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# Management of urban shoring during a seismic emergency: advances from the 2009 L'Aquila (Italy) earthquake experience

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***ABSTRACT*** Starting from a brief history of strategies for securing interventions after recent earthquakes in Italy, the problems and advances in the management of provisional works related to the 2009 L'Aquila earthquake are examined here. In particular, specific strategies and decision-support tools developed by the National Fire Department for the management of a complex and extensive operation of urban shoring, within the Italian system of civil protection, are illustrated. The problem of defining seismic action for sizing provisional structures to be realized during a seismic emergency phase is illustrated, and a specific macroseismic criterion is presented. Safety measures for workers and on field applications are also discussed. Finally, a useful possible link between new tools and official sheets adopted for damage assessment of the cultural heritage is proposed and the importance of a holistic framework and the need for systematic coordination between the different agencies involved in the problem are highlighted.

**Key words:** post-earthquake management, provisional works, L'Aquila earthquake.

## 1. Introduction

A destructive earthquake resulting in serious structural damage requires urgent securing operations, and in particular, provisional works. A provisional work represents the intervention necessary to fix a leaning, partially collapsed or severely damaged building in order to make it temporarily safe until permanent solutions are found and implemented.

From a functional perspective, the aim of provisional works is to contrast further mobilization of the kinematics activated by the earthquake, avoiding the damage evolution or the collapse of the building. This also in order to protect those areas where strategic operations are need.

Whilst at the individual building scale, the provisional work is mainly an engineering issue, at urban level it is aimed at:

- guaranteeing the survival of historical centres hit by an extreme event;
- reusing roads and infrastructures unusable because of damaged structures, guaranteeing a relatively safe accessibility of strategic facilities.

Therefore, post earthquake extensive intervention of provisional works in a damaged area, or in short "urban shoring", can be defined as a process of urgent intervention through which an urban area, hit by an earthquake and where extensive damage has occurred, may be made reasonably safe for its reuse or to start recovery interventions.

In order to define safety conditions over large parts of the affected area (for instance, main roads) or to protect and preserve the cultural heritage, the realization of provisional works is often already needed in the earlier phases of the emergency and requires specific intervention strategies and priorities. In particular, when a great number of provisional works must be realized in urban areas, it is important to plan the right sequence of interventions and to identify the most opportune solutions, taking into account the overall emergency scenario.

The design procedures for the single intervention have to consider the characteristics of damage, the building typology, the level of response performance for forecasted seismic loads expected by provisional structures and the problems related to the operational context and in particular to the safety of workers realizing the provisional works.

Damage and operational contextual scenarios and further seismic actions must be considered in order to define a holistic framework for the whole process of the problem management. Engineering and rescue strategies have to take into account the seismological and safety characteristics of the immediate post-earthquake scenario.

The main progress in this area has been made for cultural heritage. Ordinary buildings follow the approaches and advances made in that field where most research efforts have been devoted to developing a systematic approach for problem management.

## 2. Damage assessment and definition of emergency repair measures for cultural heritage

The two major Italian earthquakes, in 1997 in Umbria-Marche and in 2002 in Molise, represented key moments for the management of the cultural heritage during an emergency (Cifani *et al.,* 2005) prior to the 2009 L'Aquila earthquake.

For the first time, in 1997, a form was used to assess damage to churches (which made up most of the historic architectural heritage) acting as a real guide for the recognition and analysis of the damage mechanisms in buildings hit by the earthquake (DPCM, 2006). The form represented an important summary of retrospective studies on seismic vulnerability of churches developed in the previous years, in particular following the 1976 Friuli (north-eastern Italy) earthquake (Doglioni *et al.*, 1994).

The approach used for the damage assessment, which requires a kinematic analysis of the different parts of, say, a church (the "macro-elements"), was known, until 1997, only by a small group of experts who carried out studies on the subject. The method proved highly effective, in emergency conditions, particularly during the Umbria-Marche earthquake when it had been possible, given the large number of architectural heritage sites on the affected territory, to carry out the damage assessment to the churches through technicians of different backgrounds and expertises. For this reason, damage recognition had to be preceded by an intense field training of the involved technicians.

The operational tool consisted of a sheet used during the field observation for collecting the architectural building data and analysing the different macro-elements of the church (Fig. 1). An abacus with schemes of typical damage mechanisms, attached to the form, allowed inspectors, to recognize the damage by comparison, and to assess its severity following standardized criteria.

The sheet also proved fruitful as a decision-support tool. The damage assessments were made with standard criteria and decision-makers had access to technical reports, immediately understandable and comparable, for the process of post-earthquake reconstruction. The sheet was

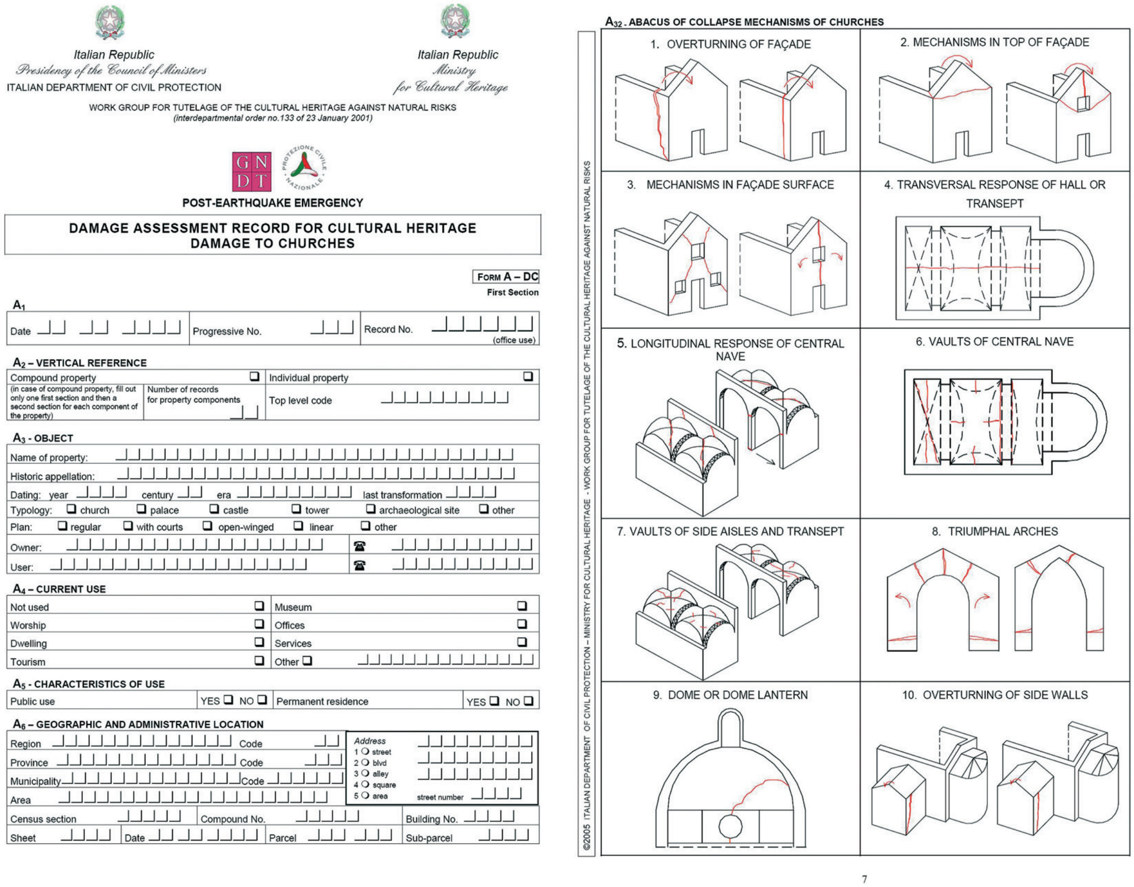


Fig. 1 - Extract of the sheet currently used to detect damage to churches, set up in 2006 by the Department of Civil Protection and the MiBAC (Model A - DC).

tested and improved, and used in each event after the Umbria-Marche earthquake, becoming the official instrument of the Department of Civil Protection and the Ministry of Cultural and Architectural Heritage (MiBAC) for damage detection to churches (A-DC sheet) and other buildings (sheet B-PD).

In the current version, the sheet includes a section where technicians, during the inspection, identify and describe the emergency measures they consider to be necessary for the safety condition.

The technical information on safeguard measures (Fig. 2) is however, highly synthetic and does not provide guidance for the implementation of the work necessary. The design and construction of the securing structures are then decided case by case, with specific size and performance criteria.

Provisional works, largely realized in Italy on the occasions of the 1976 Friuli and 1980 Irpinia earthquakes, started to follow specific strategies and techniques of intervention after the 1997 Umbria Marche earthquake (Bellizzi, 2000). Nevertheless, the adopted sheets showed only an indication of the need that emergency repair measures were required and recommended subsequent specific evaluations for the provisional works design (Fig. 3).

Until the 2009 L'Aquila earthquake, this evaluation was carried out by experts of structural intervention on cultural heritage (experts of universities and MiBAC) and the realization was mainly assigned to specialised enterprises. However, after the 1997 Umbria-Marche, 1998 Pollino, and 2002 Molise earthquakes, several short-term countermeasures were made by the personnel of the National Fire Department (CNVVF). Some of the main technical references for sizing provisional structures in seismic emergency, at the moment of the L'Aquila earthquake, were the OPUS Manual (Dolce *et al.*, 2006) and the Shoring Operations Guide elaborated by the U.S. Army Corps of Engineers (FEMA/USACE USAR, 2009).

## 3. Urban shoring after the 2009 L'Aquila earthquake

On April 6, 2009, at 3:32 a.m. local time, a 6.3 $M_W$ earthquake occurred in central Italy. The epicentre was in Tornimparte, a little village located 7 km NW from the town of L'Aquila, capital of the Abruzzo Region (central Italy). This earthquake occurred on normal faulting in the Apennine mountains and was a shallow event with a hypocentre depth of approximately 8 km. The main shock was followed by many aftershocks. Since seismic waves associated with shallow quakes can reach the surface without losing substantial energy, they produce stronger shaking and more significant damage. In fact, high values of PGA were recorded in the near field (0.66 g WE component at AQV RAN station located 4.85 km from the epicentre) while smaller values (< 0.15 g) were recorded just 20 km away from the epicentre (Luzi *et al.*, 2008; Masi *et al.,* 2010; http://itaca.mi.ingv.it).

So, even if this earthquake is classifiable as only of moderate magnitude, L'Aquila town and its surroundings, located in the near field area of the earthquake, were affected by a level of ground motion able to provoke heavy damage in the whole urban area.

The population was completely displaced from the affected area and the whole historical centre of L'Aquila, where the principal government and administrative buildings were placed, was declared a "red zone", accessible only to rescue teams.

The whole city and its hinterland had been brought to its knees, even in terms of accessibility and the functionality of its administrative centres was compromised. The number of unusable buildings was high. Many buildings were declared unusable even if the damage suffered was slight because they were not reachable in safe conditions or there were hazardous situations determined by dangerous nearby buildings. Most heritage buildings needed shoring interventions in order to preserve them but the unsafe condition of the roads did not permit companies to operate effectively. The complexity of the post-event situation, the urgency and nature of the interventions to make the roads safe and to preserve the heritage buildings and monuments with the necessity of operating in a red zone led to the involvement of the CNVVF as a primary function, for shoring interventions.

For the first time, an extensive operation of urban shoring was required of the CNVVF. In order to respond to this complex request, a special Unit for the Coordination of Provisional Works (NCP) was set up within the CNVVF at the Regional Directorate of Abruzzo, located in L'Aquila. Its tasks were to ensure uniformity in the implementation of temporary works carried out by the fire-fighters and to monitor their progress in synergy with the system of civil protection

**A25 – EMERGENCY REPAIR MEASURES RECOMMENDED** (* limited interventions ** extensive interventions)

| | MEASURES | * | ** | | MEASURES | * | ** |
|---|---|---|---|---|---|---|---|
| 1 | Inspection of roof surface | ☐ | ☐ | 8 | Reactivating the draining of meteoric waters | ☐ | ☐ |
| 2 | Temporary covering | ☐ | ☐ | 9 | Monitoring | ☐ | ☐ |
| 3 | Provisional structures | ☐ | ☐ | 10 | Protection or reinforcement on fixed works of art | ☐ | ☐ |
| 4 | Clearance of rubble | ☐ | ☐ | 11 | Cataloguing and taking apart unsafe sections | ☐ | ☐ |
| 5 | Closures/ fencing / protection | ☐ | ☐ | 12 | Removal of movable works of art | ☐ | ☐ |
| 6 | Localized reinforcements | ☐ | ☐ | 13 | Systematic gathering of fragments | ☐ | ☐ |
| 7 | Installing hoops and/or tie beams | ☐ | ☐ | 14 | Collecting and protecting fragments | ☐ | ☐ |

Provisional works

Fig. 2 - Section of the "churches" sheet, showing emergency measures suggested by the inspectors. There are no indications of a typological nature. The phase of the damage assessment is separated from the phase of the executive project for securing measures.

authorities in charge of the national emergency management headquarters.

In particular, the NCP was appointed to carry out the following functions:

- the definition of technical and organizational procedures for the management of interventions in an emergency-specific operational context, developing agreements and partnerships with external organizations [central coordination structure (DICOMAC), joint coordination centres (COMs), superintendent of MiBAC, universities, scientific community, local authorities, etc.];
- the development of design and standard solutions for temporary works of urban shoring;
- the technical advising, informing and training of personnel carrying out works of particular complexity;
- the monitoring of the interventions related to the implementation of temporary works through the acquisition and management of the data.

In the following is a brief description of the tools and organizational solutions developed.

The development of design standards led to the preparation of a field handbook (Vademecum STOP: Grimaz, 2009; Gruppo di Lavoro NCP, 2010b) containing the information sheets for shoring operations that illustrated the most common design solutions to secure damaged buildings such as props and retention support, tiles, etc., including any related construction detail (connections between elements, joints, anchorages, etc.).

The aim of the handbook is to make the assessment and sizing of on-site works by CNVVF teams easy and practical, starting from the earliest stages of the emergency phase.

The design proposals have been identified taking into account the means and techniques used by the CNVVF, the type of material available and the issues related to building operations, such as worker safety, simplicity and implementation timetables etc.

The fact-sheets, conceived as a decision-support tool have been divided into different sections where the following essential aspects, to guide the design and implementation choices, are briefly reported:

- type of structure damaged, counter collapse mechanisms in place;
- general information and diagrams for sizing the primary and secondary elements;

- highlighting of critical situations to be managed along with executive information and details;
- instructions for using the sheet.

Diagrams and schedules are the summary of the considerations that combine theoretical and scientific aspects with the knowledge gained through the high capability and experience of the CNVVF, both in present and past disasters. Through approaches such as "work in progress", based on a continuous feedback between the design and monitoring systems, the various contributions of the NCP unit experts and the fire-fighter carpentries, including the CNVVF-SAF special unit (Alpine Caving and River Rescue), have been put together (Gruppo di Lavoro NCP, 2010b).

The possibility of speeding up the definition on site, of the material needed for the work implementation, has also allowed one to supply the material needed in a more standardized and faster way, speeding up the securing process. The definition of details and the standardization of the solutions have allowed the elimination of difficulties related to both the feasibility of the works and the turn over of workers and supervisor teams.

## 4. Problems for provisional works: planning, design and realization

Three main problems have been considered for the management of urban shoring:

1. the opportunity of defining the sequence of interventions within a strategic plan;
2. the necessity of defining the seismic action for sizing the single provisional work;
3. the need to take into account operational and managerial problems during the realization.

### *4.1. Strategic planning*

Immediately after rescue operations, historical and strategic buildings and roads were mapped and classified in terms of damage and importance in order to define the sequence of interventions within a strategic plan. The priority criteria were related to: the need for restoring a safe passing through the main roads; the indications of MiBAC aimed to preserve the cultural heritage; the need to access strategic buildings and facilities, according to the assessments of the Civil Protection Department.

### *4.2. Seismic action definition*

If the provisional work must be realized during the earlier phases of a seismic emergency, its performance has to be referred to the seismic actions that could occur in the short-time after the main shock.

After an earthquake of large magnitude, aftershocks will occur. The mean rate of aftershocks depends on the mainshock magnitude and decreases with increasing elapsed time from the mainshock occurrence. The ground motions from the aftershock show typically high variability in the event-to-event, number, size (Yeo and Cornell, 2009a, 2009b).

In the earlier phases, the provisional structure is likely to be stressed more often. The stronger the main shock, the earlier one has to realize the provisional work and the stronger the actions affecting the structure will be and the higher the number of times that the structure will be solicited.

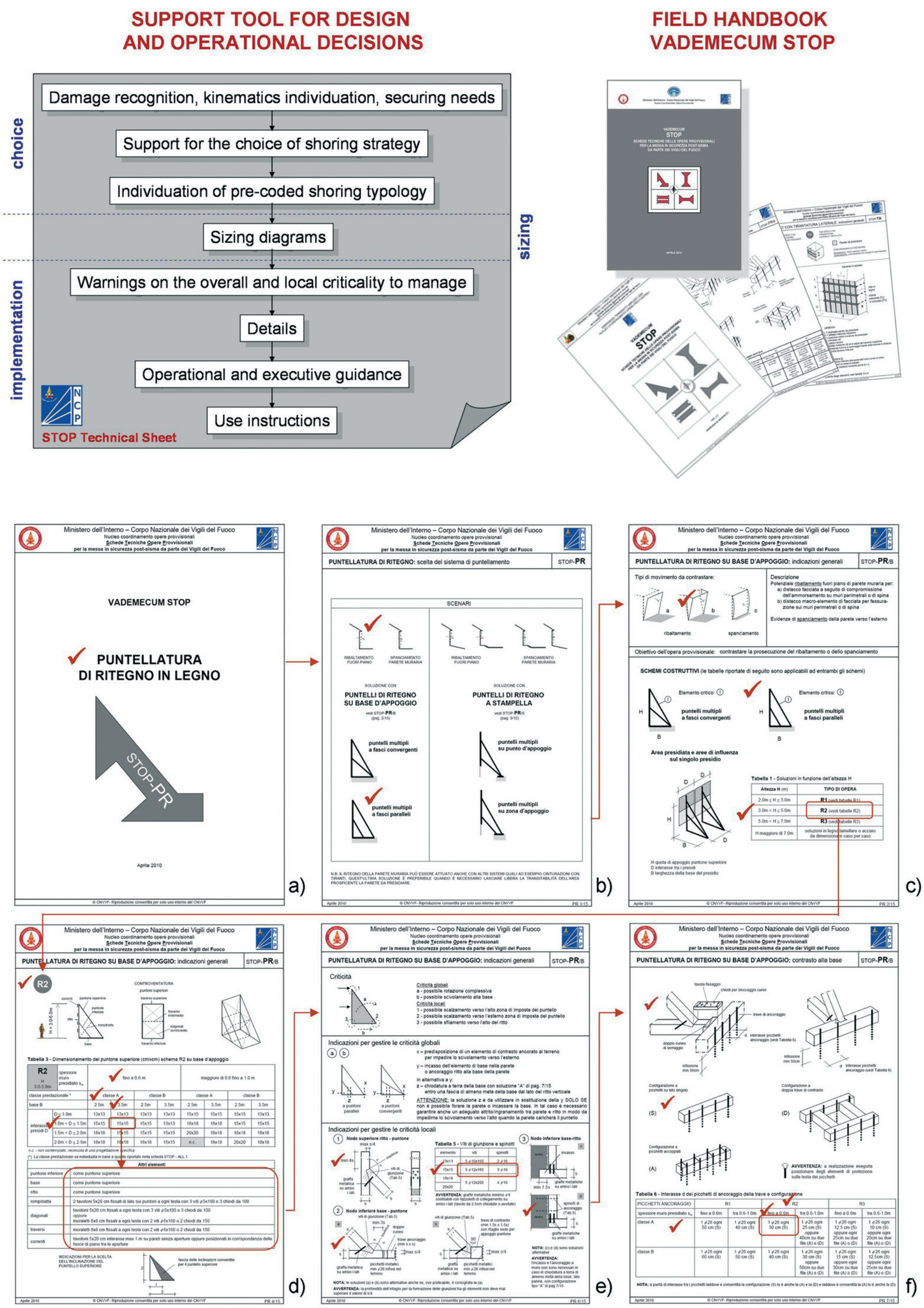


Fig. 3 - The handbook of STOP (in Italian) sheets developed by the CNVVF [special unit for coordination of provisional works (Gruppo di Lavoro NCP, 2010b)]. The structure of the sheets allows one to make an immediate connection with the collapse mechanisms identified in the "churches" sheet (see Fig. 2). An extract of the wood shoring sheet is reported in the lower part of the figure. Red ticks and lines define the way to use the sheet: a) and b) indentification of the typology of solution; c) identification of a pre-codified typology depending on the geometric size; d) definition of the size of various elements of the provisional work; e) management of the global and local criticalities; f) execution of constructive details.

For sizing provisional structures, a definition of design seismic action is, therefore, necessary. Experience shows, that after a destructive earthquake many aftershocks occur, generally having an intensity lower than the main shock, unless another earthquake is activated in different seismogenic areas. Usually, within that acute phase, the hypocentres of aftershocks affect the same seismogenic structure activating the main shock.

An action of magnitude comparable with the main shock magnitude may be used as a seismic design action for sizing the provisional structures to be installed in the short time after the main shock.

It seems less appropriate to follow the criterion used by the Italian seismic design legislation referring to probabilistic hazard values (NTC, 2008). This, for two main reasons:

a) the main shock has already occurred and, therefore, it is known although it may be different to that expected by hazard analysis;
b) it is outside the field of probabilistic forecasting in the medium/long term and has moved into the need for short-term post-event observations.

Aftershock probabilistic seismic hazard analysis (APSHA: Yeo and Cornell, 2004, 2005, 2009a; Franchin and Pinto, 2007) should be used to define the level of action to be taken into account for sizing provisional works. Nevertheless, for structures realized by rescue teams in the short term, it seems easier to apply a macroseismic criterion, even though it may be indirect.

Even in the absence of on field instrumental records, a quantification of the effective severity of the seismic action related to the main shock may be derived by empirical relationships between the observed macroseismic intensity and peak ground acceleration (PGA). The macroseismic intensity makes an intrinsic functional zonation for the provisional works possible. They are of necessity, limited within the affected areas recording MCS intensity grades lower or equal to VII, and extensively within the areas with intensity grades equal or greater than VIII MCS.

Furthermore, an extensive and urgent intervention in the affected area needs pragmatic criteria in order to indentify solutions applicable on a large scale in a short time. This suggests the definition of a strategy based on standardized design solutions, sized with reference to two performance classes related to the grade of observed macroseismic intensity (Grimaz and Ponticelli, 2010). More precisely, the "performance class" identifies the characteristics of the provisional work necessary for responding adequately to a sequence of ground motion actions equal to or less than a predefined level of reference.

In particular, considering the empirical relationships between the macroseismic intensity and the PGA, two levels of ground acceleration have been defined as seismic action for the two classes of performance (see Fig. 4).

In Table 1, the macroseismic criterion for the definition of the performance class of the provisional works is described. APSHA could be used in order to estimate the time when the hazard remains high (Yeo and Cornell, 2004, 2005; Franchin and Pinto, 2007), otherwise it is reasonable to consider, conservatively, a period of six months.

The performance classes required in the different zones of the affected area may be defined immediately after the event, on the basis of the observed macroseismic intensities and the sismotectonic knowledge of the area. The performance class for each zone of the affected area could be reported in a map or a list of municipalities, prepared by the authorities.

The definition of the seismic design action has to take into account the site effects. Referring

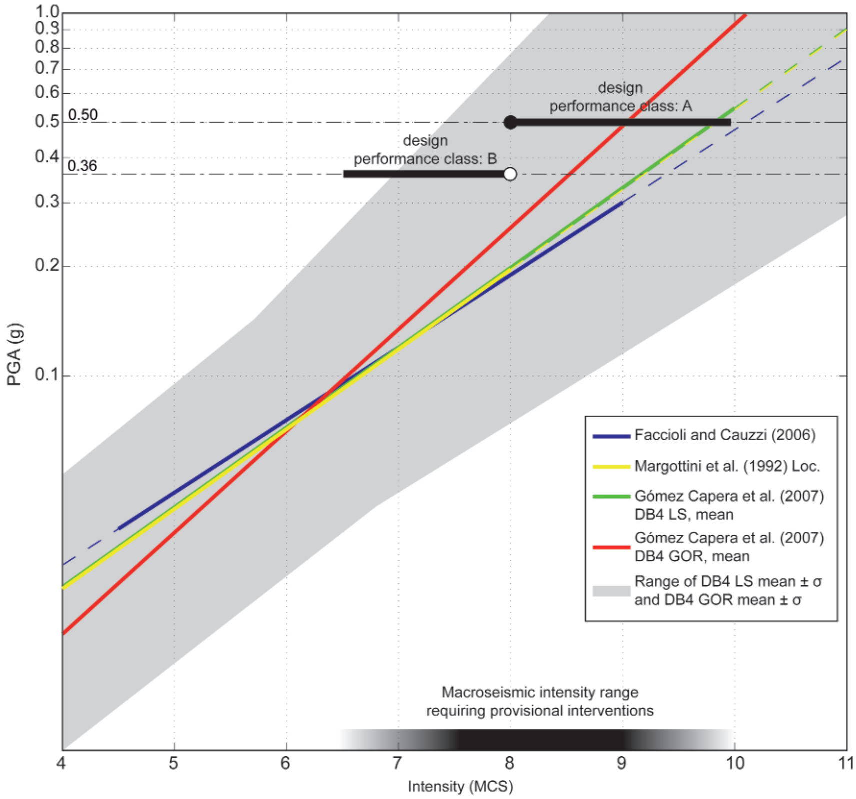


Fig. 4 - Empirical relationships between macroseismic intensity and PGA, with indications of the position of the two design seismic actions for the two performance classes A and B within the range of macroseismic intensities associated to damage which require the installation of provisional structures.

Table 1 - Macroseismic criterion for the definition of the performance class of the provisional works

| Performance class | Area of intervention | Reference acceleration |
|---|---|---|
| A | Installations within damaged areas characterized by recorded or forecasted1 macroseismic intensities equal or higher than VIII grade of MCS scale | 0.50 g |
| B | Installations within damaged areas characterized by recorded and forecasted macroseismic intensities lower than VIII grade of MCS scale<br>or<br>Installations within damaged areas realized a long time after the main shock (more than six2 months) | 0.36 g |

(1) In the immediate post-event phase, an extension of the maximum macroseismic grade to the whole faults system area determining the main shock, is opportune. This in order to take into account the possible aftershocks' hypocentre migration.
(2) A more detailed definition of the amount of time after which aftershocks are significantly less hazardous than the mainshock could be defined by APSHA analysis (Yeo and Cornell, 2004, 2009a, 2009b).


Fig. 5 - Shoring of the church of Sant'Eusanio Martyr in Sant'Eusanio Forconese (AQ). A standard solution provided in the vademecum STOP has been adopted: a) assemblage of the structure on the ground in a safe place; b) lifting of the structure by crane; c) positioning of the structure and anchorage at the base; d) provisional work completed.

to observed macroseismic intensity gives the advantage of connecting to the effective ground motion at the site and, therefore, considering the site effects which could have incremented the ground shaking in comparison with a horizontal, hard rock site. The amplification effects, due to the site characteristics, in fact, concur in the definition of the effective ground motion also for the aftershocks.

In the case of the L'Aquila earthquake, the two conventional PGA values at the ground are comparable respectively with the maximum values recorded, in proximity to the epicentre and to the surrounding area where damage required securing interventions.

### *4.3. Managerial and operational problems*

After the L'Aquila earthquake one of the main problems to handle during the realization of provisional works was the safety of the workers. Securing the damaged buildings required a rapid realization of provisional structures (later as the provisional structures were introduced, more of the structures could be affected by a damage evolution as consequence of the aftershocks). This meant the immediate realization of provisional structures during a phase in which other, strong, seismic actions could occur. From the point of view of the safety of the workers and provisional structure characteristics, realizing a provisional structure during a seismic emergency is,


Fig. 6 - Intervention to secure the belfry of the steeple of the church of San Felice Martyr in Poggio Picenze (AQ) by using carbon fibre: a) the precariousness of stability generated by damage to the bell tower with the possibility of collapse onto the church; b) application of carbon fibres by using techniques from the staff share in CNVVF-SAF; c) securing of the belfry completed.

therefore, very different from building the same structure in ordinary conditions.

In order to secure the safety of the workers, a new philosophy of designing and realization was adopted. In particular, every time it was possible, the structure was assembled in a safe place and then installed using cranes or other mechanical devices in order to reduce the permanence of the operators in dangerous zones. Furthermore, all operations related to the provisional works during the emergency phase were conceived and managed with the principles and criteria of rescue interventions in critical scenarios (i.e., using specific safety operating procedures).

A second problem was the necessity of verifying and optimizing on site, the solutions designed and the training of operators. With this prospective during the finalization of the sheets, prototype works were implemented, and used for internal training. The church of Sant'Eusanio Martyr in Sant'Eusanio Forconese (AQ) is an example of this procedure (Fig. 5). Many successful improvements and innovations were implemented thanks to the feed back, mainly during field experiments, between designers and operating teams.

In addition to standard development, the NCP, together with the MiBAC scientific representatives, implemented complex and specific temporary works, testing new technologies (i.e., the use of carbon fibres) in emergency operations and, particularly, in difficult operational conditions in terms of operator safety. An example has been the securing of the belfry in the steeple of the church of San Felice Martyr in Poggio Picenze (AQ) (Fig. 6).

A third problem was related to the need to coordinate different agencies and participants involved in the management of the urban shoring. In terms of organization, a workgroup for operational connection between the representatives and operators MiBAC and CNVVF, whose meetings were held daily, was set up. This permitted them to work together, making corrections and variants that were validated in real time by the people involved and allowed a significant speeding up in the transition between the definition of the solution/design change and its effective implementation.

Finally, the search for solutions to problems related to the turnover of rescue teams and to the providing of materials were facilitated thanks to the standardization of the interventions obtained from the use of the vademecum STOP and the adoption of specific procedures. Fig. 7 shows some examples of provisional works realized by the CNVVF.

In all, more than 350 buildings (churches, palaces, and other structures) were secured by CNVVF personnel. Chains, ties, props and shores were adopted as countermeasures, taking into account the necessity of maintaining the transitability of the roads. Material as polyester straps, steel and wood were mainly used. The equipment of CNVVF (cranes, trucks) was utilized for transporting materials and assisting the realization of the works. Provisional works were realized by firemen teams of about 10 people each and the time to complete each job varied from a few hours to some months, depending on the complexity of the scenario (Gruppo di Lavoro NCP, 2010a).

## 5. Conclusions

The 2009 L'Aquila earthquake experience shows, practically, that the development of decision support tools, both for operational and managerial fields, can improve the effectiveness of the civil protection response, producing very positive synergies between the institutions involved.

In the 2009 L'Aquila earthquake, unlike what happened on the occasion of other recent earthquakes in Italy, the realization of provisional works was mainly assigned to the CNVVF, who set up a specific technical unit for the coordination and guidance of operations. The unit standardized the intervention procedures, developed design standards and effective technical documentation for the construction of provisional works (a field handbook named vademecum STOP).

The management approach aimed to set up decision support tools for rescue teams, who have to work quickly in a post-seismic emergency context. A macroseismic criterion was introduced for sizing of the provisional works, and technical fact-sheets were elaborated following a logical path. Starting from the needs, the technical fact-sheets define the sizing of single elements and include executive details and suggestions given during the realizations of the work. At organizational level other tools, such as the unit of coordination of temporary works, the operational inter-forces meetings and specific institutional procedures have been designed and adopted.

All these tools and managerial solutions have made the connections between the activities easier and faster, also for the promotion and the implementation of synergies able to eliminate the


Fig. 7 - Examples of provisional works realized by the Italian National Fire Department in the L'Aquila area.

various and almost inevitable bottlenecks and obstacles for the coordinated research of effective solutions during emergency operations (Grimaz and Moretti, 2009).

On the other hand, further steps aimed to facilitate and to expedite the transition between the phase of damage assessment and securing interventions could be taken. An improvement could be obtained by the introduction in the damage assessment sheets of a specific section directly linked to the standard solutions provided by the vademecum STOP of the CNVVF. This allows a description of the type and location of the provisional structures, and its definition with a interdisciplinary approach made directly during the inspection.

Even though further improvements are possible, the experience of urban shoring managed after the 2009 L'Aquila earthquake has shown that the definition of decision-making support tools is a determing factor in order to obtain good results and that the linkage of the different steps within an unique holistic framework could make the post-earthquake repair process more rapid and effective.

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## REFERENCES

Bellizzi M.; 2000: *Le opere provvisionali nell'emergenza sismica.* Agenzia di Protezione Civile, Servizio Sismico Nazionale, Roma, 96 pp.

Cifani G., Lemme A. and Podestà S.; 2005: *Beni monumentali e terremoto. Dall'emergenza alla ricostruzione*. DEI, Roma, 304 pp.

Doglioni F., Petrini V. and Moretti A.; 1994: *Le chiese e il terremoto. Dalla vulnerabilità constatata nel terremoto del Friuli al miglioramento antisismico nel restauro. Verso una politica di prevenzione.* Lint Editoriale Associati, 320 pp.

Dolce M., Liberatore D., Moroni C., Perillo G., Spera G. and Cacosso A.; 2006: *Manuale per le opere provvisionali urgenti post-sisma (OPUS).* Convenzione tra il Dipartimento della Protezione Civile, Ufficio Servizio Sismico Nazionale e l'Università degli Studi della Basilicata, <http://postterremoto.altervista.org>.

DPCM; 2006: *Decreto del Presidente del Consiglio dei Ministri del 23.2.2006. Approvazione dei modelli per il rilevamento dei danni, a seguito di eventi calamitosi, ai beni appartenenti al patrimonio culturale.* G.U. del 7.3.2006 n.55.

Faccioli E. and Cauzzi C.; 2006: *Macroseismic intensities for seismic scenarios estimated from instrumentally based correlations.* In: Proc. First European Conference on Earthquake Engineering and Seismology, paper number 569.

FEMA/USACE USAR; 2009: *Shoring Operations Guide.* U.S. Army Corps of Engineers, 2nd Edition, 152 pp.

Franchin P. and Pinto P.E.; 2007: *Transitability of mainshock-damaged bridges.* In: Proc. of 1st US-Italy Seismic Bridge Workshop, Pavia, Italy, 18 pp.

Gómez Capera A.A., Albarello D. and Gasperini P.; 2007: *Aggiornamento relazioni fra l'intensità macrosismica e PGA.* Progetto DPC-INGV S1, Deliverable D11, <http://esse1.mi.ingv.it/d11.html>.

Grimaz S.; 2009: *La messa in sicurezza post sisma degli edifici. Soluzioni e strumenti messi a punto in occasione del terremoto de L'Aquila.* In: Atti del 28° Convegno nazionale GNGTS, Trieste 16-18 Novembre 2009, 451-455.

Grimaz S. and Moretti A.; 2009: *Implementazione di supporti alle decisioni nella messa in sicurezza post-sisma del patrimonio culturale.* In: Atti del 28° Convegno nazionale GNGTS, Trieste 16-18 Novembre 2009, pp. 455-458.

Grimaz S. and Ponticelli L.; 2010: *Criterio macrosismico per il dimensionamento delle opere provvisionali nell'immediato post-terremoto.* In: Atti del 29° Convegno nazionale GNGTS, Prato 26-28 Ottobre 2010, pp. 338-341.

Gruppo di Lavoro NCP (Grimaz S. coord.); 2010a: *Manuale. Opere provvisionali. L'intervento tecnico urgente in emergenza sismica.* Corpo Nazionale dei Vigili del Fuoco - Ministero dell'Interno, Roma, 411 pp.

Gruppo di Lavoro NCP (Grimaz S. coord.); 2010b: *Vademecum STOP. Schede tecniche delle opere provvisionali per la messa in sicurezza post-sisma da parte dei Vigili del Fuoco.* Corpo Nazionale dei Vigili del Fuoco - Ministero dell'Interno, Roma, 119 pp.

Luzi L., Hailemikael S., Bindi D., Pacor F., Mele F. and Sabetta F.; 2008: *ITACA (ITalian Accelerometric Archive): a web portal for the dissemination of Italian strong-motion data.* Seismol. Res. Letters, **79**, 716-722.

Margottini C., Molin D. and Serva L.; 1992: *Intensity versus ground motion: a new approach using Italian data.* Engineering Geology, **33**, 45-58.

Masi A., Chiauzzi L., Braga F., Mucciarelli M., Vona M. and Ditommaso R.; 2010: *Peak and integral seismic parameters of L'Aquila 2009 ground motions: observed vs code provision values.* Bulletin of Earthquake Engineering, doi: 10.1007/s10518-010-9227-1.

NTC 2008: *DM 14 gennaio 2008. Norme tecniche per le costruzioni.* G. U. della Repubblica Italiana n. 29 del 4 febbraio 2008, Suppl. Ordinario n. 30.

Yeo G.L. and Cornell C.A.; 2004: *Building tagging criteria based on aftershock PSHA.* In: 13th World Conference on Earthquake Engineering, 1-6 August 2004, Vancouver, B.C. Canada, Paper n. 3283.

Yeo G.L. and Cornell C.A.; 2005: *Stochastic characterization and decision bases under time-dependent aftershock risk in performance-based in Earthquake Engineering.* Technical report 149/2005, The John A. Blume Earthquake Engineering Center, 174 pp.

Yeo G.L. and Cornell C.A.; 2009a. *A probabilistic framework for quantification of aftershock ground-motion hazard in California: metodology and parametric study.* Earthquake Engng. Struct. Dyn., **38**, 45-60.

Yeo G.L. and Cornell C.A.; 2009b: *Post-quake decision analysis using dynamic programming.* Earthquake Engng. Struct. Dyn., **38**, 79-93.

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