Shoring and reinforcement

in emergency disaster situations

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Abstract

Natural disasters, especially earthquakes, produce harmful effects on buildings and infrastructures. To prevent the worsening of damage, shoring and other emergency reinforcements shall be applied. These allow temporary support to structures, providing stability and security to search and rescue operations and the continuity of economic and social activities.

Some documents are presented reflecting the emergency shoring and strengthening practices adopted in the USA, Italy, Australia, Brazil, Spain and Portugal, aiming to synthesize the information and support future research, based on the bibliographic review on the internationally adopted manuals.

Vertical, diagonal and horizontal shoring systems are presented, with variants for each model, together with images of practical solutions, construction rules and recommended dimensions.

The differences between the manuals are highlighted, together with new shoring typologies and strengthening techniques as the use of rod metal bars and column tying and jacketing.

Real shoring solutions applied in post-earthquake interventions are displayed, the more relevant being the L'Aquila and Northridge earthquakes, for which the applied shoring and strengthening procedures are shown.

To show the potential application to the Portuguese territory of lessons learned from real-life situations, are analysed possible shoring and reinforcement solutions in structures (especially churches) damaged in the Faial earthquake, Azores.

Finally, conclusions are presented about the need to use temporary shoring and reinforcements in emergency situations and on the effectiveness and applicability of the available solutions, Also analysed are possible future developments in the reinforcement techniques for emergency situations and future research activities in this field.

Keywords: Shoring; strengthening; earthquake; emergency.

Introduction

The need for emergency shoring under disaster situations stems from the obligation to ensure the protection of people and property, guaranteeing that the shored structures do not suffer more significant degradation, preserving them temporarily until other rehabilitation measures can be taken and allowing in their vicinity the continuation, as far as possible, of the distress or even current activities.

Among the emergency situations that advise or require shoring, the ones resulting from intense seismic actions are the worldwide most commonly met and the most studied ones.

In masonry or reinforced concrete buildings there is often damage to the structural elements with significant material rupture and/or collapse located on the partition walls, or on the facades and sustaining walls, that can cause collapse and serious diagonal cracking on the walls, leading to excessive deformation of doors or windows, among other.

The shoring is a set of actions that provides support and prevents collapse of the whole or part of a building, ensuring temporary stability and safety for workers. It can be used when there was "poor construction, material’s degradation, earthquakes, storms, explosions and fires". [1]

Other temporary reinforcement actions are possible, in particular using polymeric or metal materials, steel bars and columns jacketing.

State of the art - emergency shoring

There is a set of international legislation and manuals adopted to guide the shoring and reinforcement interventions in emergency situations, after an earthquake or as a result of other natural disasters, which was produced in countries such as the United States of America (USA), Italy, Australia, Brazil, Spain and Portugal.

In the United States of America, due to the high seismic hazard in several areas, and to a greater technical-scientific preparation and economic capacity, there are a large number of emergency shoring regulations, standards and recommendations, which are the main source of knowledge in this area at the international level.

The most relevant are the Structural Collapse Technician Training Manual of the Federal Emergency Management Agency (FEMA) [2], the Shoring Initiatives Operation Guide (SOG) [3], the Field Operations Guide (FOG) and the Field Guide For Building Stabilization And Shoring Initiatives Techniques.

Italy is one of the most prone countries to earthquakes in the Mediterranean area, due to its geographical location coinciding with the area of convergence between the African and the Eurasian plates.

In Italy there is a 2007 publication, by the Joint Research Centre of the European Commission, entitled Field Manual for post-earthquake damage and safety assessment and short term countermeasure and the *Schede tecniche delle opere provvisionali per la messa in sicurezza post-sisma da parte dei vigili del fuoco*, also called STOP, published in 2010. [4]

In Australia, which has some regions of greater seismic hazard, although the earthquakes occur almost over the whole country, the more relevant documents are the "Urban search and rescue capability guidelines for structural collapse response" presented by the Emergency Management Australia (EMA) and the General and Disaster Rescue Manual 35, which is in its fifth edition. [5]

Brazil, which is located within the South American plate, where the highest seismicity zone is the region close to the Andes, has recommendations for rescue operations and rescue in general, which include the *Manual de Salvamento Terrestre*, whose chapter 8 is dedicated to Emergency Shoring. [6]

In Spain, a country of moderate seismic intensity, the areas with the greatest probability of seismic activity are the regions in the south and southeast and the Pyrenees. The Emergency Manual (ME) compiled by Spanish Army, without date of publication, is used. [7]

In Portugal, situated in an area of average to moderate seismic activity, in 2013 was launched the *Manual de Escoramentos de Emergência* (MEE) by the Firefighters Brigade (RSB). [1]

Emergency shoring

The temporary T vertical shoring, shown in Figure 1, is used for initial stabilization in an area at risk of collapse until a more permanent vertical shoring is built. This model is unstable and requires that the shoring is centred with the load. [6]

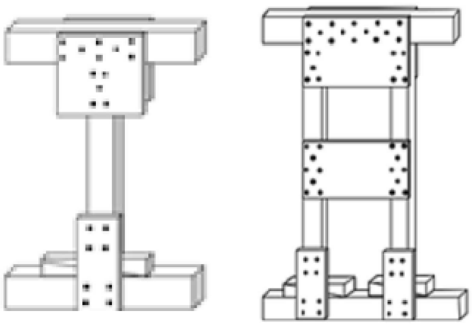

Figure 1 – T-shore and Double T-shore [3]

This type of shoring is referred to in the following manuals: SOG, STOP, *Manual de Salvamento Terrestre*, Spanish emergency manual and in the *Manual de Técnicas de escoramentos*. An alternative model is the temporary vertical double T, referred in SOG, *Manual de Salvamento Terrestre* and the Spanish emergency manual.

This system, although still for local reinforcement, is more advanced than the previous one, allows for greater stability and less stresses in the shoring elements.

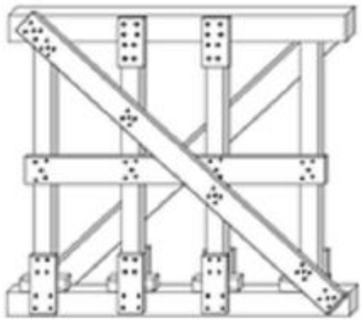

Figure 2 – Vertical shore [3]

The vertical shoring is adopted for situations where it is necessary to underpin a damaged beam or pavement, being the load distributed by the various elements, as shown in Figure 2. This model is presented in all previously referred manuals.

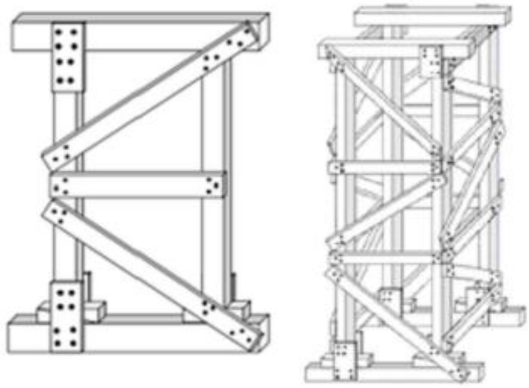

Figure 3 – 2-Post vertical shore and Laced post shore [3]

The model presented in Figure 5, at left, is called 2-post vertical shore, can be partially pre-manufactured, already provides a greater lateral bracing, and is referred to in SOG and the Spanish Emergency Manual. On the other hand, the right figure presents a "shelter", consisting of 4 elements of double posts, locked in the two directions, possibly with plywood, and may have a maximum height of 6 meters. It is indicated in FEMA, SOG and *Manual de Técnicas de escoramentos*.

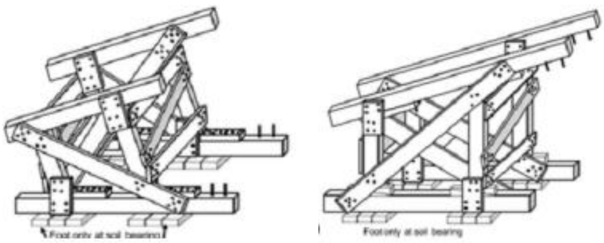

Figure 4 – Sloped floor shore and sloped post shore [3]

For supporting inclined elements, there are models as the ones presented in Figure 4 . In the left model the support is achieved fixing it to the ground, when the element is conveniently braced. When there is a possibility of sliding, a shoring for inclined planes is used as indicated on the right figure, fixing the structure to the inclined plane.

Figure 5 – Cribbing [Photos transferred by RSB]

The cribbing system, presented in Figure 5, allows adjusting the height of the element being shored, varying the number of pieces per layer and the height of each piece. It can also be adopted for inclined elements if wedges are applied between layers. This system is evidenced in FEMA, SOG, *Manual de Salvamento Terrestre* and Spanish emergency manual.

The shoring of openings such as doors and windows are presented, with some variations, in all the referred manuals. In the FEMA manual and in *Manual de Técnicas de Escoramento*, the shoring is built on the edge of the opening without inside braces. In the case of the *Manual de Salvamento terrestre* and STOP the shoring is done with inside braces as shown in Figure 6.

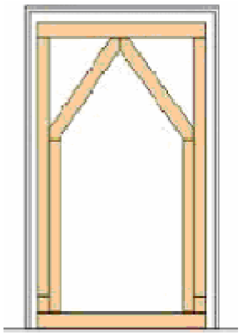
Figure 6 – Door shore [6]

The diagonal shoring systems have three variants, depending on the soil conditions and the existence of rubble next to wall to be braced. The diagonal system to support elevated elements, shown in Figure 7a), is limited by the size of the vertical element to be shored, being widely used in situations where there is a large amount of rubble near the wall. This model is referred in FEMA, SOG, Manual 35 and the Spanish emergency manual. However, when the amount of rubble is reduced, an incomplete base model is adopted (Figure 7c), which is referred to in SOG and Manual 35. On the other hand, there is a complete base model (Figure 7b) used when the space near the structure to be shored is not compromised, that is, when it is without rubble and when the soil allows good fixing conditions. This element is displayed in all the referred manuals.

a)

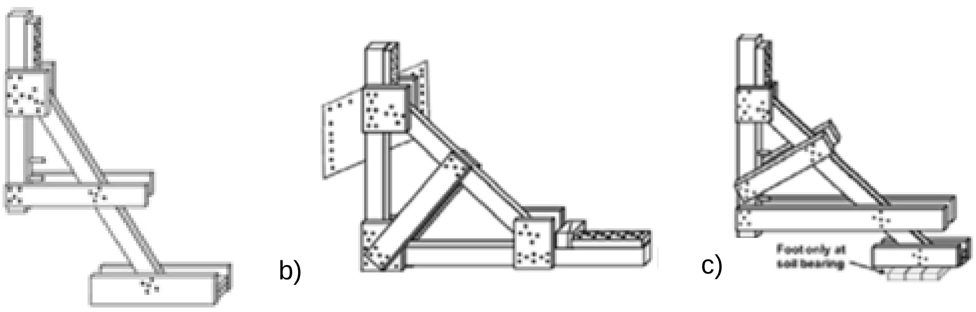

Figure 7 – Raker shore systems [3]

The *Manual de Salvamento Terreste* and the Australian Manual 35, also mention a diagonal system with multiple bracing levels, referred as multiple shoring. Figure 8 shows a possible variation of this type of shoring, in this case an inclined triple shoring.

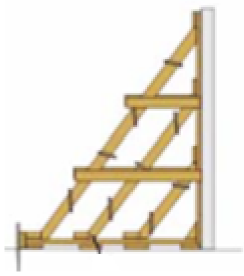
Figure 8 – Triple Raker shore [6]

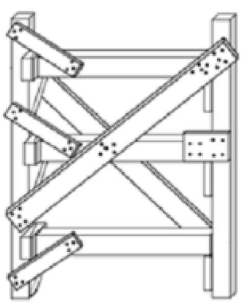
Figure 9 - Horizontal shore [3]

To shore a vertical element with a tendency to collapse out of its plan, there is still a horizontal strut, mentioned in all referred manuals. This system, shown in Figure 9, is applied when there are walls of small rooms, corridors or stairway enclosures in poor condition [1].

There are still systems intended to support banks of ditches or even to ensure lateral containment between buildings. In the application of pneumatic or hydraulic braces any one of the above mentioned models are used.

These elements are widely used during the construction of a full wood shoring to support the loads and are then removed. However, in situations of redemption and rescue they are built to support the rubble even before a later construction of a complete wood shoring.

The STOP manual also presents arch shoring elements, displayed in Figure 10, for masonry structures. The arches or vaults are constructions of high instability. This manual provides guidelines for the construction of the reinforcement where the structure discharges the loads.

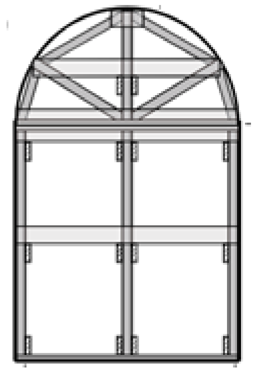

Figure 10 – Arch Shoring [4]

In this manual are still referred some techniques of structural reinforcement as the application of metal bars, wrapping of pillars and even jacketing of masonry walls. These techniques have been very applied after the earthquake in L'Aquila, in 2009, and are presented below.

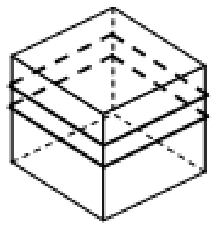

Figure 11 - Application of steel binding straps [4]

Figure 11 shows a diagram of application of steel tie rods for the reinforcement of structures at risk. In the STOP manual are referred the recommended dimensions, spacing between rods, the tie rods mounting typologies, characteristics of steel cables, supports to adopt in the corners and safety procedures for the ties handling.

This manual also presents a reinforcement system for columns and pillars. The system is applied in situations of high internal forces in columns or pillars where due to high compression there is inner material expansion. Figure 12 shows the implementation of polymer wraps in masonry columns or pillars to increase the global confinement and thus the compression resistance. This solution is not adequate for reinforced concrete columns.

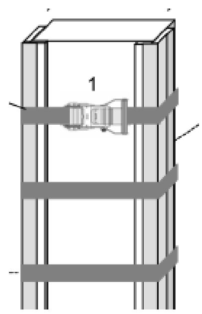

Figure 12 – Wrap of pillars [4]

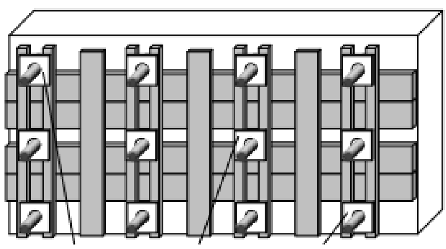

Figure 13 - Jacketing of masonry walls [4]

The jacketing of walls, shown in Figure 13, consists on the application of wood planks, plastic or metal nets, fixed to the wall along the entire element, in order to obtain a global confinement, increasing the resistance to compression internal forces.

Real situations of emergency shoring and strengthening

The shoring interventions in various buildings in the wake of several earthquake occurrences are not in a great number. These interventions are often in historic buildings or architectural heritage constructions, in order to allow their subsequent recovery, in cases in which the buildings offer risk of collapse that puts at stake the movement of people and/or cannot be demolished or its recovery is justified.

To display some of these occurrences, are presented some interventions in L'Aquila, in Italy, in 2009, in Northridge, 1994, in the United States of America, and in the Bourmerdes earthquake, in 2003 in Algeria.

In April 6, 2009 there was an earthquake of magnitude 6.3 in Italy, approximately 85 km northeast of Rome. This earthquake resulted from fault ruptures in the chain of mountains of the Apennines. These ruptures are related to the collision between the European and African plates and the Tyrrhenian basin. [8]

In Figure 14 are visible three types of interventions, all applied to stone masonry buildings (two churches and a large public building), the first with a diagonal strut, the second with an overall wrapping of an area of the building and the third with a wrap of columns in a system of arches outside of the building, through strapping of polymeric bonds, allowing a very quick implementation.

Figure 14 - Temporary consolidation procedures [9]

On January 17, 1994, at 4h30, there was an earthquake in Northridge, in the northern part of the Los Angeles metropolitan area, in California, having reached a magnitude of 6.6 on the Richter scale. [10]

Figure 15 (left) shows the shoring of windows similar to those presented in the Italian manual STOP for a large opening, set between 1.5 and 3 meters. The right figure shows a T shoring of a column, similar to the one presented by SOG in Figure 1.

Figure 15 – Shoring used in Northridge [11]

In May 2003, following the earthquake in the Boumerdes province, Algeria made an appeal for international aid, which Portugal responded positively. A division of the Firefighters Corporation for emergency and rescue was directed to operations of search and rescue and medical assistance. Unfortunately, the firefighters only supported the redemption of bodies. In Figure 16 is shown the performance of the battalion in post-earthquake operations.

Figure 16 - The RSB in Algeria [Source: Photographs kindly supplied by RSB]

In the left figure it is possible to see the implementation of three braces to support the rubble of the building and create a tunnel, allowing the advancing to the place where the victim is. On the other hand, the right picture shows the exact location of a rescue operation, where it is possible to see the application of blocks and pillows.

Case Study

The analysed case study is based on the field work conducted by the team of IST, for inspection and evaluation of some structures which, following the Faial earthquake, in the Azores, in 1998, were important for the life of the people, in particular, schools and churches. Taking as a basis situations occurred in that earthquake, are envisioned shoring and reinforcement interventions in buildings that could have been made in the context of a post-earthquake intervention.

In a way a little arbitrary, and seeking only to cover different situations, are analysed some possible shoring and reinforcement interventions in the churches of Ribeirinha, Pedro Miguel and São João, in the islands of Faial and Pico.


Figure 17 - Solution for shoring of arch

Figure 17 shows a possible solution to this type of shoring, which would allow the support the loads that were transmitted to the arch also contributing to restore support and capacity of resistance in the transverse direction of the church. This solution is the same that is presented in Figure 10, from the SOG Manual.


Figure 18 - Solutions of shoring and B-pillar reinforcement

In Figure 18 it is possible to observe the damage of a square masonry pillar that, as several others in the same church, was highly fissured, in a situation of pre-collapse by rupture by compression. In figure 18 two systems of shoring and strengthening are recommended.

The left figure shows a strengthening possibility, that applies a system of wrapping with polyester strapping, similar to the one shown in Figure 12 of the Manual STOP. On the other hand, if the pillar presented no resistance, a wood shoring system as shown in Figure 5 would be recommended, for being self-supporting, assuring the transmission of loads even in the event of a collapse of the pillar.


Figure 19 - Solution wrap the tower

The Church of São João, in the Pico Island, revealed major structural damage and relatively extensive, mainly in the tower with large diagonal cracking and the corners denoting outward displacements. The recommended procedure would be the wrapping of the church tower. Polyester strapping, shown in Figure 19, would provide containment to the constituent elements of the tower.

This application would lead to a temporary conservation of the damaged structures. The application of shoring would be useful in schools and churches, which are buildings of great importance to society and widely used. This way, the population would be permitted to attend the school spaces and worship without risk, while waiting for a permanent and definitive intervention.

Conclusions

In accordance with the objectives set out at the beginning of this work, was carried a comprehensive review of the existing literature and recommendations on the application of shoring and reinforcement in disaster situation. In this work it was found that there is a lot of information compiled on what to do as regards the application of shoring and reinforcements but would be desirable to have more information on the constructive process with indications of quantitative value for load capacity and strength of the parts to be taken.

This collection of information has led to a variety of types of buildings as well as shoring and reinforcements. However, there is no clear definition about spacing values, load capacity and dimensions of the parts, in order to standardise the procedures.

The application of shoring with the intention to preserve the structure of the building is reduced in real situations. The situations in which it is involved are more related to search for people and rescue of bodies with the application of hydraulic or pneumatic braces, as well as blocks and pillows.

On the other hand, the application of wood shoring becomes relevant in situations of buildings of greater architectural and cultural heritage relevance, such as churches, monuments and important buildings, as was the case in L' Aquila in 2009 and Northridge in 1994.

As future work, it is recommended that the quantification of actions be made, for a later association with the resistance of the systems to be used. Also important is to promote continuity in the study of new possible geometries, as well as new materials.

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