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Structural Assessment of Lisbon's Historical Buildings

Evaluation structurale des bâtiments anciens de Lisbonne

Tragfähigkeitsbeurteilung der historischen Bauten von Lissabon

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SUMMARY

Due to various reasons, far too many of Lisbon's historical buildings are being replaced instead of being repaired. Clearly a decision for preservation is needed, based on a correct evaluation of the situation. The paper presents a study aiming to develop a rational intervention strategy for the preservation of some of Lisbon's historical quarters. The envisaged actions, the methodology of evaluation and inspection are presented as well as the results of a preliminary survey.

RÉSUMÉ

Beaucoup trop de bâtiments dans les quartiers anciens de Lisbonne ont été remplacés récemment, au lieu d'être conservés. La décision d'une conservation doit être basée sur des données sûres quant aux dommages structuraux résultant des années. Ce rapport présente une étude visant au développement d'une stratégie d'intervention rationnelle pour la conservation de quelques-uns des quartiers historiques de Lisbonne. Les actions envisagées, les méthodes d'évaluation et d'inspection de même que les résultats d'une expertise préliminaire sont présentés.

ZUSAMMENFASSUNG

Aus mannigfaltigen Gründen werden zu viele Gebäude in den alten Quartieren von Lissabon ersetzt anstatt erhalten. Natürlich soll die Entscheidung über die Erhaltung eines Gebäudes auf zuverlässigen Daten über die im Laufe der Zeit entstandenen Schäden gründen. Dieser Bericht enthält eine Studie über die Entwicklung einer rationalen Interventionsstrategie mit dem Ziel der Erhaltung einiger der historischen Quartiere Lissabons. Die Vorgehensweise, die Bewertungs- und Untersuchungsmethoden sowie ein vorläufiger Expertenbericht werden vorgestellt.

1. INTRODUCTION

The majority of the buildings in the old quarters of the city of Lisbon are from after the catastrophic **earthquake of** November 1st 1755.

For the reconstruction of the areas affected by the quake, carried out under the supervision of then prime minister Marquês do Pombal, instructions were issued for what can be considered **the first aseismic buildings** distinguishable by the following features: incorporation of a three-dimensional well-connected wooden frame ("gaiola", meaning "cage") in the masonry walls; horizontal diaphragm action by means of timber trusses at floor and roof levels; limitation of building height to four storeys.

With time, memories of the 1755 earthquake dimmed. Buildings grew in height and volume whilst maintaining the same wall thicknesses or even reducing them; material and workmanship of inferior quality were used; the wooden "cage" degenerated into a system of poorly connected trusses and eventually was left out altogether, its purpose not well understood by constructors. In some of these latter buildings metal connectors were used to improve bonding of intersecting walls.

From the middle of last century until the full advent of reinforced concrete in the early fifties, a number of **identifiable structural typologies** evolved. The buildings of this period range usually from five to six floors above ground (attic included) and may stand isolated or integrated in a block of buildings. The load bearing walls are of unreinforced masonry, whether of stone, brick or rubble, single or double leafed; the floors initially of wood were later replaced by concrete slabs. With the diffusion of reinforced concrete and of steel structural work, mixed solutions were adopted. A typical example is the adoption of external masonry bearing walls together with internal beams and columns made of wrought iron. Many of the mixed solutions that can be seen nowadays are a result of enlargement/reconstruction operations where entire walls have been replaced by steel or reinforced concrete beams/frames or where additional storeys have been raised above top floors.

Buildings are, in themselves, a testimony to the history of urban development. For this reason some of the **older quarters** have been officially recognized as being of historical value and are now protected by municipal laws (eg. Baixa Pombalina, Alfama, Bairro Alto, Mouraria, Madragoa)[1].

Regarding the other **not so old quarters (circa 1880 - 1950)**, discussion is undergoing on whether to accept the costs of undertaking their preservation. It is clear however that if no active measures are taken towards this end and the situation is left to the dictates of the market based on economic considerations alone, ultimately, we will witness the demolition of most of the old buildings and their replacement by new highrises. The cost for achieving urban renewal this way would entail a loss of the architectural heritage and a change in the type of occupation with dwellings being replaced by offices. To support the process of decision making in this matter a study in now being carried out.

2. OBJECTIVES OF THE STUDY

A political decision for preservation is urgently needed. However, to be convincing, arguments have to be based on a correct evaluation of the situation. An answer must be given to the question: "What are the costs? For what results?". Most probably it is not possible to argue for full preservation, but based on objective data, it is possible to aim at more realistic goals.

It is the objective of the study [2] to develop a rational intervention strategy for the preservation of some of Lisbon's historical quarters. The approach envisaged for achieving this objective contemplates the following fundamental actions:

Phase 1:
- **Classification of the buildings according to a global rating based on "remaining structural capacity".**

Phase 2:
- **Definition of repair/strengthening measures needed to achieve an "acceptable level of safety" for gravity loads as well as for seismic actions; analysis of the costs involved.**

Phase 3:
- **Definition of a maintenance policy covering both preventive and remedial measures for the most common structural problems.**

As part of the strategy underlying the evaluation process it was decided to concentrate efforts on a restricted but characteristic area (**Avenidas Novas**) where the problems of structural deterioration are more acute, and, for this particular high priority area, develop a methodology which could later be extended to other areas.

3. SELECTED STUDY AREA. OBSERVED DAMAGE CONDITIONS

For the purpose of obtaining a general overview of the situation, a preliminary survey was conducted in 1986 [3] which enabled the definition of the main structural typologies and the identification of the higher priority buildings. Special buildings such as churches, monuments and mansions were not included in this survey. The assessment of the structural conditions of the over 1000 buildings was performed exclusively on the basis of visual inspections, carried out by a team of experienced surveyors under the supervision of two civil engineers, precautions being taken to ensure as far as possible the application of an uniform set of criteria. The general results are shown in Table 1.

The results of this survey show that of the 1028 buildings requiring intervention(*), 37% need corrective measures of some importance and 4% need major repairs.

Buildings	**Number**	
New or in very good condition	350	(24%)
In need of preventive measures(*)	611	(43%)
In need of corrective measures(*)	378	(26%)
In need of major repairs or for demolition(*)	39	(3%)
Under construction or undergoing overhauling	33	(2%)
Vacant lots from demolition of existing buildings	27	(2%)
	1438	

Table 1: Preliminary survey. Classification of buildings

Fig. 1: Two surviving buildings in the **Study Area**

In the **Study Area** constructions dating from the late 19th - early 20th century (1880-1930) predominate. These constructions have a characteristic structural typology (termed "gaioleiro"), featuring:

- external walls of irregular stone and weak mortar, single or double leafed, the exterior leaf made of brick masonry;

- internal walls of solid or perforated bricks, with or without a wooden frame (lower floors), and light wood panelling (upper floors);

- wooden floors and staircases; wooden roof structures;

- small inner courtyard (central or lateral) for admission of light and ventilation, enclosed by single or double leafed masonry walls;

- balconies at the back of the building, with tile flooring supported by a light (metal) structural frame.

The causes of damage are many, some having to do with normal lifetime deterioration and others with man's actions. The deterioration process caused by the exposure of the materials to environmental aggression is here drastically aggravated by the neglect of maintenance measures both at the preventive and the corrective levels. Of special significance are those needed to keep water away from masonry, resulting from leaky roofs or ruptured pipes. However very often interventions are performed only when an emergency is at hand.

Some of the observed damages suggest there may be inherent construction weaknesses which may be at the root cause eg. foundation weaknesses, overloading of certain critical areas due to the architectural layout (ie. the inner courtyard and the area affected to the balconies). A structural assessment may show that the level of safety is low due to these inherent weaknesses, even under the assumption that no strength degradation has taken place.

The most common damage inducing actions attributable to man were identified as:

- excavation works, both at the surface and underground, in the proximity of, or under existing buildings, resulting in localized differential settlements of the wall foundations;

- demolition of one of two buildings having a common separation wall, resulting in the destruction of the original connection between intersecting walls, both at the façade and at the back (Fig. 2);

- alterations to the existing structural system involving the total or partial demolition of load bearing walls (negative shoring-structure interaction);

- overloading through a change in building usage (eg. office archives in previous dwellings).

Fig. 2: Damaged masonry wall due to demolition of an adjoining building

4. METHODOLOGY OF EVALUATION

The evaluation of existing masonry structures in terms of remaining structural capacity involves an analysis for both gravity loads and seismic actions.

Where the latter are concerned, the more sophisticated approach to the problem would be the calculation of the time history inelastic response of the structure to ground excitation caused by a series of probable accelerograms using the Finite Element Method. The difficulties associated with this type of analysis are the great number of intervening parameters, the uncertainties related to them and the sensitivity of the results to these parameters. In view of these, where it concerns the systematic study of a great number of buildings, a linear elastic method of analysis will be used. Criteria will have to be established for the extrapolation of the results of elastic analysis to ultimate load behaviour.

The evaluation of the load bearing capacity of existing masonry structures must take into account both the type of construction and the extent and influence of deterioration on structural capacity. Information is needed regarding: construction details (eg. wall thicknesses, constituent materials, workmanship, degree of interconnection between walls and walls/floors); level of deterioration of the construction materials; extent and type of structural defects such as cracks and fissures, distortions, bulges and deviations, missing bricks and blocks, loss of interconnection between diaphragms, etc.

To obtain the relevant data, a programme has been established for in-situ and laboratory investigation of individual buildings, taken as representative of groups of buildings. The investigation will include a survey of the architectural and constructive features, a survey and assessment of the damages and a testing programme to determine the mechanical parameters of existing masonry structures.

For the identification of the dynamic behaviour of structures (natural frequencies, modal shapes and damping ratios), experimental in-situ tests will also be performed.

Because of the destructive or at best semi-destructive nature of the initial investigation (such as corings, removal of masonry blocks and flat-jack tests), operations will be restricted to buildings awaiting demolition or contemplating intervention.

5. IN-SITU MASONRY TESTS WITH FLAT-JACKS

The envisaged testing programme for the quantitative assessment of the residual mechanical characteristics of old masonry relies to a great extent on a technique based on the use of flat-jacks.

The flat-jack technique was originally developed for the determination of residual stresses at the surface of rock masses, particularly in tunnel and gallery walls. The method adopted at LNEC [4] consists in applying, by means of a thin copper sheet jack, a uniform pressure of up to 20 MPa to the walls of a slot cut in the rock mass by a diamond-edged disk. The state of stress is given by the pressure needed to cancel the deformation at the surface of the wall due to the cut. This technique can also be applied in masonry to determine the state of stress in walls for calibration of analytical models.

A relatively recent development of the flat-jack technique permits also the determination of the strength and deformability characteristics of in-situ masonry. The technique consists basically in the insertion of flat-jacks in two parallel cuts made in the surface of the masonry wall. By applying pressure through the jacks, the masonry block between the two cuts can be tested for deformability (axial and transverse) and compressive strength [5].

The LNEC testing equipment consists of a set of hydraulic jacks, a cutting machine (fitted with a 600 mm diameter diamond disk), a device for extracting the jacks, pressure gauges and deformeters. The available equipment permits cuts from depths of 100mm up to 240mm (Fig. 3).

6. INTERVENING PARTIES

The outlined study, still in its early stages of development, is being carried out by LNEC (Laboratório Nacional de Engenharia Civil) for CML (Câmara Municipal de Lisboa), Lisbon's Municipal Authority. This study is conducted in conjunction with normal consultancy activities on behalf of CML.

SNPC (Serviço Nacional de Protecção Civil), having established a programme for the seismic risk assessment of Lisbon's quarters, launched in the early eighties, has already shown interest in the results of the planned tests and field inspections. As work progresses, a liaison with SNPC will be established.

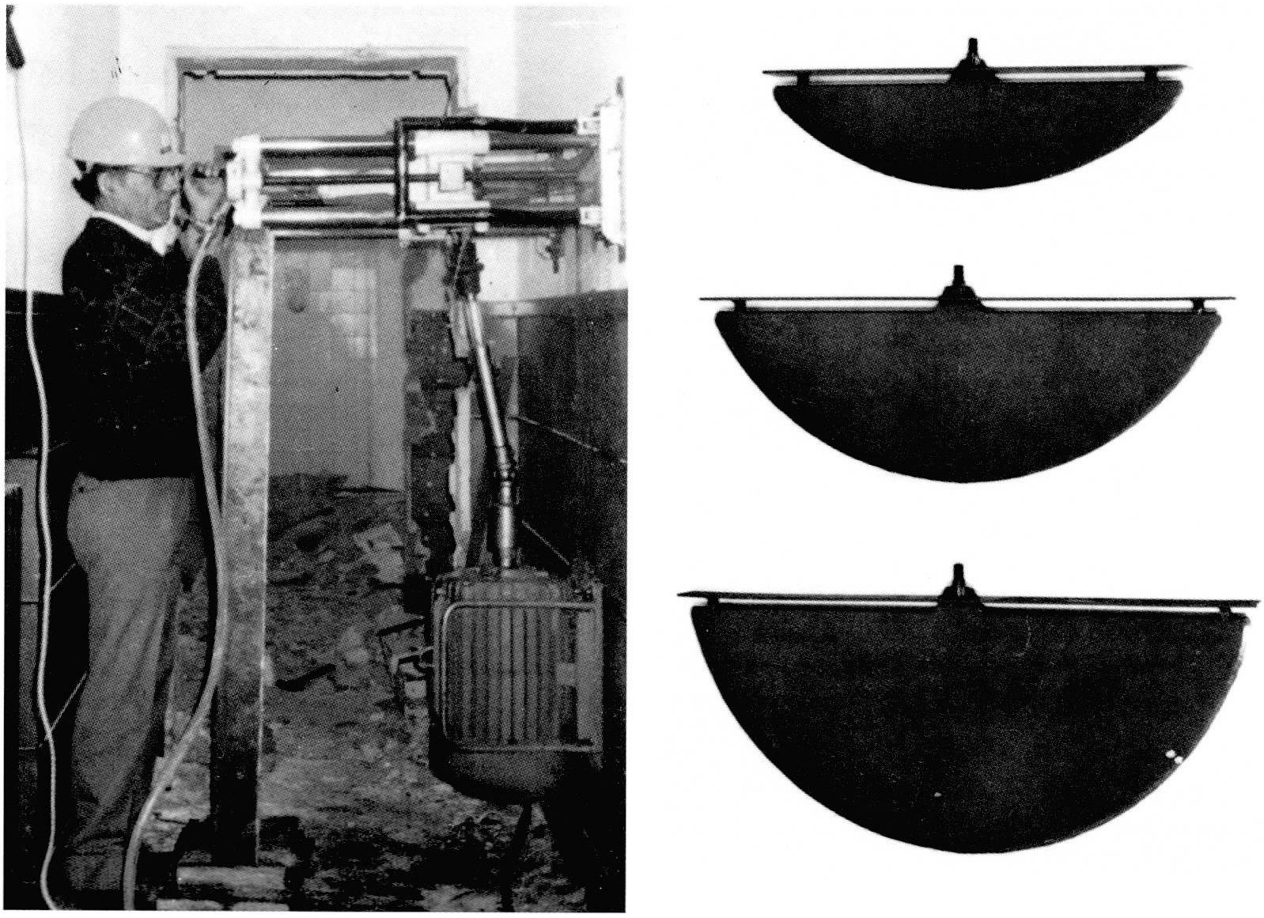

Fig. 3: Cutting operation in a flat jack test

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