REDUCING THE SEISMIC VULNERABILITY OF THE BUILDING STOCK

National Association of Engineers

Lisbon, April de 2001

Edited by:

SPES – Portuguese Society for Earthquake Engineering

GECoRPA – Portuguese Association of Companies for Preservation and Restoration of the Architectural Heritage

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FOREWORD

The *Sociedade Portuguesa de Engenharia Sísmica - SPES* (Portuguese Society for Earthquake Engineering) and the *Grémio das Empresas de Conservação e Restauro do Património Arquitectónico - GECoRPA* (Portuguese Association of Companies for Preservation and Restoration of the Architectural Heritage) are jointly responsible for the edition of the present book, in the sequence of a Meeting held in April 2001, at *Ordem dos Engenheiros* (National Association of Engineers), with a view to discuss and improve the Programme for Mitigating Seismic Risk.

SPES is a non-profit making cultural and scientific Association of which the main purposes are the development of seismology and seismic engineering in Portugal and their international representation. Throughout the last few years, that Association has organised National Meetings on Seismology and Earthquake Engineering. Recently, the periodicity of those Meetings has been reduced from 4 to 2 years. The last Meeting took place in Faro, November 1999, the next Meeting being scheduled for 24 to 26 October 2001, in Ponta Delgada, Azores. The Meeting will be followed by a visit to Faial to observe the reconstruction works that have been under way since the earthquake of July 1998. The main issues discussed in those Seismology and Earthquake Seismic Engineering Meetings refer to technical and scientific aspects within the fields of seismology and earthquake engineering. Furthermore, contributes to the development of areas associated with earthquakes, namely preparation of technical codes and studies in support to Civil Protection activities and plans, etc., are also debated in those Meetings. Nevertheless, the debates have been restricted to a very secluded technical community, which consists mainly of university researchers and state-owned laboratories, as well as (a few) people from Design and construction Companies and Town Councils.

GECoRPA is, in its broader sense, an association of companies devoted to the rehabilitation of the built patrimony and which are particularly aware of the fact that the interventions in that area cannot be limited to façades, but rather they should be extended to the structural resistance of buildings, and, particularly to their resistance.

In the last few years, the two associations have become aware that further steps were required in order to draw the attention of the civil society for the seismic risk, so that by a conjugation of efforts it would be possible to mitigate that risk more effectively. In fact, not only it is necessary to conduct studies and create codes as the ones already available, but also it is necessary to put them into practice. In order to achieve that, the main agents involved and concerned by that field, i.e., the whole society, must become fully committed. Moreover, it is known that there is a high number of old buildings, built when the seismic behaviour was poorly known, which are consequently more vulnerable to that type of action. Therefore, it is of the utmost importance to understand the problem and adopt corrective measures, by strengthening those buildings or by progressively replacing them. The proposal submitted by the two associations “Contribution to a National Programme for the Reduction of the Seismic Vulnerability of the Building Stock” came in response to that problem. The comprehensive debate promoted during the Meeting was ultimately intended to lead a higher number of bodies, comprising a wide range of economic and social agents, to validate the “Programme”.

Therefore it is legitimate to ask if too little has been done in terms of research and development? And why this issue has only now been addressed?

Obviously, there has been significant investment in research and teaching; the number of researchers in this field has increased in the last few years. Nowadays, there are more schools providing knowledge in the field of seismology and seismic engineering. We know more about the seismic risk but there is still much to be known in that area. Relevant efforts have been recently done in that sense, from among which reference can be made to the Project of the Metropolitan Area of Lisbon promoted by the National Civil Protection Service.

The reduction in the seismic risk in Portugal requires the efforts that are now proposed to be undertaken. The historical past as regards earthquakes is well known. Furthermore, we also know to what extent the Portuguese patrimony has been devastated, on several occasions, throughout the last few centuries, by simply knowing the Portuguese earthquake history from the XVI Century until today, including the major earthquakes that occurred in the Portuguese mainland and in the Azores.

In the XX Century, the seismic activity in the Portuguese mainland has been reduced, only a few earthquakes with a minor or localised destructive effect have occurred in 1909, 1941 and 1969. This has indeed been a quiet phase that may abruptly come to an end. Nevertheless, in Azores, major earthquakes occurred in 1926, 1950, 1973, 1980 and 1998.

The notion of strengthening of buildings has been initially associated to Prof. Frank Press's statement in 1984, in which he urged people to consider the 90s as the Decade for Reducing the Hazard deriving from Natural Catastrophes, by implementing programmes involving practical aspects.

Of note is also the fact that Programmes with similar objectives are currently under way or being implemented in other countries such as:

- USA: programmes for seismic strengthening of bridges, buildings, monuments and infrastructures date from the 70s. These programmes were launched as a result of the lessons from the 1971 San Fernando earthquake and were further developed after the 1994 Northridge earthquake.
- New Zealand: a programme for the seismic strengthening of bridges has been implemented for quite a few years.
- Japan: various programmes for strengthening have been launched after the 1995 Kobe earthquake.
- Italy: regional programmes for reducing seismic vulnerability of constructions are under way.
- Turkey: after the 1999 earthquakes and in view of the high probability of Istambul being submitted to an earthquake of high destructive potential in the next few decades, the Turkish authorities are presently defining programmes with objectives similar to the one proposed, which are to be complemented by special measures to improve the quality in construction.
- At a national level, special emphasis must be given to the Azores, where a major effort has been done as regards seismic strengthening of buildings in the last 20 years, as a result of destructive earthquakes, particularly the 1980 Terceira earthquake. Nowadays, in an attempt to proceed with a preventive policy as refers to mitigation of the seismic risk, the Regional Government of Azores has assumed the Reduction of Seismic vulnerability as an objective of the Region. Therefore, adequate legislation has been developed for the purpose, which is intended to be representative of the reality of the Autonomous Region of Azores. We would like to thank the representatives of the Regional Government of Azores, who have participated in the Meeting, for having shared with us the experience gained with the latest events and with the development of the policies presented above.

The SPES and GECoRPA wish to thank the authors of papers and invited participants for having taken part in this event. We also wish to acknowledge the National Association of Engineers for its valuable support and for kindly having provided the facilities for the Meeting.

Schedule of Sessions

Place: Portuguese Association of Engineers, Av. Sidónio Pais, Lote 13, Lisboa

Date: 3 April 2001

09h 30m – **Opening Session**

Engineer Francisco Sousa Soares, *Bastonário* (Chairman) of the Portuguese Association of Engineers

Presentation of the proposed Programme

09h 40m – National and European Framework

Prof. Carlos Sousa Oliveira, President of the Portuguese Society for Earthquake Engineering

09h 55m – Description of the Programme

Engineer Eduardo Cansado Carvalho, Vice-President of the Portuguese Society for Earthquake Engineering

10h 10m – Technical feasibility of the execution of the Programme

Engineer V. Cóias e Silva, President of the Portuguese Association of Companies for Preservation and Restoration of the Architectural Heritage

10h 40m – Coffee Break

Papers from participating bodies

11h 00m – Mitigating Seismic risk in Portugal. The Role of LNEC

Engineer Eduardo Cansado Carvalho, *Laboratório Nacional de Engenharia Civil* (National Laboratory for Civil Engineering)

11h 15m – Mitigating Seismic Risk. Contribution of the European Commission to Promote Joint Programmes and Concerted Action

Engineer Artur Vieira Pinto, Centro Comum de Investigação de Ispra (Ispra Joint Research Centre)

11h 30m – Seismic Factor in Assessing the Patrimony

Engineer A. Briosa e Gala, Associação Portuguesa de Avaliações de Engenharia (Portuguese Association for Engineering Reconnaissance)

11h 45m – A few Considerations Prior to the Assessment of the Economic Impact of Earthquakes

Prof. Nogueira Leite, Lisbon New University

12h 00m – The Importance of Quality in the Seismic Strength of Buildings

Dr. Mário Lopes, Instituto Superior Técnico ,Lisbon

12h 15m – The Lisbon Mega-Earthquake in the XXI Century or the Seismic Vulnerability of The Lisbon Constructions

Engineer João Appleton

12h 30m – The Seismic Risk and the Industrial Park

Dr. Mário Lopes and Prof. Carlos Sousa Oliveira, Instituto Superior Técnico

13h 00m – **Lunch-Break** (sponsored by SPES and GECoRPA)

14h 30m – Aspects of a Housing Policy Intended to Reduce Seismic Vulnerability in Azores

Dr. Ricardo Silva, Direcção Regional da Habitação dos Açores (Regional Directorate for Housing in Azores)

15h 00m – **Debate**

Moderator: Engineer Artur Ravara, Chairman of the General Assembly of SPES

18h 00m – **Closing Session**

National Programme

Contribution to Prepare a National programme for Reducing the Seismic Vulnerability of the Building Stock

1. Introduction

1.1 Framework

In the seismic history of Portugal there have been some seismic events with devastating effects. Nevertheless, under the current scientific knowledge it is not possible to make short-term earthquake prediction. However, in view of the nature of the seismic mechanisms, we know beforehand that if a certain region has been subjected to an intensive earthquake in the past, we can thus assume that intensive earthquakes are likely to affect the same region at any time. Therefore, new potentially highly destructive earthquakes are expected to occur in the future, in Portugal.

Nevertheless, the damage caused by earthquakes, both to people and to constructions, depends not only on the harshness of the seismic action but also on the strength and quality of these same constructions, i.e., it ultimately depends on the vulnerability of the constructions to that action.

Most constructions in the zones of highest seismic risk in Portugal namely, Azores, Algarve and particularly the city of Lisbon, are in highly precarious safety conditions, as far as the possibility of an intensive seismic shock is concerned.

For instance, the masonry buildings, which are a great part of the buildings in Lisbon, have not been submitted to a specific seismic design and, depending on their typology, they present various deficiencies, such as:

- Deterioration of the properties of the structural materials;
- Highly weak construction, in some cases with insufficient bracing;
- Highly weak rehabilitation, in some cases, after the 1755 earthquake;
- Addition of floors and basements;
- Alterations, particularly as regards the lower ground floors, which have been defectively designed and/or executed, and which consequently decrease the strength of walls and foundations;
- Unplanned introduction of metallic and reinforced concrete elements without criterion;
- Walls with reduced thickness, lacking strength and in insufficient number;
- Defective foundations, in some cases;
- Use of heavy decorative elements.

Also the reinforced concrete buildings present some deficiencies, particularly, the so-called “non-ductile” ones, which are the majority of the reinforced concrete buildings. The structure of those buildings has a reduced ability to dissipate the energy transmitted to them by the earthquake through the deformation and redistribution of loads by the various structural elements and to continue responding as a whole without significant loss of strength.

The most recent buildings, which were designed in accordance with the current 1983 code, may have or not an adequate seismic strength, because actually there is no quality control for design and construction, unless specified by the owner. Therefore, the vulnerability of those buildings can be highly variable, depending on the qualification and motivation of the people involved in the construction of each building.

1.2 Objectives

The main purpose of this Programme is to reduce significantly the vulnerability of Portuguese Building Stock, through its seismic rehabilitation, with a view to provide the buildings with a strength capable of:

- Ensuring the protection of people, goods, as well as the serviceability of the elements in risk for a moderate and relatively frequent earthquake (short recurrence interval) and
- Preventing the collapse of constructions for an intensive and relatively rare earthquake (long recurrence interval).

In this way, it would be possible to reduce both the economic and social losses that the next high magnitude earthquake could cause in the Portuguese territory.

Reference must be made to the fact that such a type of Programme for Reducing the Seismic Vulnerability is a preventive approach intended to avoid losses rather than a reactive approach for minimising the disaster consequences, such as the approaches included in the Civil Protection emergency plans.

The Programme is mainly intended to mitigate the hazard of existing constructions, essentially housing and office buildings, due to the high complexity and magnitude of the problem. Therefore, the programme does not include lifelines, industrial buildings, monuments and historical buildings or buildings of high architectural interest, for which specific programmes intended to reduce the seismic vulnerability must be developed.

The Programme presupposes the existence of mechanisms intended to ensure articulation among various bodies, such as: associations of entrepreneurs in the building construction sector, real estate sellers, insurance companies, landowners and tenants, financing institutions, etc.; as well as government bodies (State, Municipalities, Civil Protection, Standardising Institutions). The success of the practical application of the Programme will also depend on the support given by building owners and tenants, i.e., the population. Therefore, instead of remaining confined to the limited circle of experts and researchers, this issue should become a subject of national interest and concern.

2. Tasks to be developed

The Programme implies a set of tasks and a scheduling for their execution.

T1 – Surveying the housing stock and assessing the hazard

General survey of the constructions located in the zones that are likely to be the most affected by earthquakes, by characterising them from a structural and patrimonial point of view.

Assessing the seismic risk at a national level, which implies determining the economic and social losses, as a result of future earthquakes, as well as the probability of occurrence of these losses within a certain period of exposure for a set of elements.

T2 – Defining the most effective intervention strategies

Establishing an intervention strategy, which involves the specification of different variables, such as: (i) the type and level of strenghtening or protection to be adopted, (ii) the typologies on which we are to act, (iii) the geographic intervention areas, (iv) the percentage of buildings from the different typologies to be strengthened, in view of the existences of the region and, lastly, (v) the costs and benefits of each intervention strategy.

Identifying and defining the best intervention strategies for reducing the seismic risk of the building stock, in accordance with one or more previously defined criteria.

Part of the above tasks have been already included in ongoing studies[1], which nevertheless require further development.

T3 – Improving solutions for seismic rehabilitation

Establishing a programme for studying and developing solutions for seismic rehabilitation, with a view to establish recommendations intended to facilitate the subsequent interventions. This study aims at:

- Characterising the technical effectiveness of solutions in terms of improvement of the seismic performance which is expected to be provided to the construction.
- Providing details about the different solutions, including standard-designs, specifications of methods and materials, as well as standard-charts of quantities and prices.

T4 – Creating support legislation

a) The launching of the programme must be preceded and accompanied by essential legislative measures, namely the aspects referring to: certification of technicians and designers; definition of the situations compulsorily requiring seismic rehabilitation; alteration of the rules for licensing of works and designs; adaptation of the “Law that regulates the access and permanence in the activity of public works contractor and civil construction entrepreneur” and its articulation with the Portuguese Quality System and with the future “Law for the quality inspection and civil responsibility in the building construction designs and works”; alterations in the rent law and in the Municipal Master Plans; revision of the insurance system; creation of a tax incentive scheme; and lastly, preparation of technical legislation.

T5 – Training and dissemination

Introducing the necessary alterations in engineering and architecture “curricula” by specifically emphasising rehabilitation in general and seismic rehabilitation in particular. Simultaneously, the criteria of good seismic design in new constructions should also be emphasised.

Creating complementary training programmes in the area of seismic rehabilitation, with a view to “recycle” those who are already working in the field and to promote the training of intermediate staff and labourers skilled in seismic rehabilitation techniques.

Implementing projects for demonstrating the main solutions and disseminating among the general public the issues related with seismic vulnerability.

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[1] Special reference is made to the study promoted by the National Civil Protection Service for the Metropolitan Area of Lisbon, involving Research Centres from the Department of Geography and from the Faculty of Sciences of the University of Lisbon, from the Technical university of Lisbon and from the National Laboratory for Civil Engineering, as well as to the study referring to the Mitigation of the Seismic Risk in Portugal, which has been under way at that Laboratory and which has been subsidised by the Foundation for Science and Technology.

T6 – Preparing master plans for seismic rehabilitation

Systematic development of seismic rehabilitation plans at a municipal level. It is essential to analyse and disseminate the plans for the seismic rehabilitation of urban buildings that are already under way in other parts of the world where this problem has been faced.

T7 – Carrying out the works

3. Costs and schedules

In view of the resources that must be made available for implementing the proposed Programme, the latter must necessarily be carried out during the next few decades. The main purpose is to complete the programme around year 2025. The table below shows a proposal for scheduling the corresponding tasks:

Task	**Beginning**	**Completion**
T1 – Surveying the housing stock and assessing the risk	2001	2004
T2 – Defining the most effective intervention strategies	2001	2004
T3 – Improving solutions for seismic rehabilitation	2001	2006
T4 – Creating support legislation	2001	2004
T5 – Training and dissemination	2001	Unlimited
T6 – Preparing master plans for seismic rehabilitation	2003	2006
T7 – Carrying out the works	2005	2025

Since, in the light of the current knowledge, it is very difficult to estimate in detail the costs of the proposed Programme, it is however essential to have a perception of its order of magnitude. By taking as basis the existences of the building stock and its characteristics in the zones with highest seismic risk[2] and by assigning to each structural type a seismic rehabilitation cost in percentage of the cost of new constructions, it is roughly estimated that the overall cost of the proposed Programme will be approximately 25 000 000 000 €, i.e., about 20% of the Gross Domestic Product.

Obviously such an investment volume requires the staging of the execution of the programme throughout the next few decades. In this way, a 25-year period for completing the works is proposed. In these conditions and considering the cost estimate mentioned, the investment associated with the programme would require the allocation of about 1 000 000 000 € per year. Nevertheless, with the implementation of an adequate policy, the government would only have to ensure the necessary subsidies for encouraging the private sector, the latter being responsible for supporting a great part of the costs. Alternatively, there is the risk of concentrating a major economic loss in a single moment, with all the aggravating circumstances that are associated with a high disturbance in the social and economic fabric and with the loss of human lives.

[2] In these zones (Lisbon and Tagus Valley, south of the Portuguese Mainland and Azores) and in accordance with the 1991 *Censos* and with the National Statistic Institute estimates, the existences as follows are assumed: (i) 940 thousand buildings (1998 estimate), 2.0 million housings (1998 estimate), e 3.8 million dwellings (1991 *Censos*).

Sessions

Technical Feasibility of the "National Programme for Reducing the Seismic Vulnerability of the Building Stock"

V. Cóias e Silva

(*GECoRPA – Portuguese Association of Companies for Preservation and Restoration of the Architectural Heritage*)

Abstract

The purpose is to demonstrate that it is technically feasible to reduce the seismic vulnerability of Portuguese building stock through structural rehabilitation, taking into account the means available in the country, and the existing technologies and materials.

1. Introduction

The context of seismic rehabilitation of the Portuguese building stock in areas of significant seismicity has been the object of a paper presented by the author at the Meeting commemorating the 50th anniversary of LNEC. The same subject was also approached in former papers of the present conference therefore will not be developed here.

The major objective of the National Programme for Reducing Seismic Vulnerability of the Building Stock ahead referred to as the "Programme", is to promote a gradual but substantial reduction of the vulnerability of the Portuguese building stock, through its seismic rehabilitation.

The launching of such an innovative and comprehensive plan necessarily presupposes some adjustments, as well as the correction of some deficiencies, both at the level of the business fabric of the sector of Civil Construction and Public Works (CC&PW) and at the level of the bodies supervising and regulating that activity.

The technical capacity of the business fabric is decisive for the feasibility of the Programme, since the companies will be the agents that will be summoned up to develop most of the involved tasks.

The main purpose of this paper is to carry out a first assessment of the technical capacity available in the country, in order to achieve the objectives of the Programme.

2. The buildings to be rehabilitated

Fig. 1 shows the evolution of the construction typologies of Lisbon buildings throughout the millennium that has just ended. As and when the size of the buildings increased, the materials used evolved from timber to masonry and, in the last century, to reinforced concrete.

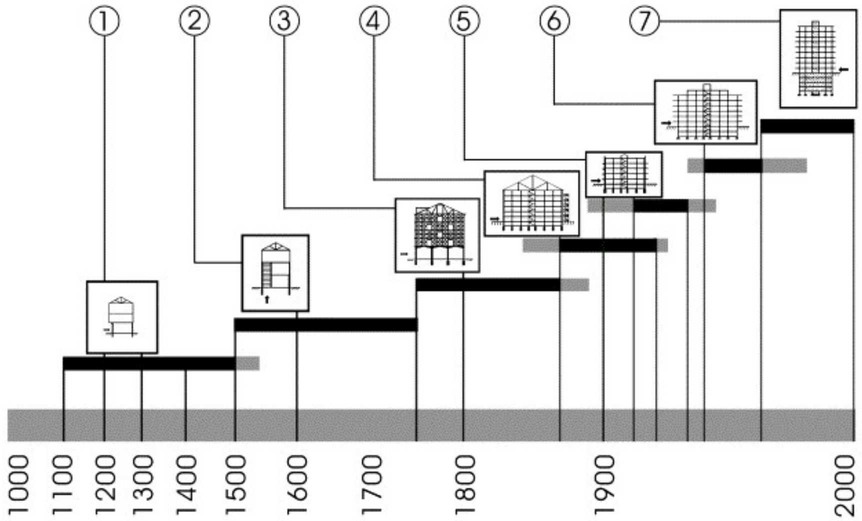

Fig.1 – Evolution in the common construction procedures used in Lisbon buildings. 1,2 – prior to 1755; 3 – "pombalino"[1]; 4 - "gaioleiro"[2]; 5 – masonry walls and "placa"[3]; 6 and 7 – reinforced concrete

Table I shows the distribution of masonry and reinforced concrete buildings currently existing in Lisbon, according to the typologies referred to above.

Table I - Distribution of Lisbon buildings according to the main structural typologies

Structural typology	Quantity	%
Prior to 1755, "cage" type buildings and "gaioleiros"	28 000	50
"Placa" buildings	11 200	20
Former reinforced concrete, "non-ductile"	13 900	25
Recent reinforced concrete, "ductile"	3 137	5

Note: This table results from a calculation based on the data collected by the INE (National Statistics Institute) in Censos 91, which distributes the 57 000 masonry and reinforced concrete buildings by the six existing typologies, and using as reference the parcelling study already conducted in more restricted zones [LNEC, 1990, Oliveira,1986, 1987].

According to the statistics, in overall terms there are in Portugal more than 1 000 000 buildings constructed before 1945, which represent more than 40% of the total, and there are about 360 thousand buildings requiring urgent rehabilitation work. Most of Lisbon constructions and, in general, on the zones with the highest seismic intensity of the country, are in highly precarious safety conditions, as regards the possible occurrence of an intense seismic shock. The masonry buildings that are about 70% of the Lisbon stock present, depending on their typology, deficiencies such as:

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[1] This type of buildings will be designated from now on as "cage" type buildings. In fact, their structure integrates an anti-seismic timber framework that resembles a cage.

[2] Buildings of this type of were built in a period subsequent to the "Pombalino" buildings, with the difference that their structure does not have an "anti-seismic" timber framework.

[3] Used to designate buildings with masonry load-bearing walls and reinforced concrete floors.

Degradation of the properties of structural materials;

Highly precarious construction, in some cases, with insufficient bracing;

Highly precarious rehabilitation, in some cases, after the 1755 earthquake;

Addition of floors and basements;

Alterations, particularly as regards the ground level stores, which have been defectively designed and/or executed, and which consequently decrease the strength of walls and foundations;

Unplanned introduction of metallic elements and reinforced concrete;

Walls with reduced thickness, lacking strength and insufficient in number;

Defective foundations, heavy decorative elements.

Annex IV describes with more detail these deficiencies and presents a few examples of application of techniques to solve them.

Also the reinforced concrete buildings present some deficiencies, particularly the so-called “non-ductile” buildings, which represent about 25% of the whole Lisbon building stock. In this typology, the structure of the buildings has a much reduced ability to dissipate the energy transmitted by the earthquake, through the deformation and redistribution of loading by the different structural elements, and to continue responding as a whole without significant loss of strength. The group of reinforced concrete buildings considered “without ductility” comprises the buildings of which the design and construction are prior to the 1958 “Safety Regulations of Constructions against Earthquakes” (Decree 41 658 of 31 May 1958), as well as the buildings that, though dimensioned in the light of those regulations, are against the basic rules of a good anti-seismic design (as for instance, the buildings with soft storeys or those with insufficient horizontal bracing).

Annex V presents in more detail the deficiencies of reinforced concrete buildings and also a few examples of the application of techniques to eliminate them.

3. Tasks to be developed

In order to achieve its goal, the Programme lists a set of seven actions or tasks to be developed:

T1 – Surveying the housing stock and assessing the hazard;

T2 – Defining intervention strategies;

T3 – Improving rehabilitation solutions;

T4 – Creating support legislation;

T5 – Training and dissemination;

T6 – Preparing master plans for seismic rehabilitation;

T7 – Carrying out the works.

Table II classifies those tasks, by further differentiating them in a matrix representing the responsibilities of the different agents and partners. In operational terms, the completion of those tasks involves mainly the companies related with the CC&PW sector. Nevertheless, it requires also the participation of many other entities, such as the regulating bodies or the bodies representing different interests, apart from the State itself.

The figures in Annex I represent a flow chart that contains a first arrangement of the different tasks and also shows the entities involved.

The technical feasibility of the Programme must be assessed by taking into account four fundamental factors:

"Know-how";

Organising structure of the entity that is to co-ordinate and monitor the Programme and the group of partners that are to detail and carry it out;

Allocated technical staff;

Availability of human operational and technological resources.

Table II – Tasks to be developed: participation of the different bodies and partners

Task	Entity / Designation	Central government	LNEC	IIU (1)	ISP (2)	CMs (3)	IPQ, Certif. Ent.(4)	IMOPPI (5)	General contractor association	GECoRPA	APPC (6)	Professional architects and engineers Associations	Cenfic and others training centre	APMC (7)	FCT (8), AdI (9)	Comp. Group I	Comp. Group II	Comp. Group III	Comp. Group IV
T4	General planning; prioritization; criteria def. (zoning, training, qualification, certification). Legislation. Incentives	X	X	x	x	x	x	x	x	x	x	x							
T1, T2, T5	Collecting and producing base-documents, incl. specification (survey, inspection and execution of works)		X	x												x			
T5	Training technical staff (design and planning)		x	X												x			
T3	R&D and improving materials, products and technology, incl. technical documentation		X	X											X	x		x	x
T4	Certification of materials, products and technologies		X				X			x				x		x		x	x
T1	Surveys and inspections															X	X		
T5	Training operational technical staff		x	X					x	x		X							
T5	Training workers												X						
T6	Alteration of Urban Master Plans and of licensing rules	X				X										x			
T4	Qualification of companies of Group I		X				X			x	x	X							
T4	Qualification of companies of Group II		X				X	x		x									
T4	Qualification of companies of Group III						X	X	x	x									
T4	Qualification of companies of Group IV		X				X			x				X					
T7	Exec. of works (incl. survey, inspection and testing, design, exec. and supervising)															X	X	X	X

Notes: (1) Universities and Research Institutions; (2) Portuguese Insurance Institute; (3) Municipalities; (4) Quality and certification agencies; (5) Contractor qualification Institute; (6) ; (7) Association of product manufacturers; (8) Foundation for Science and Technology; (9) Innovation Agency

3.1 T1 – Surveying the housing stock and assessing the hazard

This survey is an indispensable condition for planning the Programme. The survey began already a few years ago, but it has been meanwhile discontinued. If the aim is to restrict the Programme to those zones of the country with highest seismic risk, then it will be necessary to extend the survey to the whole Lisbon and Tagus Valley region, as well as to the Algarve and Azores. This means covering about a million buildings. The execution of such a survey does not present particularly significant technical difficulties in terms of “know-how”. Nevertheless, it may present a few difficulties in terms of availability of human operational resources, due to the involved quantity. It presupposes an adequate qualification of companies of Groups I and II (or professional engineers), which will be involved in the execution of this task. Such qualification, obviously implies specific training, which will only be possible based on specialised manuals and on specific audio-visual equipment. Its completion within a four-year period would imply that about 250 000 buildings per year were to be inspected, i.e., a thousand buildings per day spread throughout the three regions involved. If each inspection team (an engineer and an assistant) saw four buildings a day, it would be necessary to recruit 250 teams. There is some experience in this type of work, such as for instance, the systematic inspections performed before carrying out underground construction projects.

3.2 T2 – Defining intervention strategies

This is a task that includes only a comprehensive study about the main construction typologies involved. It comprises the systematic application of the same methodology as the one followed in the design of structural rehabilitation interventions. It may involve a more or less developed experimental component. LNEC, the “Research and Interface Institutes” related with the universities, as well as the companies of Group I have the technical conditions to carry out this task without significant difficulties.

The cost-benefit analysis presents, in some cases, relevant limitations, which derive, on the one hand, from the lack of reliable data about the cost of the seismic rehabilitation interventions, for different types of buildings and in various regions. On the other hand, those limitations result from the difficulty in assessing the probability, the number and the sequence of earthquakes, as well as in estimating the amount of damages avoided, etc. [Comerio, 1991].

At an operational level, the seismic rehabilitation of a building can be achieved by the application of one or more of the strategies indicated below. The potential of each strategy, in the case of the buildings under study, varies and therefore the strategies are not all equally promising. Anyhow, the availability of those strategies is a real and very interesting alternative to mere demolition and reconstruction. In fact, the latter usually is much more expensive solution, which has a higher environmental impact, both in overall terms (transportation and waste fill, consumption of unused materials, fuel and power consumption) and in terms of the direct urban surroundings (production of noise, dust and waste, overload of the road network, etc.).

The recommendations of [Building Seismic Safety Council] indicate the seven main strategies:

1. Local modification of structural components;
2. Elimination or reduction of irregularities and discontinuities;
3. Increase of overall stiffness;
4. Increase of overall strength;
5. Mass Reduction;

6. Seismic isolation;
7. Increase in the energy dissipation capacity.

The definition of strategies aiming at the seismic rehabilitation of buildings does not involve significant technical difficulties.

3.3 T3 – Improving rehabilitation solutions

LNEC, as well as the Research Institutes related with Universities, and the companies of Group I are prepared to carry out this task without significant difficulties, in conjunction with companies of Groups II and IV and with the support of bodies, such as FCT (Foundation for Science and Technology) and AdI (Innovation Agency). In this context, mention must be made of the COMREHAB project [Silva, 1999]. This is an Eureka project which has been under way since 1999 with the EC support and has been co-ordinated by AdI, of which the first stage is expected to be completed by mid-year. Annex II shows a few aspects of the designed system, of specimens and of the tests already completed. At an international level, the objective is to develop materials and application techniques of low cost and low curing energy pre-impregnated composites to be used in the repair and strengthening of structures. Apart from the Portuguese company Stap, research companies and bodies from Spain, United Kingdom, Italy, Slovenia and Romania also take part in the project.

For the Portuguese partner, the project is particularly relevant as regards the applications aiming at the seismic rehabilitation of existing structures, especially as refers to old constructions and to the architectural heritage. In the latter case, the possible reversibility of applications is particularly significant.

Its main purpose is to develop a strengthening system intended to provide the buildings with a seismic performance capable of ensuring the principles equivalent to a “Basic Safety Objective” BSO [ATC, 1996]:

Protection of the users’ life for a moderate and relatively frequent earthquake (short recurrence interval)

Prevention of collapse for maximum intensity and relatively rare earthquakes (long recurrence interval).

Specifically, other than the “cage” type structural typology, the project also aims at the “gaioleiro” [Silva, 1997b] and “placa” typologies [Silva, 1996]. In fact, if the mild intrusive solutions are particularly appreciated in the case of buildings with architectural relevance (the case of the “cage” type buildings of the downtown area of Lisbon), they are also useful in current buildings, since they reduce disturbance and nuisance caused to users. In fact, they allow to carrying out the rehabilitation works without needing to dislodge users.

Within the framework of the COMREHAB project, the studied solutions consist of flexural strengthening of stone masonry walls (masonry pilasters), using composite materials based on high strength fibres. Actually, this is a type of strengthening that may be particularly relevant in the field of historical buildings and monuments. The advantages, as opposed to solutions based on reinforced concrete, are several: fewer disturbances, both in terms of users and of the very structure; less loading, with consequent reduction in the seismic action and dispensing the possible strengthening of foundations. The adjustment of the different solutions and the assessment of their efficiency, as refers to seismic applications, are to be made through different types of tests, which will be performed by different bodies, during the three stages of the project.

3.4 T4 – Creating support legislation

This designation covers, apart from the fundamental legislative framework, the activities of general planning, prioritisation and definition of criteria for different decision-making areas: zoning, training and qualification of agents, certification of procedures and materials. The co-ordination of these activities may be entrusted to an existing body or may lead to the creation of an independent body, due to its extent, duration and complexity. Once the co-ordinating body has been structured, this task does not place significant technical difficulties.

Incentives are one of the mechanisms to be created within the legislative framework. In Los Angeles, for instance, the town council exempts the applicants from a set of impositions, such as the one of building a parking lot, and grants a few derogations as refers to some requirements established in the regulations, provided that the applicants carry out the seismic rehabilitation of their buildings. A few tax incentives are also available, such as a 20% credit for expenses related with the seismic rehabilitation of buildings at risk, which, in the case of buildings with historical value, may be increased to 25%; acceptance of reduced periods of writing off the investment, etc. There are also other incentives that can be implemented through insurance companies: the premiums could be reduced for seismically rehabilitated buildings.

3.5 T5 – Training and dissemination

The deficiencies of the various parties involved, which will be further analysed in paragraph 4, may put into jeopardy the success of the Programme. Therefore, it is essential to eliminate all the possible deficiencies. In order to achieve that, it is necessary to accomplish a major training and dissemination effort, duly based on well-structured and high quality documents. In this context, reference can be made to the example of the Federal Emergency Management Agency (FEMA). In fact, ever since 1984, when its seismic rehabilitation programme has been launched, twenty publications, as well as software and audio-visual training material have been produced, which have been distributed to design companies, technical staff of services that supervise the construction of buildings, teachers, researchers and general public. That technical material is included in the following trilogy:

1) A method for the quick identification of buildings that may be hazardous in case of earthquake, which can be done without having access to the building itself;
2) A methodology for assessing the buildings with more detail, as regards deficiencies that may lead to collapse in case of earthquake;
3) A compendium of the techniques most used in seismic rehabilitation.

Other than structural documents, a study has been done on costs [FEMA], and a *software* has been created for the application of cost/benefit models to be used by public and private bodies. Furthermore, other subjects of interest to society have also been developed, as well as the identification of a matrix of socio-economic issues that might be raised when carrying out a programme of seismic rehabilitation of constructions. Ever since 1997, the USA have a complete set of commented handbooks or manuals about the seismic rehabilitation of buildings. These documents provide the designers with the possibility of choosing the adequate approaches at different seismic safety levels, by taking into account the geographic location, the performance objectives, the type of building, the occupancy and other relevant factors. These documents have been circulated through a wide variety of bodies involved, being representative of the range of potential users. The work has been accomplished by private consulting companies, involving a cost higher than sixteen million dollars throughout more than 13 years.

A similar preparation effort must be done so that the Programme may reach its objectives. This task presupposes a fairly extensive and meticulous work, a high technological knowledge and a significant ability in complying with specifications. It also requires disciplined and organised staff, therefore the ISO 9000 certification is a justifiable selection criterion.

3.6 Master plans for seismic rehabilitation

Developing, at the municipality level, the principles that are likely to be adopted and integrating them in licensing rules. This is an activity to be supervised by town councils and developed by companies of Group I. It does not place any relevant technical difficulty.

3.7 T7 – Carrying out the works

The last task of the Programme, carrying out the seismic rehabilitation in works, involves the companies of all four groups. This task includes:

Complementary survey, as well as the test for characterising materials and anomalies found;

Preparation of design, specifications, measurement and budget charts and of all the actions necessary for launching the contract works;

The very execution of works, including their adequate management and monitoring.

In this activity, the qualification of involved companies must correspond to the four difficulty classes of works, to the risk involved and to the technology used. Therefore, a few alterations must be introduced in the law for classification and certification of companies. In order to ensure the technical feasibility of the different stages of the process, from design to monitoring, in terms of the four factors referred to above (“know-how”, structuring, technical staff, as well as human and technologic resources), the law should comprise the four groups of companies involved and not only the contractors, as has been current procedure.

4. The business fabric of CC&PW

The final quality of the rehabilitation interventions to be carried out highly depends on the quality of the performance of each of the agents involved, particularly of those responsible for **design, execution, planning and control**. Consequently, any attempt to assess the performance capacity must differentiate four groups of companies (Table III):

Table III – Groups of companies in the sector of CC&PW

Group	Designation	Functions
I	Design, monitoring and consulting offices	Design, planning and control
II	Experts in surveys, monitoring and tests	Support to design, control
III	General contractors and specialist contractors	Execution
IV	Manufacturers and/or distributors of products and specific materials	Support to execution

4.1 Group I – Design, monitoring and consulting offices

It is in the design phase that we can find the causes for most of the anomalies that unfortunately assume high proportions in buildings, even in the case of new buildings. For instance, as refers to structure design, studies conducted in several countries with a more severe design control, [Costa], have led to the conclusion that about 50% of costs involved in the rehabilitation of new affected constructions were the result of errors or omissions in the design phase. According to a recent study done in the north of the country, [Ribas], 64%

of the designs classified in accordance with their quality levels were rated as *“mediocre” or “poor”*, and only 2% were rated as *“good”.* Therefore, the question to be asked is: if Portuguese designers in general have that poor quality level when preparing the designs of new reinforced concrete buildings (the prevailing material in the curricula of courses), what level is to be expected when designing the interventions in existing constructions, with materials and technologies that are only superficially taught in their courses? Another study [Lourenço] demonstrates that the very use of calculation tools is dismayingly defective.

If, in the case of new constructions, the use of design tools is defective and if design in general terms is also defective, the reservations in the case of old constructions are tremendous. In fact, the degrees in architecture and civil engineering are almost entirely focused on new constructions, with results that are apparently below the desired level. In the case of old constructions, in which the training of technicians at the level of university degree is almost non-existent and in which the technical complexity and the need for interdisciplinary knowledge is the highest, it seems legitimate to conclude that the quality of designs is extremely low.

4.2 Group II – Experts in surveys, monitoring and tests

The rehabilitation actions presuppose a preliminary collection work of the data necessary for defining the intervention strategy. That work involves the inspection of those constructions and the execution of different kinds of surveys and tests, usually “in situ”, and which are non-destructive or mildly intrusive, in order to characterise the construction, its structure, the materials forming it and the possible anomalies. The “in situ” tests may be completed with the collection of samples for subsequent laboratory test. Similar methods are also used for controlling the quality on site.

Since these are new and poorly known procedures, their use in Portugal has not been, in most cases, the object of regulations, rules, specifications or manuals. The very training of the different bodies involved in the interventions – owners, designers, surveyors, contractors – does not embrace beforehand the familiarisation with those techniques. Such circumstances lead to envisage the application of those techniques with a certain spirit of adventure.

4.3 Group III – Contractors

The regulation of the activity of contractor companies, which are ultimately responsible for either success or failure of interventions, is a tradition in Portugal. If we consider the low quality standards of the current civil construction works, it is easy to understand why the success of much more complex interventions such as those involved by seismic rehabilitation is seriously put into jeopardy, if those interventions are not entrusted to companies with the necessary qualification. In order to permit an adequate framework of seismic rehabilitation system interventions, it will be necessary to introduce a few modifications in the traditional qualification of the CC&PW companies and, particularly, to promote their effective application, apart from allowing a higher participation of specialised professional associations.

4.4 Group IV – Manufacturers and/or distributors of products and specific materials

There is a wide variety of materials on the market intended for the rehabilitation of old constructions, among which special reference can be made to pre-dosed and pre-mixed mortars, which are sold in bags and to which we just have to add water on site. Nevertheless, those mortars and similar materials often present the inconvenient of not fulfilling the fundamental requirement of repair materials, which is the compatibility with the original materials used in the construction to be rehabilitated. This serves to explain the high failure rate in that type of interventions. The polymeric materials use as basis epoxy and polyester resins, however, in the future, other types of resins are likely to be used. Unlike the products based on hydraulic binders, these are organic products, which are chemically inert and more deformable than cementation products and therefore they do not place, with the same severity, the problem of compatibility.

Table IV briefly indicates the main deficiencies of each of the groups of companies, which result from corresponding failure risk factors.

Table IV – Deficiencies and failure risk factors associated with the different groups of companies

Group	Most frequent failure risk factors
I – Design, consulting and monitoring offices	Prepared mostly for new construction and for aspects related with aesthetics (architecture offices), or with analysis (structure offices), in detriment to those related with technology, quality and durability of rehabilitation interventions.
II – Specialists in inspections and testing	Defective organisation. Absence of quality assurance systems. Doubtful competence, in some cases.
IIIa – Large contractors	Mostly devoted to new construction. Tend to become managers and intermediaries between the owner and the sub-contractor. Tendency to use unskilled work force. The choice of specialised sub-contractors is only based on price. Absence of after-sales services.
IIIb – Small contractors	Insufficient structuring. Lack of technical capacity. Use of untrained work force. Insufficient financial resources. Absence of quality assurance systems. Dubious reliability, in some cases (“cowboy builders”).
IV – Manufacturers and/or suppliers of materials	Tendency to supply “black box” products. Sale through unqualified applicators. Defective supervision of application.

Furthermore, to the deficiencies and failure risk factors of the above agents, we must add those inherent to the very Owner:

	Unsufficient awareness as to the need in preserving and rehabilitating the heritage. Unawareness of the technical issues involved in conservation and rehabilitation. Difficulty in correctly establishing the objectives and interventions. Low selectivity in the choice of the designer and contractor. Too much weight of short-term factors.

5. Technical competence of companies

The specialisation of a company is basically related with the “know-how”, and the human resources, complemented by the available equipment. The nature of that knowledge and of the resources available to put it into practice makes it possible to establish the specialised services that the company is able to provide. Nevertheless, not only the knowledge and the available resources must be adequate, but they also must be structured in a balanced way, so as to ensure their serviceability.

The assessment of the technical competence of companies usually takes into account the following aspects:

A) Knowledge or “know-how”;

B) Permanent technical staff;

C) Resources, particularly as refers to specialised staff and technology;

D) General structure, being particularly focused on its organisation and size.

The considerations presented below refer only to companies. The execution of the Programmes also presupposes the technical competence of regulating bodies of the sector in which they are to intervene, i.e., the state institutes and departments, at the level of the government and municipalities.

5.1 “Know-how”

In order to achieve successful interventions, the companies must have specialised knowledge in the different areas involved in seismic rehabilitation. The “know-how” of the company is therefore the “know-how” of its staff members, but it is worth more than the sum of the individual knowledge of all its workers. Consequently, the lesser the rotation of its staff members and the higher the sharing of knowledge among team elements, the more perceptible this effect is. The company’s policy may promote, to a higher or lesser extent, the up keep members and valuation of the “know-how”.

5.2 Technical staff

In view of the specialisation level and of the quality policy, the companies need a more or less comprehensive technical staff. Therefore, considering the same circumstances, the companies might need to hire staff of higher technical levels and follow more demanding criteria in selecting engineers and other degree holders than in the case of current construction works. The companies must also have intermediate staff with adequate training. The company’s staff is then to include professionals with a work contract with the company, included in the company’s personnel list for the social security and, except in the case of higher level staff, exclusively devoted to the company.

5.3 Resources

5.3.1 Specialised personnel

The efficiency of specialised workers depends on:

Basic school training;

Acquired professional training;

Integration in duly structured qualification systems;

Professional career;

On-site practice.

The skill areas can be divided into three groups:

Current skills: skills currently in use;

Traditional skills: skills corresponding to the ancient “Arts and Crafts”;

Non-traditional skills: skills resulting from the application of non-traditional techniques and materials. Whenever applicable, they are governed by the special procedure regulations. These procedures are submitted to continuous monitoring and control of the selected parameters, so as to ensure that the requirements are exclusively fulfilled and accomplished by qualified operators who have been subjected to a certification process.

5.3.2 Technologic resources

All the equipment, tools and facilities necessary to implement effectively the different expertise services provided by the company.

5.4 Structuring

The companies carrying out the interventions involving further responsibility or requiring a higher technical level should have a Quality Assurance System (QAS), in accordance with standards NP EN ISO 9000, depending on the qualification group required. This implies a sufficient development of departments to carry out different functions within the company.

The companies performing the interventions involving responsibility or requiring an intermediate technical level should be duly integrated in the framework of the “System for Certifying Quality in Building Construction Companies”, which also comprises the Sectorial Committee for Construction of the National Council for Quality (CS/10). This system considers three levels, which are to be chosen by each company and gradually implemented:

Level 1: 4 requirements;

Level 2: 8 requirements;

Level 3: 12 requirements.

The after-sales services are a natural consequence of quality assurance. The QAS of the company should contain a programme of permanent monitoring of the works completed.

The companies should have security systems necessary for ensuring compliance with the regulations and with additional requirements adequate to the risk involved by the special techniques and materials used.

6. Certification of companies according to intervention classes

Not all rehabilitation interventions require the same technical competence from companies, therefore, four levels can be distinguished (Fig. 2).

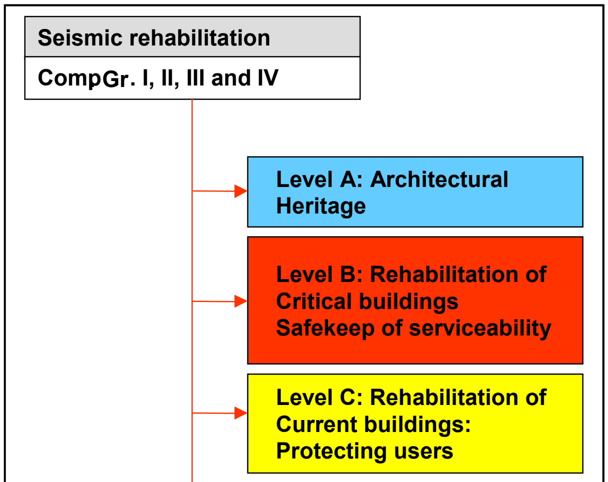

Fig. 2 – Levels of seismic rehabilitation interventions

The certification of companies (recognising their aptitude to fulfil specified requirements) must be adequate to the corresponding intervention levels. To establish a correspondence between the performance capacity of the companies and the works that they are considered able to carry out, the following aspects should be taken into account:

The different seismic safety levels, by considering the geographic location, the performance targets, the type of building, the type of occupancy and other relevant factors;

The risk involved by a certain intervention, assessed in terms of integrity of the very building and of the safety of persons and property;

The specificity of the techniques that are to be used;

The level of possible classification of the building to be submitted to the intervention: by decreasing importance, the national monuments, buildings of public interest, buildings of the classification which is under way, as well as old buildings in general.

7. Corrective measures

In order to implement one or more of the strategies referred to in 3.2, so as to eliminate the deficiencies of the four typologies of buildings, a number of corrective measures must be adopted, which can be organised as shown in Table V.

Table V – Corrective measures by typology

Typology / Corrective Measures	"Cage" type buildings	"Gaioleiros"	"Placa"	Reinforced concrete	Advantages and disadvantages
Improving foundations	x	X			
Correcting previous alterations (addition of floors, removal of structural elements)	X	X	X		
Improving bending strength of masonry pilasters and gables, in the plan and outside the plan	X	X	X		Non-intrusive, if performed from the outside.
Improving compressive strength of masonry pilasters and gables		X			Idem
Repair and/or strengthening of the original bracing structure	X				
Improving the connection masonry pilasters/floors	X	X			Unexpensive
Improving the connection masonry pilasters/"frontal" wall[1]	X				Idem
Improving the connection masonry pilasters/roof	x	x			
Improving the diaphragm effect of the roof	x	x			
Improving bracing between opposite walls	X	X			Unexpensive
Introducing shear resistant walls			X	X	Highly intrusive, if performed inside.
Introducing an additional steel structure	x	x	x	x	Intrusive, if performed inside.
Introducing an additional reinforced concrete structure	x	x	x	x	Highly intrusive, if performed from the inside. Of reduced effectiveness.
Strengthening the existing reinforced concrete elements				x	More or less intrusive, depending on the procedure used.

Note:

"X" Most adequate corrective measure; "x" feasible corrective measure

8. Available techniques. Examples

The techniques that can be used in seismic rehabilitation can be divided as follows:

A) Current techniques: they use the traditional CC&PW technology, and usually are fairly intrusive from the point of view of the disturbance caused by its application to users and to the very building;

[1] Used to designate timber framed wall with diagonal bracing

B) Mildly intrusive techniques: aim at reducing that disturbance:

B1) Using current materials: use of materials usual of CC&PW: cement, steel;

B2) Using non-traditional materials: use of new materials, such as: resins, composites, non-traditional metals.

Annex III contains a list of the techniques that can be used to effectively achieve the corrective measures included in Table V, in view of the seismic rehabilitation of buildings. A few examples are presented below, being divided into masonry buildings and reinforced concrete buildings.

8.1 Masonry buildings

The figures included in Annex IV present examples of the application of some of these techniques in “cage” type buildings, “gaioleiros” and “placa” buildings.

8.2 Reinforced concrete buildings

The figures included in Annex V present a few examples of the application of some of the techniques intended to reinforce concrete buildings.

No technical problems are to be found in this area, apart from the higher or lesser intrusiveness of the adopted solutions. The publications from [UNIDO] and [CEB] contain numerous examples.

9. Cost of interventions

The attempts to establish average values for the costs associated with rehabilitation of buildings, which have usually proved to be unsuccessful, are well-known. The same applies to costs associated with seismic rehabilitation, which obviously depend, on several factors. The final value can easily range from a small percentage to a value equal to that of building replacement.

The final result of the estimate highly depends on the extent of interventions. In order to study this effect [Pontes, 1994], a social housing building design has been used. In this design, four different situations have been simulated: construction of an equivalent new building and three rehabilitation hypotheses: light, average and heavy.

The three intervention hypotheses intended to repair the corresponding deterioration scenarios had, nevertheless, a few common tasks of acting on the whole building. In the three scenarios simulated, an increasingly comprehensive intervention has been proposed. Thus, in the case of light rehabilitation, limited deterioration was assumed (for instance, replacement of only 10% of the roof covering, cleaning of ashlars with steel brush, repaint without replacing the existing frames), whereas in heavy rehabilitation the systematic replacement of almost all the elements that were not part of the coarse work of the building was assumed (for the same examples, total replacement of the roof including the structure, replacement of ashlars, replacement of all the window and door frames).

Table VI shows the results obtained in the simulation of those three hypotheses. The same table also shows the percentage that each type of simulated intervention represents in terms of the construction of an equivalent new building, the later being defined as 100, for reference.

Table VI – Intervention scenarios. Cost components (%)

Solution	% new
New building	100.0
Light rehabilitation	21.4
Average rehabilitation	54.7
Heavy rehabilitation	101.6

It can be thus observed that an intervention at a non-structural level may reach up to 100% of the cost of a new building. Since an intrusive intervention may imply extensive destruction of facings cust and finishings, the possibility of its value reaching similar magnitudes cannot be excluded. Therefore the values indicated by [Platt] for the cost of seismic rehabilitation seem to be low. In fact, he estimates the costs in percentages from about 10 to 30% of the total cost of the new building.

A systematic study has been carried out [FEMA], within the framework of the NEHRP. Table VII includes prices in USD per sqft and EUR per m2, for buildings with an average area (1000 to 5000 m^2).

Table VII – Prices in USD per sqft and (EUR per m2), for buildings with an average area (1000 to 5000 m^2), "safekeeping of lives" criterion (1993, state of Missouri)

Seismicity Typol. group.	Very High	High	Moderate	Low
1 – Unreinforced masonry	18,04 (194)	13,61 (146)	10,7 (115)	9,33 (100)
4 – Reinforced concrete (bending)	25,04 (269)	18,89 (203)	14,86 (160)	12,95 (139)

Notes: 1 m2 = 10,76 ft; 1USD ≅ 1 EUR

Therefore, the values below can be considered as orders of magnitude:

125 €/m2 for masonry (except "gaioleiros")

150 €/m2 for reinforced concrete.

Assuming that the construction cost is 500€/m2, then the percentages obtained for the seismic rehabilitation would be in the range of 30% of the cost of the new construction. It should be mentioned that these costs refer only to the structural rehabilitation work, not including other construction costs, such as:

a) those related with the earthquake;

Non-structural rehabilitation, demolition and reconstruction, repair of damages;

b) unrelated with the earthquake;

Improvement of facilities, accessibility, removal of hazardous materials.

Furthermore, the estimate does not include costs such as those not directly related with the construction, namely management of the work, design fees, re-location, as well as tests and licences.

Consequently, on the basis of the statistical data [Sequeira] presented in Table VIII, it is possible to make an estimate of the whole costs associated with seismic rehabilitation.

Table VIII – Distribution of the Number of Buildings and of Built Area by Construction Period, in the City of Lisbon

Year of completion	Number of Buildings	%	Building Area	%
Before 1755	1742	3.0%	568241	1.0%
1755 – 1880	15711	27.0%	7368383	13.0%
1880 – 1940	14067	24.0%	8154327	14.0%
1940 – 1960	12328	21.0%	11566708	20.0%
After 1960	13876	24.0%	29498556	52.0%
Total	57724	100.0%	57156215	100.0%

Note: Building areas in m2

Table IX shows that calculation.

Table IX – Calculation of the cost of seismic rehabilitation

1	2	3	4	5	6	7
Year of completion	Building area (m2)	Unit cost of rehabilit. (€/m2)	% of rehabilit. for seismic strengthening	Unit cost of seismic rehabilit. (€/m2)	Cost of seismic rehabilit. (M€)	Relative weight (%)
Before 1755	568 241	400	30	120	68,2	0,81
1755-1880	7 368 383	400	30	120	884,2	10,57
1880-1940	8 154 327	400	50	200	1 630,9	19,49
1940-1960	11 566 708	200	80	160	1 850,7	22,12
After 1960	24 582 130	200	80	160	3 933,1	47,01
Total					8 367,1	100,00

Notes: Lisbon and Tagus Valley + Algarve + Azores (3,4 x Lisbon) = 28 450 M€;
According to the publication [SEH], about 22% of dwellings require more or less extensive rehabilitation interventions.

By taking 22% of the sum of the products of columns 2 and 3, we obtain an amount of 3000 M€ for rehabilitation of dwellings in the city of Lisbon. By extrapolating that calculation to the rest of the country, a sum of approximately 24 000 M€ can be obtained. This amount is well compared to the value estimated for the potential market of rehabilitation of the building stock, of approximately 25 000 M€ (Forrehabil's study quoted by [Sequeira]). The introduction of seismic rehabilitation in the regions of Lisbon and Tagus Valley, as well as in the regions of Algarve and Azores will then correspond roughly to doubling that amount.

Nevertheless, these overall sums have only a statistical meaning: since that amount will be diluted throughout 25 years, the additional expenses measured in budgetary terms will be approximately 1 000 M€ per year, i.e., less than 1% of the current GDP[2]. On the other hand, a judicious incentive policy will make it possible that the necessary sums be spent by the very owners of the buildings, the State budget only having to allocate the sums corresponding to those subsidies included in the Programme to stimulate such actions.

[2] In comparative terms, it is estimated that an earthquake similar to the 1755 earthquake could represent 50% of the country's GDP, which would be necessarily spent within a short period.

10. Situation in other countries

Several countries are already implementing seismic rehabilitation programmes, the USA being the most advanced example. *The National Earthquake Hazards Reduction Program* (NEHRP) has been under way in this country ever since the end of the 70s. According to that Programme, the federal agencies involved must identify, assess and correct the unacceptable seismic risks in all federal buildings in the seismic zones of the USA. The methodology to be chosen and the minimum standards to be adopted are described in a set of user friendly guidebooks. The elimination or reduction of the hazard may involve solutions such as demolition, reduction of occupancy, alienation or rehabilitation of the building [Todd].

The city of Los Angeles has been implementing, since 1981, a municipal code "Earthquake Hazard Reduction in Existing Buildings", aiming at promoting public safety and well-being by reducing hazards in non-reinforced masonry buildings built before 1934. The experience of that city has demonstrated that this type of buildings has the tendency to partially or totally collapse during moderate to strong earthquakes [Shepherd].

11. Final considerations

Three and a half years after the author's paper at the commemorative Meeting of the 50th anniversary of LNEC, where the major lines of the Programme have been presented, the situation remains unchanged, even though five of the seven tasks included in it are easy to accomplish and could have been already initiated or, simply pursued (the case of survey of constructions, which has been meanwhile interrupted). We believe that the present paper has proven, in a first approach, the technical feasibility of such rehabilitation, i.e., it has demonstrated that the country, and particularly the business fabric, has the adequate and necessary technical competence to accomplish such project.

11.1 Measures to be immediately implemented

Apart from the five tasks that can be immediately initiated, there are obviously some situations that must be corrected without delay, regardless of the Programme being initiated or not, in order to provide, the new buildings at least, with the minimum seismic safety conditions.

11.1.1 Design review

Considering what has been mentioned in 4.1, as refers to the low quality level of structural design, the procedure currently adopted by the town councils consists of not reviewing those designs and simply adding to the process a declaration from the designer stating that the corresponding regulations have been duly fulfilled, which may prove itself irresponsible in case of a strong earthquake. As in other countries, this review should be entrusted to duly certified companies of Group I, in co-operation with insurance companies.

11.1.2 Requirements as regards technical supervision and inspection of works

Considering the amateurism and the low technical level of most companies devoted to the construction of buildings for sale, the practice currently adopted by town councils of not demanding an effective technical supervision of works and again simply adding to the process a declaration by the responsible engineer, along with the established practice of engineers "giving their name for permit purposes", may also prove to be disastrous in case of a strong earthquake. The same applies to the low stringency level of the inspections carried out by the town councils, which very often are just mere pro forma procedures, not to mention the established corruption. Similarly to design review, this responsibility should be transferred to duly certified companies of Group I, together with insurance companies.

11.1.3 Compulsory character of seismic rehabilitation in all rehabilitated buildings in seismic zones

To date, the rehabilitation of urban buildings (Programme RECRIP – General application, support to condominium-owners; Programme RECRIA – General application, Programme REHABITA – Exclusive application to historical quarters), has privileged the façades, or the housing conditions at most, but has completely disregarded the structural strength. Thus, full advantage should be taken of the architectural and functional rehabilitation of buildings in seismic zones, such as Lisbon, in order to prepare those buildings to endure seismic actions.

11.2 Additional advantages of the Programme

The launching of the Programme would have various additional advantages, such as:

a) Providing the country with technical capacity and experience in this area, which could be made available within the EU, to all countries in the south of Europe, which have similar problems, and outside the EU, to all countries in the seismic regions of the planet having constructions with inadequate seismic strength.

b) Encouraging the building construction sector to focus on rehabilitation, with all the known advantages: reducing the number of new constructions; reducing the activities with excessive impact on the natural environment and built environment; improving employment conditions, both quantity (rehabilitation requires more labour force) and in terms of quality (rehabilitation requires workers with a higher qualification level); etc.

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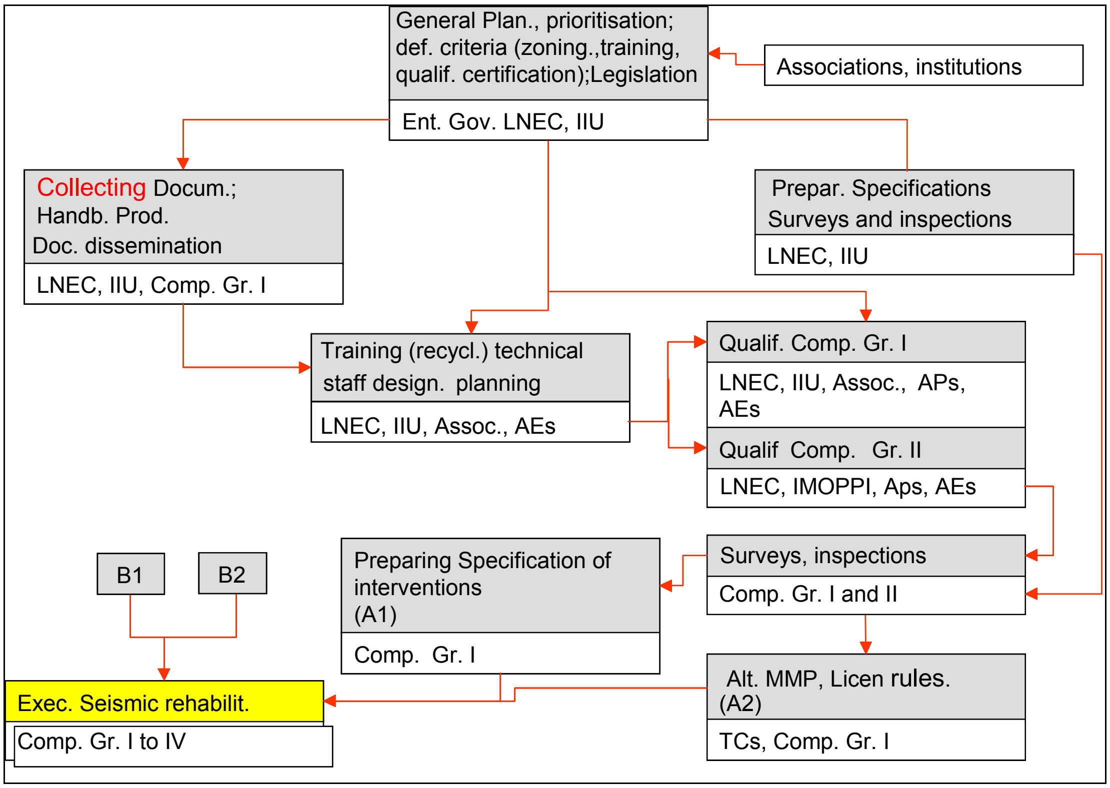
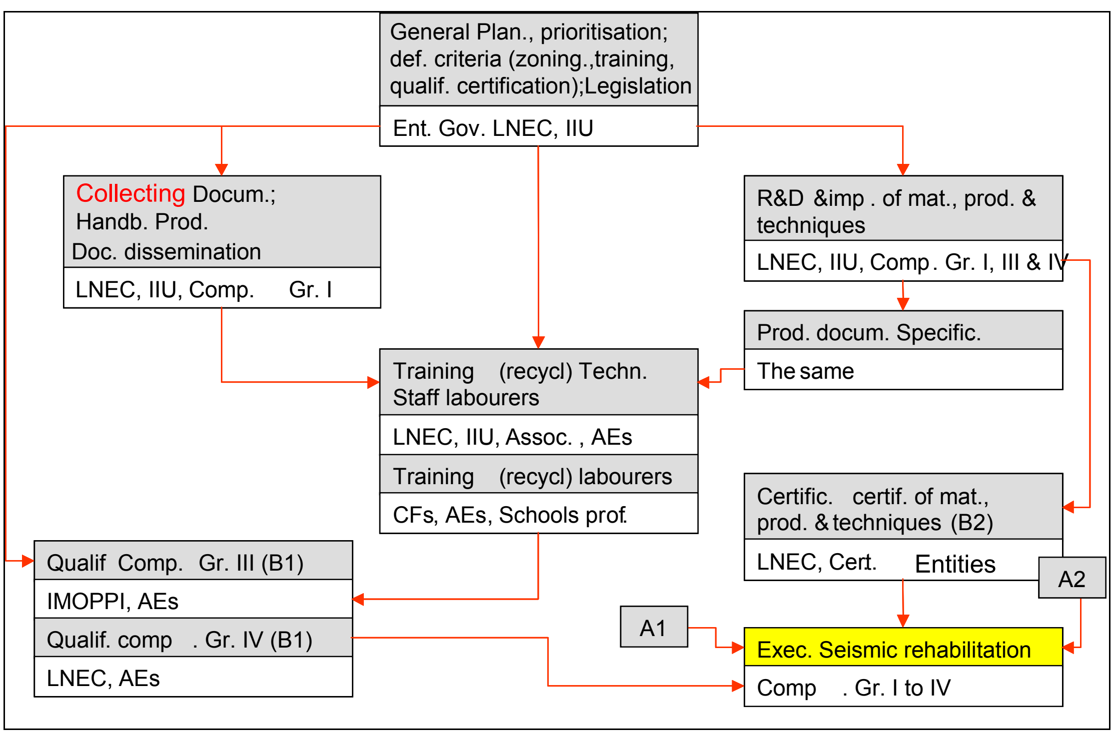
Silva, V.C. e Soares, I.	Use of reinforced concrete in the seismic strengthening of masonry buildings. The case of "placa" buildings (in Portuguese) – Magazine "Betão Estrutural", LNEC, 1996
Silva, V.C. e Soares, I.	Seismic vulnerability of Lisbon "gaioleiro" style buildings and possible measures for its reduction (in Portuguese) – 3^{rd}. Meeting on Seismology and Seismic Engineering. SPES – (Portuguese Society for Earthquake Engineering). Lisbon, 1997
Todd, D.	*Joint Interagency Seismic Evaluation and Rehabilitation Standards for Existing Federal Buildings*. ASTM – Standards for Preservation and Rehabilitation, 1996
UNIDO - United Nations Industrial Development Organization	*Building Construction under Seismic Conditions in the Balkan Region* – Vol. 5 Repair and strengthening of reinforced concrete, stone and masonry buildings, Vienna, 1983
Oliveira, C.S. et al.	Analysis of the Lisbon building stock. Survey into the Campolide-Beato "ring". Presentation of results (in Portuguese), LNEC, 1986
Oliveira, C.S.	Surveying the Lisbon building stock. Inquiry-Form. Collection of results referring to the *Anjos* area (in Portuguese). LNEC 1987
LNEC	Analysis of the Lisbon building stock. Surveying the riverside zone (western sector) – in Portuguese. LNEC, 1990
Oliveira, C.S.	Structural characterisation of the Lisbon building stock (in Portuguese). Association of Portuguese Engineers

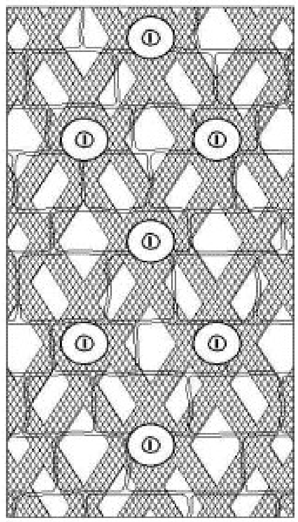
Annex I – Flow charts

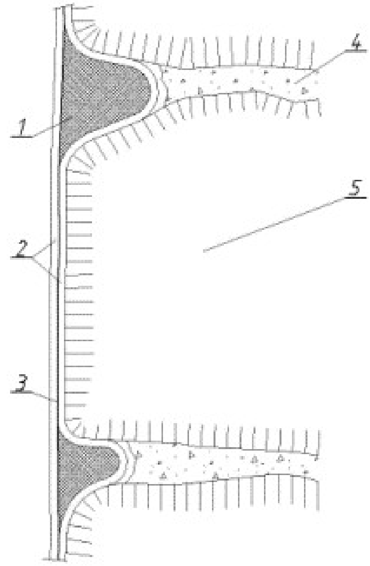


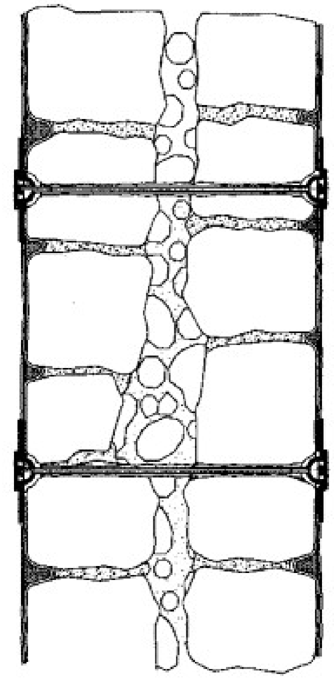


Note: See meaning of entity designations in Table II.

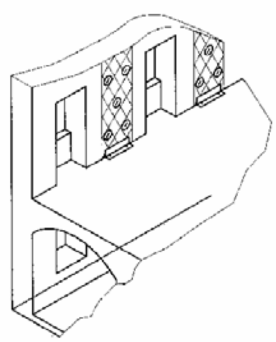
Annex II – COMREHAB Project

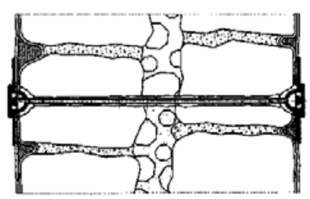


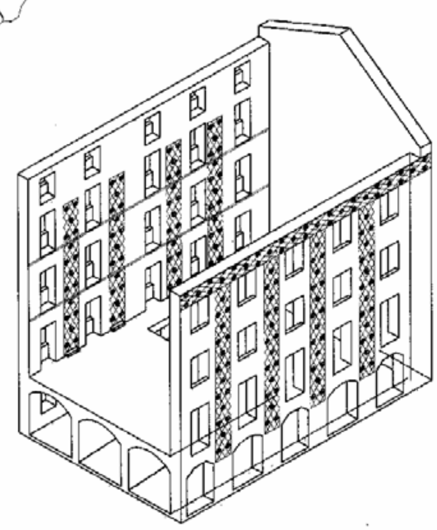




Improving rehabilitation solutions.
Example: Project "COMREHAB"

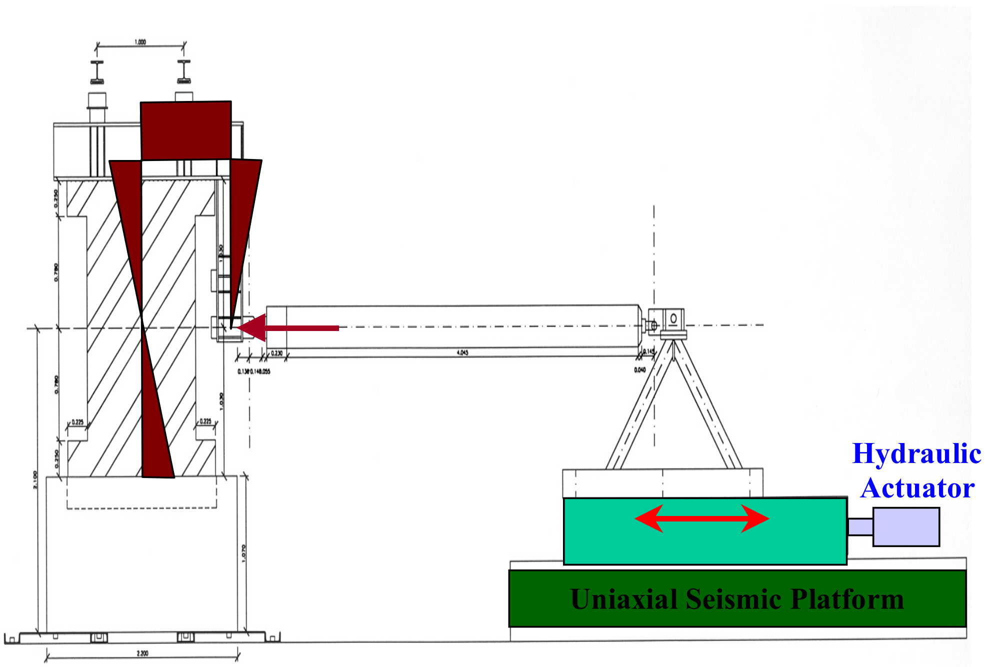






STATIC TESTS

1ST STAGE of TESTS STAP (Project COMREHAB)
Tests on masonry Pilasters Subject to in plan loading



Annex III – List of intervention techniques

Procedure

Designation of the technique

Abridged description	Main applications	Equipment
Stiffening and Strengthening of Old Masonry		
Alterations in old masonry without decompression		
After bracing of the existing structure, new structural elements are made or installed (for instance, beams). These new elements are progressively placed under load, which makes it possible to remove the underlying material, for instance, for opening a span.	Opening of spans in load bearing masonry.	Hydraulic equipment for application of large loads. Monitoring equipment.
Preplaced aggregate concrete on masonry		
Making of reinforced concrete, usually in contact with existing elements, by assembling a waterproof shuttering, placing aggregates and by subsequently introducing cement grout.	Strengthening of structural masonry elements by increasing cross-section in situations requiring a perfect monolithism and in which the use of concrete is acceptable.	Equipment for manufacturing grout; equipment for grouting inorganic binder mortars at moderate pressure.
Application of shotcrete in old constructions		
After preparing the surface to be covered one or more layers of shot concrete are applied, which are usually reinforced with an expanded steel galvanised mesh.	Strengthening of structural masonry elements by increasing cross-section.	Concrete spraying equipment; weighting and mixing equipment; hoses, valves, etc.
Placing mechanically fastened masonry confinement connectors		
Drilling of small diameter holes, on carefully chosen places, in which the connectors are placed and fastened. These are equipped with distribution plates that can be dissimulated or not by the thickness of rendering.	Improving the compressive strength of masonry, through confinement and a better connection between walls.	Dry process drilling equipment, without percussion, for stone masonry.
Placing injected sock masonry confinement connectors		
Drilling of small diameter holes on carefully chosen places, for placement of connectors. The adhesion to the masonry is achieved through deformable socks.	Improving the compressive strength of masonry, through confinement and a better connection between walls.	Dry process drilling equipment, without percussion, for stone masonry.
Making of masonry buttresses		
Masonry buttresses are made on selected locations.	Improving stability under horizontal actions. Stiffening of vaults and arches.	
Dismantling wooden floors for replacement by reinforced concrete slabs		
The wooden floors are disassembled and, in their place, reinforced concrete floors are cast by current procedures.	Rehabilitation of old buildings.	
Injecting masonry with inorganic binder grouts		
Introducing, in the masonry, grouts based on inorganic binder at controlled pressure.	Improving the mechanical properties of masonry by increasing its cohesion and density.	Colloidal mixer; agitator; piston grouting pump; equipment for controlling pressure and flows; packers; pressure gages.
Improving shear strength between blocks by cramping		
Drilling small holes perpendicular or in the very plan of joints, stainless steel or composite bars (dog cramps).	Improving connection between stone blocks or between successive joints of dry-stone masonry.	Dry process drilling equipment without percussion, for stone masonry.

Procedure

Designation of the technique

Abridged description	Main applications	Equipment
Casting of a new reinforced concrete structure cutting the existing masonry		
A new reinforced concrete structure is made by current procedures throughout the interior of the existing masonry building. Construction details are necessary so as to ensure a good connection between the two structures: the old and the new one.	Strengthening and stiffening of old buildings.	
Grouting of inclined core rods in masonry		
After drilling holes parallel to the masonry walls, steel rods protected against corrosion or composite material rods are placed in those holes and are subsequently grouted with adequate grout. The composite rods may be replaced by flexible cables, which can be given a more adequate configuration.	Repair and strengthening of masonry.	Dry process drilling equipment, without percussion for stone masonry; grout equipment and equipment for grouting inorganic binder; packers; equipment for monitoring pressure and flows.
Reinforced sendering		
Cleansing of the masonry, sendering made of mortar with adequate formulation integrating a metallic or polymeric mesh (about 2-3 cm thick).	Repair and strengthening of masonry.	Equipment for making mortar. Grout equipment at moderate pressure.
Strengthening of load bearing masonry components with composite materials		
Strengthening is achieved by applying to the wall strips of composite material of surface strengthening, intended to stand tensile and compressive loads. These elements are normally used together with confinement connectors.	Seismic rehabilitation of existing structures, particularly old constructions and the architectural heritage. In the latter case, the possible reversibility in applications is particularly relevan.t	Equipment for surface preparation.
Strengthening of masonry by concrete jacketing		
Casting of reinforced concrete, by traditional methods, in contact with existing masonry elements.	Strengthening of structural masonry elements by increasing cross-section, for instance, in walls. Stiffening of vaults and arches.	Equipment for manufacturing and placing concrete.
Strengthening of masonry structures with external post-tensioning		
After placing, in accordance with the design, the high strength steel cables, these are tensioned, so as to introduce in the structure a new load system.	Suppressing masonry walls while maintaining them on upper floors.	Hydraulic equipment for post-tensioning application. Monitoring equipmen.t
Installing active (post-tensioned) tie-rods		
Installing tie-rods made up by steel cables or rods or by composite materials, either inserted in holes in the structure or placed on the outside and post-tensioned.	Strengthening and consolidation of old constructions. Stiffening of vaults and arches.	Dry process drilling equipment, without percussion for stone masonry; Hydraulic equipment for application of post-tensioning; equipment for grouting with inorganic binder mortars; packers; equipment for monitoring pressure and flows.
Installing non-tensioned grouted tie-rods		
After performing chases or holes parallel to the masonry walls, protected steel or composite material rods are inserted and end-anchored. Subsequently, they are sealed with a cement grout.	Strengthening and stiffening of old constructions. Stiffening of vaults and arches.	Dry process drilling equipment, without percussion for stone masonry; tightening equipment with torque control; equipment for grouting with inorganic binder mortars; packers; equipment for monitoring pressure and flows.
Installing non-tensioned non-grouted tie-rods		
They consist of protected steel rods or of composite material and are end-anchored.	Strengthening and stiffening of old constructions.	Dry drilling equipment, without percussion, for stone masonry. Tightening equipment with torque control.

Procedure

Designation of the technique

Abridged description	Main applications	Equipment
Improving overall structural performance of constructions		
Cutting throught structural joints in old constructions		
In order to allow a certain structural movement, joints can be cut at selected locations of structural members (for instance, masonry walls), providing the building with the ability of adjusting itself to the imposed deformations.	Differential settlements of the foundation. Improvement of the seismic performance.	Diamond cutting equipment.
Installing seismic dissipation devices		
These devices are introduced in the structure to improve the ability of the structure to dissipate seismic energy.	Reducing seismic loads in the superstructure of buildings, by improving their seismic performance.	
Installing seismic isolation devices		
Different modifications are introduced in the structure, so as to make it possible to install seismic isolation devices between the infra-structure and the super-structure.	Reducing seismic loads in the superstructure of buildings, by improving their seismic performance.	Hydraulic equipment for application of heavy loads.
Storing and Strengthening of Structural Wooden members		
assembling and reconstructing timber braced walls		
Total or partial manual disassembling timber braced walls, after removing plastering and storing deteriorated elements.	Repairing deteriorated timber braced walls.	
Strengthening structural wooden components with composite materials		
Wooden components are strengthened through the addition of laminates of composite material fabric.	Strengthening structural wooden elements.	Equipment for mixing polymeric resins.
Repairing wooden components by replacement		
The structural wooden elements presenting deteriorated or weakened parts are repaired by replacing those parts, saving the existing timber and by introducing metallic elements.	Traditional repair of structural wooden elements.	
Local strengthening of wooden structural components with metallic parts		
The wooden elements are strengthened by installing metallic parts, particularly in joints.	Strengthening of wooden structural elements.	
Reconstituting structural wooden components		
Bracing, removal of deteriorated wooden parts. Drilling holes cutting chases on the sound part of the element, where composite material rods are sealed, using epoxy resin mortar. The part removed from the element is reconstituted with epoxy mortar.	Repairing and strengthening structural wooden components, usually in old buildings, saving original parts.	Equipment for drilling wood and for removing deteriorated zones. Bracing material.
Strengthening wooden pavements with steel girders		
Steel girders are placed under the existing wooden floor, usually under the main beams. The girders must be pre-tensioned, being subsequently shimmed.	Strengthening and stiffning wooden floors of old buildings.	
Strengthening wooden floors and structures by addition of the same material		
The existing wooden floors or roofs are strengthened by adding the same material.	Increasing the load capacity of floors and improving bracing of masonry buildings.	

Procedure

Designation of the technique

Abridged description	Main applications	Equipment

Modification and Demolition of Concrete Structures

Drilling, cut, modification and demolition

Abridged description	Main applications	Equipment
Using adequate equipment, concrete masonry drilled and cut.	Alterations in structures. Creation of joints. Demolition in particularly demanding conditions.	Electric drilling equipment. Electric-hydraulic drilling and cutting equipment. Diamond core bits and saws.

Repairing and strengthening concrete

Strengthening reinforced concrete with pre-placed aggregate concrete

Abridged description	Main applications	Equipment
Making of reinforced concrete, usually in contact with existing members, by assembly of waterproof shuttering, placing the aggregates and subsequent placing of mortar.	Strengthening of reinforced concrete structural elements by increasing the cross-section in situations requiring a perfect monolithism.	Equipment for manufacturing mortar; grout equipment and equipment for grouting inorganic binder mortars at moderate pressure.

Casting Pre-placed fibre concrete

Abridged description	Main applications	Equipment
Casting of a high performance fibre concrete, usually in contact with existing members, by previous placement of fibres, usually steel fibres, in the form of blanket and subsequent placement of cement grout, by injection (preferably) or by gravity.	Strengthening of reinforced concrete structural members by increasing the cross-section, especially if the aim is to obtain an increase in ductility and in the impact resistance, as well as energy dissipation ability.	Equipment for mixing grout. Injection equipment for grouting with inorganic binder mortars at moderate pressure.

Application of shot concrete on reinforced concrete structures

Abridged description	Main applications	Equipment
Cleansing and preparation of surface of the element to be repaired or strengthened. Cleansing of reinforced bars. Spraying of a mixture of aggregate with studied grain size, cement and admixtures, by means of a high performance pneumatic system, either by dry means or wet process. In the dry process, the water is added only at the end of the spraying hose.	Repairing and strengthening of reinforced concrete structures.	Spraying equipment; weight dosage equipment; hoses, valves, etc.

Epoxy resin grouting

Abridged description	Main applications	Equipment
A low viscosity epoxy resin with high adhesion to concrete and fast polymerisation is injected in the cracks.	Restoring the structural monolithism. Eliminating water leakage. Repairing and strengthening concrete structures.	Electric equipment for metering, mixing and injecting.

Strengthening reinforced concrete structural members with composite materials

Abridged description	Main applications	Equipment
Preparing the surfaces of structural members, strengthening with composite laminates or with high strength textile fibre epoxy resin sheets, and acting as external reinforcement.	Strengthening of reinforced concrete structures.	Equipment for surface preparation.

Strengthening with steel plates and sections

Abridged description	Main applications	Equipment
Preparing the surfaces of structural members and strengthening with steel plates acting as external reinforcement, attached to the concrete by means of high strength steel anchor bolts and epoxy resin placed by injection.	Strengthening of structural reinforced concrete members by increasing cross-section.	Equipment for drilling concrete. Equipment for injecting epoxy resin.

Strengthening of reinforced concrete by jacketing and addition of concrete

Abridged description	Main applications	Equipment
Casting reinforced concrete, using the traditional method, in contact with existing elements.	Strengthening of structural reinforced concrete members by increasing their cross-section.	Equipment for mixing and placing concrete.

Procedure

Designation of the technique		
Abridged description	**Main applications**	**Equipment**
Strengthening of concrete structures with external post-tensioning		
After placing, in accordance with the design, high strength steel strands, these are tensioned, so as to introduce a new loading system in the structure.	Strengthening bridges and viaducts and other types of structures.	Hydraulic equipment for application of post-tensioning. Monitoring equipment.
Foundation strengthening and stiffening and Slope Stabilisation		
Making of mechanical anchorages		
Installing "Manta Ray" anchors consisting of a steel rod, anchored in the soil by percussion and fixed by means of a movable steel plate.	Transmission of tensile loads to the ground. Stabilisation of soil support works.	Driving equipment post-tensioning; tensioning equipment.
Foundation Underpinning with load transfer		
After bracing of the existing structure, the new foundations or the units extensions are cast. The new foundation is progressively loaded, by relieving the original foundation, using specially designed devices.	Stiffening or alteration of foundations, while minimising sellements in the superstructure.	Load transfer devices (hydraulic pumps, flat jacks, or other types of jacks, instruments for monitoring forces and displacements).
Installing helical piers and anchors		
Helical steel piers, protected against corrosion, are introduced by sections in the ground, until the required depth, so as to transmit a tensile or compressive load.	Strengthening foundations and underground structures; strengthening and stabilisation of support works; stabilisation of slopes.	Hydraulic torque motor; hydraulic equipment for application of loads; torque control equipment; pressure gages.
Installing micro-piles and root piles		
Installing small diameter columns, with metallic reinforcing bars, with or without sealing bulb, with single or group operation.	Strengthening foundations and soil retaining structures; stabilisation of trends and slopes.	Rotating drilling equipment; equipment for injection of inorganic binder grouts or mortars; simple and double packers; equipment for monitoring pressure and flows.

Annex IV – Examples of seismic rehabilitation solutions for masonry buildings

1. Deficiencies of old masonry buildings

From the analysis of the figures shown in Table I, it can be easily noticed that the masonry buildings are significant. In fact, they still represent the majority of buildings in Lisbon. These buildings can be divided into three main typologies as follows:

> **"cage" type buildings:** regular geometry, the main walls having a stone masonry of reasonable quality, the interior walls in "gaiola" style "frontal", wooden pavements, except the first, which, in higher quality buildings, consists of tile arches; junction elements providing reasonable bracing;
>
> **"gaioleiros":** stone masonry walls with reasonable or poor quality, wooden pavements, defective bracing;
>
> **"placa" buildings:** stone masonry walls of reasonable quality, interior brick masonry walls, reinforced concrete slabs.

Nowadays, there is only a very small number of buildings constructed before 1755. These have a very uneven geometry, bad quality masonry walls, in general, and have wooden pavements.

All the buildings above pose serious doubts as refers to their performance in case of an intensive earthquake. Table I.1 indicates the main reasons.

The figures below show examples of the three typologies.

Table I.1 – Main weak points of the different types of masonry buildings

Typology	Weak points
"Cage" type buildings	Deterioration of the properties of wooden structural elements; Addition of floors; Alterations, particularly as regards stores, which have been defectively designed and/or executed, and which consequently decrease the strength of walls and foundations Unplanned introduction of metallic and reinforced concrete elements.
"Gaioleiros"	Highly precarious construction, in general, with abandonment of the anti-seismic "cage" type structure; Defective bracing; Walls with reduced thickness, with reduced strength and in insufficient number; High height and headroom; Very large gables; Generally defective foundations; Heavy decorative elements; Alterations in the structure.
"placa" buildings	Very heavy structure; Poor resistance to horizontal loads; Addition of floors; Clandestine structural alterations, which have been defectively designed and/or executed, and which consequently decrease the strength of walls and foundations.

2. Possible corrective measures

2.1 “Cage” type buildings

In this type of buildings we have to differentiate those relevant in architectural terms from those that are not. In the first, the corrective measures to be adopted must necessarily be less intrusive than in the latter, so as to preserve, as much as possible, their authenticity and their historicity. This is for instance the case of the “cage” type buildings of the downtown area of Lisbon, where the solutions involving comprehensive structural alterations must be excluded.

The possible solutions are, namely:

Repair and/or strengthening of the original anti-seismic structure, particularly the wood structure;

Correcting alterations previously performed;

Reducing the mass by eliminating the floors that were previously added;

Improving junction of anti-seismic bracing elements placed under the floors at the alignment of masonry pilasters, either involving or not the inner courtyard, and being equipped with shear-link capacity;

Improving overall strength using a reinforced concrete “box” executed on the exterior of the inner courtyard walls.

2.2 “Gaioleiros” buildings

The issue of architectural relevance does not generally apply to these buildings. Nevertheless, the adoption of poorly intrusive solutions is justifiable because the rehabilitation must be made by causing the least possible disturbance to users.

Replacing deteriorated elements, particularly in wooden pavements;

Improving junction by means of anti-seismic bracing elements placed under the floors in the alignment of masonry pilasters, and equipped with shear-link capacity;

Strengthening by introducing a metallic structure in the inner yard;

Improving rigidity using “angle beads” at the corners of main walls, with a reinforced concrete plate either sprayed or applied by grouting;

Increasing the strength of main walls at the masonry pilasters, with a reinforced concrete plate either sprayed or applied by grouting.

2.3 “Placa” buildings

The following measures can be implemented:

Strengthening of masonry walls, with metallic elements or reinforced concrete plates, either sprayed or moulded by grouting;

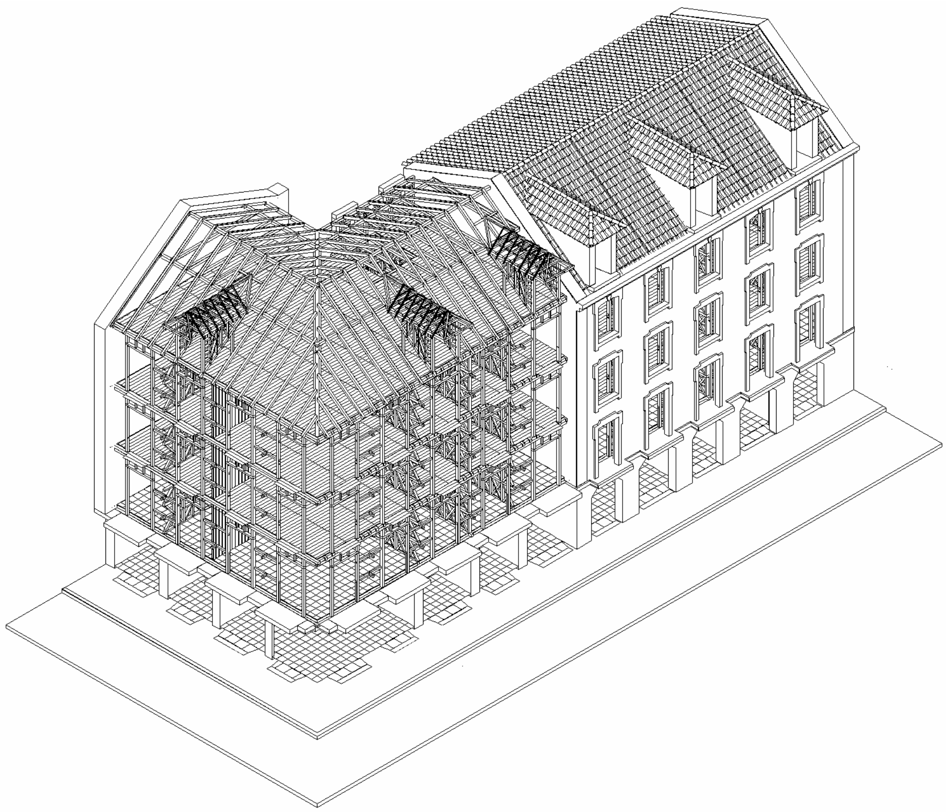
Introducing a complementary vertical concrete structure (shear walls), supported by micro-piles;

Reducing the mass by eliminating previously added floors;

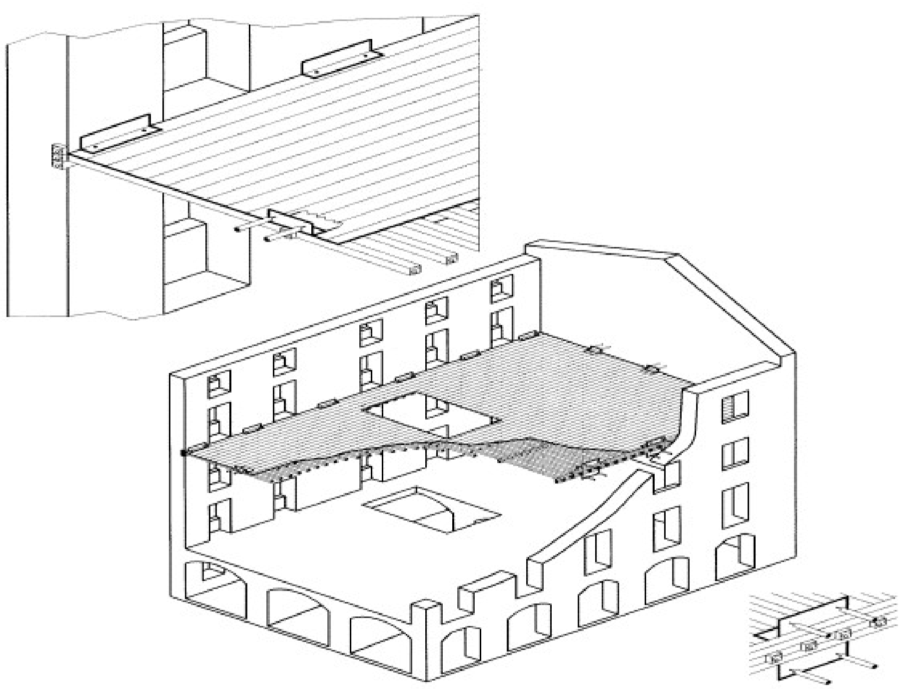
Reinstalling previously removed structural elements (the ground floor, for instance).

The use of reinforced concrete particularly applies to the “placa” buildings. In fact, these are constructions where the reinforced concrete has already been used, on the floors, and which lack mainly vertical elements with shear and flexural strength.

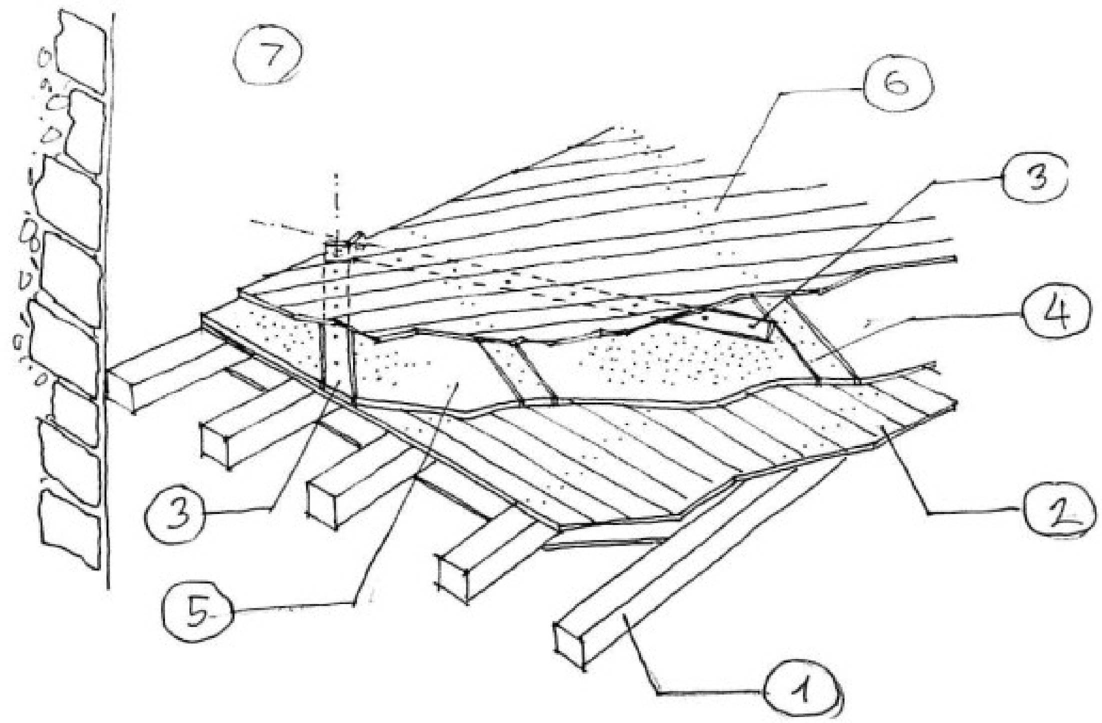
The figures below show some construction details, namely how the strengthening with reinforced concrete can be achieved in those buildings.



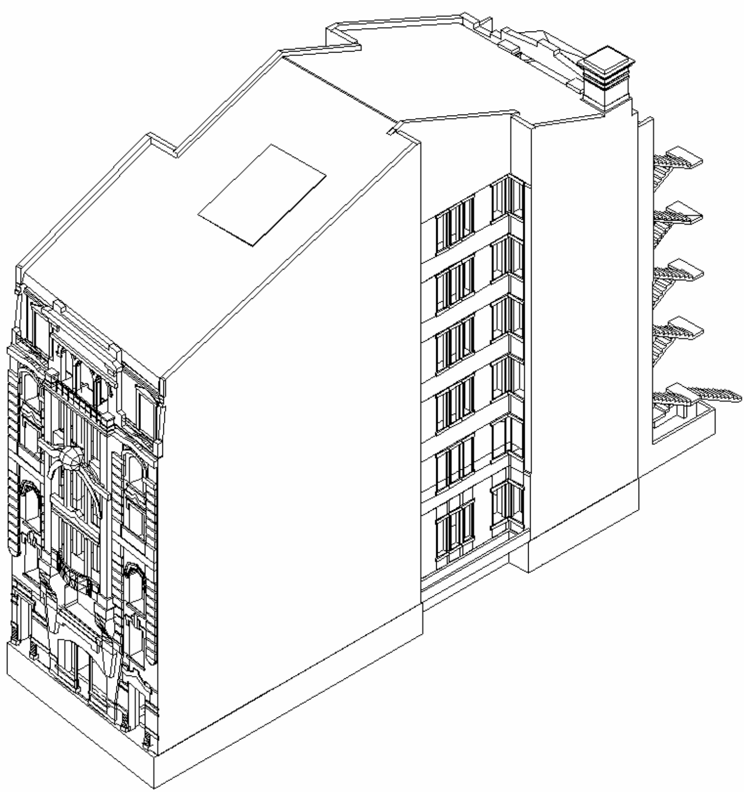
"Cage" type buildings – structure



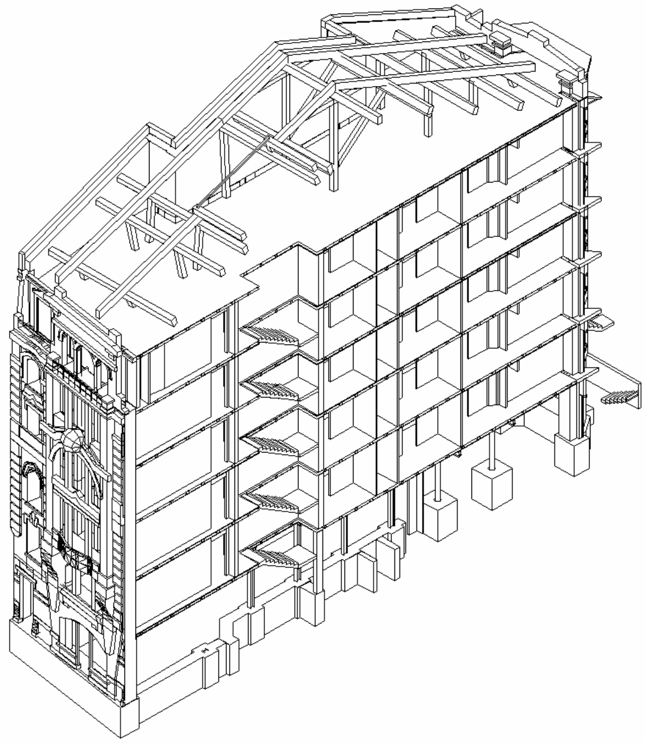
"Cage" type buildings – strengthening of the junction between floors and main walls



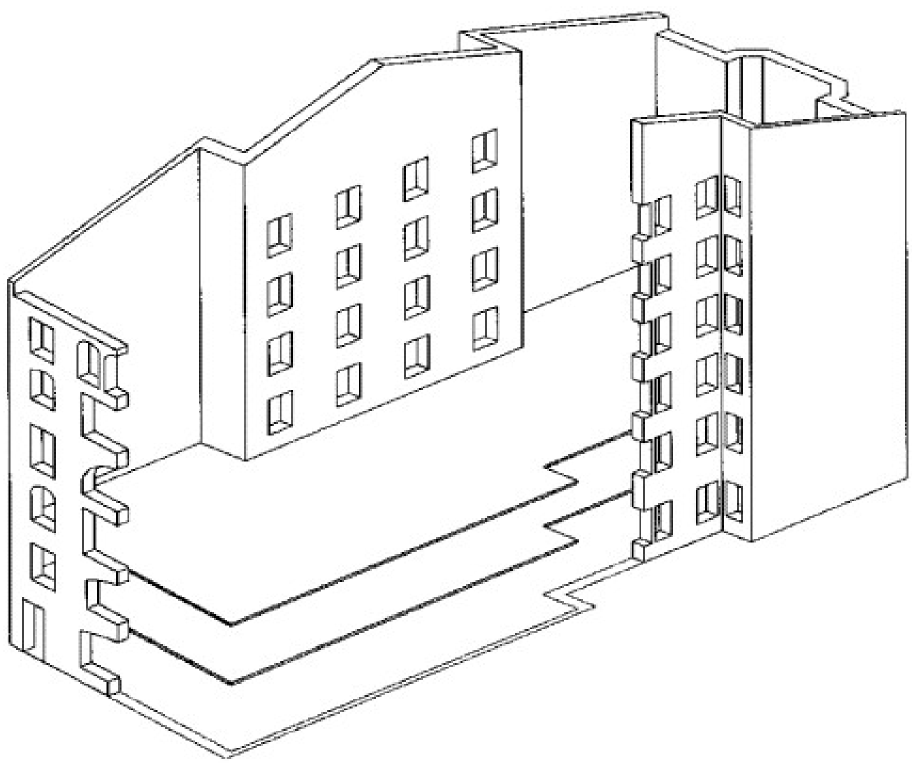
"Cage" type buildings – strengthening of wooden pavements



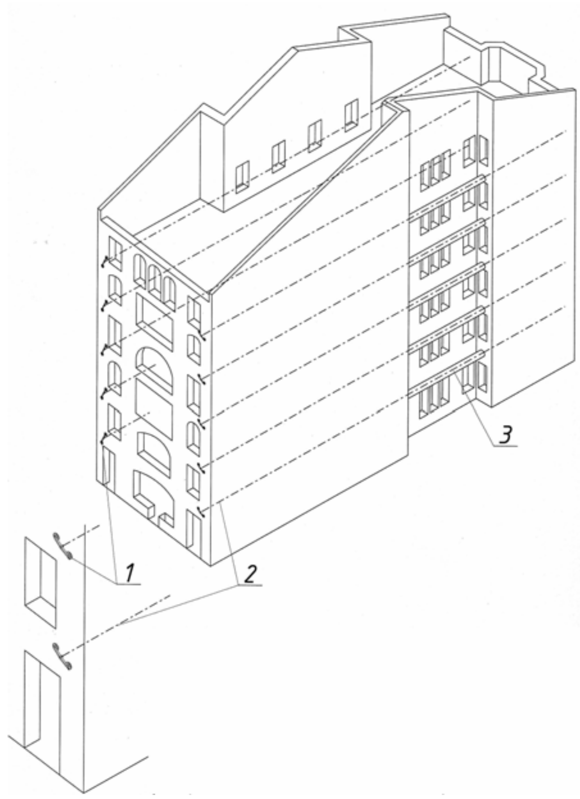
"Gaioleiros"



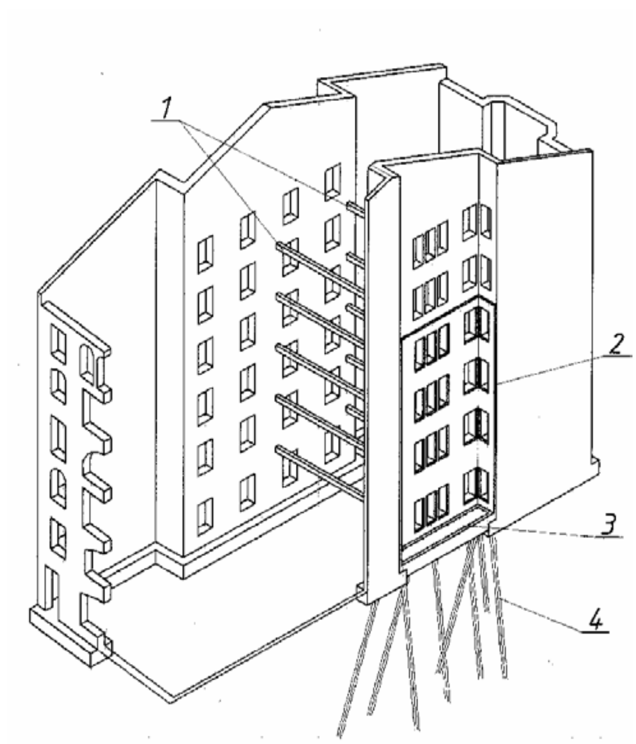
"Gaioleiros" – structure



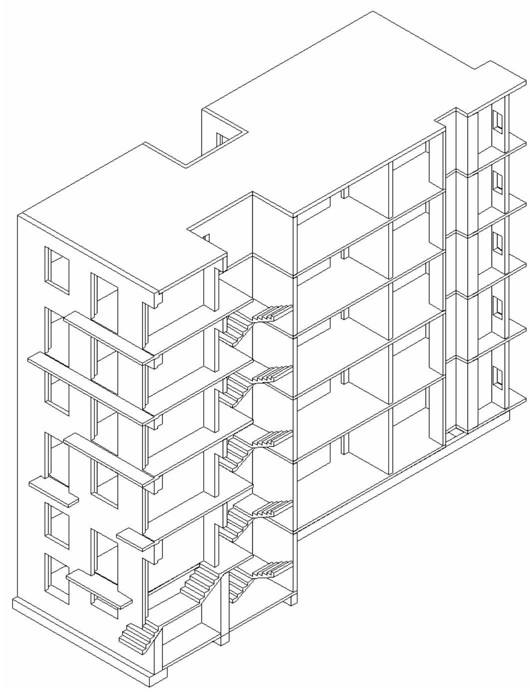
"Gaioleiros" – strengthening of floors



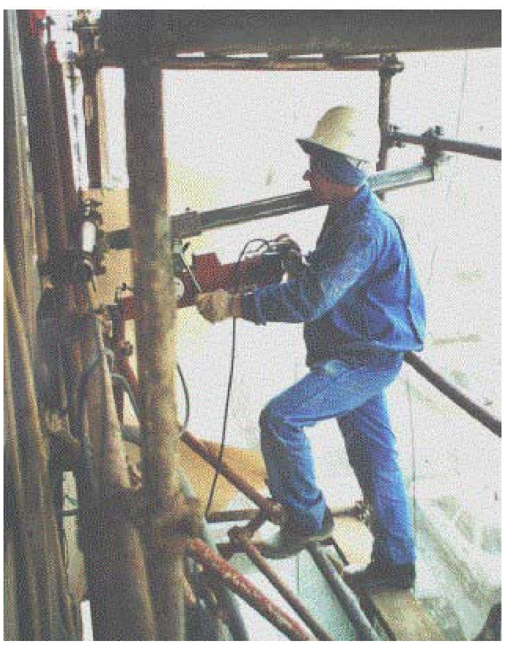
"Gaioleiros" – traditional tie-rods

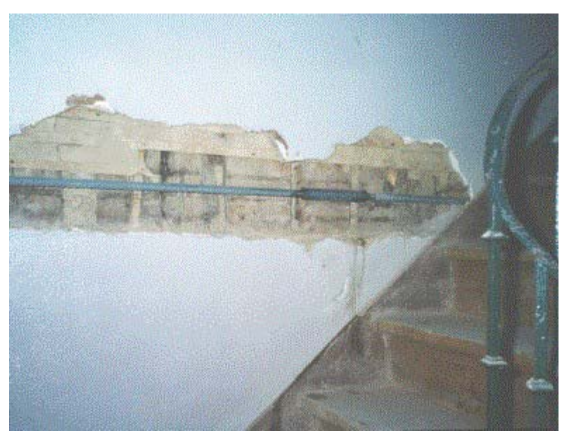


"Gaioleiros" – Strengthening taking advantage of inner courtyards

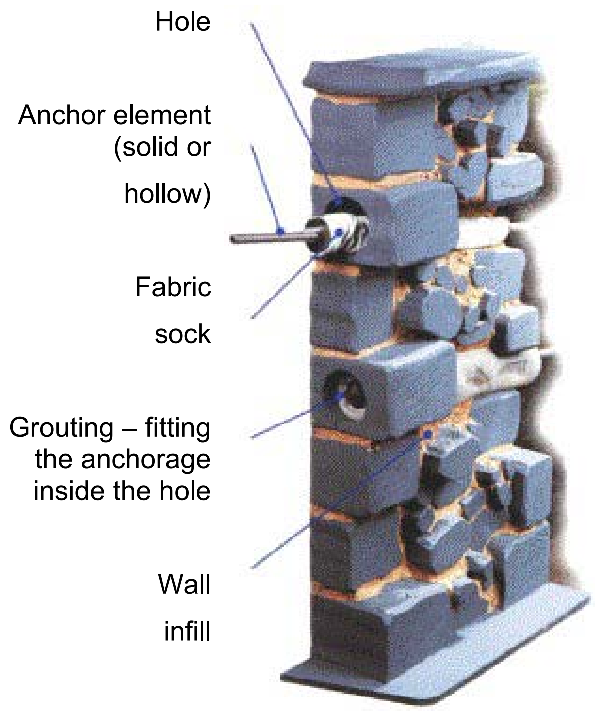


"Placa" style buildings – structure



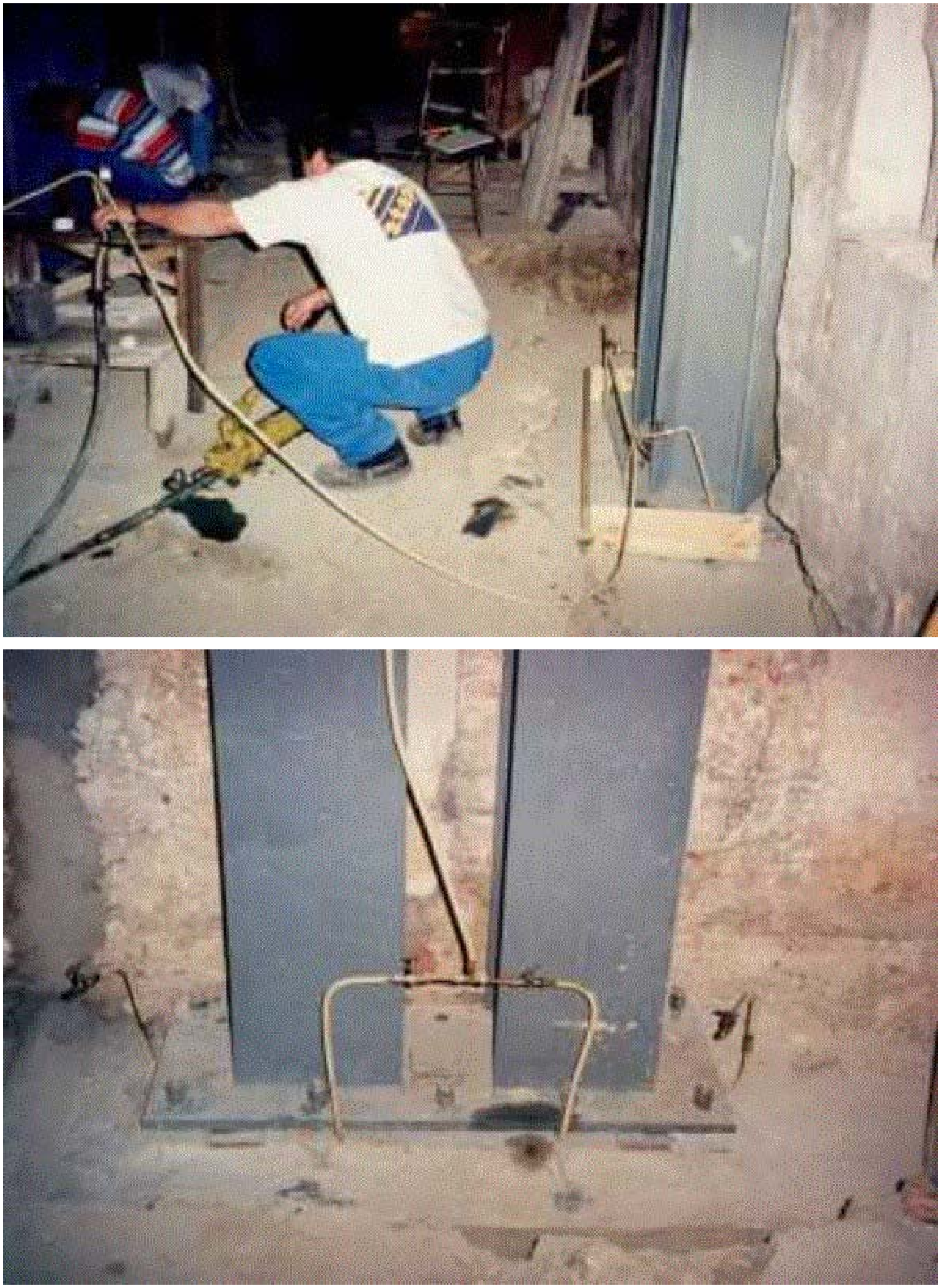


Masonry buildings – applying traditional tie-rods



Masonry buildings – “Cintec”anchor

Masonry buildings –grouting



Masonry buildings – structural strengthening with load transfer

Masonry buildings – structural strengthening with load transfer

Annex V – Examples of seismic rehabilitation solutions for reinforced concrete buildings

1. Main deficiencies of reinforced concrete buildings "without ductility"

Ductility is considered here as being associated with the performance of the whole building, and therefore attention is paid not only to the construction details but to all the structural response. This means, the ability of the structure in dissipating the energy transmitted to it by the earthquake, through its capacity of deformation and redistribution of loads through the different structural elements, by responding as a whole without significant loss of strength.

1.1 Buildings previous to 1958/1961 regulations

Absence of resistant walls

Defective detailing of reinforcing bars. Examples: Beam/column joint, without hoop and without adequate tying of reinforcing bars; discontinue a large part of soffit reinforcement near the supports.

1.2 Buildings with soft storey of the 50s and 60s

The columns of this floor concentrate high loads that easily lead to their collapse.

Other deficiencies

- Strangling of columns cross-section and eccentricities;
- Columns supported on beams;
- Prevalence of plane column/beam frames in one axis/direction;
- Defective detailing of reinforcing bars;
- Beams too rigid comparatively with columns.

1.3 Other typologies without ductility

Buildings with alleviated pavements formed by pre-stressed joists and brick domed floor with insufficient bracing in the cross-sectional axis.

2. Possible corrective measures

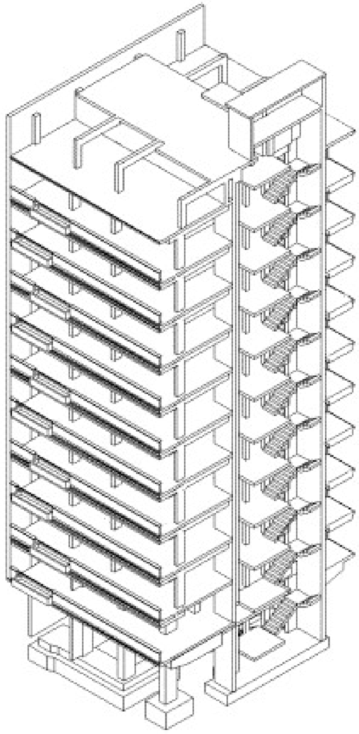
Strengthening of structural elements, particularly of the beam/column joint, the joint hoop being likely to be used (increase in strength and in shear-link capacity).

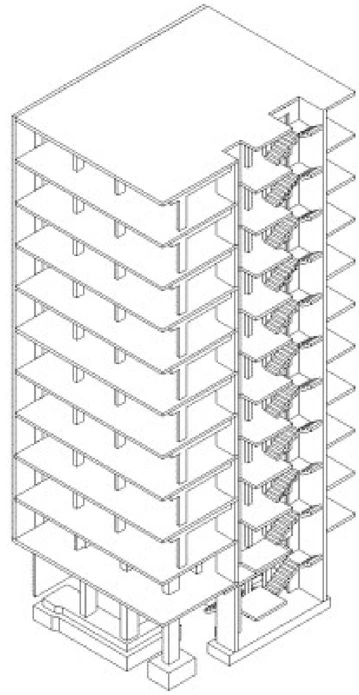
Strengthening of existing walls or construction of rigid walls appropriately connected to the existing structure, on both main directions of the building (increase in rigidity).

The two previous solutions can be used in buildings with soft storey. Furthermore, the introduction of diaphragms formed by bars – strut/tie rod between two columns of the soft storey can also be used. These elements lead the columns to undergo a joint deformation in the presence of horizontal loads, thus producing braced wall panels.

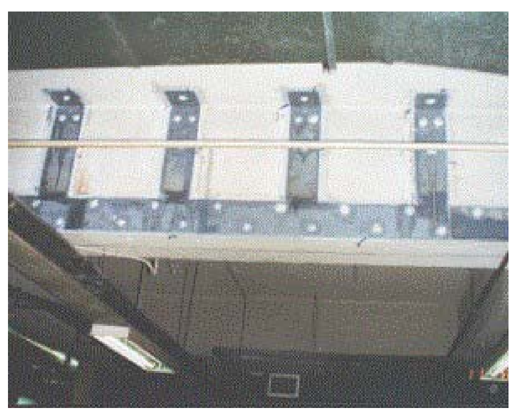
3. Examples

The next figures present a few examples of the application of techniques that can be used to implement the corrective measures previously referred to.

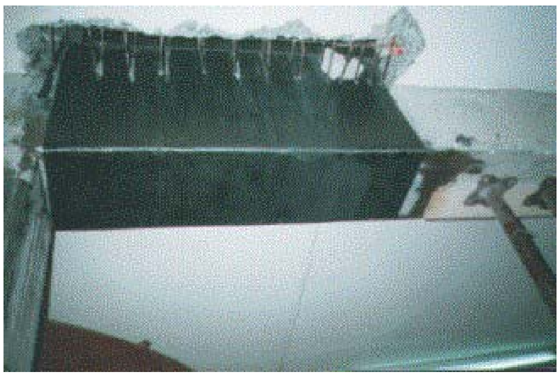


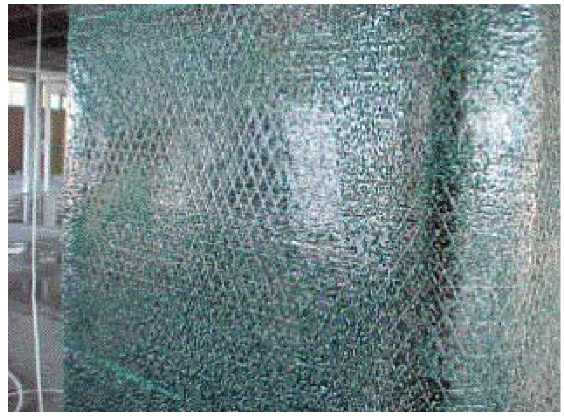


Reinforced concrete buildings

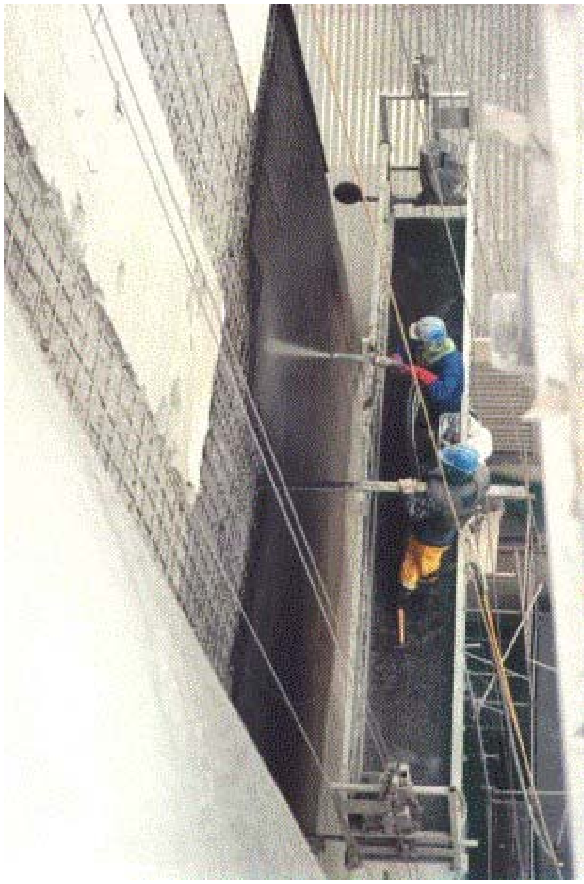


Reinforced concrete buildings
(strengthening with plates)

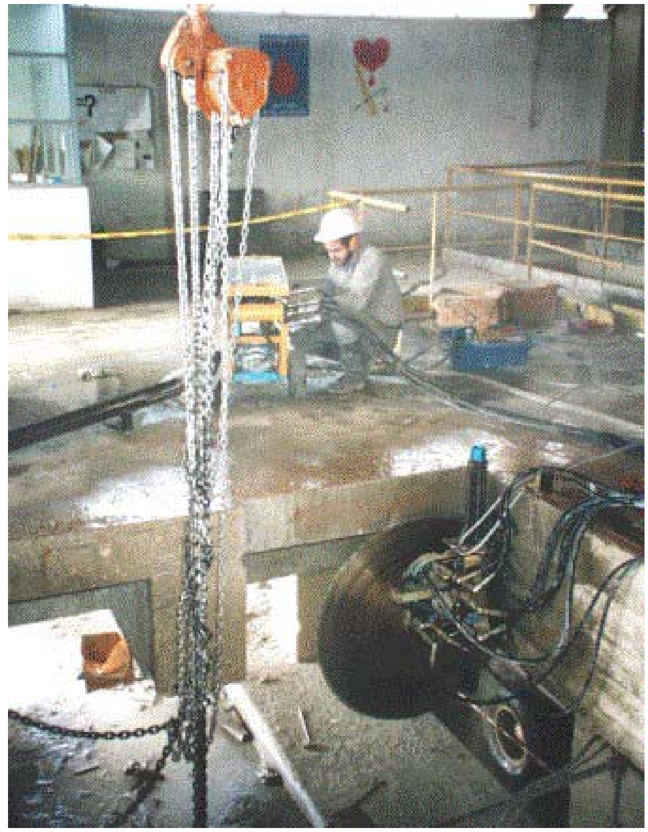




Reinforced concrete buildings – strengthening with composites



Reinforced concrete buildings – strengthening with sprayed concrete



Reinforced concrete buildings – structural alterations

Mitigation of Seismic Risk in Portugal. The role of LNEC

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(LNEC Group of Seismic Engineering Studies and Equipment)

1. Introduction

As is known, Portugal was struck in 1755 by one of the greatest earthquakes in History and which devastated Lisbon and a large part of the south of the country. Apart from this earthquake, which is probably the best known, other earthquakes have affected the country with devastating effects, and undoubtedly others are likely to occur in the future.

There have been mainly two types of seismic events that have affected the Portuguese mainland. In the first place, reference is made to the earthquakes associated with the fracture developed from Azores and continuing beyond the straits of Gibraltar and contouring the boundary between the Euro-Asian and African plates. Particularly at the Gorringe zone, about 150km Southeast the S. Vicente Cape, the movements of the plate boundary referred to above led to strong earthquakes that affected the Iberian Peninsula and the North of Africa. Reference can be for instance made to the previously mentioned 1755 earthquake and to the earthquake of February 1969, which particularly affected Lisbon and Algarve.

In the second place, mention is made to earthquakes originated in faults inside the Euro-Asian plate, for instance the 1909 earthquake in Benavente and probably the 1531 earthquake in the region of Vila Franca de Xira.

Apart from these earthquakes, the historical data of the last millennium refer to the occurrence of catastrophic earthquakes in the Portuguese mainland in 1009, 1356 and 1856.

The seismicity of the Archipelago of Azores results from the volcanic and tectonic activity of the Atlantic ridge, being characterised by crises with a very high number of earthquakes. This Archipelago also has a significant historical seismicity, from which mention must be made of the earthquakes that affected S. Miguel in 1522, 1810, 1852 and 1881, Terceira in 1547, 1614, 1800, 1801 and 1841, as well as S. Jorge and Pico in 1757.

In the XX century, reference can be made to the crises due to the earthquakes of 8th. May 1939, which affected mainly S. Miguel and Santa Maria islands, the earthquakes of November 1939 in Pico and Faial islands, the earthquake of 1st. January 1980, in Terceira, S. Jorge and Graciosa islands and very recently, the earthquake of 09th July 1998, which affected Faial, Pico and S. Jorge islands.

In these circumstances, the protection of populations against the effects of earthquakes must be a nation-wide concern.

Such protection, apart from the Civil Protection aspects, which are very important for minimising consequences of earthquakes after their occurrence, but which are not discussed in this paper, can only be the result of measures intended to reduce the seismic risk in Portugal.

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2. The seismic risk

The seismic risk represents the losses that will be endured by a certain exposed element, as a result of future earthquakes, as well as the probability of their occurrence for a certain exposure period.

The element in hazard may be a building, a town, a country, the respective population, an infrastructure system (for instance, networks) or a specific economic activity. The definition of the element in hazard will therefore condition the way the losses or the seismic risk are assessed. This can be done either in terms of direct cost of the damages in buildings, of the number of casualties, or of the number of injured or dislodged people, as well as in terms of costs deriving from the interruption of a certain economic activity, etc.

The damages caused by earthquakes in constructions depend on the intensity of the seismic action and on the strength and quality of the construction, i.e., on the vulnerability of constructions to that action. In this way, the assessment of the seismic risk comprises three fundamental components, as figure 1 defines: (i) characterisation of seismicity for a certain exposure period and region (seismic risk), (ii) assessment of the vulnerability of exposed elements and (iii) assessment of damages and risk of the seismic region under analysis.

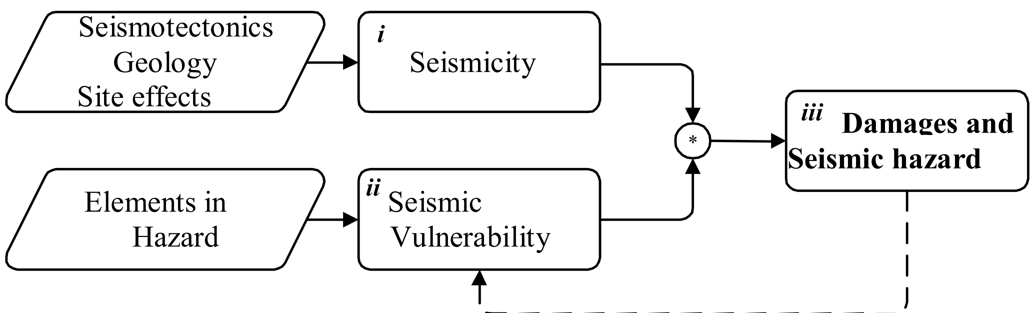

Figure 1 - Components of the procedure for assessing the seismic risk.

It is then understandable that a certain region, regardless of it being subject to intensive earthquakes, may have a reduced seismic risk if scarcely populated, because in this case the exposed elements are reduced. On the contrary, in another region subject to earthquakes of the same magnitude, the more vulnerable the existing structures are, the higher the seismic risk will be.

Figure 2 – Difference in the vulnerability in buildings – Faial earthquake, 8 July 1998.

Figure 2 clearly demonstrates the vulnerability concept. The photograph has been taken after the 1998 Faial earthquake and shows the obvious difference in the vulnerability of the two buildings. Even though the two of them have been exposed to the same seismic action, the one on the left, which had been recently strengthened, suffered no damage, whereas the one on the right collapsed.

3. Mitigating the Seismic Risk

In view of the inevitability of the occurrence of earthquakes in certain regions, the mitigation of the seismic risk undoubtedly depends on the diminution of the vulnerability of constructions or of other elements exposed to the seismicity of the site.

As starting point for any process of this nature, the need to assess the present seismic risk is obvious. In fact, only on the basis of that assessment it will be possible to define the strategy for reducing the risk.

Obviously, the objective of reduced vulnerability of constructions applies both to existing constructions (some of them being fairly old) and to works presently under construction and that are to be built in the future.

As regards existing constructions, their vulnerability must be specifically assessed and, should that vulnerability be excessive, the appropriate corrective measures must be taken, which basically will correspond to strengthening or demolition within a given period.

As regards the works under construction or to be constructed, apart from the permanent effort in updating design regulations, above all, the fulfilment of existing regulations, which establish the design rules that provide the constructions with seismic-resistant characteristics, must be ensured. On the other hand, the execution of works must be dully monitored by an active Surveying, which is to ensure full compliance with the structural design.

Lastly, as refers to existing constructions and to future constructions, all efforts must be made so as to ensure that they are adequately used and subject to periodic maintenance and that they are not submitted to alterations being likely to decrease their seismic strength.

4. The role of LNEC in mitigating the seismic risk in Portugal

The Laboratório Nacional de Engenharia Civil – LNEC, as a state department for research in the area of Civil Engineering, has contributed and intends to continue contributing to mitigating the seismic risk in Portugal.

Obviously, that contribution has been particularly fulfilled by the research works on Seismic Engineering that have been carried out by LNEC.

The activity of LNEC in this field practically began with the creation of LNEC, about 50 years ago, and has been disseminated through the various LNEC departments. In fact, presently, research works related with Seismic Engineering have been under way at the Structure Department, at the Dams Department, as well as at the Geotechnique Department and at the Buildings Department.

As refers to approached subjects and considering Seismic Engineering in a broader sense, reference must be made to the studies related with:

- Seismicity and tectonics
- Seismic risk and seismic action
- Structure and soil dynamics

- Non-linear performance of structures and soils
- Seismic response of structures
- Seismic response of complex systems such as Dam-Foundation-Reservoir interaction
- Seismic assessment of structures, as well as repair and strengthening techniques
- Development of national and international regulations

The activity has both an analytical and experimental character, the latter mostly corresponding, if not exclusively, to the use of the triaxial seismic test platform of LNEC.

This platform has unique features (4,5 x 5,5 m size in plan, maximum load of models of 400 kN and simultaneous triaxial motion) that place it among one of the largest in Europe. It has been integrated in projects of the Programme of Large European Union Facilities.

Many of LNEC research projects in the area of seismic engineering have been developed in co-operation with foreign bodies and with the financial support of the European Union. Nevertheless, the main purpose here is to emphasise the most relevant activity that has been presently carried out at a national level.

In the first place, reference is made to the study under completion that has been conducted at the request of the *Serviço Nacional de Protecção Civil – SNPC* (National civil Protection Service). This study has been performed in conjunction with other three Portuguese research bodies and its main purpose is to assess the consequences of the occurrence of earthquakes (under different harshness scenarios) affecting the Metropolitan Area of Lisbon and some adjacent councils, so as to act as support to the creation of emergency plans by the SNPC. The activity of LNEC in this study has been mainly focused on the assessment of the housing stock and of the so-called vital points (facilities with important functions for the rescuing operations in case of earthquake).

Another study that deserves mentioning is the set of tests that have been conducted at the request of the company STAP, which are integrated in the project Comrehab, and which refer to measures for strengthening old masonry constructions using composite materials. The study includes the execution of 18 tests on the seismic platform.

Lastly, particular mention must be made of the project designated as “Mitigation of the seismic risk in Portugal” subsidised by the Foundation for Science and Technology and by the very research budget of LNEC.

The project, which was launched at the end of 1999 and is mentioned in the base text of the present Meeting, includes both analytical and experimental activity and its main purposes are as follows:

- assessing the seismic risk in Portugal as refers to housing buildings
- identifying and assessing the effectiveness of the measures for structural strengthening aiming at reducing that hazard
- preparing draft regulations that may serve as basis for implementing seismic rehabilitation actions.

As an illustrative example, a few of the results deriving from this project are presented.

As regards seismicity in Portugal, figure 3 shows the envelopes of the response spectra for 278 councils in the Portuguese Mainland, which are divided into four seismic zones for a recurrence interval of 975 years and for the two seismic generation mechanisms (intra-plate and inter-plates) [1]. These results may be used as basis for a future revision of the current seismic zoning.

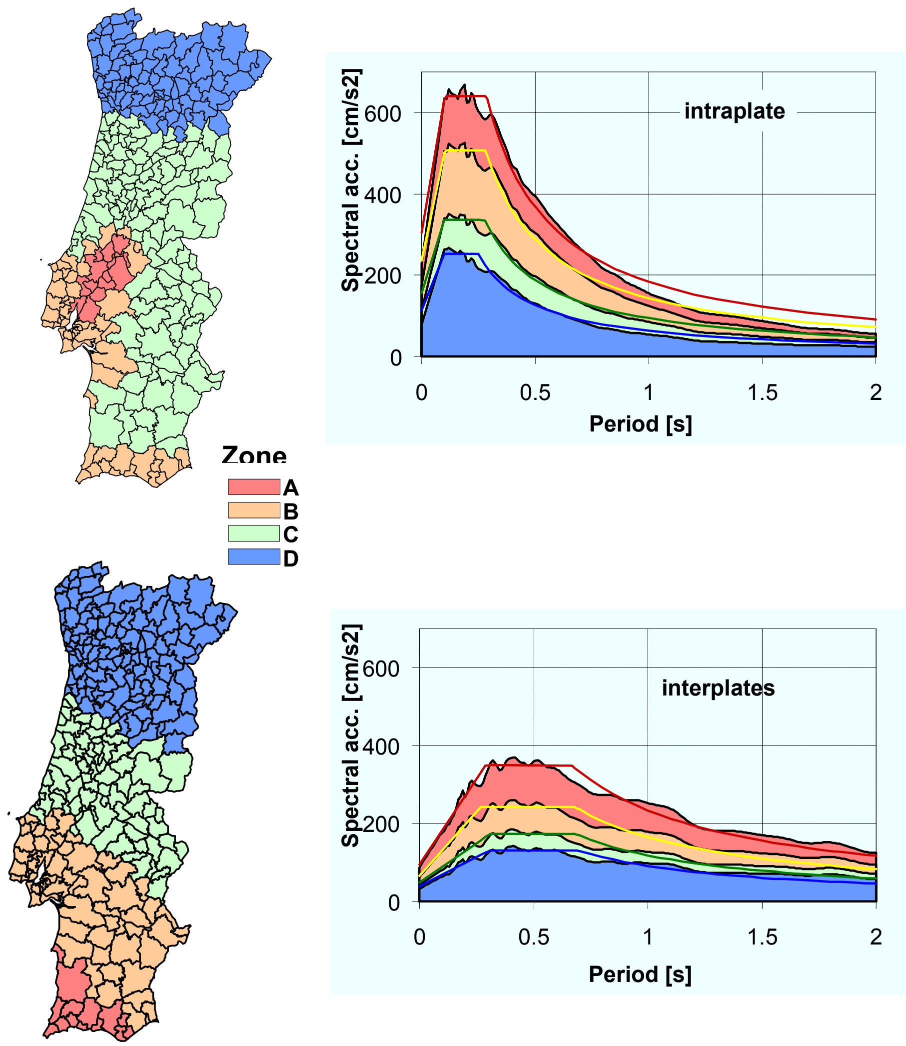

Figure 3 – Envelopes of the response spectra for 975 years of recurrence interval for all the councils of the Portuguese Mainland divided into four seismic zones.

Figure 4 shows the desegregation of the construction typologies in accordance with the data made available by *Censos 91* as refers to housing [2]. The desegregation refers to dwellings existing in 1991. Presently, within the framework of the project, that data is under updating based on other data published by the INE (National Statistic Institute). Furthermore, the ongoing publication of the results from *Censos 2001* is expected to produce a more reliable information as refers to the present national housing stock. Besides, reference must be made to the fact that, at LNEC request, in the housing enquiry of that *Censos*, a few questions were included with the purpose of better assessing the seismic vulnerability of buildings.

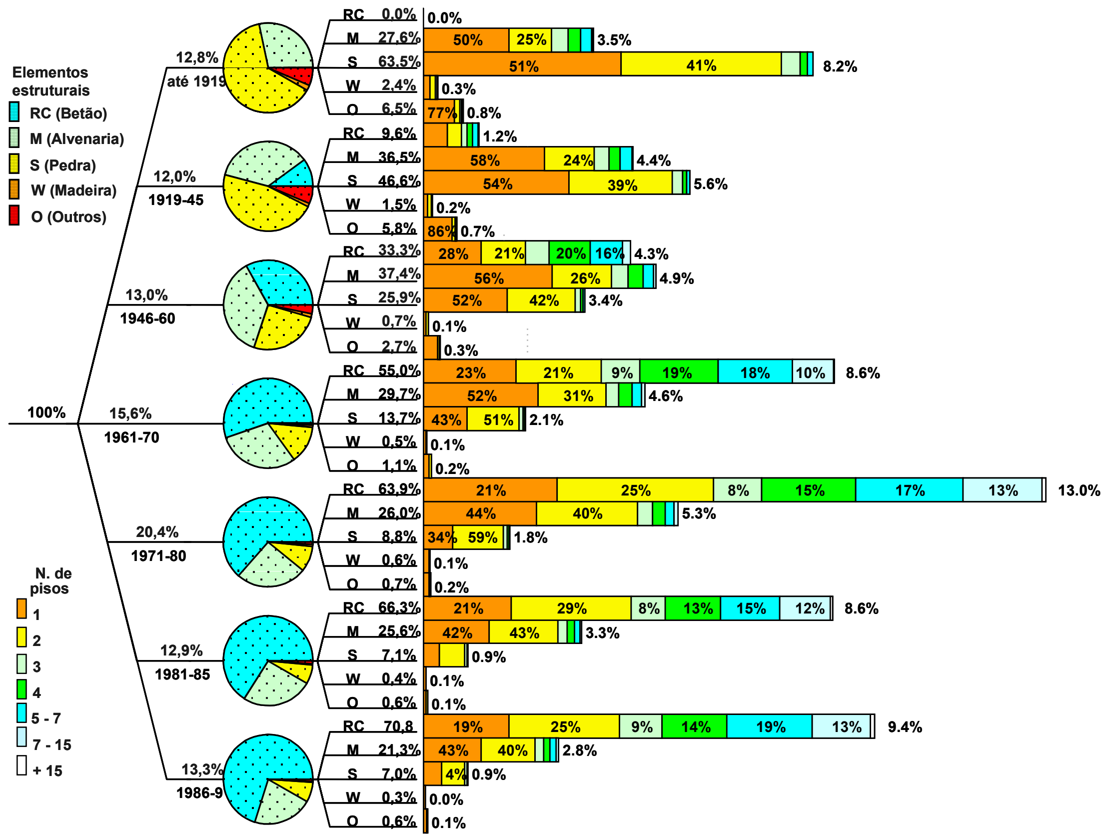

Figure 4 – Desegregation of construction typologies of dwellings in the Portuguese Mainland (Censos 91).

Despite the fact that the data from Censos 91 are not updated, Figure 4 illustrates the aspects as follows:

a) Most dwellings are located in buildings with 1 to 2 floors

b) 45% dwellings are located in buildings with a reinforced concrete structure

c) A significant part of dwellings (25%) is located in buildings more than 50 years old (1991 figures)

d) As per 1991 figures, 62% of dwellings are located in buildings constructed after 1961 (approximate date of the coming into force of the seismic regulations in Portugal)

Lastly, Figure 5 refers to inhabitants and illustrates the percentage of population in each council living in buildings constructed after 1961, i.e., after the coming into force of the seismic regulations [2]. In overall terms, 66% of the population in the Portuguese Mainland lived in buildings constructed after that date. Even though the construction date, on its own, does not ensure an appropriate seismic strength of constructions (particularly, because there is little information about the way those regulations are effectively implemented), it is considered that Figure 5 illustrates, to some extent, the level of exposition of the population to the higher or lesser seismic vulnerability of constructions.

Apart from the research activity, LNEC is also trying to create the mechanisms for transmitting the results obtained from that research to the technical community. The development of regulations has played a significant role as regards the latter aspect and, traditionally, this has been one of its intervention areas.

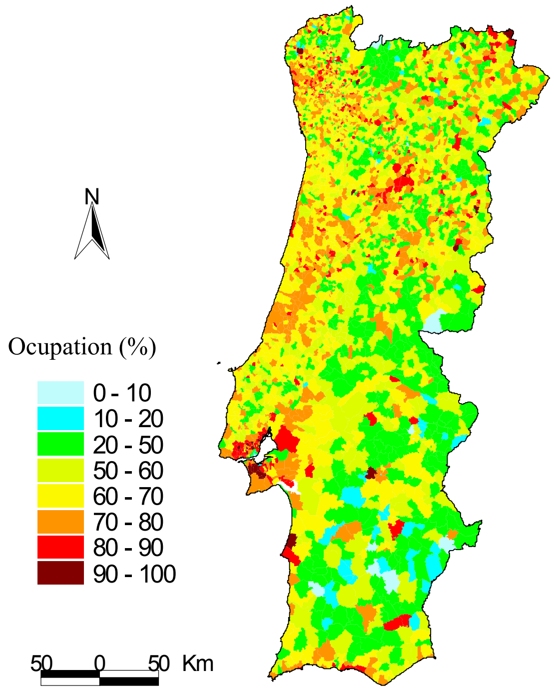

Figure 5 – Percentage of the population of the various councils living in buildings that were constructed after 1961 (Censos 91).

The structural regulations that are presently in force in Portugal have been prepared at LNEC. Furthermore, this institution has been closely following the development of Eurocodes, which, in a not so distant future, are expected to have a standard application to the structural design in all the European Union, by replacing all the regulations and norms existing in the various countries.

The follow up of the preparation of Eurocodes has been developed within the framework of the Technical Committee CT115 with headquarters at LNEC. On the other hand, LNEC has been responsible for the Secretariat of the Sub-Committee of the CEN (European Standardising Committee) that has been in charge of the preparation of Eurocode 8 referring to the design of seismic-resistant structures.

The updating of regulations and rules for anti-seismic construction must be based on results obtained by the progress achieved in scientific research, which makes it possible to understand the interaction between these two components of the activity of LNEC.

Despite the importance of the research and of the existence of regulations adequate to mitigate the seismic risk, these are not, on their own, enough to achieve that objective. Other aspects are also relevant.

One of them is the need to ensure the quality of the design and of construction at all levels, from the most sophisticated construction to the smallest individual dwellings. In fact, the earthquakes are extremely effective in identifying the design errors and the construction deficiencies no matter how dissimulated they are.

Even though the survey of design and construction is beyond the framework of LNEC activities, this entity will support all the initiatives aiming at improving the Quality in construction in Portugal, of note being its action as refers to the awarding of LNEC Quality Mark to some projects.

Another aspect that must be taken into account is the seismic rehabilitation of existing constructions. This aspect corresponds to the fundamental issue of the present Meeting. In this case, apart from the need in developing and disseminating specific knowledge for this purpose, the mobilisation of society and of the financial support to this type of large scale operations is also of vital importance.

Portugal is presently launching a set of urban rehabilitation operations and it is important that these operations should also include the aspects associated with the seismic rehabilitation of constructions. From this point of view, LNEC may contribute with the technical data to the preparation of specific regulations. Besides, as referred to above, the latter aspect is likely to be one of the expected results of the research project under way at LNEC about the “Mitigation of the seismic risk in Portugal”.

The rehabilitation of existing constructions may indeed contribute to decrease effectively the exposure of populations to seismic risk, as well as to ensure a better safekeeping of existing constructions, which is an important aspect in the cases when those constructions are part of the Portuguese cultural heritage. As the recent earthquakes have shown, we must prepare ourselves for that eventuality. This is to be achieved by strengthening of the vulnerable constructions or by adopting measures for their planned elimination, if the latter proves to be the best option. Otherwise, we are most likely to be faced in the future with a major disaster, both in terms of human and economic losses.

5. Conclusions

Portugal, even though being a country with moderate seismicity at a world level, has a high seismic risk in some regions. Actually, the existence, in its building stock, of many buildings with defective original seismic strength, together with the existence of buildings with advanced deterioration, significantly contribute to that high seismic risk.

It is possible to identify different intervention lines for the mitigation of the seismic risk, of which special reference can be made to those as follows:

(i) as regards new constructions, the buildings must be designed and built in compliance with the regulations in force, i.e., an effective monitoring of all the construction process is indispensable;

(ii) as regards existing constructions, it is necessary to assess the corresponding seismic safety and establish an overall and systematic programme for reducing the seismic vulnerability of existing constructions, which is to be dully supported by adequate regulations and legislation;

(iii) also as refers to existing constructions, it is indispensable to ensure that these are not submitted to any intervention (alterations or enlargements, for instance) that is likely to affect their seismic safety;

(iv) concerning dissemination, the population must be made aware of the problem of the seismic risk. Seismicity in Portugal is characterised by long quietness periods and consequently its effects are easily forgotten by society. In fact, the Portuguese population, with the likely exception of the population of Azores, seems to have no adequate perception of the seismic risk, and therefore, it does not exert an effective pressure as regards the need to provide the buildings with an appropriate seismic safety.

In all these aspects, and within its specific field of activity, LNEC is willing to contribute, at a national level, to such an objective of undeniable national interest as is the one of the mitigation of the seismic risk.

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[2] Sousa, M. L., Candeias, P. X. et al: Surveying the housing stock of the Portuguese Mainland for studying its seismic vulnerability based on Censos-91 (in Portuguese), Report 260/00 – C3ES, National Laboratory of Civil Engineering (LNEC), Lisbon, October 2000.

Mitigation of the Seismic Risk.
Contribution of the EC Joint Research Centre to Promoting Joint Programmes and Concerted Actions

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1. Introduction

The European Commission has developed a set of actions related with the protection (people and goods – constructions) against earthquake effects. Reference can be made to the support provided to the preparation of Eurocodes, particularly of Eurocode 8 (General Directorate – Entreprise), as well as to a wide set of supports to research, in the fields of Seismology, Earthquake Engineering and rehabilitation of the built patrimony. The latter were integrated in the thematic programme – Energy, Environment and Sustainable Development (General Directorate – Research) of the fifth Framework-Programme (research, technological development and demonstration activities).

Nevertheless, there is no specific EC programme embracing these subjects and it can be easily deduced that such a programme will only be possible if clearly requested by the national authorities. The questions to be raised are as follows: is the problem of seismic protection placed in an important group of member-states (both member and candidate countries)? Should the Commission contribute to reduce possible asymmetries in seismic protection? What are the direct and indirect benefits? What is the contribution to the sustainable development and creation of employment? What are the benefits of a joint action at the EC level, namely in reference to competitiveness of the European industry in internal and external markets?

The responses to those issues are clearly positive for the technical and scientific community involved in those subjects, but this is not enough! In fact, it is necessary to promote actions of a technical, social and political character with a view to make the authorities well aware of the problems. The "Meeting on the Reduction of the Seismic Vulnerability of Constructions in Portugal" is certainly an important action in this field.

2. Workshop - "Mitigation of Seismic Risk – Support to Recently Affected Countries"

After the earthquakes that have occurred in Greece and in Turkey in 1999, the Joint Research Centre – JRC of the European Commission has accepted the proposal from the Commissioner for Research, Philippe Busquin, to organise a workshop devoted to that subject and having as general objective to discuss and propose a set of actions intended to reduce the seismic risk in Europe. The JRC, together with the General-Directorate for Environment – Civil Protection Unit, have organised the workshop "Mitigation of Seismic Risk – Support to Recently Affected Countries", which took place in November 2000, in Belgirate, Italy, and had the support of various national and international institutions having been attended by more than 180 participants, including representatives from the

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governments of Portugal, Greece and Italy, as well as representatives from the national Civil Protection agencies, from international organisations and from a significant part of the European technical community.

During the round-table organised at the end of the workshop, a set of actions aiming at reducing the seismic risk in Europe have been discussed and identified and which have been considered as being part of a “Plan of Action” in the European Union with the purpose of: 1) promoting the mitigation of seismic risks; 2) promoting co-operation among National Civil Protection Services and establish their co-ordination at an international level in order to improve their efficiency. Five relevant aspects of that plan of action at a EU level are listed below:

1. To involve all the institutions and organisations that are likely to and should contribute to the protection and safety of citizens as refers to risks associated with earthquakes, namely: the European Commission, the national Governments, the Authorities/regional Governments, national and international Associations, Civil Protection Services and the private sector (including insurance companies);
2. To emphasize the importance of the seismic protection (people and property) in European Union policies and stressing the importance of the mitigation of seismic risk in Europe, extended by the future enlargement of the European Union. In fact, a significant part of the candidate countries have a high seismic hazard and the vulnerability of their constructions is also high. Countries such as, Turkey, Romania and Slovenia are examples of the highest risk, as has been recently demonstrated by the Kocaeli (Izmit) earthquakes;
3. To establishing a list of issues related with the mitigation of the seismic risk that require further development and actions within short, medium and long term (research, regulations, civil protection, assessment and strengthening of existing vulnerable constructions);
4. To create a platform at an EU level intended to: a) promote the formal co-operation between national agencies for mitigation of the seismic risk (as for instance: the Servizio Sismico Nazionale, in Italy), and, b) act as an advisory and priority-setting element, which will be able to provide assistance to the Commission and to other international organisations, as regards the definition of policies;
5. To promote an effective international co-operation, namely between the European Union, the United States of America and Japan, by taking full advantage of the opportunities offered by information technologies.

2.1 Research and technological development

As regards research, as well as technical and technological development, the following aspects are considered as priorities: development of rational methods for assessing and strengthening structures, particularly for re-design; development of tools for assessing the social and economic consequences of earthquakes, as well as for assessing the seismic risk, both being indispensable data in decision-making and in priority-setting processes. Simultaneously, seismic strengthening solutions must be studied, which provide a good cost-benefit relation and which make use of innovative materials compatible with sustainable development (architectural preservation, compatibility with environment and durability). In the field of Civil Protection, which will certainly integrate the development referred to above that is ultimately intended to make it possible to identify the zones and constructions of higher risk and to define intervention strategies and plans, new techniques must be developed for detecting people in the debris and for making the rescuing operations quicker and more effective.

Nevertheless, reference must be made to the fact that the way research in the field of earthquake engineering is implemented at a EU level is extremely important. In fact, it is common opinion that the efficiency and applicability of research results can be significantly improved by establishing research programmes, in detriment to the solution based on small/medium projects that are very often punctual and have no general framework, and which have been the solution adopted in framework-programmes. The definition of research programmes in this area may effectively integrate interdisciplinary activities of "seismic engineering" and include plans for developing research results, namely their integration in regulations.

Recently, during the Portuguese presidency (January – June 2000), the European Council has approved the Commission's proposal designated as "European Research Area (ERA)", which is expected to launch the basis for a higher effectiveness of research in Europe and simultaneously to guide the preparation of the next framework-programme (FP6). Apart from the European Parliament, which strongly supports the ERA proposal through its Resolution dated 18 May 2000, also the Economic and Social Committee and the Committee of the Regions support that same initiative. Special reference can be made to some of the general objectives of that proposal, such as: "improving the performance of European research, namely by network linking and by the co-ordinated execution of national programmes, as well as by the network linking of both public and private excellence centres (namely at a university level) existing in the Member-States, and by the execution of major oriented research projects, namely industrial research".

Obviously, the proposals from the technical and scientific community involved in seismic protection can be integrated in the objectives of the ERA, but this is not enough to ensure development and financing of a specific programme in this area. What can be thus done? In fact, we should demonstrate the need for a research programme in the area of seismic protection and make the national governments (Ministries of Science and Technology, in Portugal, and others) more aware of the problem and lead them to propose and strongly support such initiative before the Commission.

2.2 Existing buildings and infra-structures

It is widely known that a significant part of existing buildings and infra-structures (for instance, bridges and viaducts), which were designed and built without specific characteristics for enduring earthquakes, are the main risk factor and may be responsible for the majority of human losses and for the high number of injuries during high intensity earthquakes. Nevertheless, it has been recognised that, very often, their strengthening or replacement by new constructions represents an effort that is, in most cases, beyond the owners' economic possibilities and "technical knowledge". In fact, we should create strong incentives and find/adopt both alternative and attractive financing solutions/policies, within an area involving the bank sector, insurance companies, the government and the European Union.

Moreover, the technical and scientific communities, when required by the authorities and/or by owners, must be ready to: 1) provide the tools necessary for establishing pre-disaster scenarios in order to supervise and promote timely interventions; 2) Establish joint methodologies for vulnerability studies, for damage assessment criteria, including non-structural losses; 3) carry out risk analyses for infrastructure systems (telecommunications, gas, water, electricity, roads, bridges and viaducts, as well as other transport infra-structures,…) either national or supranational, as well as into industrial facilities, in their space and urban environment; 4) provide the authorities with data and assistance in the decision-making process referring to interventions, including the possibility (technical and economic) of execution and definition of priorities; 5) develop regulations and documents (with typical examples) in support to the assessment of vulnerability and to the re-design of constructions.

2.3 Regulations and Norms

The design regulations and codes are of extreme importance for ensuring the design and construction of seismic resistant structures. The introduction of new regulations or the revision of regulations in different European countries, during the last two decades, is an important step towards the design of structures with substantially improved seismic-resistant characteristics. The process of preparation, improvement and "approval" of Eurocodes, particularly Eurocode 8 (national application documents), is also a significant step within CEN. That process has been partially subsidised by the European Commission and serves to demonstrate that the co-operation and participation of different national institutions and authorities make possible to develop and apply common and standardised methods, rules and legislation, even in fields where tradition and practice have assumed relevant asymmetries.

Nevertheless, a few aspects must still be improved, namely in terms of simplification and understanding by the technical community and possibly in terms of a higher rationalisation in defining limit-states. Additionally, we must create the conditions and mechanisms for the periodical revision, as well as the appropriate mechanisms for ensuring adequate application.

On the other hand, the governments of the countries candidate to the European Union must be encouraged to participate in the preparation of Eurocode 8 and in other associated activities.

Other particularly relevant aspects are: the mandatory character of the application of regulations and of their control; the quality assurance in design and construction; the fight against "sub-standard" construction; the rationalisation of the role of insurance industry and the definition of designers and other construction agents' responsibilities/duties. In fact, these are interdependent aspects that must be analysed by the authorities and by public or private insurance companies.

Furthermore, it has been considered that a certification system of building construction products must be developed, especially for most recent products, such as: dissipation and isolation devices for seismic protection, as well as for new materials, since such certification is considered to be feasible and common procedure for conventional products.

2.4 Civil Protection

On the Commissioner's for Environment initiative, who is responsible for Civil Protection, the Commission has proposed a set of mechanisms for co-ordinating the interventions of the civil protection services, which are intended to provide supra-national assistance to the regions affected. Such initiative is important, but other actions are also necessary, namely an imaginative campaign for promoting the risks associated with earthquakes, which will be able to make the economic agents and the populations aware of this issue, as well as of the potentialities of the interventions in the reduction of such risks. As regards civil protection agencies, special reference is made to some aspects that may highly contribute to an effective action, namely as refers to: 1) obtaining data about the "existing building stock" and its treatment, specifically by accomplishing vulnerability studies, quick prediction of "post-earthquake" damages, etc.; 2) periodical drills to test emergency plans; 3) training; and 4) total control of communications during emergency periods.

2.5 Education and Training

The adequate training of engineers and construction technicians is also an important objective to be achieved. These must also have a perfect knowledge and awareness of consequences, which are very often tragic, as well as of the poor quality of design and construction. Therefore, it is recommended that a minimum level of curricular training in seismic engineering should be mandatory, with occasional co-ordination - standardisation between programmes and studies at universities and at middle and higher-level institutes. The implementation of MSc courses in seismic engineering should be encouraged.

Furthermore, seminars (training/improvement courses) should be organised for: 1) future surveyors (inspection), 2) rescue volunteers, 3) construction technicians, as well as continuous training schemes for engineers, architects and other construction agents, particularly in the phase of introduction of new regulations.

3. Contributing to a rehabilitation programme by considering the seismic aspects

A national programme for reducing the seismic vulnerability of constructions, such as the one proposed in this Seminar, is a challenge for the technical and scientific communities, as well as for the institutions involved, and requires a strong political will to cope with a serious safety problem both to citizens and property, including the built heritage. It involves significant human and economic resources, but these must be regarded as an investment in the prevention of damages and as a source of creation of employment and wealth within short to medium term.

Which are the possible external contributions, particularly those depending on the European Commission, that may be mobilised? These can be separated into two groups: those with existing mechanisms and others requiring new mechanisms and programmes. As illustrative examples we can refer to:

- Taking full advantage of research financed by the fifth framework-programme (FP5) (e.g.: 'The city of tomorrow and cultural heritage' as refers to two relevant objectives: *"**Protection, preservation and rehabilitation of Europe's cultural heritage** - Diagnostic technologies: preservation and restoration; integration into the urban environment; etc. **Preservation, renovation, construction, and demolition of buildings, in particular in major complexes** - Fighting hazards and deterioration; security and safety; resource planning; management of the inner-urban environment; etc.")*
- Allocating part of regional funds, while still available, to the execution of demonstration projects, as well as to the rehabilitation of deteriorated high-risk zones.
- Asking the government to include in its "European Agenda" the problem of the seismic risk and requiring its specific introduction in the subsequent framework-programmes; moreover, the government should propose the creation of an EC task-force devoted to rehabilitation and seismic strengthening, relying on appropriate funds, and having a function similar to regional funds. We are certain that this proposal will be enthusiastically supported by countries such as: Greece, Italy and other countries in risk, as well as by a large part of candidate countries. Mention must also be made of the fact that, generally, the European construction industry will certainly benefit from such a programme, since it is expected to participate in it (single and open market).

4. The Laboratory ELSA of the JRC

The Laboratory ELSA (European Laboratory for Structural Assessment), of the Joint Research Centre, has been carrying out, since 1992, an intensive research activity of experimental and numerical character in the field of seismic performance of structures. This research work has been developed in close co-operation with other research bodies (universities, national laboratories…) belonging to the Member-States or to other States with which agreements on co-operation have been established. The laboratory ELSA is mainly focused on research areas related with the assessment of the performance of structures subject to earthquake action. Apart from the assessment of the structural vulnerability, studies are also conducted on repair and strengthening techniques adequate to each structural type. The assessment of the effectiveness of these techniques is accomplished through the execution of Pseudo-dynamic tests on large-scale models of buildings, bridges, as well as of parts of buildings with cultural value (historical interest and monuments).

Real scale building structures are tested, with a view to assess their seismic vulnerability and to study the adequate repair/strengthening techniques. Also in the field of buildings, the new design concepts/methods are being studied (example: Deformation Based Design).

An extensive test campaign has been performed on reinforced concrete structures representing the type of construction used in the 50s (see figure 2). The main objectives of that series of tests are the study of structural vulnerabilities and the development and validation of repair and strengthening techniques. The techniques/solutions tested have been as follows: selective techniques of strengthening of columns; application of reinforced shotcrete on masonry; bracing systems with shear-link devices; and, techniques based on the application of carbon fibres for repairing columns and joints.

Ever since the beginning of its activities, the laboratory ELSA has been carrying out experimental tests that are used as basis for calibration and verification of Eurocode 8. Recently, a real-scale structure with 4 floors has been tested, and which was calculated in accordance with the new seismic design methodologies/philosophies (DBD).

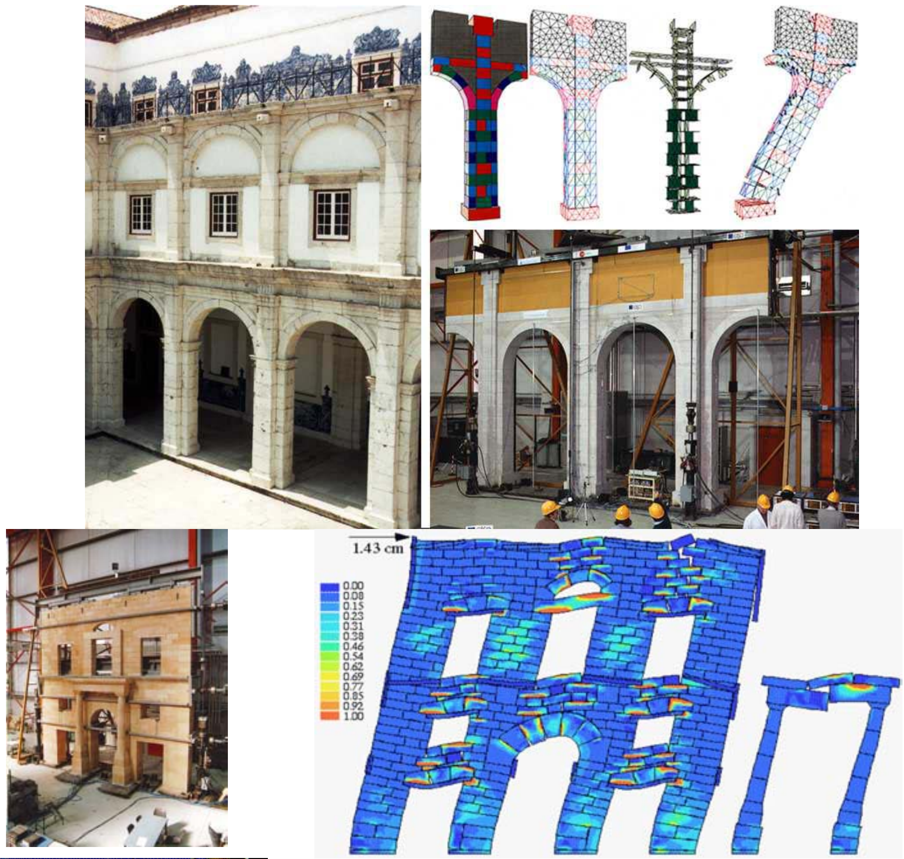
In the field of bridges, and using sub-structuring techniques, tests are performed for assessing the structural vulnerability, as well as for experimentally assessing the effectiveness of different solutions and techniques used to repair bridge piers. Non-linear sub-structuring techniques will be used in tests on large-scale models of bridge piers representing the bridges built in Europe. Tests are also performed in order to assess the effectiveness of strengthening solutions adequate to columns with rectangular hollow cross-section.

In the field of masonry structures and monuments, the laboratory ELSA has carried out tests for assessing their vulnerability. Also as refers to these structures, different strengthening techniques have been assessed (see figure 1). Various projects have been completed as refers to monuments. Of note is the protection with conventional or innovative techniques, such as: base isolation, passive shear-link systems and strengthening with new materials (carbon fibres and fibreglass, Shape Memory Alloys (SMAs), geogrids).

In conjunction with the extensive experimental work developed in the Laboratory ELSA numerical tools are developed for the previous simulation of tests and for modelling of complex structures, as well as for analysing results and for calibrating mathematical models.

5. Final remark

As an integral part of its mission, in the framework of its institutional projects and in the context of the foreseen competitive joint projects under the 6th Framework-Programme of the Commission, the laboratory ELSA will certainly provide the maximum support and contribution to the proposed programme, as well as to the actions to be developed and that are integrated in the perspective of a “Plan of Action” in the European Union. The main purpose of that action is to promote the mitigation of seismic risks and the co-operation among National Earthquake Protection services, as well as to establish their co-ordination, at an international level, so as to improve their effectiveness.



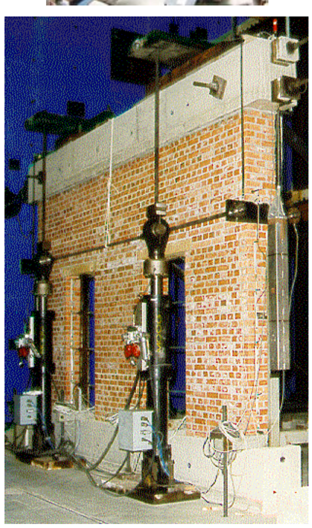


Figure 1 – Tests and numerical simulation of structures of monuments and of parts of masonry buildings in the ELSA laboratory

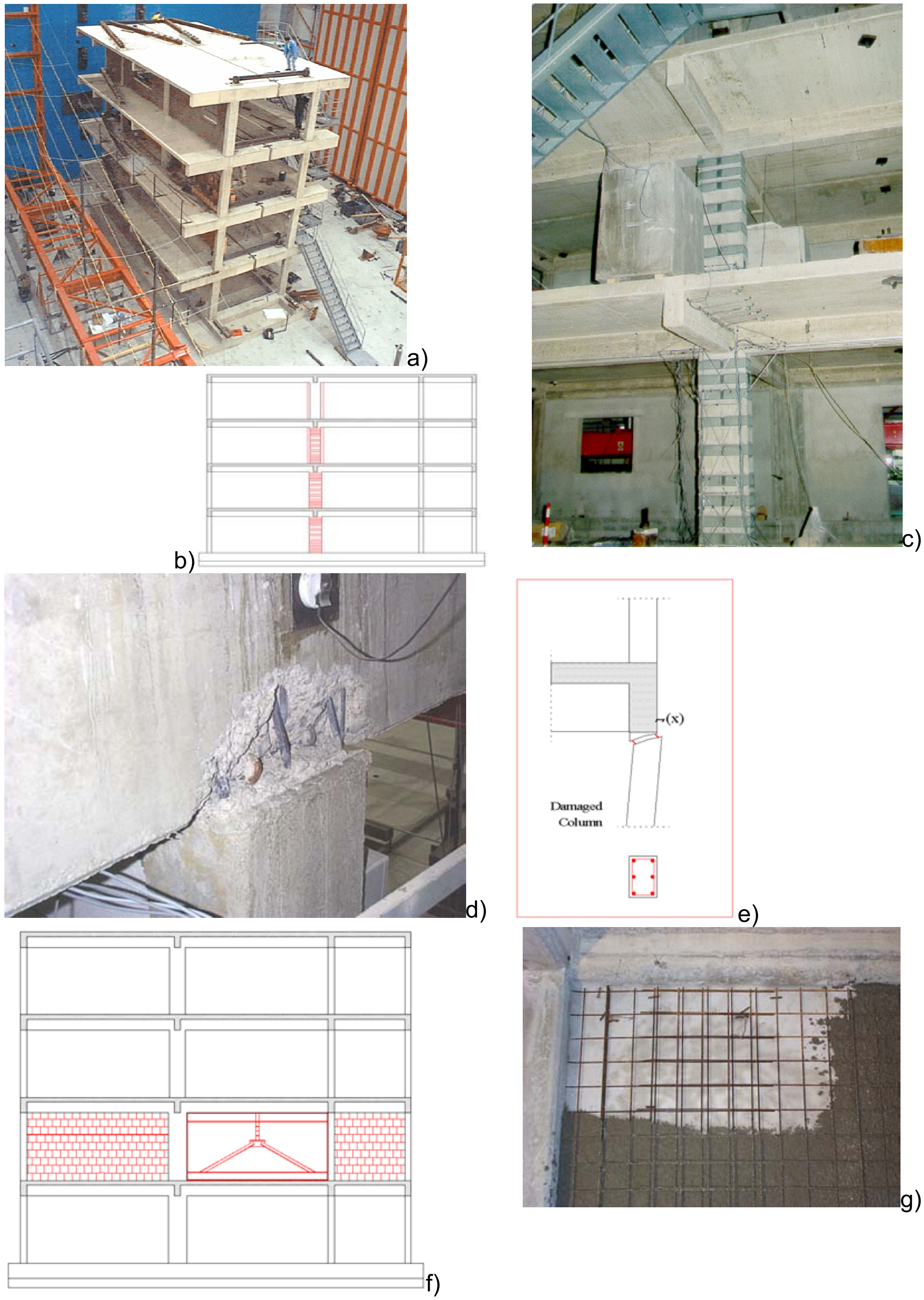
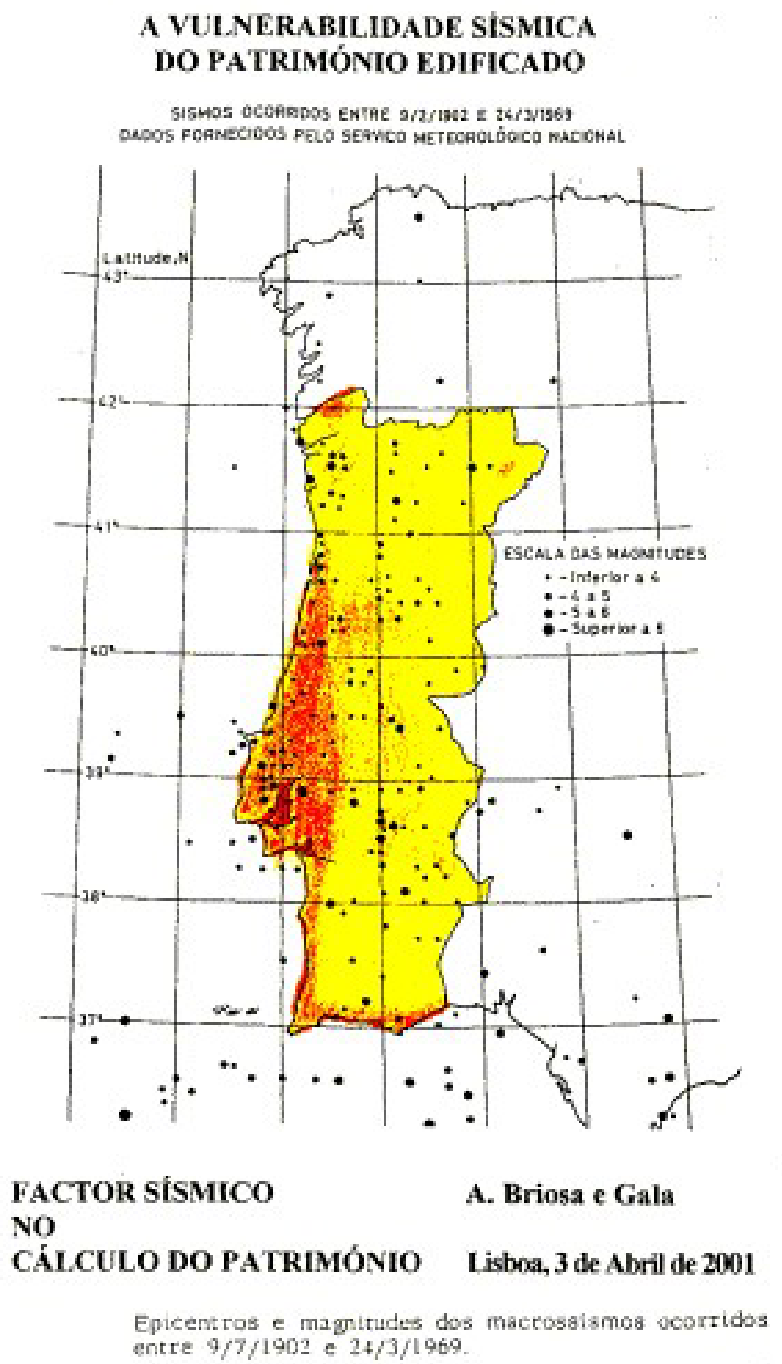


Figure 2 – Seismic tests on reinforced concrete frames representing the construction in the 50s and 60s: a) general view, b) strengthening scheme for the central columns, c) strengthened column, d) and e) damages at the top of the columns, caused by reinforced masonry panels, f) bracing system and shear-link, g) strengthening of masonry panels with shotcrete and welded steel wire mesh.

THE SEISMIC FACTOR AND THE ASSESSMENT OF THE PATRIMONY

A. Briosa e Gala

It is with great concern that I present at this meeting a synopsis of considerations that have been effectively experienced, as refers to Town Planning, Architecture and Civil Engineering.



Even without earthquakes the buildings often collapse, let alone in the presence of such phenomenon.

Expresso 03/10/98 – http://www.expresso.pt/ed1353/e221.asp

Even though on the basis of scientific data we can state that "it is not possible to predict earthquakes" or that "earthquakes are not interconnected", the fact is that we are being more and more taken by surprise by the increase in the tectonic activity all over the world. Moreover, Portugal has an earthquake history in the "Metropolitan Area of Lisbon", Algarve and Azores that is always present in our collective memory when we see all the terrifying images that come from other seismic zones of the planet, the most recent ones being from Turkey, Peru and India, without failing to mention the "famous" St. Andre fault in California and more recently the earthquake in the U.S.A. First, I would like to refer to the geopathology of the metropolitan area of Lisbon as regards geological faults, which, many of them, are disguised by sedimented rocks. Reference can be for instance made to those of *Azambuja*, Tagus Valley and *mar da Palha*. These faults, when active, are responsible for the numerous micro-earthquakes that are very frequent in the region of Lisbon and Tagus Valley.

How to reduce the Seismic Vulnerability of Built Patrimony, is the main purpose of this Meeting.

The initiative is due to the Portuguese Society for seismic Engineering, to which I would like to address my congratulations by the relevance and opportunity of this "forum".

In fact, it is essential that the scientific community will be able to contribute with the necessary considerations, in an attempt to find the solutions that will be effectively able to protect not only people and property but also the quality of the physical and psychical environment where we live. Nevertheless, this subject poses us here an accrued concern:

ASSESSING REAL ESTATE PATRIMONY. THE HAZARD SITUATION AND THE SEISMIC FACTOR.

That is the main subject of the present paper.

1. Underlying this small work, there is a whole envelope that completely exposes either the solidity or the frailty of constructions, as regards the anti-seismic strength of their structures.

   Such fact leads to the need in attributing to a certain real estate element what has been conventionally designated by seismic factor, when determining its patrimonial value.

2. Without trying to minimise a highly complex problem, as is in fact the scientific component of Seismology, special reference must be made to the main aspects of which the surveying engineer must be particularly aware:

   - The place of construction
   - The type of materials used
   - The nature and condition of structures
   - The construction procedure.

   As general principle, I will state that an anti-seismic structure will endure the oscillatory movement caused by a sudden release in energy – the earthquake – if the building operates as a whole, by oscillating as a homogeneous but simultaneously elastic mass. I.e., provided that the homogeneity and elasticity principle will operate. In fact, the collapse occurs when the limit of elasticity of materials is exceeded.

3. It was only after the earthquake, which devastated Lisbon in 1755, that the Marquis of Pombal has promulgated the first "anti-seismic" construction regulations that were, at the time, unique all over the world.

With the Benavente earthquake, in 1909, we finally became aware that we should study a few construction dispositions as refers to this issue.

Among us, the scientific research in the area of Seismology is nowadays a major reference at a national and international level, due to the joint action of: the *Laboratório Nacional de Engenharia Civil*, the College of Engineering, the Faculty of Engineering of the University of Oporto, as well as of the Portuguese Society for Seismic Engineering, to which that initiative has been due.

Stating that "The engineers, the architects and the building constructors have the means to wipe out earthquakes from the list of human calamities, provided that they are willing to do it", is an assertion full of interrogations!!!

This may be true in terms of mathematical and scientific analysis into the control of the effect of earthquakes on constructions, but, in sociological terms, this is false, particularly as regards the psychological effects on citizens an on their behaviour during the earthquake. In that area, huge costs are involved in terms of human suffering with the increase in the number of victims.

4. Below, we present a typological classification of constructions, in accordance with their efficiency level as refers to earthquake strength:

   Type I – Buildings with anti-seismic structure that, in principle, are not likely to be highly affected in case of occurrence of earthquake.

   Type II – Weakened buildings with high probability of collapse in case of occurrence of an earthquake, being in serious danger if the structural elements are defective.

   Type III – Totally unprotected buildings as refers to construction dispositions, where high material damages are likely to occur after the occurrence of the earthquake, leading thus to the collapse of the building.

5. Values proposed for the seismic factor (Sf)

   5.1 The cautious surveying engineer, when assessing a Type I building should only devalue it as refers to that psychological percentage that corresponds to the fact of the building being in a seismic zone. This is intimately related with the close or remote occurrence of an earthquake in that zone. The remotest the occurrence of an earthquake, the highest the probability of occurrence of another earthquake within medium term. Nowadays, with the information available, there is no one that can regard the seismic phenomenon with indifference. Let us assume for this case that the devaluation for the Type I building ranges between 5% and 10%. Therefore, a value ranging from 0.9 to 0.95 can be obtained for the seismic factor:

$$0{,}9 < Sf < 0{,}95$$

   5.2 As regards the Type II weakened building, since the latter has no minimally effective structure in terms of earthquake strength, we must take into account the cost associated with the strengthening of the structure, based on the condition of the building. It would be opportune to carry out that study based on a design representing the Zone. Such design should be included in the so-called "dead archives" of Town Halls, or of other bodies having an historical and cultural heritage.

   The costs associated with seismic rehabilitation may be about 45% of the value of the building, which is represented by the seismic factor Sf=0,55, depending on the specific observation of the building under study. This alteration serves to correct the former text, in view of the new scientific research works.

5.3 If it is a Type III building, with no structuring element, typology that is identified by the very nature of the construction of stone masonry, "*stone over stone*", also designated as "lime and stone" construction, its frailty is complete. This type of construction is very common in the period after World War II (1939-45), not only in Lisbon but in many rural areas. The situation of Azores is alarming and will be analysed in other paragraphs.

The estimation of the patrimony in such circumstances should not exceed the value of the land where the construction is located.

PREVENTION

ON BEHALF OF A CULTURE REQUIRING FURTHER RESPONSIBILITY, I state that:

1. The geotechnical study should be a mandatory element in the project of construction and licensing of the work, in seismic areas that due to

   - the place and history of the zone
   - the construction volume
   - the type of structure

   Will be considered as indispensable for the study of the foundations and consequent stability covering the seismic risk. There are a few municipalities that are poorly demanding as refers to this issue, and others are also poorly demanding due to the absence of a geological chart.

   I can say that the range of the objectives depends on the articulation between design and execution. This explains the need for a professionally reliable survey at the same level as the values under study.

2. It is within these procedures that new professional structures should be created devoted to the certification of quality in the real estate area and within accuracy criteria.

3. The reconstruction and remodelling of old houses in historic zones of high seismic risk must be more than mere cosmetic operations. The certification should be mandatory.

   Eminent participants

   The public authorities should be responsible for subsidising the strengthening works of buildings with a certain anti-seismic strength and the certified civil engineers should be responsible for studying effective technical solutions so as to ensure the safety of citizens.

4. It is urgent to define the technical/juridical concept of "serious and emergency situation", by putting an end to the shameful scenario of buildings collapsing, as in the city of Lisbon, even when there is no earthquake situation. And what about Azores!...

5. As for Azores, of note is the fact that other than earthquakes, we must also take into account the effects of cyclones, of flooding and thus justify additional measures.

6. Also as regards Azores, there are many people resignedly used to live with earthquakes and therefore rely on pure luck or on divine protection, but there are also cases of highest imprudence, when, for instance, someone complains because his/hers application for construction on a geological fault has been refused.

7. The housing stock of Azores must be effectively reconstructed by stages, in compliance with the anti-seismic rules, and with a spirit of solidarity at a national level.

Otherwise, the alternative solution is to wait resignedly for a new earthquake or to emigrate to the U.S.A.

The pre-fabricated constructions are not the final solution for the housing problem of Azores. These are only acceptable for a short transitory period.

Lastly

With the current rent law, it is unthinkable to concentrate the collective effort on the improvement of buildings with no anti-seismic structure.

The carelessness as regards seismic vulnerability is due to the fact that no great earthquake has occurred in the last few years. Nevertheless, this cannot refrain us, but rather, must force us to envisage urgently the planning of structural interventions at all levels.

Lisbon, April 3rd, 2001

A few considerations prior to the assessment of the economic impact of earthquakes

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1. Introduction

The assessment of the economic impact of earthquakes has not been a major concern for economists by well-known reasons. In the first place, because this is not expected to bring any further advancement to the economic science and simultaneously, and as a result, because the instruments for seriously evaluating the problem have already been created. On the other hand, the analysis into the economic impact of earthquakes has been solely focused on the assessment of the cost of the property damaged by earthquakes. Occasionally, it has also been focused on the loss of products caused by the inactivity of the economic sectors after a catastrophe.

The economists, as many other professionals besides engineers and geologists, may play a relevant part in the **adoption of preventive measures** as refers to earthquakes, namely through their contribution to assess the economic advantages deriving from the prevention of earthquake effects. Actually, the motivations for this role are significant and result from the huge losses usually associated with high magnitude earthquakes: the empirical evidence demonstrates that the extent of the losses has increased and that even relatively small earthquakes tend to involve major costs.

The reasons for the increase in losses associated with earthquakes and therefore in the potential benefits from prevention derive from many factors, namely: the increase in population, the increasing concentration of populations and goods in urban areas, the increasing complexity and the consequent vulnerability of modern infra-structures and technologies, as well as the increasing weight of the destruction of assets subject to insurance, etc.

Apart from the tremendous human suffering, some earthquakes have also caused huge economic losses. Reference can be made for instance to the Northridge (California) earthquake, which had almost no human loss but that has nonetheless involved economic losses of more than 22 500 000 000 € (almost ¼ of the Portuguese GDP). The present estimates for the economic losses associated with the repetition of an earthquake similar to the Tokyo one in 1923 are calculated in more than 10 times the Portuguese GDP.

Very often the values presented are an underestimation of the real values, since these are only limited to the assessment of the value of damaged structures. Nevertheless, these costs must be at least accrued with losses referring to cessation or reduction in the economic activity that occurs in the sequence of high magnitude earthquakes. In the Portuguese case, given the concentration of population and of the economic activity[1], these

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[1] Only for reference, mention must be made of the fact that an output loss of 3 months in the Lisbon area will correspond to 10 000 million euros.

costs will always be very high, should an earthquake occur in the region of Lisbon with a magnitude similar to the largest ones that have already occurred here in the past.

2. Risk management

Thus, the most important issue is not the *ex post* evaluation of the economic impact of an earthquake, but rather the **ex ante assessment of the net benefit of prevention**, i.e., of the difference between costs avoided by the adoption of preventive measures and the costs associated with the enforcement of those measures. Therefore, an integrated management policy of risks involved must be found, which is to comprise three stages: (i) determination of the risk involved, (ii) prevention of the risk and (iii) financing of risks.

The **evaluation of the risk** involves two components. In the first place, the evaluation of the probability of occurrence, which is difficult to achieve, since the reduced number of observations makes it impossible to know the event distribution. In the second place, the risk must be evaluated as a result of the conjugation of the probability of occurrence with the values in risk and the corresponding vulnerability. It necessarily implies the execution of an inventory of buildings and of other values exposed to the risk, as well as the differentiation and consequent analysis of both direct and indirect impacts.

The **prevention of the risk** involves three type of measures. First, the so-called awareness and preparation measures, which mainly imply the creation of an awareness environment intended to make it possible to adopt adequate measures as well as to create the conditions for possible preventive measures that are to be adopted by public authorities. Second, reference must be made to the policies that can only be implemented by public authorities and which imply administrative measures, as refers to the use of soils, to construction codes (preparation, application and supervision) and to response plans in case of occurrence of the event. On the other hand, the “technical” measures involve mainly the improvement of construction techniques and the understanding of the impacts on all the “infra-structure of development”.

As regards **financing of risks**, of note is the need of funds for reconstructing and developing the affected areas, **the amount of the necessary funds depending largely on the preventive measures**.

That financing should be shared among all (potentially) affected parties: private sector, (national and EC level) public authorities and insurance companies, the latter may play an essential role in the “financing of risks”.

In fact, the insurance companies may play a significant part in reconstruction and also in the definition of incentives adequate to prevention, for instance, by relating the insurance activity with the execution of prevention measures (*loss mitigation insurance*). Nevertheless, reference must be made of the fact that this role will only be relevant if the access to insurance is generalised. It implies thus, an intervention and monitoring of the public bodies as refers to the rate policy adopted by insurance companies and to decision-making, so as to limit the risk of the sector to acceptable levels.

3. Conclusions

The economic costs associated with earthquakes have assumed increasingly relevant importance. Nevertheless, more important than the calculation of the impact of a specific earthquake (both direct and indirect, on the overall economic fabric) is the making of all efforts as regards the adoption of measures intended to mitigate the economic impact, in case of a possible occurrence.

The **prevention effort must involve much more agents than those traditionally associated with the activity of construction,** both in terms of housing buildings or of public works and in terms of industrial and service infra-structures. The public authorities play an essential part in this area, given their possibility of intervening in various fields: prevention, surveying and monitoring of the application of preventive norms, supervision of the insurance activity. Apart from the State, also the private bodies, namely insurance and re-insurance companies must play an irreplaceable part in prevention and in the financing of reconstruction, the latter only being obviously done in case of occurrence of the events of which the effects are to be mitigated.

THE IMPORTANCE OF QUALITY AS REGARDS THE SEISMIC STRENGTH OF CONSTRUCTIONS

Mário Lopes*

(DECivil, Instituto Superior Técnico)

1. Introduction

This article is a reflection on the influence of design and construction quality on the seismic strength of constructions. For the purpose, the situation is analysed in general terms, with a view to demonstrate the vital importance of quality in the future seismic performance of constructions. In addition, the specific situation in Portugal is analysed. Various suggestions are made so as to improve the existing situation, by discussing the advantages, disadvantages and limitations of suggestions presented.

2. The importance of design and construction quality

The existence of anti-seismic regulations (political and technical responsibility) is poorly effective if not dully applied during design (technical responsibility). On the other hand, a good design is not enough to ensure a good seismic performance of the corresponding construction if not dully achieved (technical responsibility). In practical terms, in order to ensure good seismic performance of the constructions, in the presence of a scenario previously established in the codes, it is necessary to ensure both the design quality and the construction quality. Therefore, it can be concluded that the creation of adequate anti-seismic regulations in a given country is not enough, on its own, to ensure the protection of people and property against the occurrence of earthquakes.

Though what has been stated above is common-sense in the technical community of civil engineering, it does not correspond to the general perception of the public. Anyhow, the experience deriving from previous earthquakes clearly demonstrates that the construction quality completely conditions the seismic performance. The Turkish earthquake, in August 1999, has utterly demonstrated what was stated, sometimes with dramatic effects. The vast majority of the buildings in the affected area consisted of recent reinforced concrete buildings with seismic design. There, it was possible to observe cases of streets with apparently similar buildings, where those on one side of the street had almost not damage, and those on the other side of the street had collapsed. The difference in the performance was, unanimously attributed to the difference in the construction quality.

It is also possible to demonstrate what has been stated above with simple examples. Let us imagine a well-designed building, but where the reinforcing bars of columns are almost unanchored inside the footings, instead of being well anchored inside them. Usually this does not affect the performance of the structure before the earthquake. During the earthquake, the reinforcing bars are pulled out from the foundations causing the immediate and total collapse of the building. In these conditions, the building may be in excellent conditions for decades, it may be submitted to periodical repair works, and nonetheless this will not prevent it from collapsing, should a violent earthquake occur. Other analogous

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detailing or construction errors, either due to ignorance, carelessness, haste, or dishonesty, etc. may have similar effects. The quality of materials, particularly of reinforced concrete, as refers to new constructions, if not dully controlled may in fact be much less than the design specifications, with the same type of consequences. Moreover, if the designer commits a design or calculation error, also due to ignorance, carelessness, dishonesty or by fear of not completing the design within schedule, this may have serious consequences, including also the very collapse of the building.

3. Assessing the situation in Portugal

In Portugal, there are no official mechanisms of control of the quality of design and works in what regards structural safety. The surveying, when available, is usually done at the Owner's initiative. Even though formally the construction quality is one of the objectives, in many cases however the surveying activity is focused on the verification of the quantities of materials applied on site, so as to control costs and the development of the work. The surveying of the design and work, with the effective objective of ensuring the structural safety, is basically enforced in only a few of the major public works or in works of some companies that are more aware of the potential seriousness of the problem or that have a quality assurance and certification policy.

Usually, the Town Councils do not survey and approve the design of building structures. Except in a few rare cases, they only verify if the overall project is complete, including the designs of other fields of expertise. Apart from the relation between the existence of survey and the quality of designs, which will be subsequently debated, this situation leads to the submission of the projects of structures, at Town Councils, being envisaged as a merely administrative issue without any relevance from a technical point of view. Such a bureaucratic formality may cause economic damage, for instance, in the situations in which waiting for the completion of the final design of the structure to obtain the license to carry on with the work will ultimately delay the beginning of the work. In order to cope with the problem, sometimes, the current practice was to submit at Town Councils a structural design different from the one that was to be effectively carried out. This was the so-called licensing design, which, in some cases, was just a mere adaptation, without calculations, of a similar previous design. The real design was to be subsequently made and, very often, it was not submitted to the Town Council. Even though today this practice is probably less common than before, the consequences remain, i.e., many constructions do not have a reliable record of the structure that has been effectively built.

The almost non-existence of Town Council survey of structural designs has began in the 60s. At the time the legal obligation of Town Councils being responsible for approving the designs of structures has been replaced by a declaration from the structural designer stating his responsibility for the design and the compliance of the design with the code in force. The reason for that alteration has been the defective town council survey, that was a bureaucratic obstacle to the approval of designs and did not fulfil its objectives. The real situation of non-existence of effective official mechanisms for controlling the execution of the designs of structures has been thus overtly assumed, situation that still exists nowadays. As refers to works, the town council survey is mainly focused on architectural issues and only marginally on structural safety issues. In fact, there is no effective and systematic survey of the quality of execution of resistant structures of buildings.

In the absence of control, the final quality of the structure of a construction highly depends on the competence and motivation of the agents involved in the construction process: the real estate agent, the designer, the general contractor and sub-contractors. These can always be tempted to save in costs at the expense of the seismic strength of constructions. In fact, this is quite easy: in order to reduce significantly the design work and save in the surplus quantity of materials that would be necessary to ensure seismic strength, it is only necessary to fail from doing the seismic calculation. Since earthquakes only rarely occur, the lack of seismic strength of constructions is not detected after construction, which together with the absence of control leads to an impunity situation. Actually this is very difficult to counteract due to the false feeling of security that the State conveys to the population. This false perception derives from the existence of legislation that makes seismic design compulsory and from the fact that citizens assume that the latter is enforced, because the non-existence of mechanisms for ensuring that compliance is omitted.

That situation can be exemplified as follows: two real estate agents build, in two adjacent sites, two apparently equal buildings and sell the corresponding apartments to the public. The one, who was concerned with the seismic strength of the construction, sells the apartments by 155 000 €. The second has saved in design and in materials, has not surveyed the construction quality, has built an apparently similar building but with reduced seismic strength and, in the end, sells the apartments by 150 000 €. So, what would the common citizen do in the presence of such a situation? Since he is not concerned with the safety of the construction that he is going to buy, because he thinks the latter is protected by the State, he will obviously buy the less expensive building. Therefore, the first agent will have the tendency to construct in the future what the market effectively buys, i.e., constructions with reduced seismic strength. Why should he reduce its margin of profit to pay for the seismic strength of the apartments he sells, if the main interested ones, the persons who buy them, are not willing to do it?

Nevertheless, of note is the fact that the costs associated with the safety of constructions are reduced comparatively with other factors that influence the cost of constructions. For instance, the cost of the structural design, which is a fundamental element (but not enough) to ensure the strength of a construction. In fact, the structural design of a housing building, when adequately carried out by a competent designer may cost, for instance, 1% of the construction cost. Let us assume that a less scrupulous or incompetent designer, who does not make an adequate seismic design, carries out the design by 0.5%. If we only think in terms of design, the difference between the 1st. case and the 2nd. is 100%. In the current situation in Portugal, where total impunity and lack of control prevail, it is not difficult to predict what occurs in most similar situations. However it should be pointed out the fact that a huge relative difference in a factor may significantly influence the safety of a construction only has a minor relevance for the total cost. Lastly, even considering all the factors, from design to execution and quality assurance, the increase in the costs of a safe housing comparatively with a less safer one may not exceed 2 or 3% of the total cost. This means that, in new constructions, the safety assurance has a low cost.

As a result of the situation described, the quality of construction in Portugal is fairly variable, being difficult to estimate accurately which is the proportion of buildings with good seismic strength and of those with poor quality. Nevertheless, the fact of being profitable to construct poor quality buildings, together with the assurance of impunity, stimulate bad construction. Obviously, this problem is also posed in old constructions, where the problem of seismic strength is more serious, due to the lack of anti-seismic regulations at the time of their construction.

4. Analysis into the problem

In order to change significantly the situation described, it is necessary to attack its deep causes and not only its most visible symptoms. The problem is not only the possible corruption, negligence or ignorance of the people involved in the construction process. In all professions and social groups, there are both honest and dishonest people, as well as both competent and incompetent people. The problem results from the fact that the external envelope of their activity creates an environment that leads to penalise honesty and competency by rewarding dishonesty and incompetence. It can be thus concluded that the main issue is a cultural problem of the Portuguese society comprising various aspects, such as: (i) generalised unawareness of the seismic phenomenon and of its recurrence characteristics, (ii) the lack of a culture devoted to organisation and accuracy, as well as (iii) the lack of a safety culture. In fact, from the smallest works to the large State projects, the safety, particularly as regards earthquakes, is very often sacrificed by economic, functional, aesthetic reasons or just for fulfilling tight schedules. We only think about safety problems after the occurrence of disasters, their prevention being neglected. In the case of earthquakes, these factors are worsened by the fact that the last great earthquake causing massive destruction has occurred more than two centuries ago, which is a period that exceeds by far the memory of the populations. This memory lasts about four to five decades, until the generation that has felt and has not forgotten the last earthquake has completely disappeared.

It is thus extremely important, if we want to adopt practical measures intended to improve the quality in construction, to change the existing situation by rewarding the construction of safe buildings and penalising bad construction. In order to achieve this objective, the latter must correspond to a consumers' demand, which in the case of buildings are the population and the companies, i.e., the whole Portuguese society. Nevertheless, this is not presently possible because neither the population nor the authorities have the perception of the risk involved. Therefore, in order that the Portuguese will become more demanding in this field, first they must (i) become aware of the seismic problem and of its potential consequences, and (ii) know that these consequences can be drastically reduced with the available technical knowledge. Mention must be made of the fact that earthquakes are natural uncontrollable phenomena but which almost do not cause any victims. Actually, the killing and destroying factor are constructions built by Man without adequate seismic strength. Therefore, the earthquake consequences depend highly on the seismic strength of constructions in the affected zone. This means that, even though earthquakes are natural phenomena, their consequences are artificial phenomena. The common citizen's reaction, when facing the seismic problem, is that "there is nothing that can be done". This is completely wrong and derives from the lack of information. Furthermore, the non-existence of recent earthquakes and the unawareness of the fact that high destructive potential earthquakes are due to occur in the future in Portugal, leads most people to unconsciously think that this is a problem that only happens to others, such as Turkey, India, El Salvador, etc.. It is thus essential to discuss overtly these problems.

A claim that is sometimes invoked for not discussing overtly the seismic problem is the possibility of causing concern or even panic among people. Obviously, people will become concerned, when becoming acquainted with the seriousness and extent of the seismic problem. Nevertheless, this is a positive factor, because that same concern is expected to lead to a higher demanding level of the public opinion as regards the seismic strength of constructions. Moreover, failing to inform the populations in order not to worry them, is the same as failing to teach a child to check both sides of the street before crossing it, in order not to upset the child with the possibility of being run over by a car. Furthermore, the fear of causing panic is also excessive. There are zones in the world, where much stronger earthquakes with a more destructive potential are due to occur than in Portugal, such as for instance, California and Japan, and, in those zones the populations are well informed of this fact and do not panic because of it. There, the problem is rationally analysed and the necessary precautions are taken so as to minimise the consequences of future earthquakes. Why should the Portuguese people fail from doing the same? This claim is an attestation of inferiority of the Portuguese people. By knowing that the main earthquake consequences can be avoided, will the possibility of a few persons panicking the day they become aware of the problem be a justification for it remaining ignored, and for letting a future earthquake kill a few thousand persons and ruin our economy? Both the mass media and the way they will handle this issue are highly relevant as regards this aspect. A sensationalist treatment just to win audiences may have negative consequences. Ignoring the problem will contribute to maintain everything as it is. A peaceful, responsible and continuous treatment of the problem may nevertheless contribute highly to the adequate awareness of the population and therefore achieve the intended objective. As can be deduced from the previous discussion, the seismic problem can only be coped with by a major effort from all the Portuguese society, and undoubtedly the mass media will play a significant part in this, provided that they act responsibly and put their civic duties above their immediate interests. Obviously, the State also has high obligations as refers to this aspect, because the alerting and permanent information of the population is an indispensable task to ensure the seismic strength of constructions, an area in which the State has responsibilities.

5. Suggestion of new procedures

Obviously the State responsibilities are not limited to the field of information, being also extended to surveillance and to the quality control of building construction. Besides, the population's concern for the seismic problem will lead the very population to have a higher demand as refers to structural safety, but it does not solve the problem on its own. Furthermore, the State, together with other social and economic agents, must also try to create the mechanisms that will permit these concerns to have practical effects on the quality of construction, which is not an easy assignment. In this way, it is considered as important that the construction with less safety should be penalised and that the construction of buildings with high seismic strength levels should be rewarded. Below, a few ideas about the subject are presented:

- One of the possible ways to achieve this objective is to provide citizens with an indicator about the quality of constructions or about their risk level. Therefore, the very market forces would act in favour of the safest constructions, to which a higher market value would be attributed. This objective could be reached through insurance. If the premium paid by insurance covering seismic phenomena is proportional to the risk covered, then, the very premium will serve as an indicator. Even though it is difficult to assess accurately this type of risk, the premiums currently charged by Insurance companies are poorly differentiated and do not reflect the high variability of risks covered. Therefore, it would be useful to promote a few measures, such as, implementing the table of the study promoted by the Portuguese Insurance Association about this very subject, which establishes variations between 1 and 20 from the buildings with highest to those with less seismic safety levels [1]. That table could be even more detailed by considering (i) reductions for buildings having a quality control performed by competent, certified and independent bodies, (ii) deductions for buildings having been submitted to works for improving their seismic strength, particularly those that have not been previously designed for enduring earthquakes. The contracts should be established so that policyholders would not be forced to appeal to judicial courts to receive their indemnities and that any responsibility issue as refers to the cause of damages would be directly solved between insurance companies and the persons or entities assumed as responsible for the damages. This could lead to establish a higher responsibility for all the entities involved, particularly if there was a single entity surveying the whole construction process, since its beginning to its completion. Also advantageous is the fact that this is a self-maintained system, because it is based on market laws, the part played by the State in it being mainly as surveyor of the good market operation. Nevertheless, because it depends on market factors it also depends on the interests of those involved, which should correspond to the public interests. In fact, this may not be easy to achieve.

- The direct surveying performed by Public Administration agents, or by companies at the service of the Public Administration, should also ultimately contribute to improve the quality of design and construction. Nevertheless, the past experience has shown that this has not produced the desired results. This has probably been due to the fact that the Municipal surveyors have never felt that they could be held responsible for the consequences, should they not carry out their duties adequately. Since earthquakes occur with large time intervals, the persons involved may think that when the next earthquake occurs they no longer will be responsible for the consequences. Consequently, it is important to think over the ways to make the very surveying entity responsible for the consequences. To some extent, drawing the attention of the public opinion to these issues will eventually have a positive influence on this aspect. Furthermore, within the framework of the direct survey by the Public Administration, it would be interesting to study the hypothesis of not making a systematic survey of all the designs, but to carry out a sampling survey of a more reduced number of designs, for instance, 5% or 10% of the total. In this way, less staff will be required, being therefore easier to hire qualified staff for doing it, and being simultaneously possible to improve the quality of the survey and save resources. And if the number of surveyed designs is as proposed, eventually all the designers will be surveyed, which will surely have a dissuasive effect as regards any temptation to save in costs at the expense of the seismic calculation.
- Every building should have a reliable record containing the final design of the structure, as well as all its possible alterations during the work and all the alterations performed in operation. The owner must permanently have an updated record and must provide a copy of the files to the relevant municipal authority. In fact, this would ultimately avoid the current situation, in which it is impossible to know the real characteristics of many structures. Obviously, this makes it impossible to carry out a detailed analysis of their seismic performance and increases uncertainty as refers to the need and effectiveness of possible strengthening measures that could be adopted.

The different hypotheses proposed are intended to be just a few ideas for launching the public debate about how to improve the quality in construction (including strengthening works), and they are not incompatible with each others. They could even be simultaneously implemented.

6. Summary and conclusions

An undoubtedly incomplete discussion has been presented about the problem of quality in the design and construction, as refers to their seismic performance. The main purpose was to draw attentions to the importance of this issue and to promote the debate on how to improve the quality in construction. It has also been mentioned that in terms of the structural safety, in Portugal, there are no official mechanisms for controlling designs and works. It has been demonstrated that without quality control, the structural safety can be highly variable. This implies that actually the buildings may have much less seismic strength than they should have, in accordance with the existing regulations. Even though being difficult to assess the extent of the problem, it has been mentioned that aspects, such as, profit associated with the reduction in the seismic strength of constructions, impunity due to the lack of control, as well as the occurrence of earthquakes within very long periods, stimulate the poor construction quality. It has also been demonstrated that a necessary (though not sufficient) condition to create effective control mechanisms is the awareness of the public for these issues, being thus important to open the debate to the general public. Three ideas have been suggested to contribute to the debate about the quality control of designs and works, with a view to improve the safety assurance of building structures as refers to earthquakes.

References

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THE LISBON MEGA-EARTHQUAKE IN THE XXI CENTURY OR THE SEISMIC VULNERABILITY OF LISBON CONSTRUCTIONS

João Appleton*

1. Foreword – the Lisbon constructions

The seismicity of the Portuguese territory that is based on the knowledge about its history and on the record of occurrences, at least ever since the XVIII century, when on 1st. November 1755, both the city and the country were awakened by the destruction caused by the highest natural catastrophe ever observed in Portugal, has been a concern not only of technicians in the field of structure engineering, seismology and seismic engineering, but also of all those who, by being associated with civil protection, try to predict the consequences of a high intensity earthquake in a city such as Lisbon.

Even though that concern has been assumed by an increasing number of technicians and scientists, it is not obvious that there is the political awareness of the possible scenario after such a catastrophe. Furthermore, it is certain that the public opinion that represents the population's thoughts is not in the least conditioned by such an idea. In fact, except for Azores, the national territory has not been submitted to any devastation caused by earthquakes for a long period, contrary to what has been increasingly happening with the alterations in the climate, the rainy winters and the dry summers that either directly or indirectly have been causing death and destroying economies.

Lisbon has actually been a city historically affected by earthquakes, of which the XVI and the XVIII centuries have been particularly significant. Even though being possible to assume nowadays that the 1531 earthquake was almost as devastating for the capital as the 1755 one, the truth is that as a result of the latter earthquake, a comprehensive recording of the consequences of the catastrophe for the populations and their houses was for the first time accomplished. Actually that recording was, at the time, made mandatory by the Marquis's "enlightened despotism" and, eventually, it served as basis for a new way to regard the city.

It is interesting to observe how the brutality of the impact of the earthquake on the city (and on the country, at least on the South) has imposed the compliance with the application of new town planning and construction regulations that were inevitably defined, despite the lack of written documentation supporting that thesis. In fact, the fear of all those that survived the earthquake did not require further arguments. But, if we observe the subsequent Lisbon town planning and construction history, it will be possible to note how that memory becomes diluted, the fear decreases and, as and when that happens, the buildings increase in height, the walls have their thickness reduced and the quality in construction is progressively adapted to the demands and needs of the new times.

The Setúbal earthquake of November 1858 was not enough to help restoring what was being progressively lost, maybe because even though violent, it had no disastrous consequences, perhaps because the city consisted mainly of the exemplary built "cage type" buildings, from foundations to roofs. Therefore it is not surprising that a progressive deterioration of the Lisbon construction quality has been increasingly taking place and, when the peak period of the Ressano Garcia's city that was being spread to north has been

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reached, the real estate speculation and the "vertiginous" construction rhythm has brought to the city both unprepared and ambitious constructors, who were not familiar with the traditionally imposed requirements. These constructors came eventually to develop much more expedite construction methods that permitted a much quicker and more economic execution, but which were also poorer and less safer, to the point of buildings collapsing during construction.

With the arrival of concrete, which was the so-called first choice "structural material", and which was meant to last forever, the timber is the first to fall out of use, when light timber beams were replaced by much heavier reinforced concrete slabs, and when subsequently the traditional stone and brick masonry resistant walls were replaced by portal-type structures, consisting of columns and beams made of that material and forming more or less smooth linear frames. That transition, represented by experimentation and abandonment of different solutions occurs for thirty years, and lastly, in the 50s, the reinforced concrete becomes the absolutely prevailing material.

This new structural material, of high potential and much more demanding as refers to scientific knowledge than former timbers and masonry, eventually became the object of high developing theoretical and experimental studies and was meant to act as support to and to be supported by a corresponding development, in the structural analysis procedures, and by the new philosophies that came to preside over dimensioning and assessment of the safety of structures.

Thus, it can be said that in the 70s the reinforced concrete and the structures are prevailingly used. In fact, these are used almost without competition in all the buildings and constructions of the country, such as bridges, dams, storage tanks, silos, etc.. Furthermore, the new technical regulations that were being developed and published, at the time, support new structures that although apparently similar to those of the first stage of the concrete, are now based on new criteria and concepts that are to evolve as from the end of the 80s, when new concerns are introduced as refers to durability of the material, which was meanwhile refuted.

This means that in an old city that has been forever expanding, different times, as well as different structural and constructive typologies must necessarily co-exist. In fact, the representative elements of the remotest times have been systematically reduced, many either destroyed by more or less significant catastrophes or by Man, who sees modernity in what is only mere destruction, and also by inaction and carelessness that have led to the abandonment and ruin of constructions. Consequently, there are only a few constructions prior to the XVIII century, most of them consisting of highly changed buildings that were submitted to many interventions, some of them having an erudite and monumental character, others being popular buildings integrated in some of the historical districts of the city, such as *Castelo*, *Alfama*, *Mouraria* or *Bairro Alto*, for instance.

On the other hand, the XVIII century, particularly what has been conventionally designated as the city "Pombalina" (with the "cage" type buildings) is still represented by numerous civil and religious buildings, as well as by housing buildings and others. As regards these buildings, special reference can be made to the downtown part of the city with its orthogonal streets filled with profoundly modified buildings that were harmed in their purity of construction, and maybe compromised, in terms of safety, by the structural sections of their lower floors and by the vulgar increase in the number of floors, which were made feasible by the seismic peace of the XIX century.

Despite the progressive replacement of the so-called buildings "gaioleiros", by the ruin of some and by real estate speculation that has reached many others, the "new" Ressano Garcia's city has still a large number of buildings, which even though being made of masonry and timber, are completely dissociated from the "cage" type buildings. In fact, these buildings form bands and blocks of "Avenidas Novas", of "Bairro Camões", of "Campo de Ourique", etc. With a few exceptions, the buildings of that time present significant deterioration, either caused from their very construction, from the lack of adequate maintenance or from misappropriate alterations.

In a first transition stage, the reinforced concrete was ultimately adapted to designs identical to those that were formerly developed with traditional masonry and timber structures, having thus originated specific solutions that were implemented between the end of the 40s and mid-50s. At the time, use was made of thin concrete slabs supported on brick masonry walls, which were occasionally reinforced with concrete columns and beams, namely on the façades and on commercial floors that were often located on ground floors. These structures are for instance abundant in all the zone comprising “Avenida de Roma”, the east zone from “Avenidas Novas” to “Avenida do Aeroporto” from “Areeiro” to “Avenida do Brasil”, i.e., the expansion zone defined by the dynamism of another “enlightened” authority, the Minister-President Duarte Pacheco.

This is, as a result of the structural ambiguity that characterises these buildings, a housing stock of which the seismic performance places a few legitimate questions. This is made worse by its relative modernity that justifies the absence of studies intended to predict that performance and to adopt strengthening measures, since the other housing stock of the city is deteriorated and is requiring urgent intervention, so as to endure not a cataclysm but simply the climate demands.

As previously mentioned, the evolution of reinforced concrete structures began with these transition buildings and has benefited from a teaching almost exclusively devoted to that structural material and from its increasingly monopolist use. In fact, the designing engineers and the constructors were led to abandon the use of steel, masonry and timber, which, in practice, have increasingly disappeared from the market.

Those structures are the basis for almost every building constructed in the last 40 years, in a town where the non-housing buildings, which had been up to then ignored, are increasingly spreading. Also spreading are the technical solutions making use of: beam supported slabs that dominate the market until the 80s, of waffle slabs that become fashionable in the 80s, of flat slabs that are commonly used in the 90s, as well as portal-type frames with beams and columns and membranes with walls supporting the slabs.

Obviously that in each time, with the various fashions and novelties, different technical solutions may co-exist, which are very often conditioned by tradition and by each designer´s or constructor’s experience. Therefore, we cannot expect to find any well-defined separation or any rigid classification. Actually, both in time and in space, different constructions may co-exist, such as for instance, pre-“cage” type buildings with “cage” type buildings; the latter with buildings “gaioleiros”, which may also co-exist with the first concrete applications and from then on these structures evolve in accordance with the time periods and with the preferences of the technicians responsible for their conception, design and construction.

An attempt has been made to describe briefly the types of constructions existing in the Lisbon housing stock, being particularly focused on structural issues, which are indeed the most relevant aspects as regards the seismic problem and the vulnerability of constructions to earthquake action. Therefore, it is essential to try to imagine, predict and guess what will be the behaviour of the built city, in case of occurrence of a high magnitude earthquake, similar to those that affected the capital of the Empire in the XVI and XVIII centuries. Let us assume then that in the first day of November of the year 2005, exactly 250 years after the great tragedy, Lisbon is struck by an earthquake “similar” to the one of 1755, i.e., having the same source, the same epicentre and the same magnitude. In such an hypothetical situation, which is feared by many, what will happen to the city: Will it awaken devastated and in deep mourning, grieving for all the deceased? Or, on the contrary, will it endure the attack of the "beast" without suffering any damage, thus becoming a reason of pride for all the Lisbon inhabitants and causing admiration all over Europe?

In order to respond to the question above, an attempt is made to reproduce two distinct pieces of news that could be published in any hypothetical daily newspaper.

2. The news

I – Announced disaster

Lisbon, 2005-11-02

Yesterday, Lisbon has been struck by a devastating earthquake that reduced to ruins the old part of the city, but which has also affected modern constructions in all the zones of the country's capital.

The first reports, which have not been yet confirmed, as a result of the collapse in the communication and in the power supply systems that have isolated the town, contain a few estimates that give a notion of the extent of the tragedy: more than 1500 totally collapsed buildings filled the streets with debris, which prevented firemen and other rescue services of providing assistance to the more than 60000 injured.

Unofficial data also refer to 15000 casualties, of which many may have occurred with the collapse of two hospitals and seven schools. International aid is being prepared, and the United Nations have positively responded to the appeals of the national authorities by sending specialised squads for rescuing victims from the debris and by sending food, medicines and other first need goods.

A tremendous generalised discontentment is being felt, and people have began to accuse the governments of the last decades of negligence and carelessness, blaming them for not having adopted any coherent policy as regards the safekeeping of constructions and the structural rehabilitation of thousands of buildings. According to the same accusations, the governments had been made perfectly aware, a long time ago, that the buildings were not prepared to endure such a catastrophe.

II- Lisbon sets the example

Lisbon, 2005-11-02

The scientific community all over the world has been utterly astonished by the effects caused by the earthquake of magnitude 8.2 in the Richter scale, which struck Lisbon yesterday. In fact, the city has almost survived the earthquake without any damage, the only exception being the fall of about a dozen buildings, three of which, were being submitted to an integrated repair work intended to improve their structural strength.

Two delegations from the USA and from Japan integrating the most eminent international authorities within the field of seismology and seismic engineering are being prepared to come to Lisbon. Their schedule includes the participation in a course taught by Portuguese experts about the national regulations specifically devoted to the seismic strengthening of buildings and to the construction methods adopted in the last few years, which have placed Portugal in a leading position as regards knowledge in that field.

Meanwhile, a committee of enquiry has been appointed for assessing the reason for the collapse of a few dozen chimneys in Algarve, apparently because these elements have been excluded from the seismic strengthening programme. The conclusions from the enquiry will be made public in the next three days.

3. The Lisbon earthquake of the XXI century. The scenario

The two previous pieces of news are obviously mere caricatures and their symbolic date, November 2005, precisely two and a half centuries after the 1755 earthquake, has obviously no justification. However, should that earthquake occur, and probably it will, the first catastrophic scenario is not likely to take place, but least expectable will be the idyllic hypothesis of an exemplary city that we all know that only exists in our dreams. Thus, with more or less ruins, and, excusing myself for the cold expression, with more or less casualties and injured, eventually someone will survive to make a report of the situation and to indicate possible paths.

Still in the field of fiction, let us imagine that someone will be charged to present a report on the occurrences to a recently appointed “Minister for Calamities” and that the possible report states something more or less as follows:

“In the sequence of the assignment with which I was entrusted, as co-ordinator of a “Commission of Analysis into the Consequences of the Lisbon Earthquake”, it is possible to present, in the short period given for the purpose, the first results of the work done, which consisted of the collection of all data referring to damage suffered by the city buildings and of their processing with the purpose of trying to establish a relation between the structural characteristics of buildings, their state of conservation and their level of destruction, so as to support decision-making as regards re-construction of the city.

This report is only intended to be focused on buildings and on their performance as regards the earthquake, in an as cold as possible vision, even though obviously affected by the tremendous suffering that was inflicted upon our beloved city.

Despite the lack of a final survey about the extent of damages, since the files of a few areas of the city were destroyed, which has made it difficult to carry out an accurate official survey, it is estimated that the number of buildings completely destroyed is higher than 1000, and that about 7000 are severely damaged, of which about a third can be considered as irretrievable. Furthermore, minor damages have occurred in about 12000 buildings and insignificant damages have been observed in the remaining housing stock.

Only these estimates are likely to give a notion of the devastating consequences of this cataclysm that only equals the one that occurred precisely 250 years ago and that has originated the new city that Sebastião de Carvalho e Melo (Marquis of Pombal) has conceived together with Manuel da Maia and Eugénio dos Santos. Therefore, I feel that my duty as regards those outstanding personalities, to whom the History has not yet paid due homage, is to make an accurate analysis that will help to understand the catastrophe, both in terms of its natural causes and in terms of consequences of the carelessness of the various generations, which were not able to take any lesson from the past, that carelessness having occurred as soon as the 1755 drama vanished from the collective memory.

In an attempt to co-relate the content of this report with the history of buildings in Lisbon and with the types of constructions existing in the Lisbon housing stock, a brief summary of the situation will be presented in accordance with the time of construction, the following types having been considered for simplification purposes:

a) Pre-“cage” type buildings, particularly concentrated on the so-called historical districts and on important individualised buildings;

b) “Cage” type buildings, constructed from 1755, comprising the re-construction zone, focused on the “Baixa”, but reaching some zones of the old districts and even the first stage of the urban expansion of the XIX century, such as for instance, *Avenida da Liberdade*;

c) The so-called buildings "gaioleiros", which is the name scornfully given to the buildings of Ressano Garcia's Lisbon, during the expansion of the city to north and east (of note is the fact that at that time the "cage" type buildings are still moderately used by the traditional Lisbon constructors), which corresponds to the wider group of buildings scattered all over the city or concentrated on the new districts;

d) Buildings of transition to reinforced concrete, conjugating masonry walls and reinforced concrete slabs, concentrated on zones constructed from the 30s of the XX century, mainly at the zones of expansion to north (*Av. De Roma* and *Alvalade*);

e) Constructions of the 1st. stage of reinforced concrete, scattered all over the town, often in isolated buildings resulting from re-constructions and fillings of the urban network. It occurs under the application of the first concrete regulations, and has been extended to the 70s;

f) Constructions of the 2nd. stage of reinforced concrete, corresponding to the consolidation of regulations and spreading throughout the city, also prevailing at the new expansion zones that occupy the few last free areas of the city.

Under normal circumstances, it would be expectable that such a high magnitude earthquake and having the same characteristics as this, would cause decreasing damage depending on the age of the buildings. Nevertheless, a first analysis, makes it possible to observe that this has not been observed. In fact, the different types of buildings had an almost "random" performance, which is a sign that other factors different from the construction typology and the time of construction, have surely had a decisive influence.

Besides, reference must be made of the fact that at the time of the 1755 earthquake, the analysis of Parish records, at the future Marquis de Pombal's command, made it possible to carry out remarkable research works that established an obvious co-relation between the foundation conditions of the buildings and the effects of earthquakes on buildings. Actually this was an issue that was made obvious, as can be deduced from the idea of ultimately transferring the centre of the city to *Belém* area.

On the basis of the knowledge of the types of construction that characterise the Lisbon building stock, as well as on the basis of their geographic and geologic distribution and of the foundation conditions, of the level of conservation of structures and of the types of alterations performed on buildings, below, a synthesis is presented of what has been considered to represent best the earthquake consequences. This is expected to help defining a strategy for the actions of rehabilitation and re-construction of the city.

A- Pre-"cage" type buildings

There are only a few genuine pre-"cage" type buildings, the districts with the highest number of this type of buildings are: Alfama, Castelo, Mouraria and Barirro Alto. That type of construction is also found in important buildings such as Churches, Convents and Palaces. Those constructions had in general a satisfactory behaviour, of note being only the collapse of various bell towers of churches (such as in the 1755 earthquake), which caused destruction in some buildings, namely in the See, as well as localised ruins on masonry walls and on arches. Nevertheless, these are likely to be restored by means of fairly simple repair works, even though having a few severe consequences on elements of high artistic value.

The current buildings had an uneven behaviour. This was mainly due to the local geological conditions associated to the characteristics of the foundations, of note being the fact that the conservation and rehabilitation works recently performed on those buildings had no significant effect, since these were isolated interventions that did not take into account the block effect, which is fairly important as refers to the seismic performance of each building.

Special reference must be made of the excellent performance of sets of constructions at *Castelo*, where the pre-"cage" type buildings prevail (even though having undergone significant alterations). These buildings were submitted to joint interventions in which, for the first time in the city, the so-called seismic strengthening of old structures was assumed. This is an example, that may have consequences for the near future.

B- "Cage" type constructions

The lower part of Lisbon and its boundary zones, where the most significant number of "cage" type constructions can be found and which are an example of the philosophy presiding over the town planning and construction during the XVIII century, had a highly uneven behaviour, which at first seemed peculiar. In fact, that odd behaviour led to the careful consultation of the municipal files so as to characterise dully those constructions, namely those that underwent the most relevant damages.

It has been for instance observed that the set *Terreiro do Paço*/*Praça do Comércio* had an almost impeccable behaviour, except for the "Torreão Poente", which had already shown the presence of some structural problems that had not yet been adequately solved. Otherwise, extensive collapse, with an apparently random distribution, has occurred in a few blocks.

After analysis of all the available data, it has been observed that the most significant damages have systematically occurred in buildings and in sets of buildings where expansions in height, of two or more floors, had been performed (sometimes in undetermined date). This was unfortunately frequent in buildings that had been made more fragile by extensive alteration works that affected the ground floor masonry structures.

On the contrary, the buildings that remained almost unchanged, even though having had poor maintenance, had a fairly reasonable behaviour, which confirms the excellency of the original solution consisting of "cage" type buildings. Some sets of buildings, which underwent significant alterations and of which the original structures were completely suppressed and replaced by new concrete structures, had usually an equally satisfactory behaviour, special reference being made to those that were submitted to repair works from the 80s of the XX century.

From what has been observed and analysed, it can be concluded, on the one hand, that this earthquake is the best test for the qualification of the so-called "cage" type buildings and, on the other hand, the worst fears have been confirmed as refers to the carelessness with which the successive adulterations in the original structures have been performed. In fact, those alterations almost invariably failed from being accompanied with strengthening works.

C- Buildings "gaioleiros"

This type of construction has been a major concern for all those that have studied the seismic vulnerability of the Lisbon constructions, and which has been justified by the defective quality of masonry and timber structures used in the construction of those buildings.

This earthquake has justified those fears. In fact, 500 buildings of this type have totally collapsed and many other underwent extensive damage and cannot be recuperated.

From the analysis into the effects of the earthquake on those buildings, reference must be made to the fact that they are generally founded on soft soils, either clayish or sand-clayish, and are only very rarely founded on rock. This means that in zones having a higher number of these buildings, the foundation conditions have not favoured the survival of the buildings.

There can be observed that the structures with alterations such as suppression of a few walls and their “replacement” by steel bars are even more vulnerable. Nevertheless, this is an issue that requires further study.

The lack of structural bracing, represented by frailness in the connections between walls and between walls and pavements, as well as the poor quality of masonry and the original malfunctions of the foundations are probably the essential problems to understand the destruction occurred and that has led to the loss of a significant part of the city of the time of Decorative Arts.

D- Buildings of transition to the reinforced concrete

The constructions of the 40s and 50s are concentrated on the zones of expansion to the north of the city, namely on the area of *Alvalade*, *Campo Grande*, *S. João de Brito* and *S. João de Deus*. As is known, these are mixed structures consisting of solid brick masonry (in some cases, the common stone masonry still subsists and, in other cases, walls with concrete gables are used), as well as of concrete slabs and of some beams and columns, especially on ground floors.

Since fairly uniform foundation conditions have been observed, the irregularity of performance of these type of buildings of that particular time, in the presence of the earthquake (including the overall collapse of about fifteen buildings), has required an analysis into the effective characteristics of these structures. For the purpose, the municipal files that were preserved will be consulted.

It has been observed that in an almost systematic way, the most ruined buildings had been subject to works that changed their interior partition, with suppression of resistant walls, a circumstance that has introduced weaknesses and asymmetries in the structure, which proved to be decisive. The buildings that have maintained their original structure, or that have been the object of small alterations, generally had a satisfactory behaviour, which is likely to be due to the high density of walls (these are in fact buildings with a highly divided plan) and by the strapping effect provided by the reinforced concrete slabs.

E- Constructions of the first stage of reinforced concrete

The buildings constructed between the 50s and the 70s occupy new expansion zones but are also used to replace older buildings that were demolished all over the city, for instance, at *Avenidas Novas*, when the replacement process that is still underway has began there.

The defective performance of these buildings, with a few cases of collapse but with generally highly extensive damages, is due, in a first analysis, to two types of causes: defective structural organisation and use of concrete with poor mechanical performance.

The defective structural organisation is represented by the high irregularity of structures, both in planimetry and in altimetry, with beams supported on beams, high asymmetries in the location of columns and sudden changes in their geometry between successive floors, originating highly flexible structures, which underwent significant deformations that were not detected in the designs (that were very often incipient).

The poor mechanical strength of concrete used in the execution of the building structure has worsened the problems referred to above, especially at the level of column performance.

Mention must be made of the fact that, comparatively, the public buildings constructed at that time present a much better performance than the housing buildings, which undoubtedly cannot be dissociated from the fact that the first have a better technical quality in terms of structure design and that higher care was taken in the execution and survey of reinforced concrete structures, which present a much higher regularity.

F- Constructions of the second stage of reinforced concrete

People may find peculiar the significance of damages occurred in the buildings constructed as from the 70s, when the reinforced concrete was considered to be well mastered in terms of design and execution.

First, of note is the fact that it is not possible to establish in a preliminary analysis, an obvious relation between the performance of buildings and the foundation conditions. In fact, the increasing existence of buildings founded on columns, since the soils available for construction in the city are increasingly worse (this qualification being considered from a point of view of the geotechnical characteristics of superficial soils), makes it difficult to carry out that type of analysis.

Even though being recognised that in the last few decades, the engineers had at their disposal very updated structural regulations, which were intensively taught in every engineering schools, the general quality of the designs licensed by the CML (Lisbon town council) was still very low, even though from the 90s there was an improvement that may be associated with the development of major projects.

On the other hand, the sampling analysis of thirty buildings that presented different damage levels, has made it possible to observe various differences between the structures performed and those that had been licensed, simultaneously with significant deficiency in the quality of the concrete and of reinforcing bars used, these anomalies being likely to be clearly co-related with the significance of damages.

Obviously, the problems mentioned confirm the possible importance of the technical survey into a structure or of its absence, requiring undoubtedly further consideration. Furthermore, The inadequacy of designs can only be understood because, so far, it has not been possible to develop an effective system for the quality assurance of designs and including their verification and certification.

Lastly, the present report is the result of a first analysis into the consequences of the earthquake of 1st November 2005 on the Lisbon building stock. Nevertheless, despite the preliminary and summarised character of this report, it seems possible to conclude that these consequences, which have the features of an exceptional catastrophe, could have been very limited, provided that some measures had been adopted so as to ensure both the effective quality of designs and works, as well as the application of a coherent plan of consolidation and strengthening of the structures of existing buildings, especially of the most vulnerable ones.

The "cage" type buildings of the downtown part of Lisbon, where by carelessness and, at least, by ignorance, the relevant architectural patrimony has been destroyed in almost a century, are a significant example of the lack of attention of the political power and of the lack of professional accuracy of technicians. In fact, without the integral and determinant part of their "cage" type structure, the buildings became weakened and therefore collapsed.

Obviously, now, it is not only essential to pay higher attention to repair, recuperation and reconstruction but also it is fundamental to create the bases to eliminate procedures that proved to be destructive and to implement others of which the absence has also proved to be pernicious.

The quality assurance of designs, as well as of public and private works, by imposing the intervention of design surveyors and of technical surveyors of works intended to support a general assurance and a responsibility system effectively covered by insurance, is no doubt an essential step that must be immediately taken".

4. Conclusions

In the previous paragraphs, an attempt has been made to guess or to make a non-sustained prediction of the consequences of an intensive earthquake on the Lisbon buildings.

As has been made obvious, the statements presented in the fiction text produced are not the result of more or less complex structural analyses about real buildings, but are rather the result of a qualitative analysis into what has been known as the built patrimony of the city of Lisbon, together with its original characteristics, its state of conservation and the structural alterations to which the buildings, especially the oldest ones, have been subject.

By recognising the weak points of the structures constructed in different times and with different materials, it can be equally recognised that the effort developed in the rehabilitation of old districts though noteworthy is insufficient, at the same time as we assist to the proliferation of significant alterations in the structure without the adequate technical support. Equally concerning is to verify that the mean quality of the designs of building structures is poor and that the technical survey of the construction of these structures is also insufficient or even non-existent.

Maybe the next Lisbon earthquake, which we do not know when it will occur, will give us the time to do something about the situation. It will not be easy to change certain design and construction practices, but all efforts must be done so as to impose the application of structural regulations and to validate procedures for the effective quality assurance of designs and works.

It is also urgent to define procedures for improving the structural performance of weaker constructions and, simultaneously, we must prevent the destruction of existing structures by means of building height extensions or of the creation of discontinuities, namely on ground floors.

Otherwise, if this is not achieved, and certainly this must be urgently done, the previous catastrophic scenario might be made true by a future that must be feared by all of us.

THE SEISMIC RISK AND THE INDUSTRIAL PARK

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1. Introduction

In the seismic history of Portugal there have been some seismic events with devastating effects. It is also accepted and scientifically proven that earthquakes are recurrent phenomena, since their generation mechanisms are known. This implies that zones such as the Portuguese Mainland and Azores, which have been submitted to strong earthquakes in the past, will surely be affected in the future by earthquakes with a high destruction potential.

Under the current scientific knowledge it is not possible to predict with reliability the date and epicentre of the next potentially destructive earthquake. Nevertheless, the historical seismicity provides us a few useful indications. For instance, it is known that the Portuguese mainland has been subject, in the last thousand years, to strong earthquakes with a high destructive potential having variable intervals between two and three and half centuries, the latest and largest highly strong earthquake with a high destructive potential was in 1755. Apart from that earthquake, others have occurred but with more reduced effects. The fact that there is no record of an earthquake similar to the 1755 one, in the few hundred years before its occurrence, indicates that an earthquake of the same magnitude is not likely to occur in the next centuries. Nevertheless, the period of time between the largest earthquakes coupled with the time elapsed since the 1755 earthquake causes significant fear as refers to the possibility of occurrence, in this century (XXI), of another earthquake with a high destructive potential. Even assuming that this earthquake will not be as strong as the 1755 one, the concentration of population and economic capacity on the Lisbon region, which is much higher than in 1755, may lead to more serious consequences, such as a number of victims higher than in 1755.

2. Objectives

Even though the first concern when thinking about seismic issues is the safeguarding of human lives, it has been observed that in most developed countries, the public opinion is increasingly less tolerant as refers to economic damage. Therefore, there is an increased pressure on authorities and economic agents to reduce those damages. This tendency has not been felt in Portugal due to the unawareness of the public opinion and of authorities as refers to the economic risk involved by a strong earthquake. Therefore, within this framework, the main purpose of this paper, about the implications of earthquakes on the industrial park, is to try to oppose this tendency.

Thus, besides making the authorities and the businessmen in the sector more aware of that issue, it is also the aim of this paper to present a few suggestions with a view to (i) make a more detailed assessment of the problem and (ii) to reduce its potential extent.

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3. Assessing the situation

3.1 Lessons from real cases

An important source of lessons is the experience with real cases. Nevertheless, most available information referring to past earthquakes concerns the building stock. Particularly in less developed countries where the economic damages are more reduced and the human losses are very high, it is only natural that a greater attention will be paid to the latter issue. But even in more developed countries, more attention has been first paid to the buildings and bridges and, only subsequently, to lifelines and to the industrial park. Therefore, the available information as regards the effect of earthquakes on these sectors is more rare and mainly concerns the most recent earthquakes. A description is presented of the damages occurred in some industrial facilities, together with a few photographs of damages in industrial facilities and in lifeline networks during various past earthquakes.

Kocaeli earthquake Turkey, August 1999 [1]

This was a 7.4 magnitude earthquake (the magnitude can be related with the energy measure released by the earthquake at its source), which is a magnitude similar to the 1531 earthquake with epicentre at the Lower Tagus Valley. It affected one of the most industrialised and developed zones in Turkey, having caused significant damages and interruptions of the activity in the industrial sector. Some cases are presented below:

- Train factory in Adapazari. Structural failure of a building and damages in others. Figure 1 shows part of the collapsed building.

Figure 1 – Damages at Turkiye Vagon Sanayii A.S. factory in Adapazari

- Tupras oil refinery. The earthquake has caused a fire that took 5 days to extinguish and that could have destroyed the entire oil refinery. That plant produced about a third of the gas consumption in Turkey and its value amounts to about 3 500 000 000 €. The fire began with the spilling of naphtha at the top of a storage tank and it was difficult to prevent its spreading because the pipe that supplied water to the refinery was not operating due to several damages.

- Petkim petrochemical plant. It had many serious damages: in its water supply system, collapse of cooling towers and internal damages in industrial equipment. As a result, it was to remain inoperative for two months.
- Seka paper paste factory. There were some damages in a few buildings due to the collapse of roofs, the cellulose silos have collapsed. The power-operated transformer of the factory failed, sopping the entire production for two months.
- Toprak Ilic drug factory. The shelves in the warehouse have fallen, as figure 2 shows. In the laboratory, the fall of chemical products that reacted among them has caused the release of toxic gases. It has been considered that two months would be necessary to re-establish the normal activity of the factory.

Figure 2 – Fall of the warehouse shelves at the Toprak Ilic pharmaceutical drug factory

- Toprak Saglik paper paste factory. There were different types of damages, such as for instance, the fall of cabinets containing electric appliances, which is illustrated in figure 3, displacement of equipment with defective anchoring, cracking in storage tanks with spilling of water, fall of stored products, fall of a tank in the pump room, damages in columns, in non-structural walls and in glass areas.

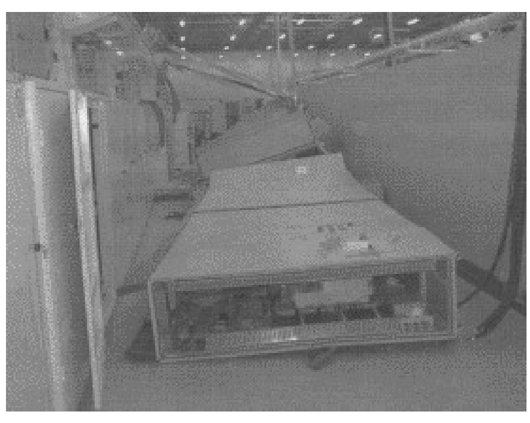

Figure 3 – Damages in electric equipment at Toprak Saglik paper factory

Mt. Parnes earthquake (Athens), Greece, September 1999 [2]

This moderate intensity 5.9 earthquake (the Richter scale is logarithmic and the variation of 1 degree corresponds to a variation of 32 times in the energy released) has began in an unknown fault localised under a suburban area of Athens, which is considered as one of the zones with less seismic risk in Greece. Given the reduced magnitude of the earthquake, the affected zone was not extensive. Therefore, most of the city was not affected. The industrial Park in the affected zone, consisting mainly of small and medium size factories, housed in reinforced concrete buildings, has been heavily affected. Most of the 30 buildings that totally collapsed, as well as most of the 143 earthquake victims occurred in the Industrial Park. The high weakness of these buildings was due to deficiencies, such as: (i) few internal separating walls, (ii) partial filling of panels of reinforced concrete frames with masonry panels, (iii) significant loads on pavements due to heavy equipment or stored products, (iv) thick slabs, as well as high and long beams supported on columns with reduced cross-sections and (v) poor quality of design and construction. The earthquake has caused an approximately 3 000 000 000 € loss, having mainly affected the industrial sector.

Other earthquakes

Reference could be made to many other examples. The figures below illustrate other cases:

Figure 4 - Damages in equipment at Kobe harbour in Japan, as a result of the earthquake of 17th January 1995 [3]

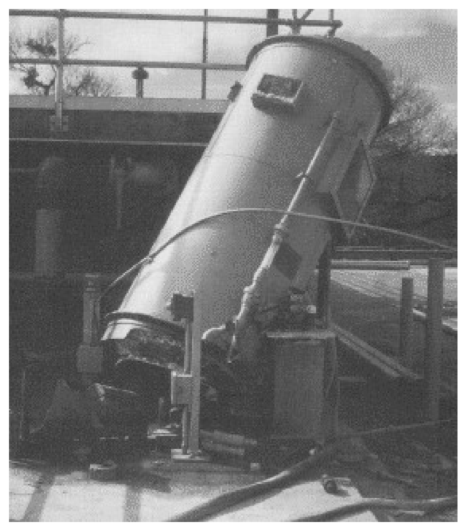

Figure 5 – Fall of air purifying equipment at a treatment plant during the Northridge earthquake, 1994 [4]

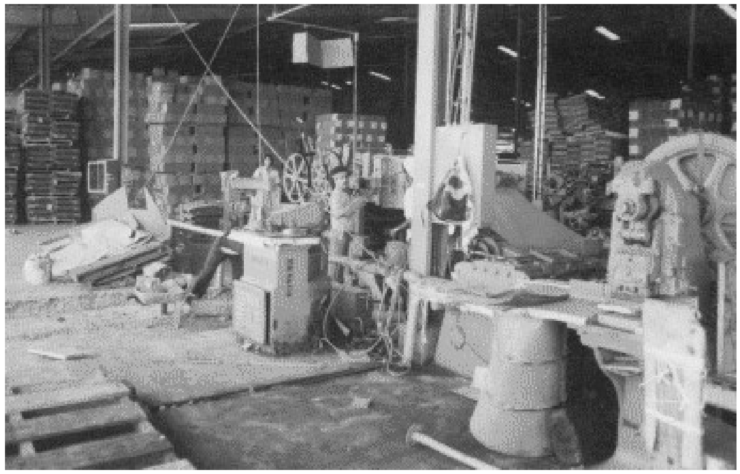

Figure 6 – Interruption in the operation of a factory in Panama due to relative movements between foundations that have deranged the mechanical equipment during the Costa Rica earthquake, on 22nd April 1991 [5]. The excavations and the other works intended to align the foundations have lasted for more than a month during which the factory has had no production.

3.2 Specific situation in Portugal

The vulnerability of buildings in the industrial park may, in average terms, differ from the vulnerability of buildings of the Building Stock (designation basically referring to housing and office buildings). The lessons from the Greek earthquake, of September 1999, indicated that many industrial multi-storey reinforced concrete buildings may be highly vulnerable due to deficiencies. The buildings with total or partial pre-fabricated structures are also fairly vulnerable due to the weakness of connections between the different elements, which very often are not designed to transmit bending moments. Another type of industrial buildings tends to be less vulnerable than those of the Building Stock. It is the case of one-floor buildings with steel structure having rigid or semi-rigid connections, which usually are light structures. In these cases, the wind calculation provides the structure with a resistance to horizontal loads, which might give it the possibility of enduring strong earthquakes. This is due to the fact that the wind action on those structures depends highly on the exposure surface, which is usually large in these buildings, whereas the action of the earthquake is exerted on the mass of the structure, which is reduced.

Therefore, it is difficult to characterise with detail the seismic strength of the industrial buildings in Portugal without adequately surveying their characteristics. Nevertheless, attention is drawn to the possibility of these having a significant seismic vulnerability, as for instance in the case of Greece.

As has been observed in 3.1, the vulnerability of the Industrial Park depends not only on vulnerability of buildings but also on vulnerability of machines and equipment.

As regards machines and industrial equipment, the unawareness of their seismic vulnerability is much higher. There might be some situations of industrial equipment characterised by their heavy weight, by connections to other equipment and occasionally by defective connections to the corresponding foundation or support structure. Such a situation, which is similar to a few ones described in 3.1, could be schematically represented as figure 7 shows.

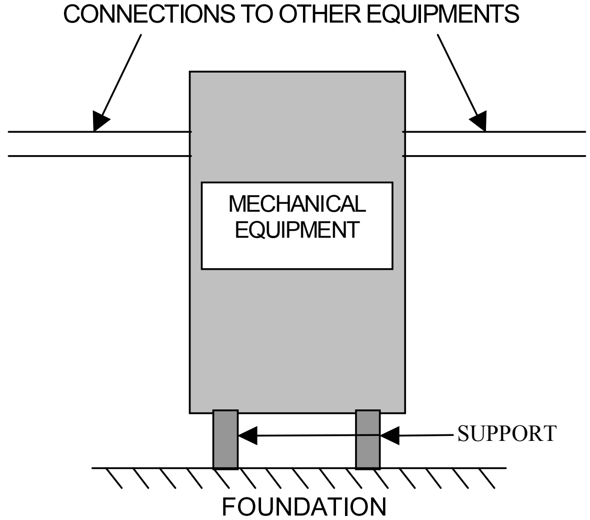

Figure 7 – Schematic drawing of industrial equipment

Let us assume, in this case, that the equipment is not highly vulnerable on the inside, i.e., the possible accelerations induced by an earthquake to its base will neither damage its interior nor its covering. This situation may also occur with other type of equipment and for different reasons: as a result of the very type of construction and of materials used, because the manufacturer sells equipment for seismic risk zones and has standardised its manufacturing, as well as at the request of the very equipment owner, etc. Other types of equipment may present internal vulnerability, as referred to in 3.1. In the previously mentioned case, the vulnerability will be essentially located on the supports. As a result of accelerations in the equipment resulting from the seismic ground motions, inertia forces occur in the equipment. If the supports do not have enough strength to transfer these loads to the foundation, the equipment may slide on the base, oscillate or even fall. These movements can cause internal damages due to impact during oscillations and/or break the connections to other equipment if these connections are not prepared to withstand such displacements.

This type of problem can be easily solved with a good connection between the machine and the respective foundation. It is a technically simple problem, of which the solution, when considered at the design stage, only implies minor costs comparatively with the value of the machine and of its foundation. If the problem is already present and if the aim is to correct it, the costs will be higher, because it will be necessary to strengthen the connections and the foundation, leading to the temporary unavailability of the equipment. Nonetheless, the costs will be considerably less than the cost of the very equipment, probably less than 5% of its cost. In case of malfunction of the equipment under the action of an earthquake, two types of costs should be considered: (i) direct costs associated with repair or replacement of the equipment and (ii) indirect costs due to its unavailability. The indirect costs include different components: the loss of income for the entity responsible for the equipment, the economic losses deriving from shortage in the supply of the product to other economic sectors that depend on it, as well as other indirect effects that are difficult to estimate. Some of these effects may last beyond the period of repair of the equipment. The relation between direct and indirect costs can be highly variable. In this case, the indirect costs would certainly be several times higher than the very equipment value. Therefore, the variable that best quantifies the earthquake consequences is not the repair cost but rather the repair time, because the latter is the variable that best quantifies indirect costs.

From the previous discussion, special reference must be made to the fact that the cost for solving this problem, before the occurrence of the earthquake, can be a few hundred times less than the cost for solving the problem after the occurrence of the earthquake. This means that it is basically a matter of prevention. Certainly that in some types of equipment already in operation the prevention cost will be higher. As is for instance the case of highly vulnerable equipment in which the solution of the problem relies on the replacement of a few parts or of the whole equipment. Nevertheless, if the seismic problem is considered in the stage of design, it is probable that the increase in costs associated with seismic strength will usually be fairly less than the cost to be supported after the earthquake. This is precisely the case of civil engineering structures.

The authors cannot estimate which is the relative representativeness of the previously mentioned situations in the whole Industrial Park. Nevertheless, this discussion, as well as the lessons obtained from the damages caused by earthquakes in other regions of the world, indicate that also in Portugal, the Industrial Park can be highly vulnerable to earthquake actions. This aspect, together with the vulnerability of constructions, is worsened in Portugal by the fact that 40% of the economic capacity of the country is concentrated on the regions of Lisbon, Tagus Valley and Setúbal Peninsula, which are among the ones of highest seismic risk in the Portuguese territory. Therefore, an earthquake strongly affecting these zones will surely have a devastating economic effect. In order to have a better insight of the potential extent of the problem, we just have to establish simple comparisons with the cases of the Kobe (Japan, January 1995) and Turkey (August 1999) earthquakes. The first affected a zone with similar population but more developed in economic terms, having caused material damages of approximately 150% of the Portuguese Gross Domestic Product. The Turkish earthquake affected a slightly more populous zone and slightly less developed, and caused a drawback of many years in the Turkish economy. In any of these cases, the relative size of the affected zone, as compared with the whole country is much less. Consequently, the normalisation of life in the affected zone and the overall economic recovery will be very difficult to achieve and will certainly take a long time.

3.3 Diagnosis

The main cause for seismic vulnerability of the equipment mentioned in 3.2 is an indirect cause: the continuous unawareness of engineers involved in the process as refers to the seismic problem and to its potential consequences. Actually, in Portugal, the mechanical and electrotechnical engineers, as well as engineers in other fields of expertise who are involved in the design, construction and installation of that equipment have no seismic engineering training. That situation is a result of the initial development of modern seismic engineering in Portugal, about 50 years ago. Despite being praiseworthy the action of the engineers and seismologists that at the time started to build the Portuguese seismic engineering, their work remains incomplete, as in most countries. Their priority goal was the safekeeping of human lives, which has led attentions to be focused on constructions built and designed by civil engineers. Nevertheless, nowadays this is clearly insufficient, not only due to the highest demanding level of public opinion, as refers to the risks for the economy, but also due to the fact that the failure of lifeline networks may also have serious consequences in terms of losses of human lives. This is actually a situation that is easily understandable. Let us consider for instance the electric network: modern societies are almost completely dependent on electric power. All the other lifelines will be totally or partially affected if the electric network fails. The economy would stop and the life of populations in the affected zones would become almost impossible. The failure of water supply networks and sewage systems would cause problems in the public health, as recently happened after one of the El Salvador earthquakes with the spread of cholera. The failure in telecommunications would launch the chaos in the economy and in the Public Administration at all levels and would significantly affect the action of the Civil Protection. Damages in the gas supply system could produce fire that would destroy many buildings and cause many casualties. For instance, in the 1923 Tokyo earthquake, abut 40 000 earthquake survivors were burnt alive in the fire caused by the earthquake. In the case of the recent Kobe earthquake, in 1995, the firemen took five days to extinguish the fires that were responsible for a high amount of damages.

The Civil Protection services recommend people, in their earthquake leaflets, to store water and food for three days. But actually there is no study about the subject stating that the lifelines will only be out of operation for such a period. Therefore, what would be, for instance, the extent of losses both in economic terms and in terms of human lives if the lifelines of the Lisbon region were to be out of operation not for three days but for three weeks instead? In this way, should a significant risk of occurrence of that situation be assumed to exist, to which the Civil Protection will never have the capacity to respond adequately, shouldn´t we act preventively so as to avoid it may become a reality?

Since it is not feasible to prevent the occurrence of earthquakes, the only possible way to cope with the problem is to provide the constructions and equipment with an adequate seismic strength so that these will not be damaged or destroyed by earthquakes. Both in terms of the Industrial Park and of the Building Stock, the possible damages and casualties deriving from a future earthquake, depend mainly on the preventive measures that might be taken to avoid them. Depending on the intensity of the earthquake affecting a certain region, the generalised and adequate application of current scientific knowledge to the Building Stock and to the Industrial Park will not completely eliminate the human and economic damages but it may reduce them in a few tens or even hundreds of times.

Therefore, it is essential that the concern in providing the constructions with adequate seismic strength will be extended to the lifelines and to the industrial sector. The experience gained with the Building Stock has demonstrated that it is also essential to ensure that these concerns are effectively achieved in the quality of design, construction and installation so as to attain the intended objectives and prevent them from being only defined on paper.

4. Recommendations

After the overall diagnosis of the seismic vulnerability of the industrial equipments and machinery, the main issue is to define which measures must be taken to solve the problem. Below, various suggestions are presented, as well as their possible co-relation with the tasks proposed for the Building Stock [6], and which are summarised as follows:

T1 – Surveying the housing stock and assessing the risk.

T2 – Defining more effective intervention strategies.

T3 – Improving solutions for seismic rehabilitation.

T4 – Creating support legislation.

T5 – Training and dissemination of information.

T6 – Preparing master plans for seismic rehabilitation

T7 – Carrying out the works.

In order to avoid the spreading of the problem, it will be necessary to attack directly the causes. For the purpose, the engineers who design and install the industrial equipments and machinery should be made more aware of the seismic problem and of how to solve it. This implies the training of existing professionals and the alteration of curricula of some engineering courses. Since generally these courses already include a base training on mechanics and vibration, the addition of new disciplines may not be necessary. Occasionally, the partial alteration of curricula of one or two disciplines may be sufficient, which would make the whole process simpler and quicker in administrative terms. This point is integrated in task T5.

As refers to the existing Industrial Park and to the lifelines, a characterisation of the problem must be first made. For the purpose, a set of facilities may be selected in accordance with their economic relevance, with their representativeness and with the possibility of releasing hazardous substances. The third aspect has a high importance for environment and for Civil Protection. The main purposes of these studies should be: (i) the characterisation of the seismic vulnerability of facilities by identifying their weaker aspects and (ii) should that vulnerability be significant, presentation of a few suggestions intended to reduce the seismic vulnerability of those facilities, and which would be subsequently detailed. Those studies should involve pluri-disciplinary teams of experts from the industrial sector and seismic engineers. Among other tasks, the manufacturers of the equipment in operation should be consulted so as to obtain data referring to the seismic strength of that equipment. In the absence of that information, the equipment should be tested. The seismic strength, or the capacity of deformation of the external connections of the equipment to other equipment and to the corresponding supports should also be analysed. When justifiable, the seismic behaviour of equipment must be assessed by taking into account the interaction with supports and foundations. This study corresponds to task T1. Nevertheless, whereas in constructions, a part of that work has already been completed or is under way, in the Portuguese industrial sector, no studies have been done as refers to the assessment of the seismic vulnerability and, as regards the lifeline networks, the process is in its initial stage. That task may be promoted by the State in co-operation with the business associations of the sector, since its execution depends obviously on the co-operation and on the commitment of the very industry.

Considering that the previous aspect cannot be put into practice without the co-operation and full commitment of businessmen of the industrial sector, these must be motivated and interested in their accomplishment. For this purpose, they must be aware of the seismic problem and of its potential consequences for the sector. This aspect corresponds to task T5 of the plan for the Building Stock. Nevertheless, it may prove more effective to do it differently. Even though on both cases the target public are the owners of the buildings or of facilities to be strengthened, in the case of the Building Stock, this means the population in general. In the case of the industrial sector and the lifelines the number of people involved is more reduced and probably it will be more effective to address directly the information and awareness actions to businessmen in the sector, for instance by carrying out those actions in co-operation with the respective business associations.

As regards purchase of new equipment, items referring to the seismic strength should be included in the technical specifications to be fulfilled by that equipment. This should apply both to new equipment and to equipment intended to replace equipment that has attained the end of its lifetime. This way the renovation of equipment may be used to reduce the seismic vulnerability. The design seismic action may be the same as the one defined in the Code for Safety and Actions in Building and Bridge Structures [7]. Nevertheless, the design criteria should be different. In buildings, the conditioning performance criterion is the safekeeping of human lives, which means that collapse must be avoided for an intensive seismic action with low probability of occurrence, but allowing significant structural and non-structural damage. For industrial equipment and in particular for lifelines, that criterion is obviously misappropriate and a higher performance criterion must be used. This results from the fact that the indirect costs due to the failure of equipment may be significant comparatively with repair costs or may even be higher than the latter. There might be some situations in which the direct costs are minor when compared with the indirect costs, if not only the income losses for the company managing the equipment but also the overall costs for the economy of the country are considered. As previously mentioned, the parameter that best quantifies indirect costs is the time of repair of equipment, that is why the design criterion must have that factor in consideration. That criterion tends to limit the type of acceptable damages. In the case of significant equipment, particularly the one belonging to lifelines, it could be justifiable to establish that the non-serviceability time assumed will be very reduced and that the design seismic action will be augmented comparatively with the current values to reduce further the possibility of occurrence of damages. That type of criterion may be also justifiable in industries where the damages are likely to have serious environmental effects, as for instance causing the release of toxic or radioactive substances.

It will be important to have adequate technical legislation for the design, construction, strengthening and installation of equipment and industrial machines, with a view to ensure their strength to seismic actions within the shortest possible term. This objective is included in task T4. That action should immediately start to be organised and developed. In the first place, it comprises the awareness, and if necessary, the training of engineers of the fields of expertise that carry out that type of works. In the second place, it comprises the analysis and adaptation of applicable foreign codes and, in the third place, it comprises the development of research in the field.

Even though the analysis done has been mainly focused on industrial equipment and machinery, reference must also be made to the vulnerability of industrial buildings, in view of their importance. Furthermore, a survey must be made into the buildings of the Industrial Park and their corresponding seismic vulnerability must be assessed. Particular attention must be paid to buildings with pre-fabricated structures, given their observed poor seismic performance. Mention must however be made of the fact that the poor seismic performance is not an intrinsic characteristic of pre-fabricated structures. In fact, this is mainly due to the weakness in the connections between elements. Therefore, that type of buildings may be provided with adequate seismic strength, by means of improving the characteristics of the connections.

The proposed tasks, which correspond to a significant part of tasks T1, T4 and T5 of the Programme proposed for the Building Stock, may begin to be implemented. The continuation of tasks T2 and T3 requires significant development of task T1. Task T6 will not be developed at a municipal level, as has been proposed for the Building Stock, but will be rather developed by sectors of activity and/or by geographic zones. Task T7 can only be initiated in a systematic way after significant advances in other tasks.

The authors have neither the means to estimate the costs nor the time necessary for carrying out a generalised intervention with a view to reduce the seismic vulnerability of the Industrial Park. On the other hand, at the level of machinery and equipment, in a few cases such as the one presented in 3.2, the necessary intervention is a surgical intervention on previously identified weak points. It is therefore much cheaper than a comprehensive intervention, as is for instance the case of the Building Stock. Even if this does not apply to many other cases, this aspect will undoubtedly contribute to the fact that the reduction in the seismic vulnerability of the Industrial Park might be less expensive than the one of the Building Stock.

At the level of the planning of major lifeline networks and of certain services essential for the good operation of the economy and of Public Administration, a policy of decentralisation and of creation of back-ups must be adopted. As previously mentioned, the Lisbon and Tagus Valley zone, where many essential services and lifelines are concentrated, it is one of the zones with highest seismic risk in the country. Therefore, the back-ups should be located at a significant distance from Lisbon so that a single earthquake would not affect simultaneously the “source” and the back-up. Since the regions of less seismic risk in the Portuguese Mainland are located on the north of the country, the back-ups must be located in that region. This task does not correspond to any of those mentioned for the Building Stock, because, at this level, there are no inter-connections as the ones existing in the lifelines, the economy and Public Administration.

In view of the fact that the authors have no detailed knowledge about the Industrial Park, it is expectable that the recommendations presented may have a few lacunae. Nonetheless, the main purpose was to assume the most constructive possible attitude, instead of just mentioning the problem and its potential seriousness.

5. Summary and conclusions

One of the purposes of this document has been to present a possible assessment of the seismic vulnerability of the Industrial Park. In the absence of any study about the subject, the indicators used were for instance: (i) the available knowledge about the consequences, for the Industrial Park, of earthquakes that have effectively occurred in other zones of the globe (ii) the analysis of specific cases in Portugal. It is possible to conclude that a part of the industrial equipment may be highly vulnerable to earthquakes and that the main cause for that vulnerability, even though being an indirect cause, is the lack of training in seismic engineering of mechanical and electrotechnical engineers, as well as of engineers in other fields of expertise and who are responsible for that equipment. It has been concluded in an analysed case that the solution of the problem in the stage of design would have fairly reduced costs, whereas the earthquake consequences may have significant costs. This demonstrates that the best approach to the problem is obviously prevention. In this way, a set of actions is suggested, which must be integrated in a more comprehensive overall plan for the Industrial Park, with a view to reduce its seismic vulnerability:

1. Change the curricula of mechanical and electrotechnical engineering courses, as well as of other engineering areas, so as to integrate seismic engineering, and train available professionals in that field.
2. Make the businessmen in the industrial sector aware of the seismic problem and of its potential consequences.
3. Promote the assessment of the seismic vulnerability of the Industrial Park.
4. Change the technical specifications, as refers to purchase of industrial equipment and machinery, so as to include the corresponding seismic strength.
5. Prepare the necessary technical legislation.
6. Take into account the problem of the seismic risk in the planing of lifeline networks and in the location of back-ups of services essential for the operation of the economy and of the Public Administration.

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Aspects of a Housing Policy Intended to Reduce Seismic Vulnerability in Azores

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Dear Sir,

I would like to thank, by directly addressing my acknowledgements to Prof. Carlos Sousa Oliveira, the kind invitation made to attend this event and the opportunity I was given to share with you one of the concerns of the Portuguese society, which undoubtedly must be made aware of the importance of the subject by the organisation of Meetings such as this. Actually, discussing the Reduction in the Seismic Vulnerability of constructions in Portugal; contributing to prepare the bases for a National Programme; as well as reflecting on the experience of Azores, as one of the zones with highest seismicity in the country, are undoubtedly ways to act on the memory of past events and to protect the future as refers to damages for persons and property.

The intensive acquaintance of the VII Regional Government – 1996-2000 -, the first to be run by the Socialist Party in the Autonomous Region of Azores, with a series of calamities – floods, landslides and earthquakes – has made the newly formed government aware of the actions that should be urgently undertaken, in view of the value of the human, economic, social and patrimonial losses. If, on the one hand, the creation of a Regional Housing Plan, as an auxiliary tool for housing policies, was a programmatic desire that was soon assumed, on the other hand, the earthquake of 9th. July 1998 that occurred at the islands of the Central Group, **originated a significant and structural alteration in the governing strategy**. The consequences have made people aware that, from now on, it would be no longer possible to adopt a reactive approach as refers to the consequences of the disaster. A public active and preventive policy should be adopted instead.

Consequently, when consulting the bases for a possible National Programme for Reducing the Seismic Vulnerability, it was with the greatest pleasure that I have verified that the Autonomous Region of Azores has been following an adequate and reliable course of action.

A) <u>Surveying the housing stock and assessing the risk</u>

In June 2000, the Regional Office for Housing and Equipment, through the Regional Directorate for Housing, has signed an agreement with the University of Azores/Volcanic Studies Centre. The main purpose of that agreement is to prepare the Chart of Geologic Hazard of the Autonomous Region of Azores (CRGRAA), which has been converted into a dynamic digital document. The main purpose of that document is to identify and classify all the seismic, volcanic, mass movements and tsunami risks for the different Azores islands, by establishing the principles and the procedure rules that should preside over decision-making with a preventive character, so as to minimise the damages resulting from possible catastrophes that are likely to affect the region.

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The CRGRAA will integrate for each island, the chapters as follows: I) General Considerations; II) Hazard Identification; III) Analysis of vulnerabilities; IV) Recommendations; V) Bibliographic Elements; VI) Cartographic Elements.

The project of execution of the CRGRAA is to be based on the analysis of the bibliographic data, including an inventory of historical records, the development of geologic campaigns for the characterisation of geologic hazards, as well as the identification of vulnerability elements. The data collected will be included in a Geographic Information System and integrated in the phase of assessment of risks, which will make it possible to produce thematic charts at different scales, and which are likely to be updated depending on the dynamics of the target systems.

The CRGRAA is to comprise studies at an island level (1:25.000 or less) and at a council, parish or small village scale, depending on the situation in terms of risk.

Consequently, the highest risk zones will be studied in a scale of 1:5.000, which will make it possible to analyse the risk situation of each house, street, square, etc.

Census 2001 will be an element to be considered in this work, provided that its data are likely to be safely included in this study, by taking into account the technical reliability of the collection.

The CRGRAA is to be carried out throughout six years. The first three years – until 2003 – corresponding to a first stage, will be devoted to the analysis of risks at an island level (1:50.000) and to the preliminary phase of detail assessment of all islands, the works referring to S. Miguel and Faial being meanwhile completed (1:25.000, 1:15.000, 1:10.000, 1:5.000 and/or 1:2000). A second phase will be devoted to the completion of detail studies of the other islands.

This important work will be accompanied by a “Catalogue of Seismic Events, Volcanic Eruptions, Mass Movements and Tsunamis” ever since colonisation until present days. Such historical record will make it possible to observe the highest time coefficients of calamities, as well as their typology, quantity and incidence zones.

B) <u>Defining the most effective intervention strategies</u>

The framework of the housing situation of Azores, requires a structural guideline of a political action that should preside over any government. This means operating on a basis that is being constructed by the VII and VIII Regional Governments and which is intended to protect constructions and to implement solutions for reducing the seismic vulnerability as refers to population. Other medium-term lines may also be created or integrated in the different political projects.

Only two of the nine islands of the Archipelago (Flores and Corvo) are located on the so-called American plate and consequently are poorly susceptible to seismic crises, whereas the other islands (oriental and central groups) are part of the Euro-Asian plate where the complexity of tectonic faults is high and therefore are highly vulnerable to seismic-volcanic crises.

A significant part of constructions in Azores is old. In 1997, in Azores **51.4% of the Building Stock had been constructed before 1945 and 31.2% had been constructed before 1918 51,4%**, whereas these values were 25,8% and 15,3% for the country and 39,9% and 21,9% for the Autonomous Region of Madeira. It is known that the anti-seismic solutions with a binding normative character have only been implemented since the 1980 earthquake.

Nevertheless, the housing buildings constructed after 1980 represent in 1997, 24.9% of the total housing stock, which is a little more than the average in the Mainland and significantly more (7,4%) than in the Autonomous Region of Madeira. The renovation of the housing stock in Terceira, Graciosa and são Jorge, as a result of the re-construction after the earthquake of 1st. January 1980, is undoubtedly responsible for those figures.

In a recent past, it has been verified that only a few councils presented a dynamics that was not associated with catastrophes, represented by a construction rate higher than the average. This clearly demonstrates the importance of the response to catastrophes in the renovation of the housing stock of Azores.

As a result of the oldness of the Housing Stock, 76% of the buildings had no reinforced concrete (columns, beams and slabs), 52% of their resistant elements being made of stone and 39% of their exterior walls being made of coarse stone and of other materials (1991 data).

On the other hand, the volcanic, geologic and tectonic characteristics of the Archipelago, recommend that the constructions should be located at a cautious distance of cliffs and of zones in risk of flood or landslide, by using construction techniques intended to reduce the risk of building collapse in case of earthquake.

Otherwise, it is essential to renew the investment in the housing sector by two reasons. First, in view of the effective potential of increase in the population of Azores, at least until 2020, which will imply an increase in the housing demand by a larger number of families, even though with less persons/aggregate. Second, the existence of a housing stock already characterised and misappropriate in terms of space, safety and comfort, which makes it vulnerable and expensive in the presence of natural catastrophes that are likely to occur in such a seismic and volcanic region.

Therefore, policies such as the following ones are integrated in the Programme of the VIII Regional government:

1. Intensifying the effort as refers to rehabilitation and maintenance of the existing housing stock, by means of adequate measures intended to renew deteriorated houses, namely unoccupied ones;
2. Creating credit lines (including anti-seismic insurance) aiming at the anti-seismic structural strengthening of old housing buildings, so as to ensure a higher safety and preservation of the architectonic characteristics of the housing stock of Azores;
3. Protecting the populations in situations of risk (close to cliffs, coast line, slopes, stream beds, etc.), by implementing projects for safekeeping of housing, and intended to reinforce the safety of life and property of citizens, or by gradually promoting alterations in their location.

As refers to the first and second measures, in accordance with the new diploma of support to deteriorated housing to be approved in the next Council of the Regional Government, all the interventions must integrate elementary anti-seismic measures, such as, the consolidation of resistant walls, preferably with reinforced plaster, and the consolidation of masonry and roofs, namely through the execution of wall top lintels and tie-rods.

The government subsidy per application will be around 15 000 €, as maximum limit of subsidy for seismic strengthening, excepting the support to which each citizen will be entitled.

The creation of special credit lines for all citizens with a certain income, housing area or with a certain public benefit already acquired, will be a second aspect to be taken into account as a strong incentive to the strengthening of less solid houses, especially the oldest ones.

This legislative support will not include the real estate that due to its characteristics or location is not likely to provide safety to its dwellers.

Still as legislative draft-project, but being scheduled until June, all the applications for the purchase of housing financially supported by the public budget will have different maximum limits, not depending on the value of the subsidy to be granted but rather on the reference limit.

Therefore, for instance, the constructions with anti-seismic structure up to a limit of 55 000 € or 60 000 € may apply for the programme, whereas the possible limit for constructions without anti-seismic structure may be 40 000 € or 45 000 €.

That intervention strategy is being continuously implemented and tested in the Reconstruction of the islands of Faial and Pico after the seismic crises of 9th. July 1998. There has been a major concern in conjugating the repair of damages with the application of adequate rehabilitation and reconstruction techniques, being solidly based and with objective criteria adjusted to the local reality. The existence of a technical document designated as "General Rules for Rehabilitation and Reconstruction of current Buildings affected by the seismic crisis of Faial, Pico and S.Jorge", which was prepared by eminent Professors as Eduardo Cansado Carvalho, Carlos Sousa Oliveira and other qualified technicians of the Regional Laboratory for Civil engineering, is being used as support to about 2500 rehabilitation works integrating solutions such as basically the following ones:

1. Elimination of deformations;
2. Consolidation of resistant masonry walls;
3. Consolidation of timber structures;
4. Consolidation of walls (crest of walls);
5. Tie-rods bracing walls;
6. Local modification of structural components;
7. Overall increase in rigidity;
8. Overall increase in strength;
9. Bracing of pavements and roofs.

The application of those solutions has been closely surveyed by a Technical Support Office that requires the intervention of other institutes whenever judged necessary. For instance, and since it was of the utmost importance to know the mechanical characteristics of component materials, the Regional Government has awarded a contract for the execution of a set of tests intended to characterise traditional masonry. Those "in situ" tests have had the participation of the University of Engineering of Porto, under the supervision of Prof. Aníbal da Costa.

We believe that as refers to that aspect, the Region already has a positive experience, which is intended to be continued and developed.

Conclusion

With the study designated as **"Analysis and diagnosis of supported housing in the Region"** (1976-1997), the Regional Directorate for Housing intends to launch the first step towards the execution of a Regional Housing Plan. This first step refers only to housing that has had, either directly or indirectly, the support of the Public Administration, in cash, in genre or in knowledge and services. This study, which has had the co-operation of the National Laboratory for Civil Engineering, through Architect Reis Cabrita, is to be completed by the end of March 2001, and is expected to produce data relevant for the future of the housing policy.

The "Analysis and Diagnosis" is intended to assess the effectiveness of the application of public resources, as well as the operation of the processes for promoting subsidised housing in the various factors that contribute to production, use and management of that housing, such as specifically: subsidies, soil, urban planning, construction, marketing, use and management of the stock.

With CRGRAA being the document that acts as support to future prevention and safety policies; together with the continuous awareness that there must be a political will-power and resolution so as to integrate in the legislative context the successive realities that are to serve what should have been considered as a national purpose – i.e., the Reduction in the Seismic Vulnerability – the main purpose of the Autonomous Region of Azores, despite the fact of it being a Seismic Region, is to continue pursuing a policy intended to ensure an increased Safety and Quality in the daily life of its population.

Ribeira Grande, 29th. March 2001.

CONCLUSIONS

SYNTHESIS OF THE DEBATE

As defined in the Meeting schedule, after the presentation of papers, there was a debate that had an intensive participation of those attending the meeting. In that debate, a consensus has been reached about the issues pointed out, such as:

1. The best way to reduce the seismic vulnerability of construction is to ensure that the latter (regardless of it being new, or rehabilitated) fulfils the codes in force. For the purpose, the quality of design and execution of the work must be ensured and must be accompanied by adequate inspection. This issue has been considered of the utmost importance.
2. The design of seismic rehabilitation has a few particularities, namely (i) regarding the complexity of structural design, which is decisive (maybe even higher than the one in structural design of new constructions), and (ii) as regards the knowledge of materials and construction technologies. On the other hand, the seismic rehabilitation is often accompanied by other rehabilitation components, which refer to serviceability and adjustment of spaces, improvement in the salubrity and comfort conditions, etc.
3. From the particularity referred to in 2., there can be deduced that the technicians and companies involved in seismic rehabilitation actions must necessarily have:
   - adequate technical training
   - have a close relationship with the technicians responsible for the other rehabilitation components. Namely at the level of design, the co-operation between architects and engineers, ever since the stage of design, is decisive for the success of the intended rehabilitation.
4. The schools, the professional associations and the business associations have particular responsibility in school and post-school training, as well as in the certification of courses and specialisation actions (both of technicians and of companies) within the field of rehabilitation.
5. The professional qualifications and the licenses of, respectively, technicians and companies responsible for the design and execution of rehabilitation works must also be dully defined in the regulations.
6. It is essential to produce documents intended to supervise rehabilitation actions. The specific creation of a Seismic Rehabilitation Manual devoted to the main typologies of the building stock is indeed an irrefutable priority.
7. It is urgent to accelerate the coming into force of the Structural Eurocodes, which, both in terms of design and in terms of quality assurance of the execution of works, approach the rehabilitation subject with more detail than the existing codes.
8. A particularly relevant aspect as refers to seismic rehabilitation is the geotechnical characterisation. It is of the utmost importance to proceed with the preparation and dissemination of procedures referring to excavation, soil retention and dimensioning of foundations in zones of high seismic vulnerability.
9. It is indispensable to take into account that a building rehabilitated from a seismic point of view, by the fact of having improved resistant capacity and ductility will also have better structural safety conditions for other actions (namely differential settlements, thermal actions and subsequent cracking).

10. It is feasible to integrate explicitly in the programme RECRIA[1], or in other similar programmes, a seismic rehabilitation component and, undoubtedly, this will be an important stimulus to draw attentions for rehabilitation actions and to encourage their implementation.

11. Implementing Work Insurance aiming at the seismic safety must be subject to the agreement of the *APS – Associação Portuguesa de Seguradores* (Portuguese Insurers Association). It necessarily implies the intervention of an independent technical control entity, which is to certify, close to the Insurance Company, the quality of the design and of the execution of the work.

12. In order to proceed with the activities necessary for implementing the Programme object of the Meeting, the most adequate option corresponds to the sequence of actions as follows:

12.1. Reformulating the programme in accordance with the conclusions of the Meeting and disseminating it to all entities that are potentially interested in its achievement.

12.2. Making the institutional Owners aware of the need for execution of pilot-actions of seismic rehabilitation on the patrimony for which they are responsible (schools, hospitals, other buildings of intensive collective use, municipal patrimony, etc.).

13. As refers to actions intended to achieve the Programme, special reference must be made to the effort that has been made in Azores, represented by seismic rehabilitation programmes, which, in terms of the problem of that Region, can be considered as paradigms of the National Programme that is proposed.

14. It is the intent of the entities promoting the present Meeting - SPES and GECORPA – to continue encouraging the development of the previously mentioned actions, with the support of all the entities interested in co-operating in those actions and, particularly, of the persons and entities that have participated in the Meeting.

[1] A programme for Urban Rehabilitation.

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