tries to make an objective description of the defects, organize the causes/hypotheses (Figure 2.6), and in some cases to propose specific methods of repair (Figure 2.7).

**Crack - in column or wall - diagonal, in one direction - tapered towards one end - widest at bottom**

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**A. Damage pattern**

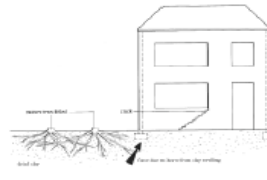
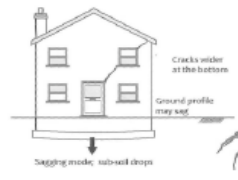
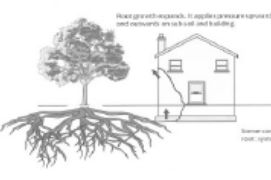


symptoms:

- S: crack
- S: crack direction is diagonal
- S: crack is tapered towards one end
- S: crack is widest at bottom, narrowest at top

context conditions included in pattern:

- G: damage appears in column or wall

Examples. [Eldridge 1976] p. 109, [Marshall et al 2009] p. 18, [Marshall et al 2009] p. 21.

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**B. Hypotheses**

- ☐ 1.B Vertical settlement: one-end-settlement / one-end-heave
- ☐ 3.1.6 Hindered dimensional changes, temperature/moisture induced, difference in conditions between below and above ground

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**C. Essential conditions**

For hypotheses and corresponding essential conditions of vertical settlement, see Part III of this to ol


Additional symptom or context condition	1.B	3.1.6
G: absence of sufficient expansion joints	■	■

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**D. Further reading**

[Eldridge 1976] p. 109, [Marshall et al 2009] p. 18, [Marshall et al. 2009] p. 21, [Marshall et al 2009] p. 22, [Marshall et al 2009] p. 24.

Figure 2.6 - Example of method for identifying defects in masonry walls [2.4]



**PE-01-FI-01**

Element	EXTERIOR WALL
Component	Panel
Anomaly	Cracking
Cause/ Evidence	Differential foundation settlement

---

**Brief description of the anomaly**  
Cracking, usually in an angle of 45° or in opposite corners of a rectangular panel, in brick concrete or stone block masonry panels, laid continuously on the ground with their own foundation or incorporated into a reinforced concrete or metal structure.

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**Possible causes**  
Typical masonry panels are rectangular, more developed across their length and, due to their rigidity and fragility when subjected to distortion loads on their own plane, they require uniform, continuous and rigid supports, a condition that is not complied in various differential foundation settlement situations, of which the following stand out:

- \_ Differential settlement of a continuous foundation, usually specific to the wall itself (in small-scale or bearing wall constructions);
- \_ Differential settlement between footings of a reinforced concrete structure.

The most frequent causes of differential foundation settlement are:

- \_ Incorrect foundation design or calculation in terms of the estimated loads and the characteristics of the soil;
- \_ Incorrect execution due to non-compliance with the design or incorrect choice of foundation stratum;
- \_ Significant alteration in soil moisture conditions, particularly in clay soils (alterations in water table, cutting of large trees, etc.);
- \_ Coexistence of building masses with different dimensions or structural functioning, aggravated by foundations built with diverse techniques and on heterogeneous soils;
- \_ Lack of foundation rigidity and/or lack/unsuitability of strapping elements between footings.

---

**Consequences**  
Cracking, usually of a serious nature, with high possibilities of creating wall instability in the future, preventing total or partial use of the building, even if temporarily. In all cases, marked degradation in appearance, degradation of cladding and accessory elements, strong vulnerability to the action of water (infiltrations).

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**Rehabilitation strategies**  
The actions to be developed always depend on a prior analysis of the building's structural safety (which influences all other rehabilitation options) and, additionally, should always include checking and correction at three different levels:

- \_ Consolidation of the foundation soil;
- \_ Increase in the foundation rigidity/resistance;
- \_ Repair of the wall which, in view of the usual expression of cracks, frequently implies demolition and partial reconstruction, the introduction of localised horizontal reinforcement and subsequent reinforced coating. The simple rehabilitation of cracks (for instance "bridging") is not usually sufficient.

Figure 2.7 - Example of method for identifying and repair defects in masonry walls [2.5]

### 2.2.2- Identification of Masonry cracking

As previously mentioned, modern masonry walls have an important role in the building's behaviour and may perform several functions. The technical research associated with the development of modern codes and standards for masonry has resulted in a general positive improvement in the quality of masonry construction.

Nevertheless, some defects still occur in masonry walls during service conditions. The main defect found in masonry is cracking in the walls and applied finishes. The repair work associated with these defects is expensive and frequently may not be totally successful. Obviously defects in masonry can be much influenced by workmanship quality but other causes can also be present.

Cracking defects are the main subject of this guide, in particular cracking of masonry walls in serviceable conditions. This defect is common in structural and in non-structural elements, including applied finishes, although the causes may be different in some cases.

The main cracking defects in structural masonry seem to be associated with ground movements (settlement of foundations or seismic events), although defects like expansion/shrinkage of masonry materials or thermal movements can also occur. Moreover, the brittle nature and low tensile strength makes masonry, in particular unreinforced masonry, highly susceptible to cracking due to small movements.

Non-structural masonry, such as enclosure and partition walls, have important roles which may include functional aspects such as aesthetics, acoustic and thermal insulation, and water-tightness. Structural safety is normally assured by independent structural elements - in particular reinforced concrete columns beams and slabs, in which the infill masonry is built. Therefore, cracking defects in enclosure and partition walls are frequently associated with incompatibility between structural components (e.g. excessive deformation of concrete slabs or beams, aggravated by long term effects), expansion/shrinkage of masonry materials (e.g. clay or cement based elements) and thermal movements (masonry and building structure).

Also when rendering or other types of finishes are applied to the walls, in general the same types of non-structural defects may occur. In the particular case of cracking, this defect can be caused by the movements of the supporting walls and it can therefore be associated with structural or non-structural defects. However, other types of cracking defects not caused by the support walls can be found in rendering systems. These defects are mainly caused by the nature of the rendering materials, the construction choice and execution procedures (e.g. cracking due to shrinkage in mortars made from a high quantity of hydraulic binders, too great a joint thickness or improper environmental and/or execution conditions). Furthermore, if there are also unsuitable design details, construction practices, or when special shaped units are not used where they should be used, cracking defects in structural and in non-structural masonry can occur. The absence of specific masonry units for particular construction situations and the reduced use of ancillary components can also increase the propensity for cracking to occur, figures 2.8 to 2.13 (Note: the schematic drawings are intentionally exaggerated).

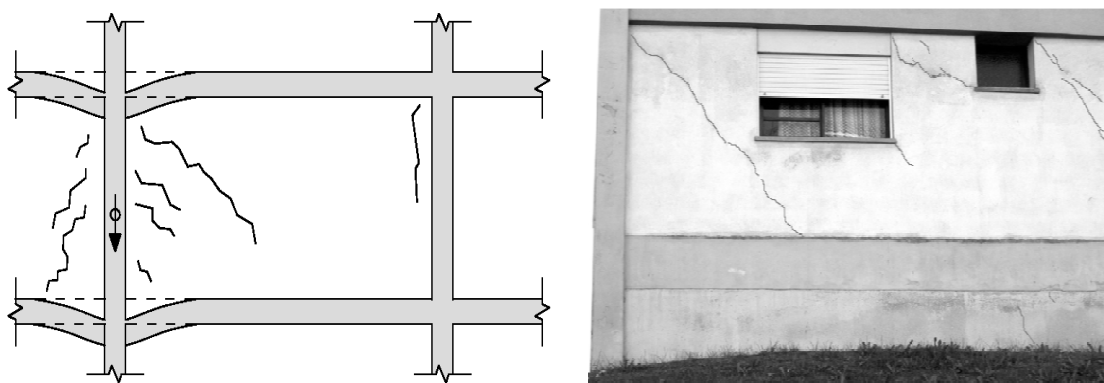


Figure 2.8 - Example of cracking in masonry due to differential settlement of foundations [Photo taken from 2.6]

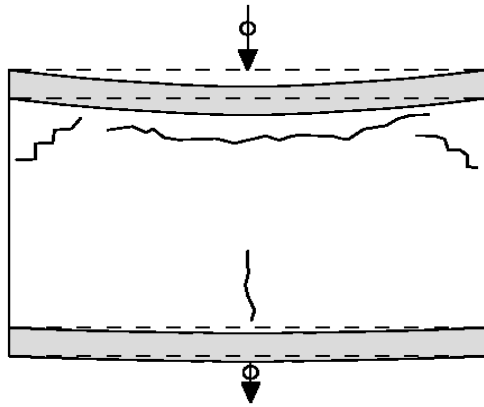


Figure 2.9 - Example of cracking in masonry due to excessive deflection of the top slab (probably, less rigid than the floor concrete slab)

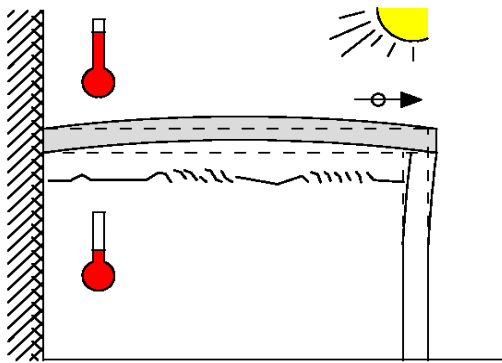


Figure 2.10 - Example of cracking in masonry due to thermal movements of roof slabs

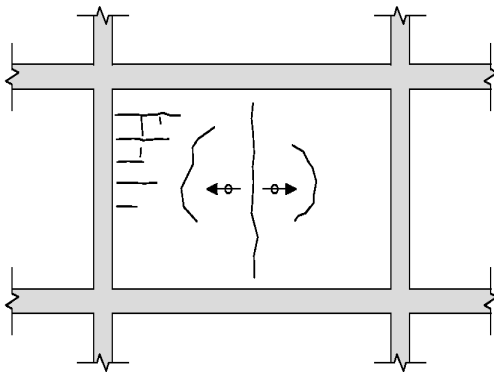


Figure 2.11 - Example of cracking in masonry due to moisture shrinkage



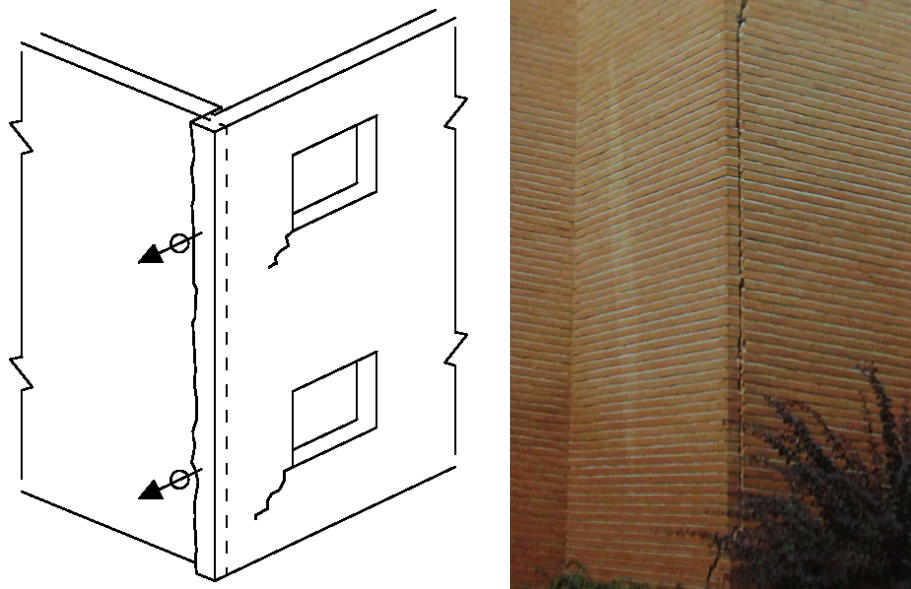


Figure 2.12 - Example of cracking due to moisture expansion of masonry walls [Photo taken from 2.7]

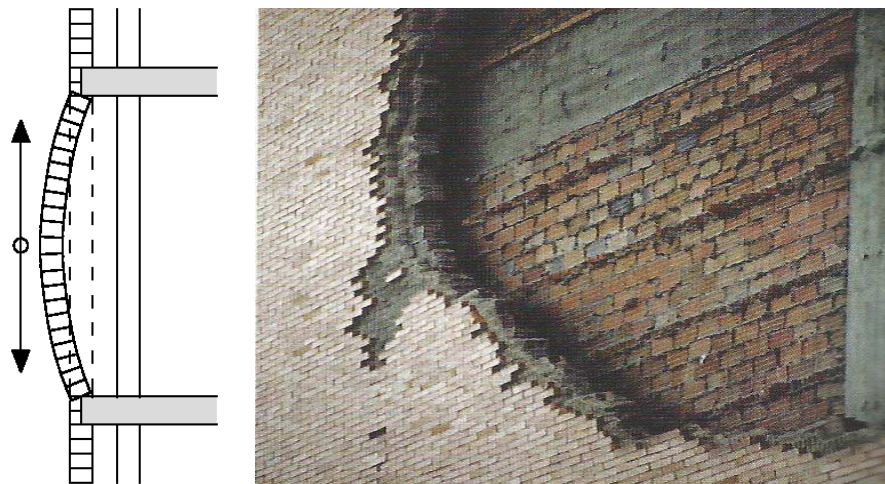


Figure 2.13 - Example of masonry cladding failing due to thermal/moisture movements and insufficient connections (ties) to the support wall [Photo taken from 2.7]

In order to help to avoid these problems, technical applied knowledge, specifications and detailing information should be available to technicians, in particular regarding serviceability conditions for enclosure or partition walls. This will be deeply discussed in Chapter 3.

## References

- [2.1] Figure 2.3 (a): “Guest House”, Villa Grabau-Italy, photo by “PicDrops”, 20/9/2004. Figure 2.3 (c): “Oberbeuren”, Baviera-Germany, photo by “Pilot Micha”, 30/5/2010. Available at <http://www.flickr.com/photos>, under the license terms: <http://creativecommons.org/licenses/by-sa/2.0/>. Figure 2.3 (d): “Terraced Houses”, Crewe, England, photo by “Espresso Addict”, 4/4/2007. Available at <http://commons.wikimedia.org>, under the license terms: <http://creativecommons.org/licenses/by-sa/2.0/>.
- [2.2] CIB (2007) - “Enclosure Masonry Wall Systems Worldwide”, S. Pompeu Santos (ed), Taylor&Francis/Balkema, London, UK.
- [2.3] PAIVA, V. et al (1985) - “Patologia da Construção” (in Portuguese), 1º Encontro sobre Conservação e Reabilitação de Edifícios de Habitação, Documentos Introdutórios, LNEC, Lisboa, Portugal.
- [2.4] DE VENT, I. (2011) - “Prototype of a Diagnostic Decision Support Tool for Structural Damage in Masonry”, Supplement to the PhD thesis, Delft University of Technology, Faculty of Architecture, Netherland.
- [2.5] ABRANTES, A.; SILVA, J. (2012) - “Método Simplificado do Diagnóstico de Anomalias em Edifícios” (in Portuguese), Livro de Obra, Gequaltec/Cadernos de Obra (ed), Porto, Portugal.
- [2.6] GASPAR, P. et al (2006) - “Técnicas de Diagnóstico e Classificação de Fissuração em Fachadas Rebocadas” (in Portuguese), 2.º Encontro sobre Patologia e Reabilitação de Edifícios (Patorreb2006), FEUP, Porto, Portugal.
- [2.7] ARGILÉS, J. (2000) - “Arquitectura sin Fisuras” (in Spanish), Arquitectura e Tecnologia (2), Munilla-Leria (ed), Madrid, España.



### 3- Prevention of Cracking in Masonry Walls

#### 3.1- GENERAL CAUSE OF CRACKING <sup>3</sup>

Masonry walls consisting of brick or block units (clay bricks or concrete blocks) and their traditional finishes are able of fully meeting their performance requirements for a long period of time. However, they often present develop cracking, humidity problems and natural (or accelerated) degradation of materials (aging). In the last decades, various features have been responsible for problems and distress of masonry walls and have repercussions on their overall performance [3.1]. Amongst them, the most relevant are:

- Introduction of new materials;
- Not well evaluated enhancements of some masonry characteristics;
- Technological changes in respect of design criteria;
- Technological changes in respect to workmanship techniques and skills;
- Introduction of new building types of components;
- Compatibility issues with concrete structural elements, window sills, etc;
- Evolution of traditional rendering solutions and the compatibility of new rendering and covering wall solutions.

Evolution of wall solutions is always linked to improvement of the wall performance as well as faster construction but inevitably, in some cases, it will also result in new unexpected defects. The growing expectation of end-users together with a growing environmental awareness form new challenges for masonry wall solutions within the construction sector (e.g. hygrothermal and acoustic code requirements).

Illustrating this, to achieve the requirements of the new thermal codes throughout Europe, concerning the need to increase the thermal resistance concrete members in an enclosure, designers and contractors adopted several methods, based on inconsistent and unknown technology. Among these methods, the more relevant one promotes an external overhang of the masonry wall of 50–80 mm, outwards from the structural member surface (column, beam or slab), which assures an external protection of the concrete members, thereby increasing the thermal resistance while preserving the alignment and other aspects of the facade. This situation leads to a high concentration of compression stresses locally which can be increased by the brick's internal geometry. In this case, cracking can be dramatic, even for very low levels of loading, depending on the specific support conditions.

These poorly-supported walls can exhibit very severe cracking and, in the worst cases, can move away from the building in the out-of-plane direction. External envelope wall solutions using solid or perforated clay brick units are well known and they are correctly built in many countries. However, the problem is different when the brick resistance is very low and the percentage of horizontal voids is more than 60%, delineated by thin clay webs of 8-9 mm thick [3.2].

The major concern is why these defects in masonry enclosure walls should occur so regularly. Why do they recur so persistently, despite the better quality of masonry units and the greater experience gained with this type of construction? Where is the benefit or result of research and technological knowledge in common practice? The gap between

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<sup>3</sup> Romeu S. Vicente – Portugal



practice and research is not effectively shaping design methods or workmanship procedures (Figure 3.1).

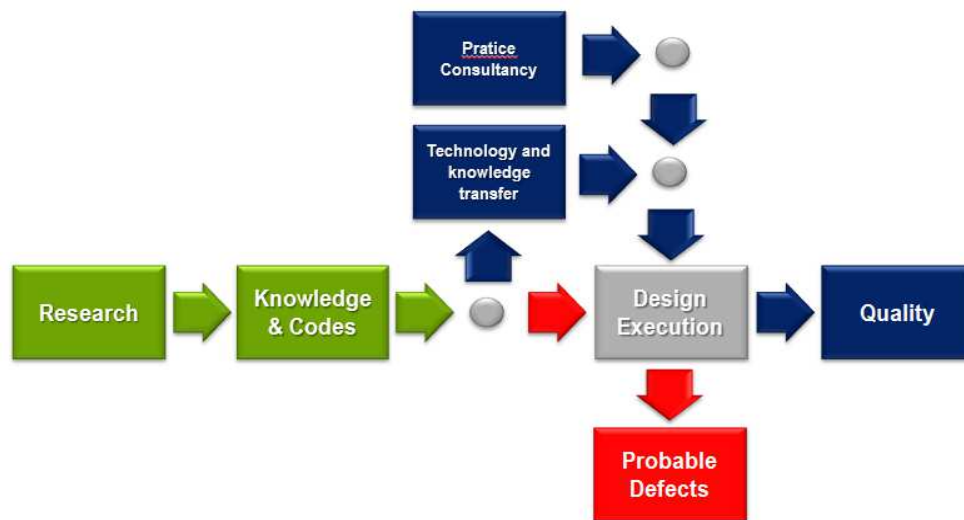
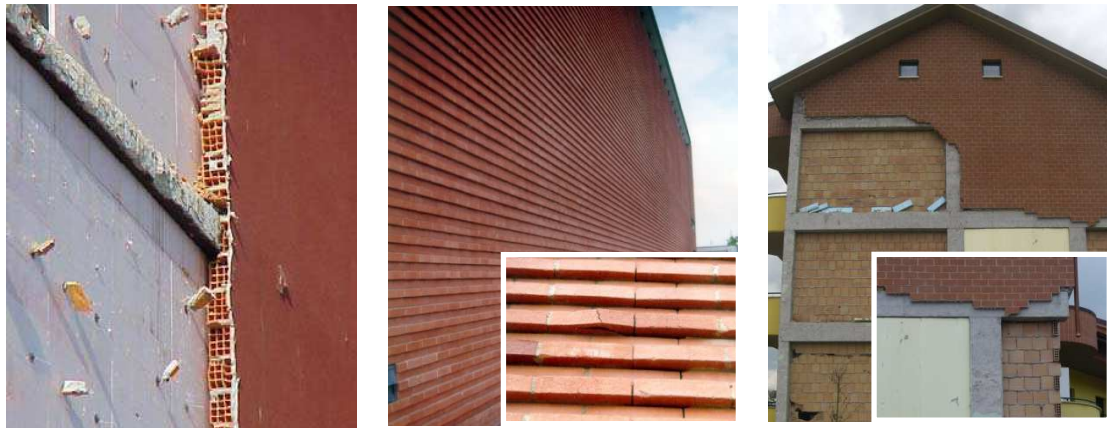


Figure 3.1 - Building quality chain

Table 3.1 - Design and execution problems

Design	Execution
Insufficient evaluation and knowledge of material properties and compatibility;	Misinterpretation of construction design details and poor workmanship;
Insufficient detailing or access to typical construction details not adapted to the construction case;	Insufficient embedment depth of wall ties and anchors;
Negligence in the estimation of potential movement, especially for enclosure masonry walls in the case of thermal and moisture expansion-contraction joints;	Deficient execution of horizontal and vertical mortar joints (influences thermal and acoustic properties of the finished wall);
Negligence in the estimation of main structure deformations and their effect over masonry walls in terms of cracking (induced stress and strain);	Incorrect execution of movement joints and water tightness layer;
Negligence in the case of wind loading, special wall geometry and support conditions (lack of specification of wall ties, anchors, etc.);	Incorrect installation of flashings and water barriers that compromise durability;
Misinterpretation of construction and design codes.	Working conditions (high solar radiation, wind, driven rain).

The challenge is to strongly reduce or eradicate common defects in masonry walls, that systematically occur: lack of movement joints, incorrect thermal bridge correction, lack of wall ties, incorrect positioning of insulation in cavity walls, deficient application of water barriers, rising damp and water tightness issues, tile and render detachment, incorrect window sill projection, estimation of the main structure deformation, poor seismic design including insufficient wall ties and / or stabilizing frame cramps.



Out-of-plane instability of the external leaf due to poor support conditions

Lack of movement joint to accommodate thermal and moisture movements

Seismic damage due to the lack of connection to the backing wall or structure (ties)

Figure 3.2 - Three major recurring defects of masonry enclosure walls

The encouragement of the use of simplified design to evaluate stresses and movements due to various factors (wind and seismic action, thermal and moisture expansion) is fundamental to identifying problems and expected behaviour. It is therefore important to survey new constructions to learn more about their behaviour and special attention should be given to very large walls. It is also very important to improve workmanship practice [3.3].

Masonry design and verification must be promoted, particularly the use of correct details. All the normative documents and design guidelines must give more prescriptive solutions for validated and tested solutions.

### 3.2- IMPROVEMENT IN SERVICEABILITY BEHAVIOUR <sup>4,5,6</sup>

#### 3.2.1- Codes and design criteria <sup>1,2,3</sup>

Serviceability Limit States (SLS) are related to deflection and cracking control, as well as to any other possible structural behaviour related to comfort or functionality issues. Changes in the appearance of non-structural masonry and finishes should also be taken

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<sup>5</sup> Hipólito Sousa – Portugal

<sup>6</sup> Rui Sousa – Portugal

into consideration when checking SLS. The same should apply to structural masonry, especially to unreinforced masonry, since the use of reinforced masonry tends to decrease the occurrence of cracking problems.

There are fundamental tools for design of masonry that should be used (e.g. Eurocode 6 [3.4], North American Code [3.5], British Code [3.6] and Brazilian Standards, developed in chapter 3.5), although they don't analyse deeply the avoidance of cracking in SLS. Recommendations associated with serviceability criteria are scarce, sometimes permitting the serviceability limit state to remain unchecked. There can be few or no specific limits for strength or deflection and references for detailing are only general, in particular for unreinforced masonry. However, the information found in those codes regarding SLS for structural walls may be used in non-structural walls as guidelines for design, as well as other design codes, such as Eurocode 2 [3.7], the French code [3.8] or the Brazilian code, which may be useful for partitions/enclosures influenced by movements of concrete structures. Table 3.2 gives a general overview about serviceability criteria found (x) or not found (-) for masonry in those design codes.

Table 3.2 - Overview of the SLS requirements associated to masonry

Design criteria	Codes of design							
	Non-structural masonry			Structural Masonry				
	Eurocode 2	French Code	Brazilian Code	British Code	USA Code	Eurocode 6		Brazilian standards
						General rules	Belgium DNA	
Strength/ Deflection control	-	-	-	X	X	X	X	X
Deformation limits	X	X	X	X	X		X	X
Tensile limits	-	-	-	-	-	-	-	X
Ancillary Reinforcement (SLS)	-	-	-	-	-	-	-	-
Movement joints	-	-	-	X	X	X	X	X

Eurocode 2 [3.7] defines limits for the relative deflection of concrete structures (span/500) in order to avoid damage in the adjacent parts, such as partition / enclosure walls in general and applied finishes. Other limits may be considered, depending on the sensitivity/fragility of those adjacent parts: the specific check on deflections may also be omitted for common cases by limiting the span/depth ratios. However no specific limits are established for structural members supporting masonry partitions or enclosure walls in particular and there is no limit for the absolute deflections.

The French concrete code [3.8] defines a similar philosophy; however it defines a more demanding limit for deflections for members with a span higher than 5m ( $\text{span}/1000+0,5\text{cm}$ ) in order to avoid damage in fragile partition/enclosure walls and applied finishes.

Eurocode 6 [3.4] states, in clause 7.1, that structures shall be designed and constructed so as not to exceed SLS, therefore preventing cracks or deflections that might damage partitions, finishings and technical equipment, as well as enclosures and their facings, thus risking impairing water tightness. However, the serviceability of masonry members should not be unacceptably impaired by the behaviour of other structural members, such as the deformations of floors. Clause 7.2 defines general criteria for unreinforced masonry walls and it specifies that allowance needs to be made for differences in the properties of masonry materials so as to avoid overstressing or damage where they are inter-connected. It also states that SLS regarding cracking and deflection are satisfied if the Ultimate Limit States (ULS) are also satisfied, removing the need to verify the members that comply with the span and depth ratios separately. However, it assumes that some cracking could result when the ultimate limit state is satisfied but no deformation limits are defined for SLS in order to avoid cracking in structural masonry or in other non-structural elements.

Part 2 of Eurocode 6 [3.9] provides further information concerning the movement of masonry and masonry movement joints in clauses 2.3.3 and 2.3.4, respectively. The first clause specifies that movement joints should be used, or reinforcement should be incorporated into masonry, in order to minimise cracking, bowing or distortion caused by expansion, shrinkage, differential movements or creep. Clause 2.3.4 states that positioning of movement joints must not affect the structural integrity of the building, specifies what the design of the movement joints should take into account (type of masonry, geometry of the structure, fire resistance, etc.) and the maximum spacing between the movement joints for the several types of masonry in non-loadbearing walls.

The British code for the use of masonry [3.10-3.12] has a similar philosophy to EC6 [3.4, 3.9], however, it defines deflection limits for some cases. For example, it suggests relative and absolute deflection limits ( $\text{span}/500$  or 20mm, whichever is the lesser) for reinforced masonry in order to avoid damage in partitions and applied finishes [3.11].

The North American Standard [3.5] follows the same EC6 [3.4, 3.9] design philosophy as far as the SLS are concerned, and it states in the deformation requirements clause 3.1.5.2 that deflection calculations for unreinforced (plain) masonry members following the Strength Design Method shall be based on uncracked section properties and a general limit of  $\text{span}/600$  is given for relative deflections. Drawings regarding provisions for dimensional changes resulting from elastic deformation, creep, shrinkage, temperature and moisture are also mandatory following clause 1.2.2 (h).

Regarding recent scientific research, there is some lack of guidance to support design and detailing in SLS. Several references to avoid cracking can be found in scientific research literature [3.13-3.21], mainly obtained from experimental studies. It is difficult, however, to establish general references due to the difference between the results obtained. For example, in these studies limits for relative deflections of the supporting structure range from  $\text{span}/770$  to  $\text{span}/3000$  and tensile stress limits for masonry range from 0.1 to 0.3 N/mm<sup>2</sup>. These deflection limits are more demanding than the ones found in the design codes for masonry (ranges from  $\text{span}/500$  to  $\text{span}/1000$

depending on the span dimension and support conditions), and no tensile strength limits are found or considered in those design codes.

In conclusion it should be noted that, in order to reduce cracking, it is important to better define and develop design criteria limits for serviceability behaviour of masonry (SLS) such as deflection/strength limits, although the given references can be used as important guidelines to design masonry in SLS. Also, in any design detailing aspects are important, such as the movement joint detail or the use of ancillary reinforcement. This is particularly important with unreinforced masonry or non-structural masonry since it is almost impossible to eliminate tensile stresses in practical cases and it is important to give more ductility to the masonry walls.

### 3.2.2- Detailing aspects of movements and joints <sup>7</sup>

Owing to changes in temperature and moisture the volume of masonry units can change, and if these movements are restrained (i.e confined), further stresses are imposed on the structure which needs to be taken into account in the design process. Shrinkage and accommodation of structural movements, creep, and deformation of horizontal members and settlement of foundations also impose additional stresses.

The types of movement experienced by the different materials are shown in Table 3.3. Eurocode 6 [3.4] states in clause 3.7.4 that the coefficients for creep, moisture and thermal expansions shall be determined by test, either carried out or available from a database, and proposes the deformation properties repeated in Table 3.4.

Table 3.3 - Types of movement of building materials [3.22]

Building Material	Thermal	Reversible Moisture	Irreversible Moisture	Elastic Deformation	Creep
Brick Masonry	X	-	X	X	X
Concrete Masonry	X	X	-	X	X
AAC Masonry	X	X	-	X	X

<sup>7</sup> Paulo B. Lourenço – Portugal

Table 3.4 - Ranges of coefficients of creep, moisture expansion or shrinkage, and thermal properties of masonry (Eurocode 6 [3.4])

Type of masonry unit		Final creep coefficient <sup>a</sup> $\phi_{\infty}$	Long term moisture expansion or shrinkage <sup>b</sup> mm/m	Coefficient of thermal expansion, $\alpha_t$ , $10^{-6}/K$
Clay		0,5 to 1,5	-0,2 to +1,0	4 to 8
Calcium Silicate		1,0 to 2,0	-0,4 to -0,1	7 to 11
Dense aggregate concrete and manufactured stone		1,0 to 2,0	-0,6 to -0,1	6 to 12
Lightweight aggregate concrete		1,0 to 3,0	-1,0 to -0,2	6 to 12
Autoclaved aerated concrete		0,5 to 1,5	-0,4 to +0,2	7 to 9
Natural stone	Magmatic	c	-0,4 to +0,7	5 to 9
	Sedimentary			2 to 7
	Metamorphic			1 to 18

<sup>a</sup> The final creep coefficient  $\phi_{\infty} = \epsilon_{\infty} / \epsilon_{cl}$ , where  $\epsilon_{\infty}$  is the final creep strain and  $\epsilon_{cl} = \sigma / E$ .

<sup>b</sup> Where the long term value of moisture expansion or shrinkage is shown as a negative number it indicates shortening and as a positive number it indicates expansion.

<sup>c</sup> These values are normally very low.

## a) Thermal movements

Contraction and expansion occur with temperature variation and the unrestrained thermal movement of a given material is obtained by the product of the temperature change, the thermal coefficient of the material and the length of the element. Eurocode 6 [3.4] proposes values for the thermal coefficient of several types of masonry, see Table 3.4, just as North American Standard [3.5] in article 1.8.3 that gives figures that also have to be multiplied by the expected temperature change, see Table 3.5.

Table 3.5 - Thermal expansion coefficients (North American Standard [3.5])

Masonry type	Thermal coefficient
Clay masonry	$k_t = 7.2 \times \frac{10^{-6}}{^{\circ}C}$
Concrete masonry	$k_t = 8.1 \times \frac{10^{-6}}{^{\circ}C}$
AAC masonry	$k_t = 8.12 \times \frac{10^{-6}}{^{\circ}C}$

## b) Moisture related movements

The volume of most absorbent materials changes with the increase or decrease of moisture and these changes can be reversible or irreversible, see Table 3.3. Clay products begin to absorb moisture immediately after firing, in a complex chemical reaction, which leads to an irreversible moisture expansion. This moisture expansion occurs mostly in the first few weeks or months after production, see Figure 3.3.



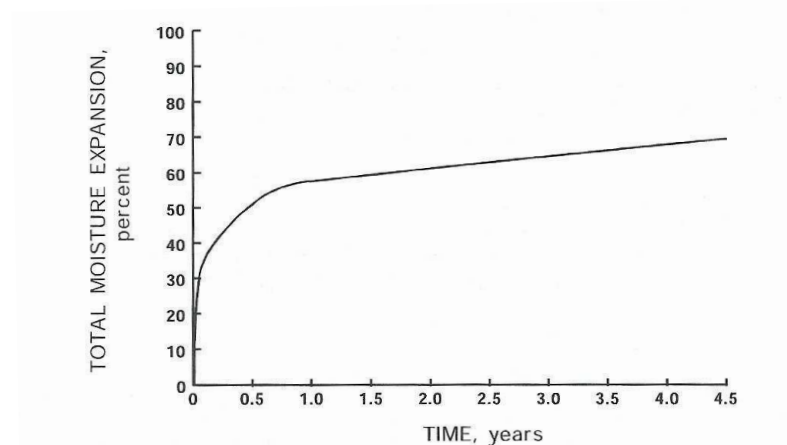


Figure 3.3 - Irreversible moisture expansion of fired clay units over time (Brick Industry Association [3.22])

Eurocode 6 [3.4] stipulates a value for these changes that already takes into consideration of long term effects, see Table 3.3, while the North American standard only refers a single value for clay masonry brick in clause 1.8.4:  $k_e=0,3\text{mm/m}$ .

The Masonry Society and Council for Masonry Research [3.23] states that the irreversible expansion values range between 0.2 mm/m and 0.9 mm/m.

### c) Shrinkage and creep

Shrinkage is important in concrete masonry, even though the process can take place in other types of masonry in the mortar joints. It occurs during the cement hydration process and, although upon wetting the units will expand to their original size, there is an overall shortening under service conditions: if the units are wetted before construction, they will expand and therefore the effects of shrinkage will be higher when they dry out again. The shrinkage of concrete masonry blocks varies within rather wide limits and the type of aggregate used and the manner in which the blocks are cured strongly influence this process - see Table 3.6. Eurocode 6 [3.9] provides shrinkage values for the different types of masonry - see Table 3.4, as the North American Standard [3.5] in clause 1.8.5:  $k_m=0,33\text{mm/m}$ .

Table 3.6 - Typical shrinkage of concrete masonry products [3.24]

Product	Aggregate	Curing	Total Shrinkage - mm/m
Block	Dense gravel	Low pressure steam	0.2-0.5
	Dense gravel	Autoclave	0.1-0.4
	Lightweight	Low pressure steam	0.4-0.8
	Lightweight	Autoclave	0.2-0.6
Brick	Dense	Low pressure steam	0.2-0.5

Creep is a time-dependant volume change under load; it is barely of significance for clay bricks. Loading at an early age, drying, and high water to cement ratio usually increases the creep of masonry [3.25]. Eurocode 6 [3.4] provides a final creep coefficient, see Table 3.4, while in clause 1.8.6 the North American standard [3.5] provides creep coefficients dependant on the load, see Table 3.7.

Table 3.7 - Creep coefficients (North American standard [3.5])

Masonry type	Creep coefficient
Clay masonry	$k_c = 0.1 \times 10^{-4}$ , per MPa
Concrete masonry	$k_c = 0.36 \times 10^{-4}$ , per MPa
AAC masonry	$k_c = 0.72 \times 10^{-4}$ , per MPa

#### d) Movement joints

Vertical and horizontal movement joints need to be introduced in masonry in order to accommodate the above mentioned movements and avoid the extra stresses. The required location and thickness of those joints depend on building geometry, wall composition, masonry material properties, and anticipated differential movements. Clause 2.3.4 of part 2 of Eurocode 6 [3.9] defines the maximum horizontal distance between vertical movement joints in non-loadbearing walls, see Table 3.8, but no recommendations are made regarding loadbearing walls.

Table 3.8 - Maximum recommended horizontal distance,  $l_m$ , between vertical movement joints for unreinforced non-loadbearing walls (Eurocode 6 [3.9])

Type of masonry	$l_m$ (m)
Clay masonry	12
Calcium silicate masonry	8
Aggregate concrete and manufactured stone masonry	6
Autoclaved aerated concrete masonry	6
Natural stone masonry	12

The North American Standard [3.5] does not give any details regarding movement joints but The Masonry Society's Masonry Designers' Guide [3.23] separates them in four different types: masonry control joints, which open to accommodate shrinkage of concrete masonry and need to be placed in specific locations, see Figure 3.4; masonry expansion joints, which close to accommodate expansion of clay or stone masonry; construction joints, which seal the gaps between columns, windows and doors; and building expansion joints, which isolate roofing and building framing systems.



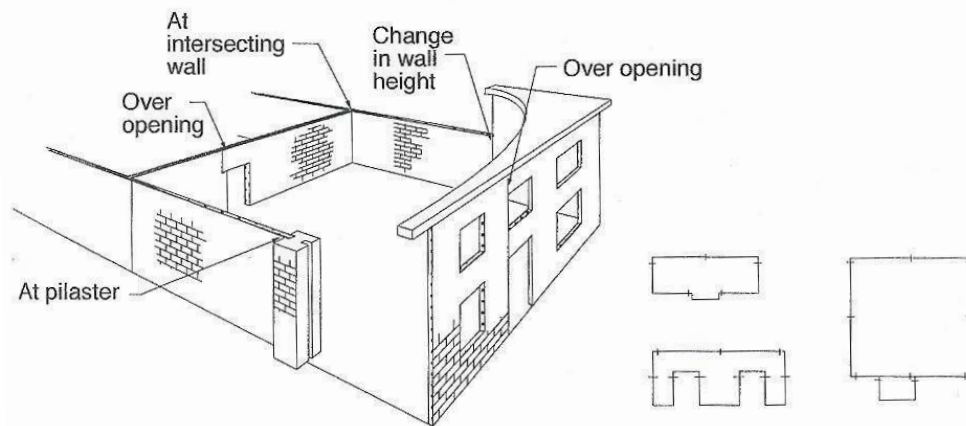


Figure 3.4 - Locations of movement joints [3.26]

The Masonry Society and Council for Masonry Research [3.23] states that vertical expansion joints are not required in concrete masonry since drying shrinkage usually exceeds thermal expansion. In clay brick masonry, however, vertical and horizontal expansion joints need to be used as the clay masonry walls expand in both directions due to the combination of thermal and moisture expansion. It also defines rules for the spacing between vertical expansion joints and their size which should match the mortar joint width (10 to 13 mm). Construction details can be seen in Figure 3.5. Drysdale and Hamid [3.24] recommend that vertical movement joints create rectangular panels not more than 7.6 m long in the case of masonry veneers.

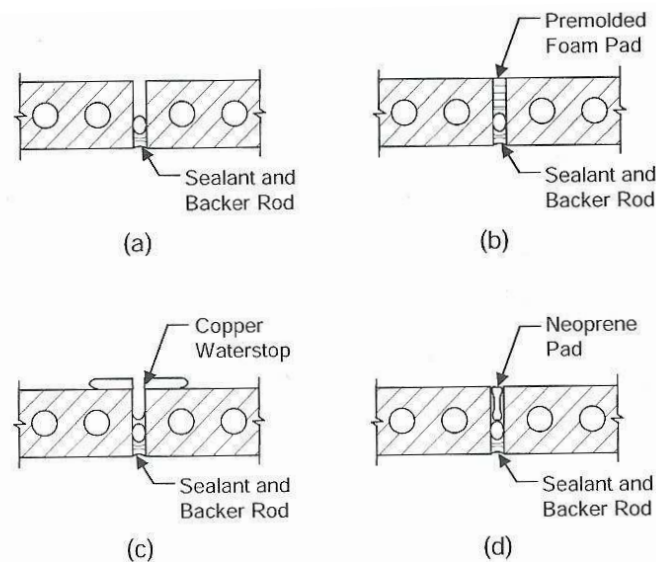


Figure 3.5 - Vertical expansion joint details (The Masonry Society and Council for Masonry Research [3.23])

Drysdale and Hamid [3.24] assume that the presence of vertical load eliminates the need for horizontal expansion joints and The Masonry Society and Council for Masonry Research [3.23] only relates horizontal joints to masonry and clay masonry non-

loadbearing elements such as veneer and infills. In the former the joints are installed below the shelf angles, see Figure 3.6, and in the later around the perimeter. The Masonry Society and Council for Masonry Research [3.23] prescribes a width varying from 10 to 13 mm, while Drysdale and Hamid [3.24] propose the equation:

$$t_j = \Delta_h / \epsilon_{\text{seal}}$$

Where  $t_j$  is the joint thickness,  $\Delta_h$  is the calculated differential movement and  $\epsilon_{\text{seal}}$  is the maximum cyclic deformation strain rating for the sealant.

Special attention should be given to construction joints between masonry walls attached to structural frames. If the walls are not intended to provide lateral stiffness, joints need to be provided, see Figure 3.7.

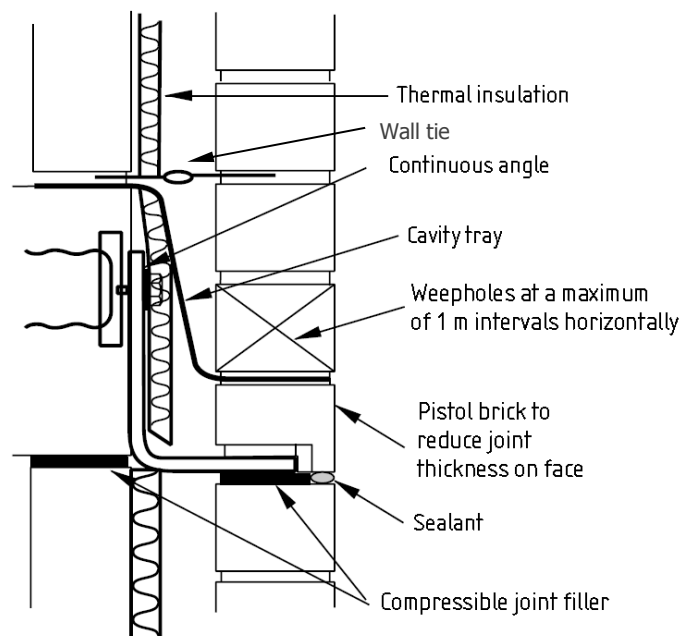
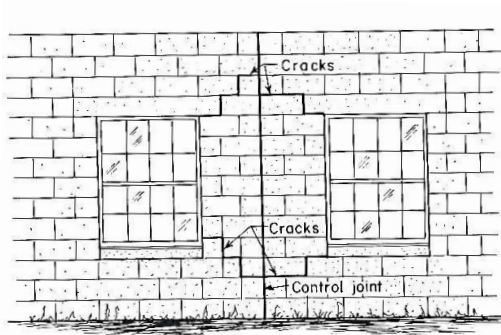
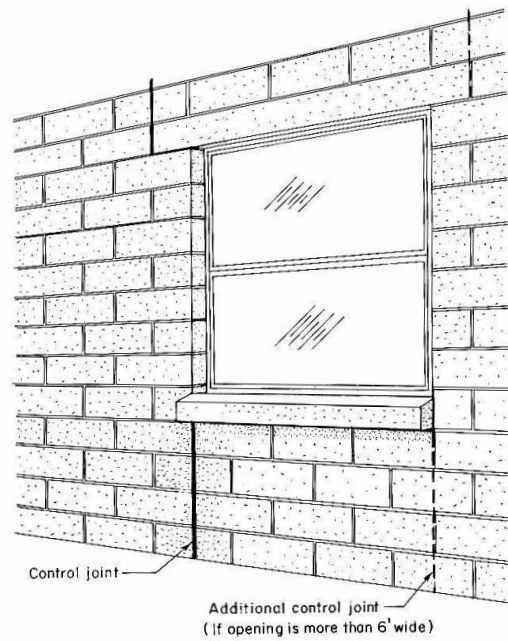


Figure 3.6- Example of support system showing provision for movement [3.27]

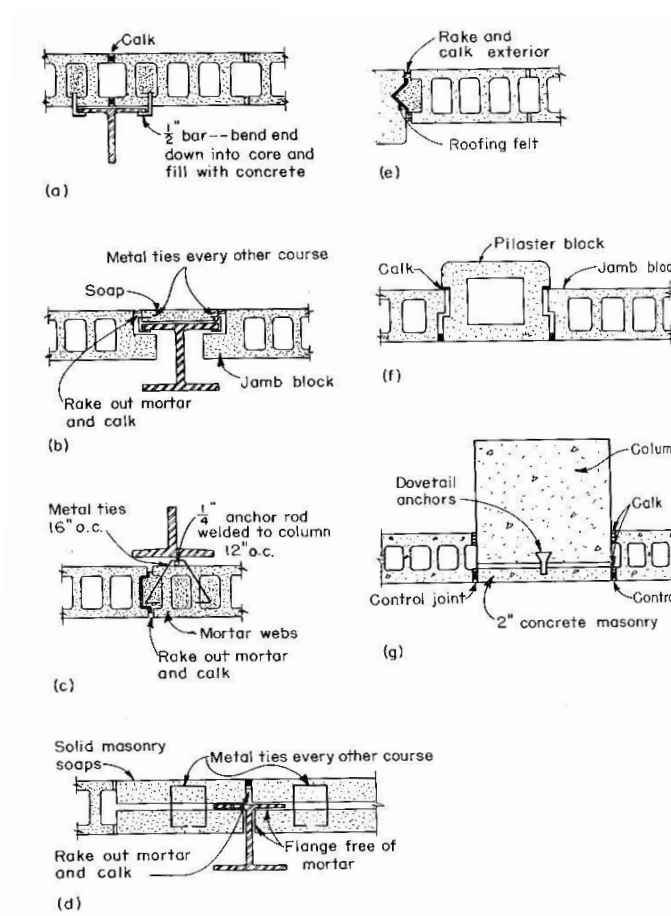
The importance of choosing the correct material for the sealant in all types of joints is also highlighted in The Masonry Society and Council for Masonry Research [3.23] and Drysdale and Hamid [3.23], both referring to water-tightness, durability, good compression properties (expansion joints) and elongation properties (control joints) as key aspects. Klingner [3.28] states that exterior sealants should be replaced every 7 years since ultraviolet light and ozone deteriorate the sealant's properties.



The wrong place for a control joint because cracks may seek a path of less restraint



Control joints located at window opening to avoid random cracking



Control joints at columns and pilasters

Figure 3.7 - Control joints [3.29]

### 3.2.3- Permissible deviations and tolerances <sup>8</sup>

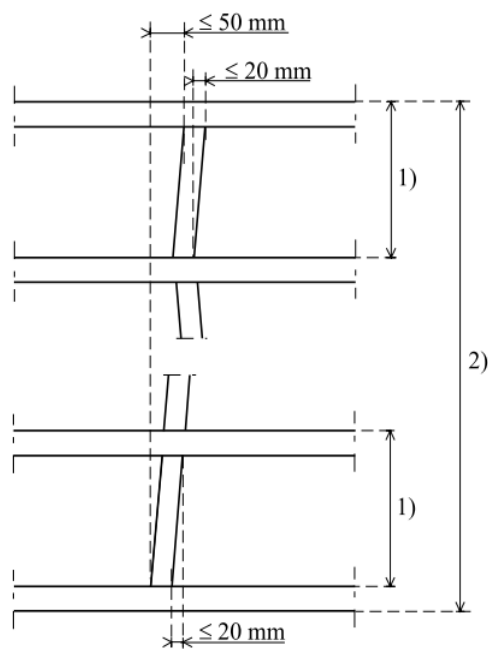
Clause 9.1 of Part 1-1 of Eurocode 6 [3.4] states that all work shall be constructed in accordance with specified details within permissible deviations and by skilled and experienced personnel. It also states that, if the requirements of part 2 of Eurocode 6 [3.9] are followed, the above mentioned specifications are satisfied, and clause 3.2 of the latter specifies that deviations of the constructed masonry should not exceed the values specified in the design, and if they are not specified then the values should be the lesser of: values on table 3.1 of Eurocode 6 [3.9] - see Table 3.9 and Figure 3.8 and values from locally accepted practice.

Table 3.9 - Permissible deviations for masonry elements

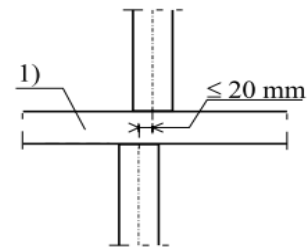
Position	Maximum deviation
<b>Verticality</b>	
in any one storey	$\pm 20$ mm
in total height of building of three storeys or more	$\pm 50$ mm
vertical alignment	$\pm 20$ mm
<b>Straightness</b> <sup>a</sup>	
in any one metre	$\pm 10$ mm
in 10 metres	$\pm 50$ mm
<b>Thickness</b>	
of wall leaf <sup>b</sup>	$\pm 5$ mm or $\pm 5\%$ of the leaf thickness whichever is the greater
of overall cavity wall	$\pm 10$ mm.
<sup>a</sup> Deviation from straightness is measured from a straight reference line between any two points.	
<sup>b</sup> Excluding leaves of single masonry unit width or length, where the dimensional tolerances of the masonry units govern the leaf thickness.	

The North American standard [3.30] defines a tolerance of  $\pm 3$  mm for the mortar bed joints of clay, concrete and stone masonry, which should have a thickness of 9.5 mm, while head joints are permitted to vary by -6.4 mm to +9.5 mm. This same standard refers that tolerances for alignment (on plan or elevation), for level (on elevation) and for plumb (verticality) should be annotated in the contract documents together with tolerances for the vertical expansion joints, which should be such that the minimum sealant joint width is not greater than the specified width minus the negative tolerance.

<sup>8</sup> Paulo B. Lourenço – Portugal



Verticality (1-storey height; 2-building height)



Vertical alignment (1-intermediate floor)

Figure 3.8 - Maximum vertical deviations (Eurocode 6 [3.9])

### 3.3- CRACKING PREVENTION IN MASONRY PARTITION WALLS <sup>9</sup>

#### 3.3.1- General

Interior walls have as their function the separation between different spaces (rooms). They don't have a structural role, so their thickness is generally only 5 to 10 cm. They are often constructed in brittle masonry materials such as clay bricks or blocks, concrete blocks (dense or lightweight), calcium silicate units, gypsum, etc.

This means that their ability to adapt to deformations in the building is very low - they are building elements that can be exposed to cracking in various forms.

The cracks have an influence on the aesthetic function and on some of their physical properties such as noise insulation.

In practice, the cracks in the interior walls can often cause litigation since repair costs can be very high if properly done.

#### 3.3.2- Origin of defects in interior walls (partitions)

Excessive deformation of slabs or beams supporting partitions is the most frequent cause of damage to partitions. While the beam or slab can deflect without any damage, the supporting brittle masonry elements cannot follow and will crack (Figure 3.9).

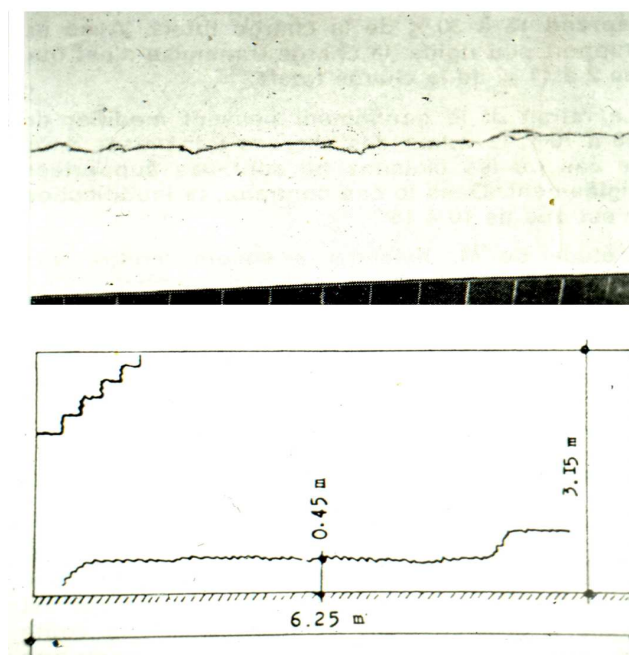


Figure 3.9 - Cracks in a partition due to the deformation of support

The form of these cracks depends on several factors:

- The ratio of length to the height of the wall;

<sup>9</sup> Oscar Pfeiffermann – Belgium

- The type and quality of the masonry material in the partition;
- The presence of door and window openings in the partition;
- Any interaction with other walls, partitions, columns, etc.

Different situations may occur.

- a) The deflection of the slab on the upper level of the partition is higher than that at the foot of the partition (Figure 3.10).

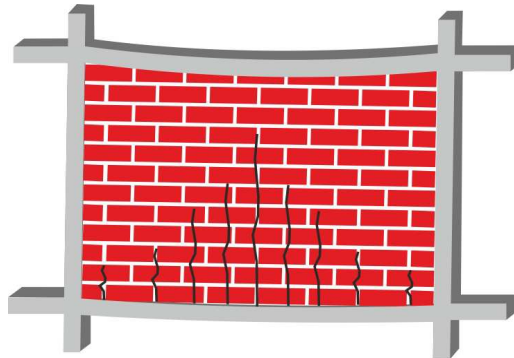


Figure 3.10 - Cracks in a partition due to the deflection of the upper support

In this case the partition takes on a structural function. It will behave as a deep beam under flexure but the partition was not designed for this function so if the tensile stresses in the partition produced by such a deflection are higher than the tensile strength of the masonry, cracks will occur (Figure 3.11).

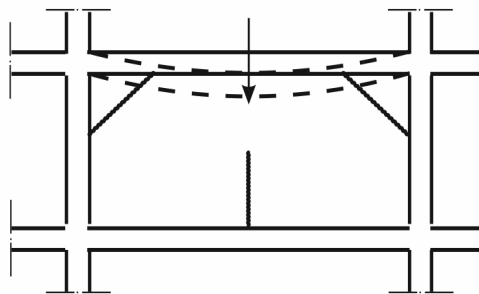


Fig 3.11 - Partition is acting as a deep beam in flexure

These are similar to the cracks in a concrete beam under flexure. In reality a new distribution of the loads occurs with the partition as a structural element. The part of the load distributed to the partition depends on:

- The stiffness of the partition;
- The rigidity of the partition support;
- The position of the partition in relation to the other supports (walls, beams, etc.);
- The physical characteristics of the masonry of the partition.



An example: a partition supported by a rigid slab situated half way between two structural walls, will take 15 to 30% of the total load.

If the support of the partition is not stiff, the transmitted load will be only 2 to 11% of the total load.

Physical elements such as shrinkage and expansion may influence 60 to 70% of the movement if the support is not stiff. In case of a stiff support this value is only 10 to 15%.

b) The deflection of the slab at the foot of the partition is excessive

This is the most common masonry defect for partitions. A relatively stiff masonry partition built on a slab or a beam cannot follow the deformation of its support without cracking. The structural elements of reinforced concrete or steel may deflect without disturbing the stability of those elements but this is not compatible with good serviceability of the masonry partition. Cracks are situated at the foot of the partition (Figure 3.12) or can often occur between the slab and partition (Figure 3.13).

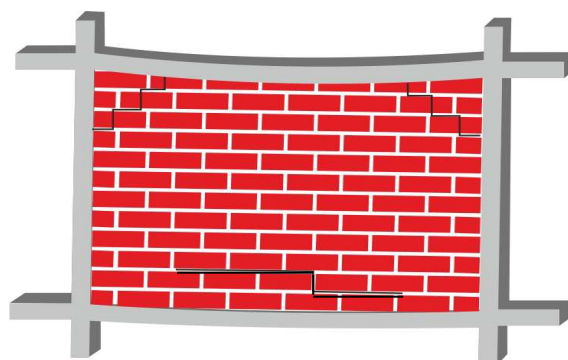


Figure 3.12 - Crack pattern by slab deflection

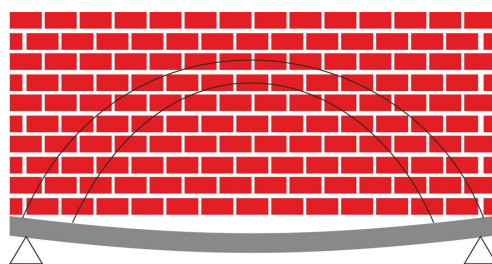


Figure 3.13 - Crack between slab (beam) and partition

Tests conducted at the Belgian Building Research Centre (CSTC) [3.31, 3.32, 3.33] showed that the cracks occur:

- By lack of shear strength within the mortar (Figure 3.14);
- By lack of bond between the mortar and support or the mortar and masonry unit (Figure 3.15).



Figure 3.14 - Crack in the mortar



Figure 3.15 - Crack between blocks and mortar (bond between block and mortar)

The tests also demonstrated other interesting points:

- After cracking, an arch (Figure 3.13) will form in the wall and the partition will act as a “deep beam”;
- The cracking pattern will depend on the dimensions, the type of masonry units used and the presence of any openings;
- A partition with a small  $l/h$  will behave as a “deep beam” and the crack will occur between the slab and the partition (Figure 3.16);
- In the case of a door opening, the crack patterns will depend on the position of the opening (Figure 3.17);
- In case of a central opening with masonry above the lintel, the cracks will have the same form as for a plain wall with a discontinuity at the opening;
- In the case of a lateral opening, the first cracks occur at the opening dividing the partition in two: one with the opening and one without the opening, this last one being similar to the behaviour of a plain wall with the characteristic cracks at the bottom (Figure 3.18).

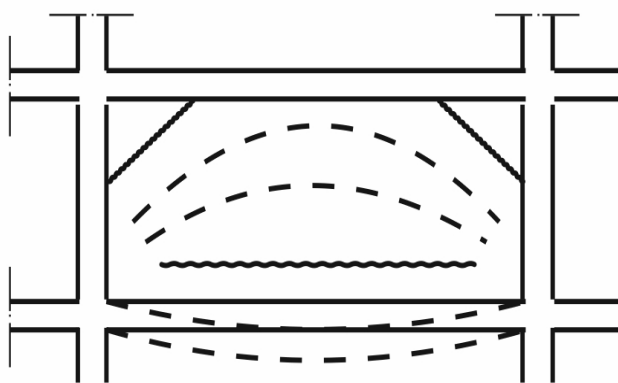


Figure 3.16 - Partition is acting as a beam crack pattern

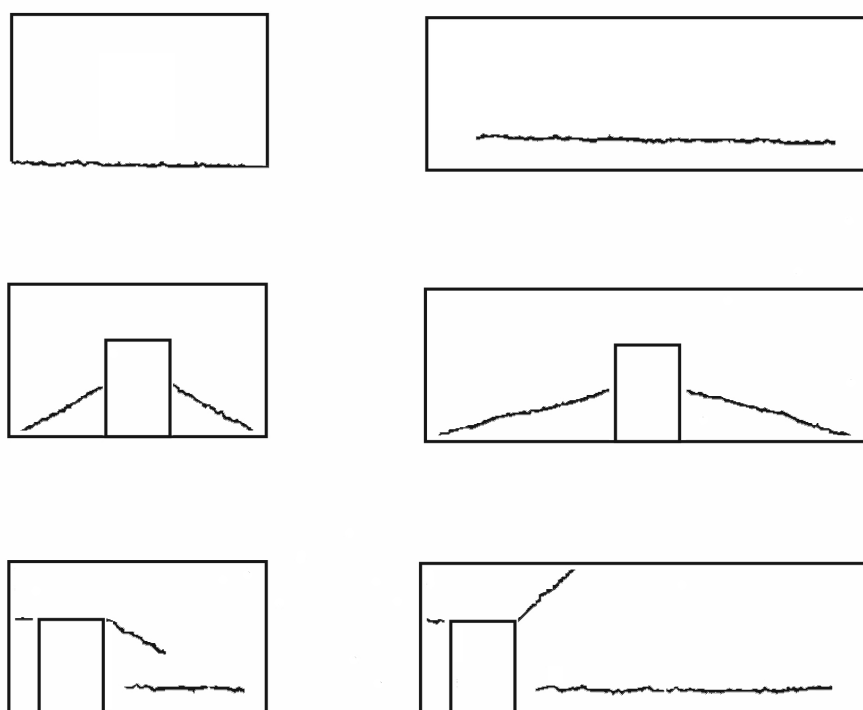


Figure 3.17 - Different patterns of cracks (without opening; with opening in different positions)



Figure 3.18 - Lateral opening

### 3.3.3- Prevention of cracks

There are 2 ways:

- Limitation of the deflection of the supports (slabs, beams);
- Increasing the deformability of the partitions.

The two ways may be used together.

#### a) Limitation of the deflection of the support

In the past a lot of studies and experimental tests were conducted to determine the maximum allowable deflection [3.31, 3.32]. The deflection is a movement of an element under flexure between two states - A1-A2 [3.34] (Figure 3.19) or two time periods (T1 – T2). There is:

- the initial state or initial time period or the reference state (A1, T1);
- the measurement state or time period (A2, T2).

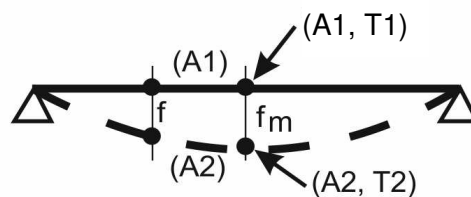


Figure 3.19 - Deflection of the support

The loads producing deflection may also be different:

- Self-weight (G);
- Self-weight and other permanent loads (G+P).

There can also be different design conditions:

- Self-weight, permanent loads and variable loads (G+P+Q).

A distinction is made between:

- The elastic deformation;
- The long term deformation due to creep in case of concrete.

The situation is complicated because of the different components of the load (permanent, transient) and the long term deformation (which is increasing with time). Let's see which deformation (deflection) must be taken into account for partitions (Figure 3.20)

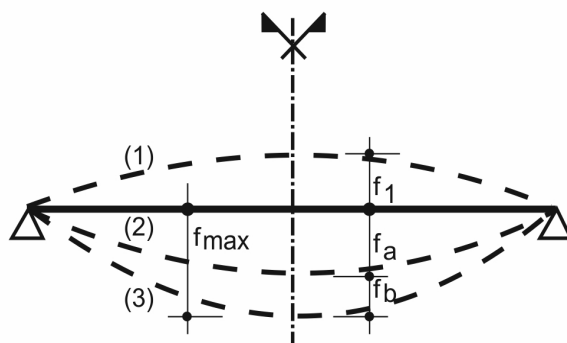


Figure 3.20- Components of the deformation of a support

- i. *Deflection ( $f_a$ ) of concrete slabs Deflection ( $f_b$ ) affecting the behaviour of the partition.*

In this case the following must be taken into account:

- An initial deformation due to construction (it can also be a camber introduced into the formwork);
- A deflection under self-weight (may be a direct deflection and a deformation in time (creep));
- A direct deformation (elastic deformation) and a long term deformation (due to creep) due to the building construction elements such as non-structural elements;
- A deformation due to the mobile loads from the utilization of the floors.

- ii. *Deflection ( $f_b$ ) affecting the behaviour of the partition.*

- Long term deflection under the already present permanent loads (self-weight, other building elements);
- Long term deflection under the new permanent loads (self-weight of the wall, other building elements);
- Elastic deflection under the permanent loads placed after the erection of the partitions;
- Elastic deflection under the transient loads.

This deflection “ $f_b$ ” is at the heart of the problems associated with partitions. In conclusion this deflection must be limited. This is not so easy. There is a complexity due to the stages of load application, to the nature and erection of the partition and last but not least the calculation of the deflection. We will see this in the next section.

- iii. *Total deflection “ $f_{max}$ ” is the deflection under the total value of all the loads (permanent, mobile) the elastic and the long term deformation.*
- iv. *The deflection “ $f_c$ ” is a deformation under the mobile loads (static and dynamic action).*

### 3.3.4- Calculation of the deflection

The deflection of a reinforced concrete slab or beam is made according Eurocode 2. This document gives the information concerning the elastic and long term deformation (due to creep). The calculation must take into account:

- The geometry of the compartments (rooms);
- The erection stages of the different construction components.

In the calculation of the deflection, a method that is often used is to consider a part of the service loads as permanent loads. In Belgium, the advice is to take as permanent load:

- $\frac{1}{4}$  of the service loads, if they are not higher than  $5 \text{ kN/m}^2$
- $\frac{1}{2}$  of the service loads if they are higher than  $5 \text{ kN/m}^2$
- $\frac{3}{4}$  of the service loads for rooms used as book storage, archives, etc.

### 3.3.5- Limitation of the deflection

As already mentioned, it is not easy to determine limit values for the deflection. A lot of factors influence the amount of deformation which partitions can sustain. A recurring theme is the lack of research concerning this subject. This may be partially due to the fact that the problem can't be solved with theoretical considerations. Different practical observations on buildings with cracks on the partitions and different laboratory tests on the deformability of the partitions [3.33, 3.34, 3.35] were made in the frame of the Belgian Building Research Station (CSTC). The tests were conducted in the Laboratory of Civil Construction of the University of Brussels.

The conclusion was that, parallel with some “guidance” values for the deflection, it must also be considered how to increase the deformability capacity of the partition.

It is impossible and not economic to provide supports stiff enough to exclude cracks occurring. It is also important to improve the construction details. Some advice will be given later concerning this technical aspect.

The “empirical” values that were proposed [3.34] and were also taken over by different countries can be summarized as follow:

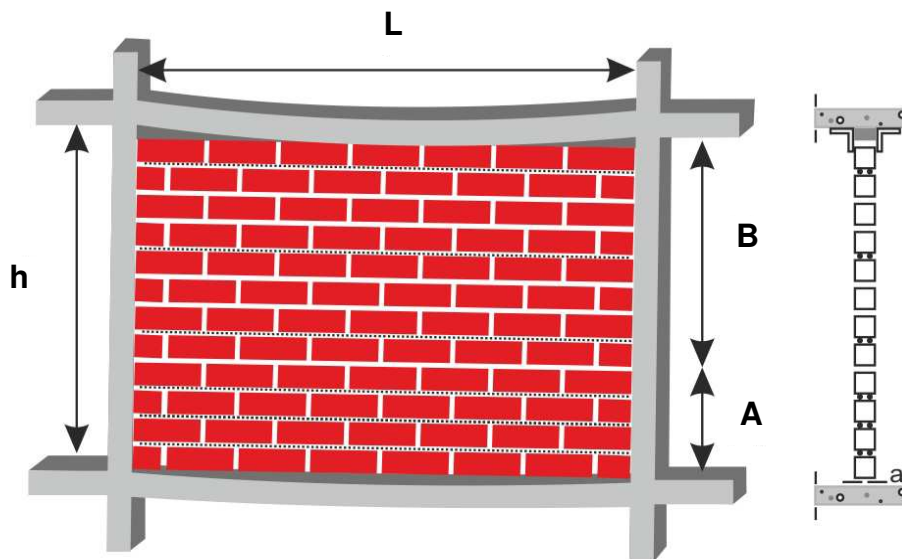
- Walls without openings on their surface  $f_b \leq L/500$
- Walls with openings  $f_b \leq L/1000$
- Walls with openings but with special technological means, to avoid cracks  $f_b \leq L/500$

Where L is the span and  $f_b$  the deflection produced after the erection of the partition.

### 3.3.6- Practical means to protect partitions from cracking

- a) Make the partition independent of the structure

This is the most efficient method (Figure 3.21) and is taken from the Belgian Standard NBN EN 1996 [3.36].



a.: bond breaking layer (d. p. c. material)

Figure 3.21 - Partition separated from its support and reinforced in the joints

The partition is separated from the bearing slab or beam with a damp proof membrane (dpc/dpm) or some other layer and with reinforcement placed in the mortar joints of the wall. Also the top of the wall must be separated to allow the deflection of the upper slab to take place without any significant loading on the wall, and the lateral stability should be ensured. The partition then behaves like a separate, reinforced wall beam and no longer follows the movement of the floor or the beam.

The eventual opening between floor and partition is covered by a decorative strip at the bottom.

#### b) Opening in the wall

Provide joint reinforcement above the opening (Figure 3.22). Try to make a joint close to the opening (Figure 3.23). In this case the two walls will deform separately, thus avoiding corner cracks.

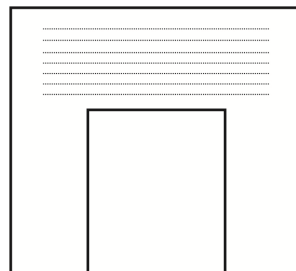


Figure 3.22- Reinforcement above the opening



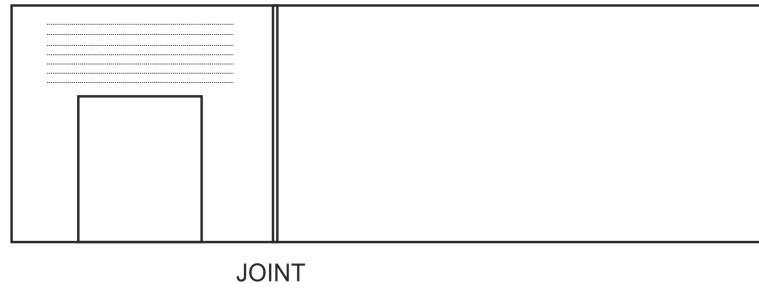


Figure 3.23 - Joint close to the opening – opening reinforced in the joints

### c) Erection of the walls

Try to do it as late as possible after the construction of the structure so that part of the deflection has already occurred. When walls are built above each other on different levels, Figure 3.24 shows two possible ways to progress the masonry construction.

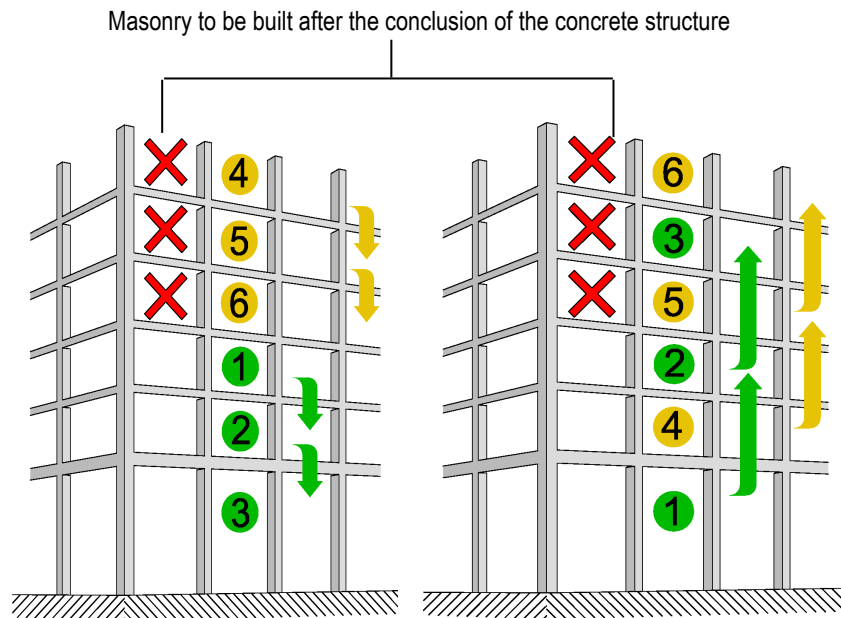


Figure 3.24 – Examples of two alternative ways of constructing masonry partitions walls in different levels of concrete framed buildings [adapted from 3.25]

### 3.4- CLADDING CRACKING IN UK AND IRELAND <sup>10</sup>

The combined moisture and thermal expansion of clay masonry units is one of the main reasons for potential cracking distress to masonry cladding to framed buildings. In the UK and Ireland, the use of concrete masonry or calcium silicate units in external cladding is generally less than that for clay and combines moisture shrinkage with thermal movement. In the UK and Ireland either steel or reinforced concrete frames are commonly used depending on the cost at the time of building and the site constraints present. The use of timber frame construction is also popular for residential - type construction of up to 5-7 floors.

Distress in cladding has been witnessed and remedies developed since the late 1950s/early 1960s when a discernible trend of multi-storey construction was seen. The commonest form of distress seen on cladding to framed buildings is the vertical or inclined crack – indicative of tension failure when the cladding is wishing to contract but restrained from doing so. Furthermore, the movement becomes apparently greater with walls of small height - such as parapets. In almost any city or urban scene throughout Europe, the trained eye can find some degree of cracking distress with masonry parapets, Figure 3.25.



Figure 3.25 - Movement failure of parapets in SE Europe

In a similar way, distress can be seen on the odd building in any city in both Europe and North America, Figure 3.26 and 3.27.

On standard storey height walls, this can take the similar form of a vertical/near-vertical or an inclined crack. This is common when the distance between vertically aligned movement joints is large. Another form of distress seen is where horizontally aligned movement joints appear to have closed causing either visible cracking distress or, indeed, signs of a visible repair. In the UK and Ireland, this form of distress is not uncommon.

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<sup>10</sup> John Morton – UK



Figure 3.26 - Movement failure of façade to framed building in USA.

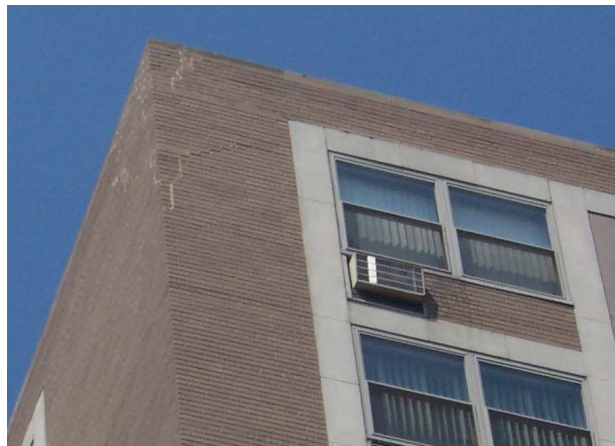


Figure 3.27 - Movement failure of parapets in a more modern building in USA

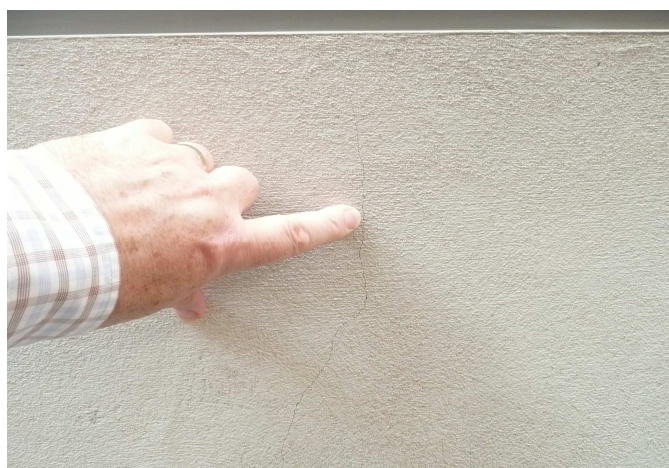


Figure 3.28- Micro cracking -in render on blockwork sub-panels within a clay brick enclosure wall. This cracking will only be detectable by professionals and, in terms of movement design, such an outcome can be considered a success



Figure 3.29 - Insufficient provision for movement has been made resulting in the joint closing allowing a build-up of stress in the brickwork façade. This will have been caused either by a poor design detail or poor workmanship

The route to avoid distress and to achieve successful cladding on framed buildings can be summarised as follows:

- 1) Acknowledge that there will be movement in the external masonry cladding and then form a plan to accommodate this movement successfully;
- 2) One way to achieve this is to place regular joints in the masonry by introducing horizontal and vertical joints at appropriate centres. In the design guidance available in any country/region, there is normally a recommended maximum horizontal distance between vertical joints so that the maximum length of any panel is restricted (such lengths can usually be exceeded somewhat when bed-joint reinforcement is used);
- 3) Depending on the type of frame and the detail of the panel support, horizontal joints may be required at regular intervals;
- 4) It is important that, in both the vertical and horizontal joints, the width of the joint is appropriate to the panel height/length – i.e. the joints don't 'close' because they are too narrow or otherwise become ineffective;
- 5) It is important too that the joint detail allows movement to take place – i.e. highly compressible fillers are specified and installed;
- 6) The designer may find it surprising when considering design aspects, that over the years, the writer has found that workmanship can be responsible for the joints becoming ineffective. Inclusion of mortar in horizontal joints can be quite common when forensic examination of masonry is done to establish the reason for cracking prior to repair; similarly, it is not uncommon to find that incompressible filler material has been used in the joints: this can be seen more than might be imagined or expected – often where correct joint details are given in the drawings;
- 7) A current trend which has some potential to cause future problems is the use of shelf angles at every 2nd or 3rd floor. In itself this should be perfectly feasible with adequately sized horizontal joint widths; some experience gleaned demonstrates that some cladding when constructed has unrealistically small joint widths when shelf angles are positioned at 10 - 12m vertical height – particularly with shrinking frames;



- 8) Additional simple ‘rules’ exist which are born more out of experience than theory; They are ‘almost’ universal although depending on the region, the odd parameter may vary – such as the maximum length of masonry between vertically aligned movement joints; These rules include:
- introduce a vertical joint at positions where the wall height changes significantly;
  - introduce a vertical joint at positions where the wall thickness changes significantly;
  - take appropriate care when mixing two different materials such as (expansive) fired clay units with (shrinking) concrete or calcium silicate units in solid walls;
  - in a solid wall, take appropriate care when mixing two different types of the same material – such as (expansive) fired clay units – both of which may have different moisture movement characteristics;
  - take appropriate care when mixing two different materials such as (expansive) fired clay units with (shrinking) concrete or calcium silicate units in cavity walling; It is possible when using solid metal ties to find the wall develops a ‘bend’ when an inner concrete block leaf is joined to an outer clay unit leaf using ties which cannot flex or accommodate moment in the vertical direction;
  - with units which have a propensity to shrink be careful with the sub panels which are formed under windows that their length does not become excessive compared to their height;
  - take appropriate care when the introduction of a movement joint might introduce structural weakness – such as at the junction between a panel and a pier in a free standing wall;
  - any ‘fixings’ placed across a movement joint must be capable of accepting the expected movement within the joint width;
- 9) Long term performance of the masonry can reasonably be expected when simple procedures such as those above are followed – modified as necessary to suit the location of the building.

Other major approaches to designing cladding on tall buildings exist which are quite different from some of the suggestions given above. One approach – off-the-frame-cladding – has been used selectively for decades and successful buildings have been constructed in Switzerland and USA. Some 30 years or so ago a few buildings were constructed in UK. This form of design approach has not caught on in the imagination of designers despite the additional freedom that it offers: it is, however, an alternative method. A greatly undervalued benefit is the almost zero propensity to workmanship ‘error’ due to the basic simplicity of the approach.

Finally, an aspect worth mentioning is the topic of education. Where, one wonders, does a young designer learn of the concept of ‘making masonry work’ in buildings. In engineering schools in the UK and Ireland, engineers may be taught the calculation methods to satisfy design codes. Having said this, most schools spend a majority of the time teaching Steel and Concrete structural design; there is usually far less content on structural Masonry and Timber design. In terms of being introduced to designing and detailing masonry cladding, one suspects that it is down to be learnt during the first job to be tackled *in anger* in practice; it is usually learnt from colleagues in the same office. The quality of learning is therefore really down to the quality of existing knowledge within the practice which suggests in part a hit-or-miss approach. In a particular office or region, for example, if the design approach with masonry is not well understood, the

poor level of design knowledge becomes self-fulfilling in the next generation of designers. In some areas/countries, there is a role for the educational community to pick this up – were this possible. In other areas/countries it is reasonable to expect that it is being adequately or well provided by the various schools.

### 3.5- BRAZILIAN STANDARDS FOR PREVENTION OF CRACKING IN MASONRY <sup>11,12,13</sup>

#### 3.5.1- Introduction

Good structural performance is related to the prevention of reaching both Ultimate (ULS) and Service Limit States (SLS). The SLS are usually related to preventing the following:

- a) damage that jeopardizes construction aesthetics, durability, sound and heat insulation or produces water ingress;
- b) excessive displacements that affect the structural behaviour or the aesthetics;
- c) excessive or uncomfortable vibrations.

Usually, national or regional Standards establish criteria that should be followed in order to avoid, or at least minimize, the aforementioned situations. Those criteria are in place to ensure that a minimum standard of working methods for the constructions is achieved. Regarding masonry buildings, detachment and cracking are the most likely causes of failure, which are directly related to SLS and briefly described in (a) and (b) below. Independent of their classification [3.38] regarding type of element and material, position and cracking pattern, cracks should not be discernible and jeopardize the building performance, despite the fact that in many cases it is inevitable, due to the intrinsic brittle behaviour of masonry. As cracking is associated with masonry deformation, the current standards normally establish parameters relating to:

- a) mortar deformability;
- b) limit of dimensions and number of chases in structural elements;
- c) movement joints;
- d) deformation limits of both masonry walls and bearing components.

The following sections show some requirements found in the Brazilian Standards for structural masonry: ABNT NBR 15961-1 [3.39] and ABNT 15812-1 [3.40] for concrete block and clay block masonry, respectively.

#### 3.5.2- Masonry deformability

Due to lack of experimental data, the following safe parameters can be adopted (Table 3.10):

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<sup>11</sup> Márcio Corrêa - Brazil

<sup>12</sup> Ercio Thomaz - Brazil

<sup>13</sup> Humberto Roman – Brazil

Table 3.10 - Properties of masonry deformation

Property	Value	
	Concrete	Clay
Modulus of elasticity	$800 f_{pk} \leq 16 \text{ GPa} (*1)$	$600 f_{pk} \leq 12 \text{ GPa}$
Poisson coefficient	0,20	0,15
Coefficient of thermal expansion	$9,0 \times 10^{-6} \text{ }^{\circ}\text{C}^{-1}$	$6,0 \times 10^{-6} \text{ }^{\circ}\text{C}^{-1}$
Coefficient of moisture expansion	-	$300 \times 10^{-6} \text{ mm/mm}$
Shrinkage coefficient	$500 \times 10^{-6} \text{ mm/mm} (*2)$	-

(\*1)  $f_{pk}$  is the 2 blocks prism characteristic compressive strength

(\*2) shall be increased to  $600 \times 10^{-3} \text{ mm/mm}$  when blocks are produced with natural curing

To verify the Serviceability limit state the following is recommended:

- reduce by 40 % the deformation modulus in order to approximately consider the masonry cracking effect;
- double the estimated elastic deformation associated to loading to obtain the approximated creep (dead load).

### 3.5.3- Limits for dimensions and cuts in masonry

#### a) Effective thickness

The standard code does not allow effective thickness smaller than 140 mm for two or more story buildings, and never less than 115 mm.

#### b) Slenderness ratio

The slenderness ratio, (height / effective thickness) must follow the limits described in Table 3.11.

Table 3.11 - Maximum values of slenderness ratio for structural walls and columns

Unreinforced elements	24
Reinforced elements	30

Note: For masonry partition walls the maximum slenderness ratio is 30.

#### c) Wall chases and recesses

Horizontal individual chases longer than 400 mm or more than one chase in a same wall adding up to more than 1/6 of the wall's total horizontal length are not allowed in walls with a structural function; vertical chases higher than 600 mm in walls define a joint between two distinct walls; water pipes shall not pass inside structural walls, except when the installation and maintenance do not require chases.



### 3.5.4- Control and movement joints

#### a) Movement joints

Movement joints should be placed at least every 24 m in a façade's length. This limit may change if a more precise evaluation of the thermal and shrinkage effects over the structure is carried out. The presence of bond beams or reinforcement in the bed joints and a more precise evaluation of the temperature and shrinkage variation effects can allow changes on this limit.

#### b) Control joints

The need for vertical control joints should be evaluated to avoid cracks due to temperature changes, shrinkage, sudden changes in loading and thickness or wall height changes; for single plane masonry walls, vertical control joints not exceeding the limits of Tables 3.12 and 3.13, for concrete and clay blocks respectively, shall be provided if and when there is no accurate assessment of the specific conditions.

Table 3.12 - Maximum distance between vertical control joints – concrete block masonry

Wall Position	Limit (m)	
	Unreinforced masonry	Masonry with reinforcement rate higher or equal to 0.04% height versus thickness
External	7	9
Internal	12	15

NOTE 1 The above limits shall be reduced by 15% if there is an opening in the wall  
 NOTE 2 If the blocks are cured in the natural environment the limits shall be reduced by 20% if there is no opening in the wall  
 NOTE 3 If the blocks are cured in the natural environment the limits shall be reduced by 30% if there is an opening in the wall

Table 3.13 - Maximum distance between vertical control joints – clay block masonry

Wall Position	Limit (m)	
	Wall thickness $\geq 140\text{mm}$	Wall thickness = 115mm
External	10	8
Internal	12	10

NOTE 1 The minimum control joint thickness shall be of 0.13 % of the distance between joints  
 NOTE 2 The above limits shall be reduced by 15% if there is an opening in the wall  
 NOTE 3 The above limits may be changed if technically justified horizontal reinforcements are placed into the bed joints

### 3.5.5- Deflection limits

The final deflections of any element, including effects of cracking, temperature, shrinkage and creep are related to its span L. They shall not be higher than L/150 or 20 mm for cantilever and L/300 or 10 mm for all the other cases (Note 1: Those values

should be revised in a future issue of the Brazilian Standards, since the consensus reached is that they are too large). These displacements may be partially compensated by in-built deformations not higher than  $L/400$  (Note2: The efficiency of in-built deformations is questionable).

Structural elements such as beams, slabs, etc., bearing masonry walls shall not have displacements greater than  $L/500$ , 10 mm or  $\theta = 0.0017$  rad after being loaded by the walls.

### 3.5.6- Observations regarding reinforced concrete structures

Reinforced concrete structures are currently being used in approximately 68 % of Brazilian residential buildings [3.41]. The standard code for structural concrete design, ABNT NBR 6118 [3.42], establishes displacement limits according to their effects, as shown in Table 3.14.

Table 3.14- Deflection limits – ABNT NBR 6118 [3.42]

Type of effect	Example	Displacement to consider	Limit
Effects on non-loadbearing elements	Masonry, window frames and rendering	After wall Construction	$L/500$ (*1), 10 mm or $\theta = 0,0017$ rad (*2)
	Light panels and Telescopic window frames	After panel installation	$L/250$ (*1) or 25 mm
	Lateral building movement	Due to frequent combination of wind actions ( $\Psi_1=0,30$ )	$H/1700$ or $H_i/850$ (*3) between floors (*4)
	Thermal vertical movements	Due to temperature differences	$L/400$ (*5) or 15 mm

(\*1) – Span  $L$  measured in the plane of the wall; (\*2) – Rotation of bearing load elements; (\*3) –  $H$  is the total building height and  $H_i$  is the level difference between two closed pavements; (\*4) – This limit applies to lateral displacement between two neighbouring floors due to horizontal forces. The displacements due to axial deformation of columns shall not be included; (\*5) – The value  $L$  refers to the distance between the external column and the first internal column.

### 3.5.7- IPT Recommendations

IPT (Technological Research Institute of São Paulo/ Brazil) proposed a document to be discussed within the building sector. This document recommends displacement limits for structural elements and foundations that support clay block partition walls, highlighting that cracking and creep effects should be taken into account. They are summarized in Table 3.15.

Special building details should be provided to separate or reinforce the interfaces between the structural element and the partition wall, when the recommended limits are exceeded.

Table 3.15 - Displacement limits - IPT [3.43]

Cause	Displacement to consider	Limit
Foundation settlements	Total	$L/400(*1)$
Deflection of slabs and beams	Total After wall construction	$L/400 (*2)$ $L/600$
Beam and slab torsion	Rotation of the support element on the wall plane	$\theta = 0,0017 \text{ rad}$

(\*1) – L is the distance between foundation elements or the wall length when the foundation is continuous; (\*2) – L is the structural element span

## References

- [3.1] SILVA, J. (2002) - “Alvenarias Não Estruturais. Patologias e Estratégias de Reabilitação” (in Portuguese), Seminário - Paredes de Alvenaria: Situação Actual e Novas Tecnologias, FEUP, Porto, pp.187- 206.
- [3.2] VICENTE, R.; SILVA, J (2007) - “Defects of Non-Loadbearing Masonry Walls Due to Partial Basal Supports”, *Journal of Construction and Building Materials*, 21, pp. 1977-1990.
- [3.3] Vicente, R.; Rodrigues, H.; Varum, H.; Costa, A.; Silva, J (2012) – “Performance of Masonry Enclosure Walls: Lessons Learnt from Recent Earthquakes”, *Earthquake Engineering and Engineering Vibration*, 10 (4).
- [3.4] CEN (2005) - “Eurocode 6 - Design of Masonry Structures - Part 1-1: General Rules for Reinforced and Unreinforced Masonry Structures (EN 1996-1-1)”, CEN, Brussels, Belgium.
- [3.5] MSJC (2005) - “Building Code Requirements and Specification for Masonry Structures” (ACI 530/ASCE 5/TMS 402 and ACI 530.1/ASCE 6/TMS 602), USA.
- [3.6] BSI (2005) - "Code of Practice for the Use of Masonry" (BS 5628- Part1, 2 and 3), BSI, London, UK.
- [3.7] CEN (2004) - “Eurocode 2: Design of Concrete Structures. Part 1-1: General Rules and Rules for Buildings (EN 1992-1-1), CEN, Brussels, Belgium.
- [3.8] BAEL (2000) - “Règles Techniques de Conception et de Calcul des Ouvrages et Constructions en Béton Armé Suivant la Méthode des États Limites“ (DTU P 18-702) (in French), Règles BAEL 91 Révisées 99, Fascicule 62, titre 1<sup>er</sup> du CCTG - Travaux Section 1 : Béton Armé, CSTB (CD-Reef V3 - Edition 156), France.
- [3.9] CEN (2006) - “Eurocode 6: Design of Masonry Structures - Part 2: Design Consideration, Selection of Materials and Execution of Masonry (EN 1996-2)”, CEN, Brussels, Belgium.
- [3.10] BSI (2005) - “Code of Practice for the Use of Masonry – Part1: Structural Use of Unreinforced Masonry (BS 5628-1)”, BSI, London, UK.
- [3.11] BSI (2005) - “Code of Practice for the Use of Masonry – Part2: Structural Use of Reinforced and Prestressed Masonry (BS 5628-3)”, BSI, London, UK.
- [3.12] BSI (2005) - "Code of Practice for the Use of Masonry – Part3: Materials and Components, Design and Workmanship (BS 5628-2)”, BSI, London, UK.
- [3.13] PFEFFERMANN, O. (1969) - "Fissuration des Cloisons en Maçonnerie Due une Déformation Excessive du Support - Part 1 (in French)", CSTC, Revue, Bruxelles.
- [3.14] PFEFFERMANN, O.; PATIGNY, J. (1975). "Fissuration des Cloisons en Maçonnerie Due a une Déformation Excessive du Support - Parte 2 (in French)", CSTC, Revue, Bruxelles.
- [3.15] DIAS, J. (1994) - “Fissuração de Paredes de Alvenaria Devido ao Movimento dos Elementos de Suporte (in Portuguese)”, 2.º Encontro sobre Conservação e Reabilitação de Edifícios, Lisboa, Portugal, p.785.

- [3.16] PFEFFERMANN, O. (1968)- “Les Fissures dans les Constructions: Conséquence de Phénomènes Physiques Naturels (in French)“, Annales de L'Institut Technique du Bâtiment et des Travaux Publics, Bruxelles.
- [3.17] PEREIRA, M. (2005)- “Anomalias em Paredes de Alvenaria sem Função Estrutural (in Portuguese)”, Msc Dissertation, University of Minho. Portugal.
- [3.18] PAGE, A. (2001)- “The Serviceability Design of Low-Rise Masonry Structures”. Prog. Struct. Eng Mater., 3, pp.257-267.
- [3.19] HOLANDA, G.; RAMALHO, M.; CORRÊA, M. (2007)- “Experimental and Numerical Analysis of Masonry Walls with Openings Subjected to Differential Foundation Settlements”, 10th North American Masonry Conference, St.Louis, Missouri, pp.26-27.
- [3.20] BERANEK, W. (1987)- “The Prediction of Damage to Masonry Buildings Caused by Subsoil Settlements”, Heron, 32(4), pp.55-93.
- [3.21] MEYERHOF, G. (1953)- “Some Recent Foundation Research and its Application to Design”, The Structural Engineer, 31, pp.151-167.
- [3.22] BRICK INDUSTRY ASSOCIATION (1991) - “Movement Volume Changes and Effect of Movement”, Technical Notes 18 Revised, Reston, Virginia.
- [3.23] THE MASONRY SOCIETY AND COUNCIL FOR MASONRY RESEARCH (2005)- “Masonry Designers' Guide”, Boulder, Colorado.
- [3.24] DRYSDALE, R., AND HAMID, A. (2008)- “Masonry Structures Behaviour and Design”, Boulder, Colorado.
- [3.25] SAHLIN, S. (1971)- ” Structural Masonry”, Prentice-Hall, Inc.
- [3.26] BEALL, C. (1987)- “Masonry Design and Detailing”, McGraw-Hill, New York.
- [3.27] BSI (2005) – “Code of Practice for the Use of Masonry – Part 3: Materials and Components, Design and Workmanship (BS 5628-3)”, BSI, London, UK.
- [3.28] KLINGNER, R. (2009)- “Masonry Structural Design”, McGraw Hill.
- [3.29] PANARESE, W.; KOSMATKA, S.; JR., F (1991) - “Concrete Masonry Handbook”, Portland Cement Association, Skokie, Illinois.
- [3.30] MSJC (2008)- “Specification for Masonry Structures (ACI 530.1/ASCE 6/TMS 602)”, USA.
- [3.31] PFEFFERMANN, O. (1975) - “Fissuration des Cloisons en Maçonnerie Due à une Déformation Excessive du Support - Part 1” (in French), CSTC, Revue, Bruxelles.
- [3.32] PFEFFERMANN, O.; PATIGNY, J. (1975) - “Fissuration des Cloisons en Maçonnerie Due à une Déformation Excessive du Support – Parte 2” (in French), CSTC, Revue, Bruxelles.
- [3.33] PFEFFERMANN, O. (1968) – “Les Fissures dans les Constructions: Conséquence de Phénomènes Physiques Naturels“(in French), Annales de l’institut Technique du Bâtiment et des Travaux Publics, Paris.
- [3.34] PFEFFERMANN, O. (1980) – “Déformations Admissibles dans les Bâtiments“(in French), CSTC – N.I.T. 132, Bruxelles, Belgium.

- [3.35] O. PFEFFERMANN (1967) – “Fissuration des Maçonneries” (in French), CSTC, NIT65, Bruxelles, Belgium.
- [3.36] CEN (2012) - “Eurocode 6: Design of Masonry Structures - Part 2: Selection of Materials and Execution of Masonry (Belgian Standard NBN EN 1996-2)”, Bruxelles, Belgium.
- [3.37] SILVA, R. et al. (2009) – “Manual da Alvenaria de Tijolo - 2ª edição” (in portuguese), APICER/CTCV (eds), pp. 163-208.
- [3.38] GRIMM, C. (1997) – “Masonry Cracks: Cause, Prevention and Repair”, Masonry International, 10 (3).
- [3.39] ABNT (2011) - “NBR 15961-1 (Ed. 1): Structural Masonry - Concrete Blocks. Part 1: Design”, Rio de Janeiro, Brazil.
- [3.40] ABNT (2010) - “NBR 15812-1 (Ed. 1): Structural Masonry - Clay Blocks. Part 1: Design”, Rio de Janeiro, Brazil.
- [3.41] CONSTRUCTION COMMUNITY (2008) - “Technological Level Poll. São Paulo, 2008”, [http://www.abcp.org.br/downloads/arquivos\\_pdf/Comunidade\\_da\\_Construcao\\_Pesquisa\\_Nivel\\_Tecnologico\\_2008.pdf](http://www.abcp.org.br/downloads/arquivos_pdf/Comunidade_da_Construcao_Pesquisa_Nivel_Tecnologico_2008.pdf) (Accessed on: 30/01/2012).
- [3.42] ABNT (2003) - “NBR 6118 (Ed. 1). Design of Structural Concrete - Procedure”, Rio de Janeiro, Brazil.
- [3.43] IPT (2008) - “Clay Block Partition Walls - Good Practice Code”, Technological Research Institute of São Paulo, Brazil.

## 4- Repair Strategies for Cracking in Masonry Walls

### 4.1- PROBLEM ASSESSMENT AND STRATEGIES <sup>14</sup>

The cracking of masonry walls results when quality standards or serviceability requirements are unsatisfactorily complied with. The selection of repair strategies is conditioned by the type of defect, its causes and the features that are intended to be improved (stability, structural and fire safety, thermal and acoustic comfort, energy efficiency, water-tightness, or others).

There are two main strategies to repair masonry walls; they can be used alternatively or combined:

- repair, locally, any single defect with a specific technique (example - local crack sealing or tying, controlled demolition and reconstruction, reinforcement of corner angles - high stress areas, etc.);
- global improvement of masonry performance, with an extended and multi-purpose repairing technique (example - global tying and bed joint reinforcement, general grouting or reinforced coating layer, external insulation, etc.).

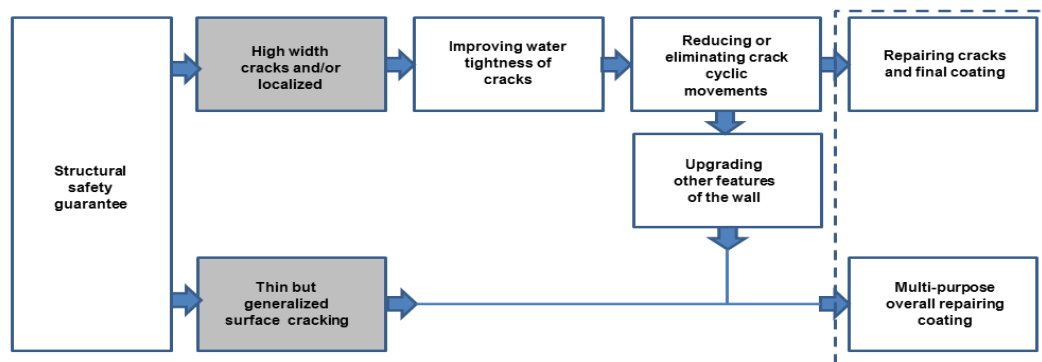


Figure 4.1 - Flowchart for typical procedures of cracking repair

Choosing one or both of these strategies depends on several factors:

- the number and spatial distribution of the defects in the wall;
- the diversity of defects observed;
- the existence of a multi-purpose repairing technique, for the multiplicity of defects, compatible with the construction of the masonry, its coating and finishing solution.

The most frequent groups of defects are cracking, water penetration, ageing and local degradation. The structural stability is only affected in a few cases of cracking but, when it happens, it is the most important factor concerning the repairing strategy and the repairing techniques [4.1].

For all the defects not having structural consequences, there are several approaches that can be taken together to obtain a more durable versus economic solution: suppression of the defect, replacement of the affected materials, concealing or hiding of the defects,

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protection against aggressive agents, elimination of causes and upgrading of specific features.

Soft techniques, such as repairing coatings and finishing - like thin reinforced mortar layers (eventually, over external insulation boards / ETICS), elastic and water-tight paints coats – are used when the main defects affect all of the wall but only its external surface (cracking, humidity, ageing, etc.). They are often used as supplementary corrective action after the local repairing of cracks using wall ties, embedded steel bars, anchors, etc.

Considering structural walls, the selected repairing techniques must re-establish the continuity that allows the correct (and, if possible, the original) transmission of compressive, tensile, shear and flexural forces, without exceeding masonry strength and avoiding local stress concentration under the expected loads and imposed deformation, although an upgrading of strength cannot be neglected if the actions responsible for the previous failure are not reduced and will remain effective [4.2]. In these situations, the repairing strategy should involve other construction components related to the masonry walls, such of slabs, beams and foundations.

For non-structural walls, if their stability is guaranteed, cracking repair should achieve the repair of other wall features – such as aesthetics.

The correct selection of repairing techniques for cracking of masonry walls should be supported by a correct diagnosis, an extended identification and characterisation of the cracks (their thickness, length, pattern, age, etc.) and also should be based on their expected development. Many authors have established a check list for assessing masonry cracking in order to assure an accurate diagnosis and repairing strategy [4.3-4.6].

A main cause of masonry cracking is thermal movement and the stresses it induces. This behaviour will be both cyclical and seasonal. Whatever the cause, cracks constitute involuntary expansion joints [4.7]. In fact, most masonry cracks change over time, for a variety of reasons:

- the crack reflects natural movements of the wall caused by temperature and humidity variation;
- the cause is cyclic or acts randomly over time;
- the cause is permanent, persistent or increases over time;
- the edges of the crack are progressively destroyed by erosion or other physical or chemical actions;
- the crack is progressively filled with particles, dust, salts, detritus etc.

The repair techniques for this situation are often aligned with one of these principles or strategies:

- if there is a high level of internal thermal or moisture induced stress, the formal creation of an expansion joint, instead of cracking repair, should be considered;
- if the transmission of forces and movements between crack sides is relevant, fixing anchors or embedded steels bars should cross the crack;
- if the expected movements are reduced and become innocuous, but can affect the final coating, a non-bonded strip repair should be used.

A clear situation for cracking repair occurs when the water-tightness of the wall should be restored. It is often necessary to enlarge the crack in order to get the ideal shape to install a water barrier, like a flexible sealant strip (mastic), before repairing the crack. It is essential to remember that the accuracy needed for the initial estimation of crack width is much lower than when it is required for monitoring its evolution. Firstly, a thorough visual inspection can distinguish between thin cracks (under 0,5 mm) and medium (up to 2 mm) or large cracks, but their evolution cannot, in general, be observed without precision equipment, able to detect and record 0,01 mm movements.

Table 4.1 - Monitoring techniques for masonry cracks

Name	Description	Specific notes
Gypsum mark	The gypsum mark crosses the cracks. If the mark is unbroken, the crack did not move. If the crack has moved, the gypsum mark will have cracked. Sometimes it is possible to estimate the extension and direction of the movement (low precision).	Recommended shape 5x50x100mm. Pure gypsum mixed with water (70%). For outside walls, lime and/or portland cement are also used.
Glass mark	The glass mark is rigidly bonded on both sides of the crack. The smallest movements of the crack will break the glass mark.	Extremely fragile. It is very difficult to estimate the extension and direction of the movements
Paper mark	The paper mark is bonded to both sides of the crack and breaks or gets wrinkled.	Only for large movements. The results are quite influenced by humidity conditions.
Graduated ruler (with or without amplification lens)	The operator places the crack test ruler on the crack and selects the width of the line that corresponds to the crack opening.	Used only to estimate the initial width of the cracks. Precision less than 0,1 mm.
Optical micrometric equipment	This device measures crack openings with a hundredth of a millimetre precision.	The equipment includes an internal graduated ruler or scale and self-illuminated.
Paper gauges	Two plastic or paper graduated components can slide one over the other and clearly show the extent and direction of movements.	Very easy to use. Medium precision. Affordable solution.
Electrical gauge	Special strain gauges with different kinds of filaments, eventually breakable. Any small movement is detected and can be automatically recorded.	As they are flexible, they are inefficient to detect width decreasing of cracks.
Potentiometric sensors	Several high precision methods use this kind of sensor. Reference spots are placed near the cracks and the distance between them is measured with high precision (0,002 mm).	The equipment can be hand used periodically (hand held versions) or permanently installed on the wall.
Digital calliper with measurement base of 3 points (stainless steel)	The change in the distance between the 3 screws (measurement base) gives the information to estimate the extent and direction of crack movements with good precision (0,01mm)	Useful for large or complex movement monitoring.

Facing brick masonry walls are quite unique, making their defects even more complex to treat. Therefore choice of appropriate repair techniques must preserve the aesthetics and colour, leaving little evidence of the repair.

The majority of defects in masonry walls can be repaired with standard techniques that are quite efficient if they are supported by a correct diagnosis and clear strategy.

#### 4.2- BRAZILIAN CRACKING REPAIR TECHNIQUES<sup>15,16,17</sup>

##### 4.2.1- Introduction

Masonry is a building construction system frequently used in Brazil, competing with other ones such as reinforced and prestressed concrete, concrete walls, steel and timber frames. The use of masonry is seen throughout the country, demonstrated by the assorted types, shapes, materials, etc. The units are typically clay bricks or blocks made of fired clay, concrete, calcium silicate, autoclaved aerated concrete and cement/soil. Both reinforced and unreinforced masonry are used in buildings, usually with 140mm thick single leaf walls. Masonry is also used for non-loadbearing walls, predominantly made of fired clay or concrete blocks, competing with internal partition dry-walls, generally with better sound and heat insulation properties.

Presently the Brazilian population is around 200 million inhabitants, with an estimated housing deficit of 5.5 million. According to Corrêa [4.8], a study developed by the Construction Community (2008) over three years and monitoring 200 Brazilian building companies throughout the country, showed that the building sector (Civil construction represents 16% of the Gross Internal Product) uses mostly reinforced concrete structures (68%), while 20% represents the participation of structural masonry (Figure 4.2).

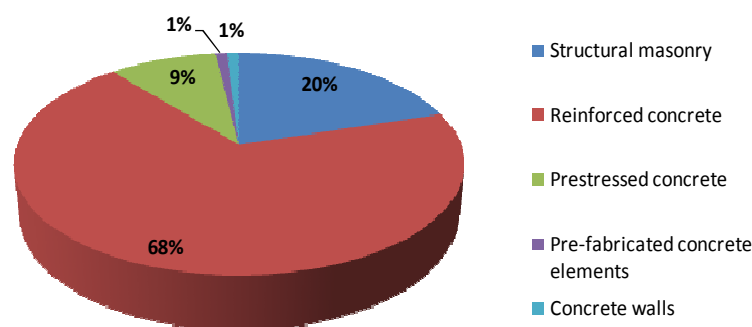


Figure 4.2 - Different structural systems used in Brazil

Roman & Antunes Silva [4.9] summarized the results of a wide range of research studies in Brazil that have pointed out failures during the whole building process. Figure 4.3 shows the main causes of defects in Brazilian constructions.

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<sup>16</sup> Ercio Thomaz - Brazil

<sup>17</sup> Humberto Roman – Brazil

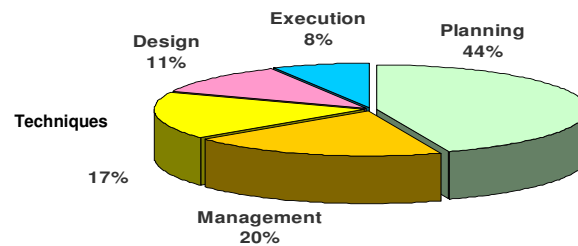


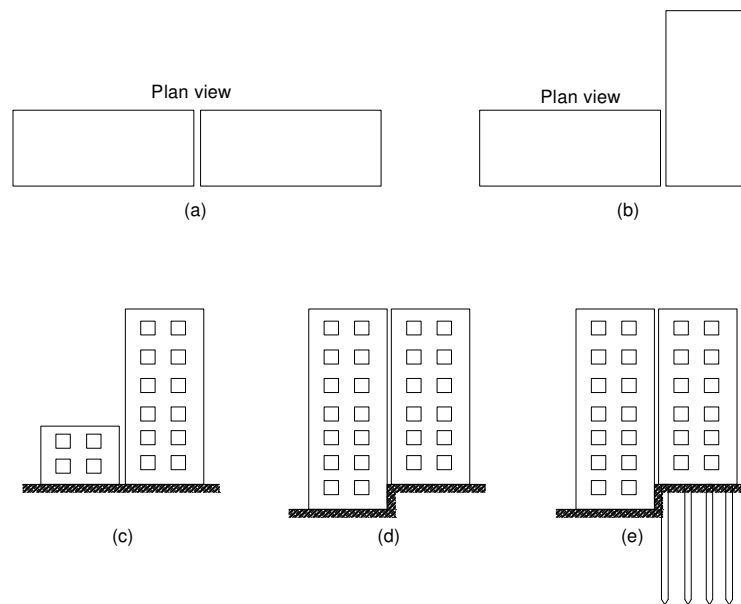
Figure 4.3 - Causes of defects in Brazilian construction industry [4.9]

#### 4.2.2- Prevention and repair

Different aspects of prevention and repair can be considered, since the problem is complex and various and simultaneous causes may be identified. The most common failures observed in Brazilian constructions are caused by: a) foundation differential settlements; b) interaction with other structural elements; c) poor design and inadequate execution procedures, and d) walls under roof slabs. The following tables summarize both prevention and repairing techniques, with some examples of common solutions applied in construction sites.

Table 4.2 - Prevention of damage and its repair related to foundation differential settlements

Prevention	Repair action
Evaluating soil parameters: increase the geotechnical investigations	Consolidation of soils and/or increase stiffness of foundation elements
Observe dimensions and shapes of the buildings: provide joints	Insertion of joints, allowing the building parts to perform as independent rigid bodies
Effect of: long dimensions in plan view, sudden change of shape, very different loads, changes in soil and foundation types, different construction periods of adjacent buildings (Figure 4.4).	Use of deep foundation when the water table fluctuates or when there are soft/deep soil layers.
Attention to existence of soft/deep soil layers, fluctuations of the water table and leaking of the drainage system that saturates the soil around shallow foundations	Fix the drainage system.



(a) One long dimension; (b) Change of geometry; (c) Different loading; (d) Building founded on different layer depths; (e) Different types of foundation

Figure 4.4 - Joints to prevent cracks caused by differential foundation settlements  
(adapted from [4.10])

Table 4.3 - Prevention of damage and its repair related to interaction between structural elements

Prevention	Repair action
Limit deformation of materials and beam/slab deflections to avoid high stresses in masonry (design).	Increase stiffness of supporting elements
Separate structural elements and masonry walls to discontinue stress flow.	Relief of stress and introduction of resilient materials between top of walls and base of beams and slabs
Provide special building details in the structural element/masonry interfaces (Figures 4.5 and 4.6).	Repair detachment of masonry walls from other interacting structures (Figure 4.8)
Include soft joints (Figure 4.7).	Repair or strengthen structural elements.

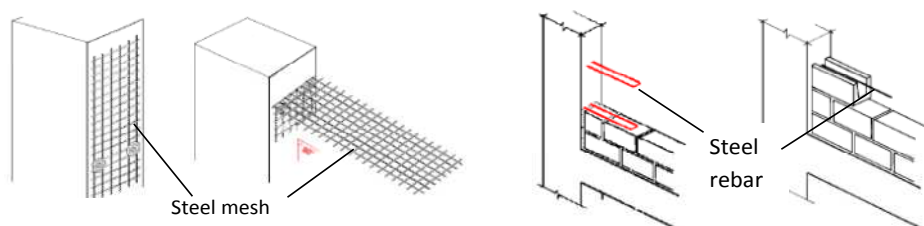


Figure 4.5 - Typical details of interfaces between RC columns and masonry walls [4.11]

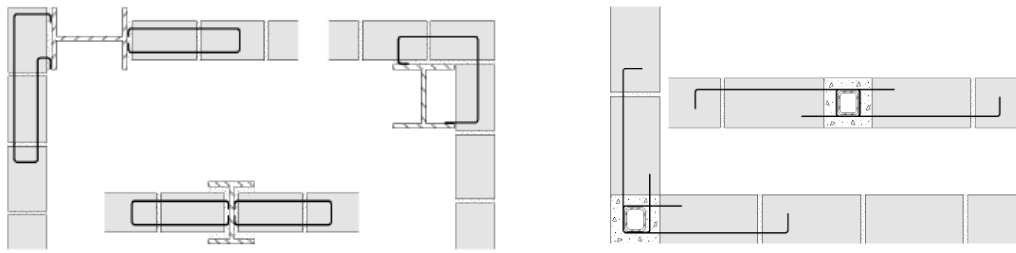


Figure 4.6 - Typical details of interfaces between steel columns and masonry walls [4.11]

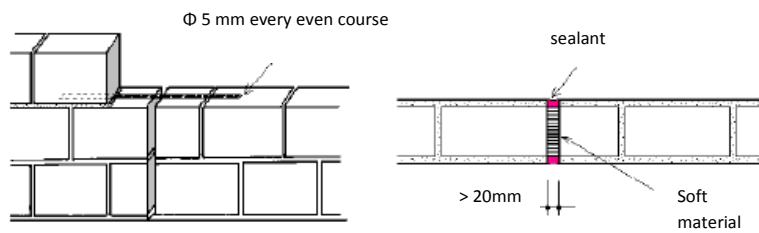


Figure 4.7 - Typical joint [4.11]

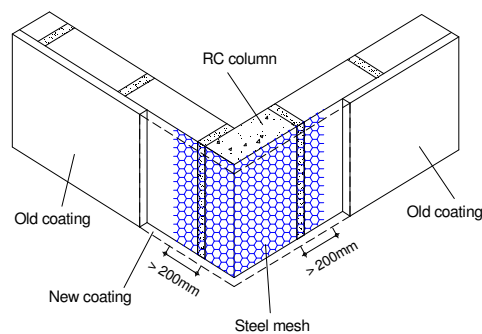


Figure 4.8 - Typical repair of detachments of RC column and masonry walls (adapted from [4.10])

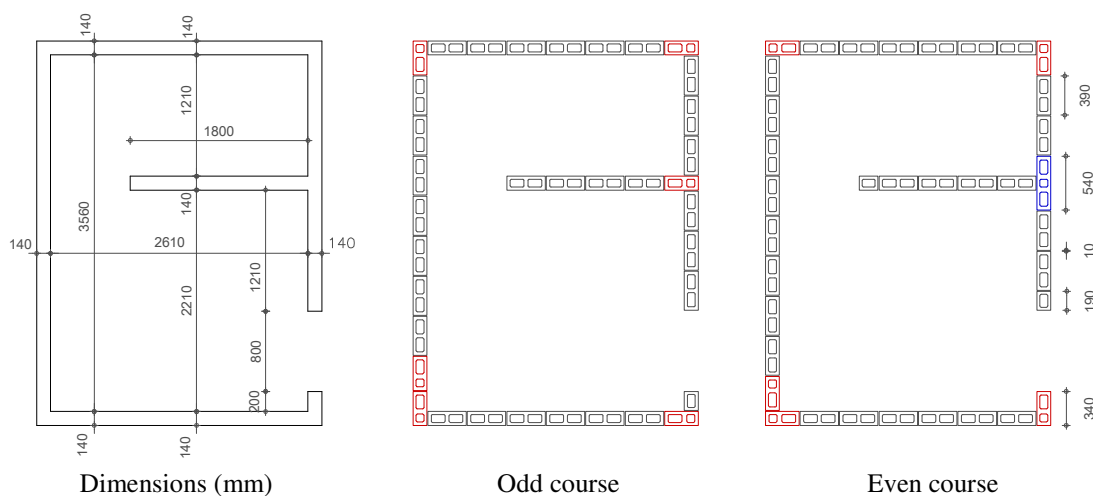


Figure 4.9 - Walls in running bond – plan view

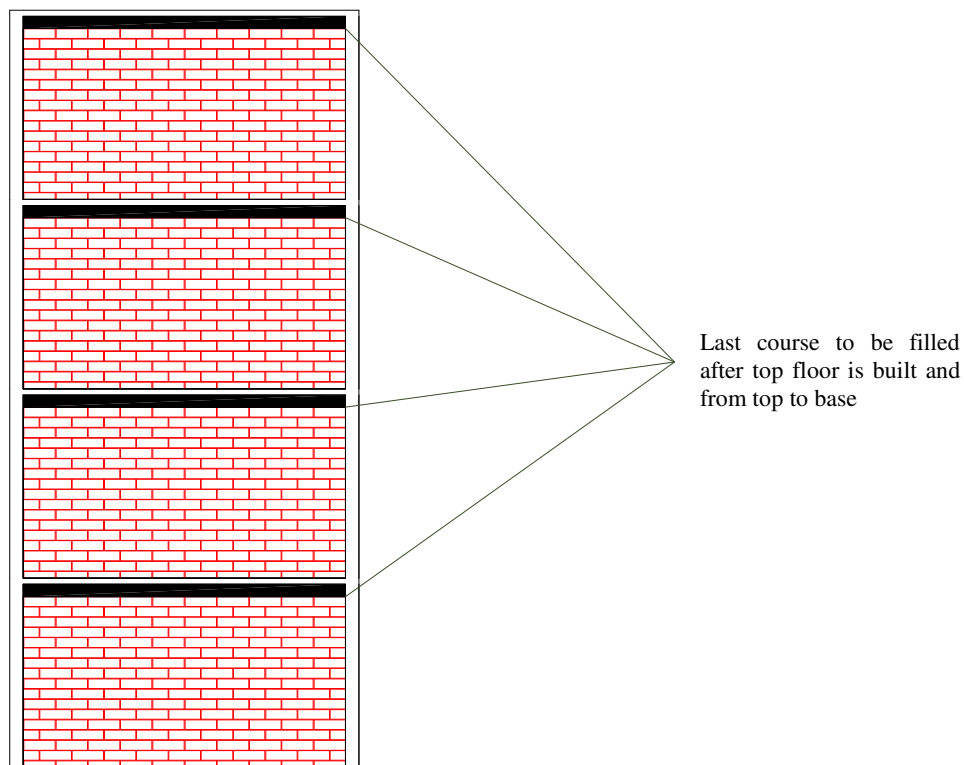


Figure 4.10 - Last courses of partition walls of a multi-storey building

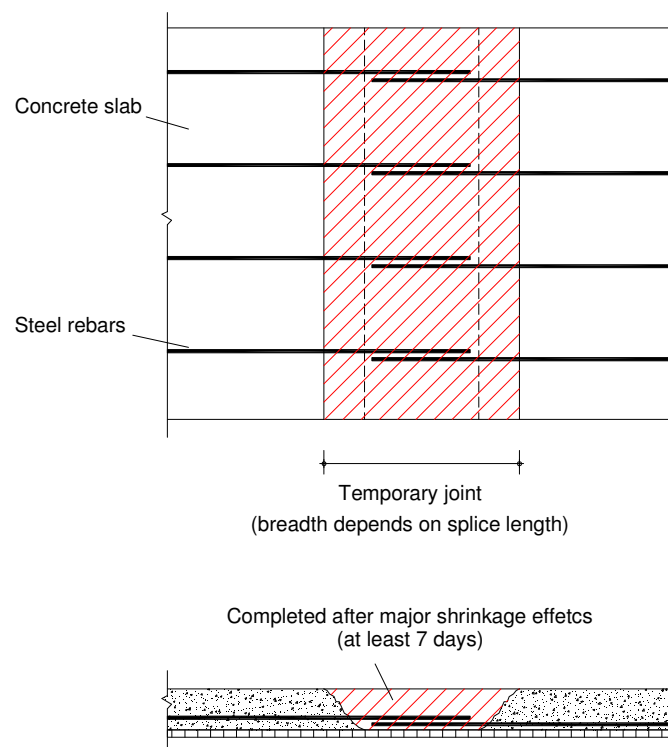


Figure 4.11 - Temporary joint to reduce shrinkage effects on concrete slabs (adapted from [4.10])



Table 4.4 - Prevention of damage and its repair related to poor design and inadequate execution procedures

Prevention	Repair action
Special care with production, transport and storage of materials. Special care with the characteristics of building materials.	Removal and replacement of damaged sections.
Precise specification of materials used, especially for the mortar, as the mortar joint is the component that has the greatest capacity to absorb deformations. Proper compatibility of the properties of the masonry components, with special attention to the use of units and mortar with the modulus of elasticity as low as possible to accommodate deformations.	Eventual demolition of part of the structural element to substitute materials with more suitable ones.
Observe the modular coordination, preferably using a running bond (Figure 4.9).	
Use control joints and movement joints.	Introduction of additional control joints.
Provide lintels and sills with sufficient lateral penetration and appropriate reinforcement. Special attention to the tallest buildings, in particular the behavior of elements near openings since they connect adjacent walls.	Repair cracks.
Special care with the transmission of loads between successive floors (Figure 4.10).	
Introduce appropriate construction details.	
Special attention with tall buildings, where sealing masonry often has an important role to protect against horizontal actions.	

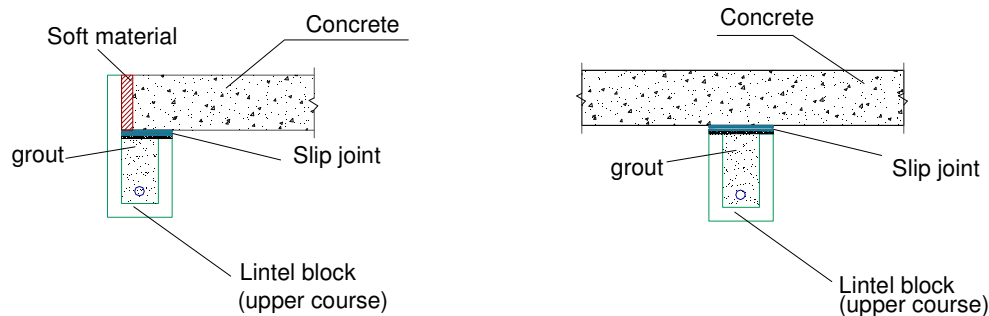


Figure 4.12 - Slip joints under roof slabs

Table 4.5 - Prevention of damage and its repair related to walls under roof slabs

Prevention	Repair action
<p>Serious problem caused by shrinkage and/or thermal movement of the roof slabs. This is a very serious problem in a tropical country such as Brazil.</p> <p>For the shrinkage of the slab, besides good curing, temporary joints can be inserted in the cast slab (later concreted) to reduce shrinkage or permanent joints can be placed in suitable locations (Figure 4.11).</p> <p>As for the thermal movement of the slabs, attention should be given to minimize the causes such as roof ventilation, shading of slab, painting the roof top with white or reflective paint, thermal insulation on the roof slab. Their effects can be minimized with the following measures: place expansion joints in the slab, cast sliding joints in the slab/wall interface (teflon, neoprene, double-layer of PVC lining or strips of melamine material, etc.) (Figure 4.12).</p> <p>Use reinforcement on the top layers of the walls (in support straps and/or reinforcement located in the horizontal joints)</p>	<p>Subsequent insertion of expansion joint in the slab, carefully cutting and filling the empty space with deformable material (Figure 4.13).</p> <p>Implement measures to mitigate the causes (Figure 4.14).</p> <p>Arrange additional horizontal reinforcement along the upper courses. Repair the cracks (Figure 4.15).</p>

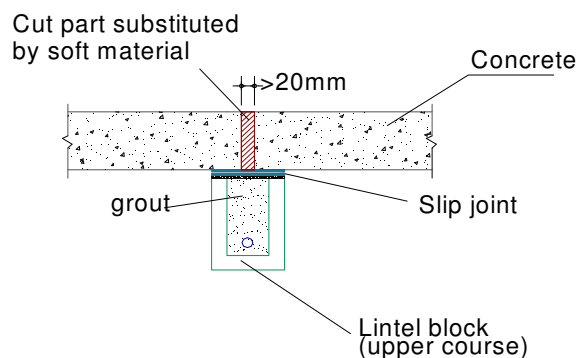


Figure 4.13 - Control joint

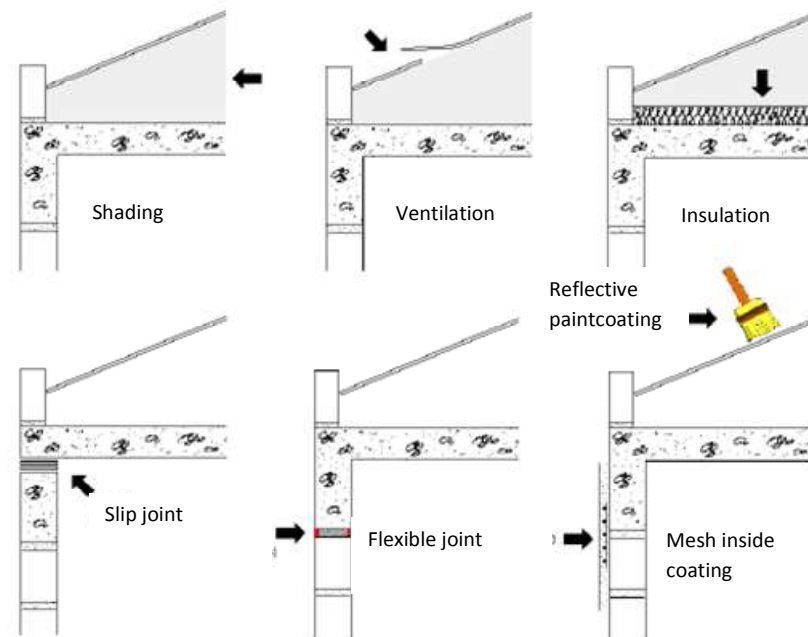


Figure 4.14 - Typical details for reducing the thermal effects on walls under roofs [4.11]

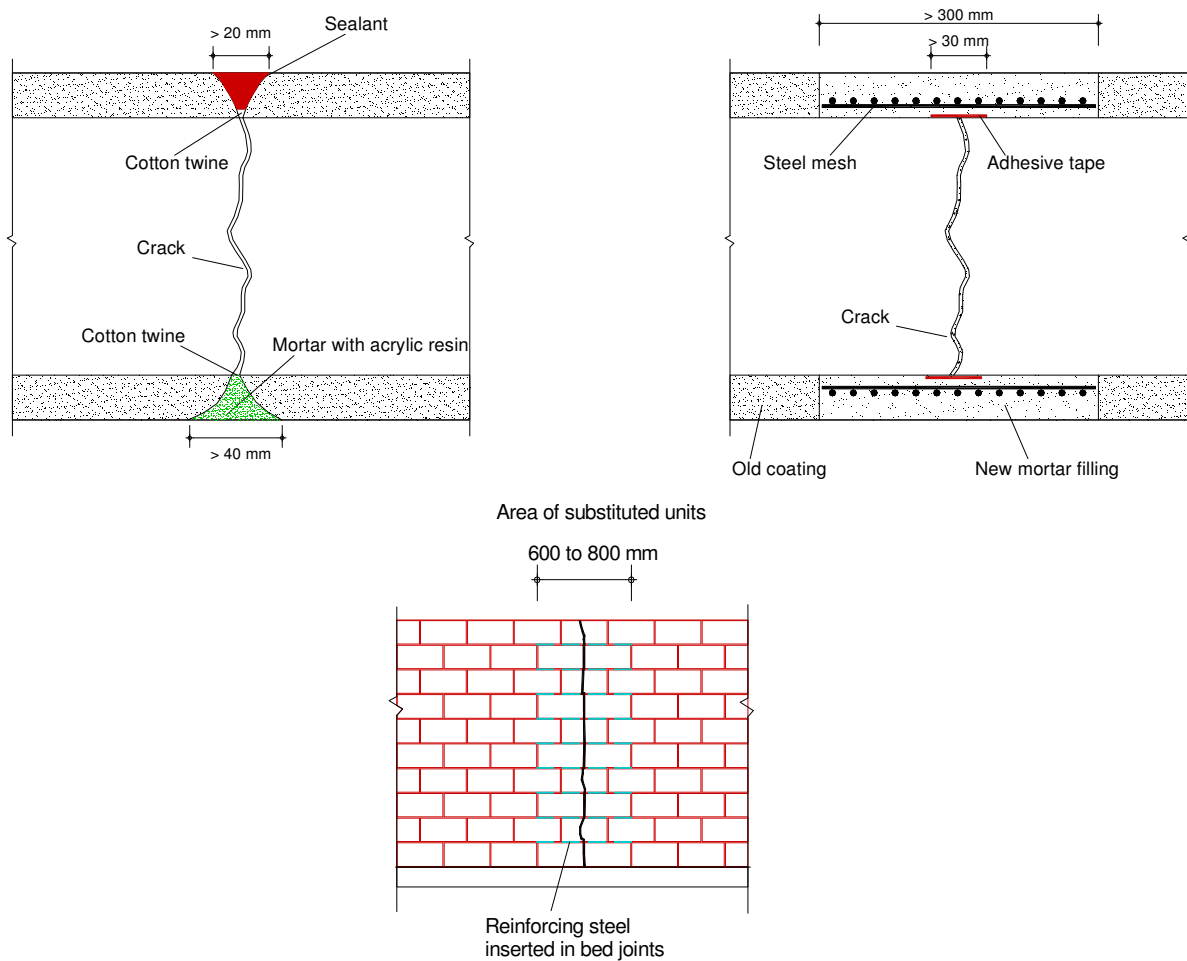


Figure 4.15 - Repairing techniques (adapted from [4.12])

### 4.2.3- Repair Methods

Deciding how the repair should be done depends on the cause of the problem and its implications. The problem may be aesthetic or it could point to a serious structural impairment. In any case, a well monitored inspection is required to stabilize the problem. Having confirmed the stabilization, according to Page [4.13], three repair methods can be chosen, summarized in Table 4.6. Note that these methods can be used together depending on the problem at hand.

Table 4.6 - Repair Methods

Method	Applicability	Observations
Raking and Re-pointing	Usually applied to cracks localized in the mortar joints. Effective for cosmetic reasons only. Requires a skilled bricklayer and correct specification of a compatible mortar.	Difficulty to completely fill the joint. Long term shrinkage of fresh mortar can cause cracking to re-appear at the same interface. The use of a polymer modified cement mortar can allow better penetration and bonding characteristics. Special care should be taken with facing brick masonry, in order to preserve aesthetics.
Re-construction of Selected Areas	Usually applied to restore structural integrity, including demolition and re-building of the damaged area. Also requires skilled tradesmen and the correct specification of materials.	Difficult to guarantee bond between new and old masonry unless a control joint is provided. The use of a new reinforced coating, when possible, is recommendable.
Resin injection	Usually applied to cracks in masonry units and to mortar joints. Requires specialized equipment and personnel.	Epoxy infection, despite the extra cost compared with conventional methods, provides mostly full penetration and effective bond. The resin must have compatible stiffness to the repaired material, to avoid local stress concentrations under future movements. Exposed resin must be resilient.

### 4.2.4- Case study

In some regions of Brazil, especially in the Northeast, some residential buildings are built without frames. They are in general 4 storeys high and similar to structural masonry, but with horizontally cored hollow blocks to both the walls and the foundations. This has caused a very serious problem. Up to now, eleven of these buildings have collapsed and more than 200 have been condemned (Figure 4.16 shows two of these buildings).



Figure 4.16 - Two types of the buildings which collapsed

Figure 4.17 illustrates the foundation of one of the buildings. These foundations normally are from 0.4 to 2 m high and are normally built in a water saturated soil. The water generally contains high levels of sulphates which increases the problem.



Figure 4.17 - Typical foundations of the collapsed buildings

Figure 4.18 shows one of the buildings after collapsing due to the foundation settlement.





Figure 4.18 - One of the buildings after collapse

Much research work has been done to establish the causes of the failures and also the safety level of the remaining buildings. Signor and Roman [4.14] proposed a new safety assessment methodology for the analysis of these buildings. Carvalho [4.15] has done experimental and numerical research applied to one cracked building in Recife. Dynamic, flat jack and acoustic emission tests have been conducted in the building. Furthermore, tests were performed in laboratories on blocks, mortar, prisms, creep and samples taken from the walls.

The main conclusion in both cases was that mortar rendering of the walls is crucially important for the buildings of the metropolitan area of Recife, although they have not been, nor should they be, designed with structural functions. This phenomenon, which is real, might be masking problems arising in the design and construction of such buildings.

Some attempts have been made to find ways to repair these buildings. The best one seems to be the proposal to enclose the foundations within another reinforced concrete system and to create a concrete framed structure to support the walls. This may solve the problem, although it has proved to be very expensive in many cases.

#### 4.2.5- Remarks

Identification, prevention and repair are mandatory to deal with defects in masonry walls, always keeping in mind Grimm's [4.16] recommendation: "Avoidance is the goal. Control is the next best objective".

## References

- [4.1] PAIVA, V.; et al. (1985)- “Patologia da Construção”, 1º Encontro sobre “Conservação e Reabilitação de Edifícios de Habitação” (in Portuguese), Documentos Introdutórios, LNEC, Lisboa, Portugal.
- [4.2] VICENTE, R.; SILVA, J. (2007)- “Defects of Non-Loadbearing Masonry Walls Due to Partial Basal Supports”, *Journal of Construction and Building Materials*, 21 (11), pp. 1977- 1990.
- [4.3] BONSHOR, R.; BONSHOR, L. (1996)- “Cracking in Buildings”, BRE, Garston, UK.
- [4.4] THOMAZ, E. (1989) - "Trincas em Edifícios. Causas, Prevenção e Recuperação" (in Portuguese), IPT/EPUSP/PINI, S. Paulo, Brasil.
- [4.5] DRÈGE, J. et al. (1997) - "La pathologie des Ouvrages de Batiment" (in French), Éditions WEKA, Paris.
- [4.6] GRIMM, C. (1988) - "Masonry Cracks: A Review of the Literature", ASTM STP 992, American Society for Testing and Materials, Philadelphia.
- [4.7] SILVA, J. (1998) - "Fissuração das Alvenarias. Estudo do Comportamento das Alvenarias sob Acções Térmicas" (in Portuguese), PhD thesis, University of Coimbra, Portugal.
- [4.8] CORREA, M. (2012)- “The Evolution of the Design and Construction of Masonry Buildings in Brazil”. *Design Management and Technology*, São Carlos, 2012, V.7, N.2, p. 3-11.
- [4.9] ROMAN, H.; ANTUNES SILVA, D. (2007) - “Typical Masonry Wall Enclosures in Brazil”, In: CIB (2007) - “Enclosure Masonry Wall Systems Worldwide”, S. Pompeu Santos (ed), Taylor & Francis/Balkema, London, UK.
- [4.10] THOMAZ, E. (1998)- “Prevention and Repair of Masonry Cracks”, *Journal of Construction Technology*, 37, pp.48-52.
- [4.11] I.P.T. (2008)- “Clay Block Partition Walls - Good Practice Code”, Technological Research Institute of São Paulo, Brazil.
- [4.12] THOMAZ, E. (1979)- “Cracks in Buildings: Causes, Prevention and Repair”. IPT/ Epusp/ Pini, São Paulo, Brazil.
- [4.13] PAGE, A. (1993)- “Cracking in Masonry Housing”, Research Report N. 085.05.1993, University of New South Wales, UK.
- [4.14] SIGNOR, R.; ROMAN, H. (2010) - “New Safety Assessment Methodology for the Analysis of Masonry Buildings in Brazil”, 8th International Masonry Conference – IMC, Dresden, Germany
- [4.15] CARVALHO, J. (2010) - “Experimental and Numerical Investigation Applied to a Building of the Metropolitan Area of Recife”, PhD Thesis, PPGEC-UFSC. Florianópolis, Brazil.
- [4.16] GRIMM, C. (1997) - "Masonry Cracks: Cause, Prevention and Repair", *Masonry International*, 10(3), pp. 66-76.





## **5- Conclusions and Guidance to Prevent and Repair Cracking in Masonry Walls**

### **5.1- GENERAL REMARKS**

From the issues exposed and presented in Chapters 1 to 4, some general remarks can be made:

- Masonry walls perform several roles in buildings: they can be structural or infilling, enclosure or partition, they can have different finishes or be the final finish and they may contribute to other functional requirements;
- The control of all functional requirements and the behaviour of masonry walls is yet far from being perfect, taking into account the relevance of materials properties and workmanship;
- The influence of regional practices, materials, and architectural solutions increases the difficulty of global approaches - common for other building components;
- Codes and standards, despite the important improvements made in recent years, have few guidance on how to minimize serviceability problems such as cracking;
- Among structural and non-structural solutions in a building, masonry is possibly the one that is given less attention in undergraduate courses in architecture and engineering despite its economic and functional importance;
- Probably the most common masonry defect is cracking. This defect has different manifestations, between those that must be considered as unavoidable and only with aesthetic implications, to those that are clearly unacceptable for aesthetic and functional reasons. The range of accepted cracking defects is very different in different cultures;
- Cracking repair depends on a correct diagnosis of the source of the movements producing the cracks and if this movement is stabilized or not;
- Cracking repair is frequently not efficient. To achieve the repair objective a strategic approach, methodology and technique should be adopted;
- It is important to consider that, due to the development of steel and concrete, reinforced concrete structures are increasingly flexibility. This leads to an increase in deflections and, therefore, an increase in cracking.
- Practices such as walls bearing on thin slabs, exclusion of mortar in vertical joints, use of 10 mm thick mortar rendering and the use of brittle materials such as rendering also have contributed to the appearance of problems with partition and enclosure walls.
- A better understanding of masonry service behaviour and the capacity for preventing defects needs more research - mainly experimental.

## 5.2- GUIDANCE TO PREVENT CRACKING

Some design aspects, such as the positioning of movements and limiting deflections as well as limiting tensile stresses, are key factors to prevent cracking. Also controlling the relationship of masonry walls with other constituents and the execution of works can help to decrease this problem. Therefore, some aspects are important to consider in the design for Serviceability Limit State (SLS) of masonry:

- Partitions and enclosure walls on deformable supports (beams or slabs):
  - The support (beams and slabs) of non-structural walls can require more demanding deformation limits than the ones specified in structural codes and should be established according to the quality of the wall and the presence of openings for SLS combined loading (permanent, live and variable loading), considering the long term effects (creep);
  - Some acceptable deformation limits to help avoid cracking in partitions could be (Figure 5.1):
    - i) deflection  $f_b \leq \text{span}/500$  for walls without openings or with constructive measures to avoid cracking;
    - ii) deflection  $f_b \leq \text{span}/1000$  for walls with windows and doors;
    - iii) rotation  $\theta \leq 0,0017$  rad;

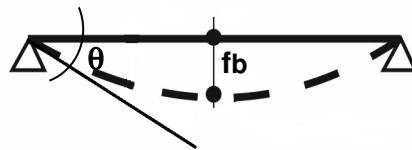


Figure 5.1 – Recommended deformation limits to help avoid cracking in partitions ( $f_b$  is the deflection affecting the behaviour of the partition after the construction of the partitions)

- Non-structural and structural partitions and enclosure masonry walls should be checked to ensure that tensile stresses are low (e.g. through a model based on the uncracked masonry section, in which the tensile strength of masonry can be considered);
- The use of low amounts of reinforcement for crack control is recommended to increase the deformation ability of unreinforced masonry without sustaining any visible cracking, given that severe deflection limits may be unaffordable. (e.g. use of bed joint reinforcement in horizontal mortar layers and mesh reinforcement renderings in general, near openings, intersection of walls or other interfaces with other elements);
- The above measure can be combined with provision of joints at the top/bottom of the partition/infill walls, in order to allow the deformation of the support structure, without compromising the stability of those walls;

- Dimensional variations of the walls due to humidity or temperature:
  - Movement joints should be designed by considering the different types of phenomena (creep, moisture, thermal nature of masonry, reversible and irreversible expansion) and masonry unit types (clay, concrete, AAC...), the dimension of walls and relationship to other elements (e.g. near large span openings or elements with different geometry);
  - Reference values for the horizontal distance of movement joints should be respected; these values can be increased by the use of reinforcement in the bed joints and/or mesh reinforced rendering;
  - The movement joints can be designed according to design codes or other technical documents referred to in this document (e.g. the distance between the movement joints is given in EN 1996-2 [3.9], according to the quality of the masonry material, the presence or not of openings and bed joint reinforcement in the wall);
  - The thermal movements of the roof slabs must be carefully considered to avoid common problems in the top floor walls, thus design procedures should provide adequate construction details to avoid problems involving thermal insulation of slabs by shading and/or reflective paintings, introduction of control joints in walls, etc.;
- Relationship of masonry walls with other constituents:
  - There is a difference between the properties of the support structure and masonry partitions/enclosure walls (except for structural masonry). As a consequence, a crack will occur at the interface of those 2 materials. There are 2 solutions:
    - i) make a visible joint between the 2 elements;
    - ii) cover the joint, giving the possibility for the covered joint for move (very important);
  - The openings in the wall are weak points with concentration of tension in the corners and the first cracks in case of a movement in the walls will occur from the corners of the opening (this fact is well understood by engineers in practice). Solutions to prevent this problem may include:
    - i) providing joint reinforcement at the corners - effectively above the opening;
    - ii) in case of a door, in some countries (Belgium, Netherlands) the opening continues till the upper part of the wall, dividing the wall in two (in this case, there is no masonry corner anymore);
  - Regarding structural masonry, tall buildings (e.g. in Brazil up to 70 m) may cause high bending stresses related to out of plumb deviations due to construction errors; also the adoption of rooms with spans from 6 to 8 m without adequate stiffness and correct bearing details for the slabs has produced bending moments in the masonry walls resulting in cracks in the top region;

- Execution of works:
  - Despite some trials with prefabricated masonry, masonry is still executed by masons and has been for thousands of years. The quality of the masonry still depends on the quality of the masons and their workmanship;
  - Some practical concepts may help on site to help prevent cracking in partitions or enclosure walls:
    - i) try to build the walls after the construction of the structure so that a part of the structural deflection can occur;
    - ii) when walls are built above each other on different levels execute them on alternate levels (see figure 3.24);
    - iii) form a joint between the upper part of the wall and the support so that the deformation of the support will not affect the walls;
  - These 2 methods avoid the increase of deformation on the lower levels, but in any case the partitions must be constructed after removing the formwork supports for the fresh concrete structure.

### 5.3- REPAIR STRATEGIES

The prevention of problems is concerned with design, construction and workmanship control procedures which are given in this manual.

Repair must always be based on a correct diagnosis of the real causes of each problem seen. The aim should always be to restore the wall to its original condition.

No repair process should ever merely conceal or cover up the original problems – since in time this might lead to a lack of structural safety or stability

### 5.4- RESEARCH NEEDS

Some aspects of the behaviour of masonry in service (SLS) should be the subject of research since there are no relevant recent studies in this area. Aspects that should be thoroughly investigated by experimental testing and numerical simulations could be:

- Analysis of the effect of the support deformation on non-structural partitions and enclosures, considering different materials and the use of reinforcement;
- Analysis of the behaviour of different interfaces masonry/support structures and the influence of different connection systems for reinforced concrete and steel structures;
- Numerical modelling of the mechanical behaviour of buildings with framed structures and infilling masonry, considering different sequences of masonry erection and the influence on the SLS.

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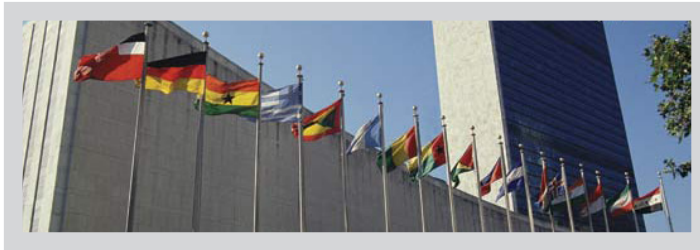
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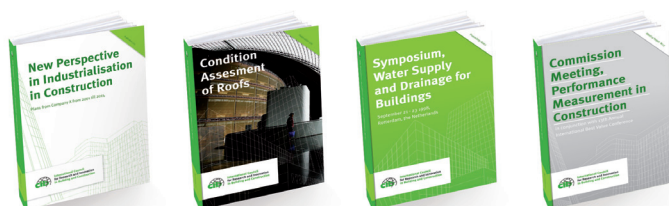
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