DESIGN AND EXECUTION OF THE POST-EARTHQUAKE REPAIR AND STRENGTHENING OF HERITAGE STONE MASONRY HOUSES

M. Lutman[1]
[1] M.Sc., Research Engineer, Slovenian National Building and Civil Engineering Institute, Department for Structures, Ljubljana, Slovenia, marjana.lutman@zag.si

ABSTRACT
Stone masonry houses represent a very important part of the architectural heritage of the mostly rural River Soča Valley region of northwestern Slovenia, which was hit in recent decades by two serious earthquakes, in 1998 and 2004. Although it was clear that the structural resistance of houses that had been repaired and strengthened after the first earthquake had been improved, some anomalies were observed after the second earthquake. The investigation, which was based on site inspections, tests and analyses, resulted in some additional conclusions. For this reason the on-going process of the design and execution of repair and strengthening works was prepared even more carefully, taking into account all the experience obtained in the first earthquake. Some additional lessons for designers were learnt, the workforce was additionally trained, and extra supervision for post-earthquake structural rehabilitation was implemented. Taking into account modifications in the structural concept of strengthening, as well as changes in the level of the design seismic load and in the design mechanical characteristics of the stone masonry, which were observed after 1998, relatively detailed instructions were prepared for designers. The use of Eurocode 8 with its design seismic load parameters has been prescribed, as well as the use of characteristic values of the compressive and tensile strength of the locally used stone masonry, determined from previous in-situ tests. Selected design reports have been subjected to supervision, and any deficiencies corrected. By means of additional on site supervision, the best possible results should be attained.

KEYWORDS: stone masonry, heritage, repair, strengthening, supervision

INTRODUCTION
Posočje, the mountainous region along the Soča River, in the most northwestern part of Slovenia, has been hit by a number of serious earthquakes over a relatively short time-span, which is not a very common occurrence. In 1976 a series of strong earthquakes, with magnitudes of up to 6.5 and epicentres in Friuli, in northeastern Italy, caused significant damage in Posočje. The strong earthquake in 1998, and the third one in 2004, were two local earthquakes with their epicentres in Slovenia - near the town of Bovec. Although, according to their magnitudes (M = 5.7 and M = 4.9) they cannot be compared with the Friuli earthquakes, the maximum local intensities and the observed damage in the epicentral area were even more severe.

While the typology of the traditional stone houses and churches, hit by these three earthquakes, remained more or less the same, significant changes were clearly observed with regard to the methods used for post-earthquake damage and usability assessment, in the technical codes for the redesign of the seismic repair and strengthening of damaged buildings, as well as in the general public's attitude towards the building heritage as a something which needs to be preserved.

CHARACTERISTICS OF THE LANDSCAPE AND ITS BUILDINGS

The Posočje area is dominated by traditional stone-masonry houses, which generally have two storeys (Fig. 1a). A lot of them were built after the World War I from the ruins. Typical structures consist of stone-masonry walls, which are often built on shallow foundations since the houses generally do not have basements. The walls were built of two outer layers of larger stones, with an inner infill of smaller pieces of stone, in poor lime mortar. Floor and roof structures are traditionally wooden. In the seventies and eighties many such floors were replaced by thinner RC slabs, supported only on the inner layer of the walls. Houses have high attics with massive masonry or wooden gable walls.

The larger houses and public buildings are those rare buildings that were not destroyed in the First World War. The stone-masonry walls of these buildings are more regular, with better connections between the stones and weak lime mortar. Compared to smaller houses, the proportion of structural walls in these buildings is higher, and the walls are more uniformly distributed in plan. However, the walls are not confined with wall ties. Some of these buildings have brick-masonry vaults above their ground floors, and wooden floors in their upper storeys.

The church buildings of the region are very diverse in both size and shape. Small churches are characterized by a bell-gable which rises above the entrance. Larger churches usually have a bell tower, which is connected to the nave walls, or constructed separately. The sacristy is often built as an extension to the church, and not attached to the church. In addition to the peripheral walls, there is a triumphal arch wall at the connection between the presbytery and the nave, which represents the only internal transverse wall. The masonry walls are built of partly dressed stone with joints fully filled with weak mortar. Whereas the nave is usually covered by a wooden roof, there is either a stone-masonry vault or a wooden roof over the presbytery.

Figure 1: a) Original stone-masonry building; b) Stone-masonry church in Bovec – the upper part of the bell wall overturned due to out-of-plane vibrations

In the case of houses and apartment blocks built after World War II, the load-bearing walls are built on concrete foundations, but without vertical ties. The types of masonry blocks vary. The floor structures are either semi-prefabricated ribbed RC slabs with hollow clay filling blocks, or thinner RC slabs. From the early seventies onwards hollow clay or concrete hollow blocks with vertically oriented holes have been the most common in Slovenia, although masonry walls of some houses were constructed out of bricks with horizontally oriented cavities.

Typical damage that was observed in traditional stone-masonry houses and buildings after the earthquakes are shear cracks in the load-bearing and partition walls, delamination of stone-masonry walls, vertical cracks in the corners of buildings and other vertical connections between perpendicular walls, horizontal cracks and overturning of gable walls. Among newer buildings the highest degree of damage developed in those with hollow brick masonry with horizontally-oriented cavities, buildings with irregularity in plan, and those with ribbed RC slabs, where only the longitudinal walls were compressed by vertical loads, whereas the lateral walls were loaded only by their own weight.

Damage patterns in churches were specific with regard to the irregularity of shape and structure. Whereas the periphery of the nave has fewer and more widely spaced openings, the periphery of the presbytery has wider and higher windows and therefore more slender walls between them. Typical shear cracks developed in the walls of the presbytery and vertical cracks above the windows in the nave. Extensive damage was observed in the triumphal arch wall, since this is the junction of two different structural parts of the church. Larger cracks developed in the cases of more explicit differences between the nave and the presbytery, in the case of the combination of a light wooden roof above the rigid periphery of the nave and a heavier stone vault above the flexible periphery of the presbytery. Damage to the bell-tower was usually limited to the upper part, where the thickness of the wall decreases. Horizontal cracks typically developed at the bottom of the bell-gable walls due to out-of-plane bending, which in some cases led to the overturning and fall of the bell-gable (Fig. 1b).

CONCERN FOR THE PROTECTION OF THE ARCHITECTURAL HERITAGE

In the post-earthquake reconstruction in 1976 preservation of the architectural heritage was not a priority consideration, since the state wanted to rehabilitate the area as soon as possible. This strategy of a quick recovery was accentuated by the second series of earthquakes in September 1976, which destroyed the houses that had been damaged by the earthquakes in May 1976. Very badly damaged buildings were demolished and replaced by modern prefabricated houses, which disfigured the affected villages [1]. However, the state also provided financial assistance for the rehabilitation of affected people. The strengthening of traditional stone houses relied on expert recommendations that were made on the basis of extensive experimental and analytical studies [2, 3]. The adequacy of the repair and strengthening of houses, which was carried out in accordance with these recommendations after the earthquakes in May 1976, was already proved in September of that year. Recovery and restoration of the affected area was carried out quickly, but with lack of control. Consequently, the measures were implemented inadequately. Rather than implementing strengthening measures, many owners performed functional renovation, and in some cases even made structural changes that decreased seismic resistance. These mistakes became obvious after a good 20 years.

The response to the earthquake in 1998 was different. In order to preserve as much of the building heritage, rehabilitation and strengthening were much more in favour than the demolition of damaged houses. This principle was already incorporated in the early post-earthquake damage assessment methodology, as buildings with damage grade 4 on the EMS-98 Scale were treated as temporarily unusable, and thus came into consideration for rehabilitation and strengthening. Immediately after the earthquake, the Slovenian government established a National Technical Office (DTP) as a temporary body for the realization of national technical assistance. This Office was responsible for providing advice and assistance in the planning and designing of reconstruction works, and for the coordination and supervision of the rehabilitation of buildings.

DTP organized a series of lectures, given by the most knowledgeable Slovenian experts in the field of earthquake engineering, for designers and contractors. Additional practical training on site was provided by experts who had gained experience since the earthquake in 1976. Qualified designers and trained contractors were then appointed by the State. The state also funded experimental and analytical studies. The mechanical properties of original and grouted stone-masonry were obtained by in-situ tests in typical houses in Posočje [4]. Additionally, examples of the seismic resistance analysis of existing and strengthened buildings were carried out [4]. Recommendations to designers and contractors were issued, and regularly updated on the basis of new experience. However, many buildings were repaired and partially strengthened without seismic resistance analysis and without a proper design project, just following the instructions and procedures that had been developed since 1976. Such a simplified procedure was permitted by the construction legislation which was valid at that time.

IMPLEMENTATION OF THE NEW SEISMIC CODE

While the rehabilitation works were going on, one more earthquake hit the region in 2004. It caused additional damage and slowed down the rapidity of reconstruction, but its consequences also provoked the anger of residents. Although they seemed to have got used to living with earthquakes, many of them expressed a loss of confidence in the sense and effectiveness of the strengthening measures applied to their houses after 1976 and 1998. Quite a number of houses, strengthened even after 1998, suffered significant damage again in 2004. Such an extent of damage was not easily accepted by their residents. Inspections of the most seriously damaged houses indicated some cases of inadequate redesign, and deviations in the quality of the repair and strengthening works after 1998 [5]. Some designers believed that the basic measures for repair and strengthening would ensure the required seismic resistance, irrespective of the redundancy of walls. Although data about the necessary mechanical characteristics of original and grouted stone masonry, obtained by in-situ testing in existing houses around Bovec after 1998, were available, proper seismic analysis was often omitted. These anomalies were identified by a review of the design projects and of the condition of the most heavily damaged buildings [5].

The need for modifications of repair and strengthening design procedures was also influenced by the fact that the Republic of Slovenia had introduced Eurocode 8 into parallel use, and by the new Slovenian construction law which required that all rehabilitation and strengthening works have to be carried out on the basis of design projects. After the earthquake in 2004, designers first have to carry out a full survey, as well as field investigations with some in-situ testing, in order to identify the condition of the structure, and then provide analytical proof that the seismic resistance and ductility meet the requirements of Eurocode 8. The design projects are then reviewed by an independent reviewer.

DESIGN OF REPAIR AND STRENGTHENING MEASURES

First, the design engineer has to review all the available technical documentation concerning any repair and strengthening works that were carried out after the earthquake in 1998. Then he has to identify the damage to the structure after the earthquake in 2004. The mandatory part of the structural evaluation is the identification of the type of load-bearing masonry and, in the case of stone masonry, verification of the grouting that was prescribed after previous earthquakes. The presence of wall ties and ties between floor structures and walls has to be verified, whereas the extent of the inspection of other elements of the structure (its foundations, floor structures and roof) depends on the observed damage and the general condition of the structure. In case of damage that appears to originate in weak foundations or overloaded soil, the foundation conditions have to be identified by the excavation of trial pits and checking the depth and width of the foundations.

Seismic resistance analysis is a mandatory part of the design project, as a basis for the verification of the requirements of Eurocode 8 with regard to seismic capacity and ductility [6]. The non-dimensional design seismic load is defined as $BSC_d = S_d(T) = a_g\ S\ S_e(T) / q$, where a_g is the design ground acceleration from the seismic hazard map of Slovenia for a return period of 475 years, S is the soil parameter, $S_e(T)$ is the value of the elastic response spectrum, and q is the structural behaviour factor, which depends on the energy dissipation capacity of the structure.

The design ground accelerations are equal to 0.225 g for the major part and 0.250 g for the minor part of the affected area. The soil parameter depends on the soil type (S = 1.0 for soil type A, S = 1.20 for soil type B, and S = 1.15 for soil type C), according to the seismic microzonation map of the Bovec Basin [1]. The margins of the basin and its valleys consisting of carbonate rock are classified as soil type A. The basin and the valleys themselves and uplands are covered either by thicker alluvial sediments of gravelly soil (soil type B), with glacial alluvia, covered by clay deluvial sediments, with alluvial sediments composed of seismically unfavourable soil (such as chalk), or the layers are thin and have a heterogeneous composition (soil type C). The value of the elastic response spectrum is 2.5 for relatively rigid masonry buildings ($T_B \leq T \leq T_C$), and the value of the structural behaviour factor depends on the masonry type (q = 1.5 for plain masonry and q = 2.0 for confined masonry).

The full value of BSC_d has to be taken into account in the case of new buildings. Given the limited possibilities for the attainment of this full value by ordinary strengthening technologies, and the wish to preserve the architectural heritage, DTP decided to permit a reduction in the design seismic forces for the redesign of heritage buildings, according to one of the drafts of Eurocode 8-3 [7] and a proposal made by the profession [8]. The proposed reduction factor γ_n depends on the seismic intensity zone ($\gamma_n = 0.67$ for $a_g = 0.30$ g, $\gamma_n = 0.84$ for $a_g = 0.20$ g, and no reduction for lower intensity zones). For a typical plain masonry building on ground of type A (soil factor S = 1.0) and the typical seismic intensity zone ($a_g = 0.225$ g) it is therefore necessary to take into account a seismic design coefficient $BSC_d = 0.80 \times 0.375 = 0.300$.

For seismic resistance analysis a storey mechanism may be assumed if structural integrity of the building is ensured. Analysis of the critical storey, usually the ground storey, is followed by an analysis of the upper storeys if required by significant differences between the storeys. Seismic resistance envelopes (Fig. 2) are calculated by a push-over analysis and limit state method. According to the principles of evaluation and redesign of existing buildings, as defined in Eurocode 8-3 [9], the analysis takes into account a confidence factor (CF), by which the characteristic strength is reduced. The value of CF depends on the extent of investigations of the masonry [8]. A value of CF = 1.0 can be used when the mechanical properties of the masonry are determined by in-situ or laboratory tests of the walls, taken from the building under consideration, whereas a value of CF = 1.2 can be used when the type of masonry is identified by removing plaster and opening up the masonry at least at one location in each storey of the building under consideration, and CF = 1.7 is used if no tests are performed, and the mechanical characteristics of the masonry are taken from the literature. In practice, most designers use the value of CF = 1.2, but often without any tests.

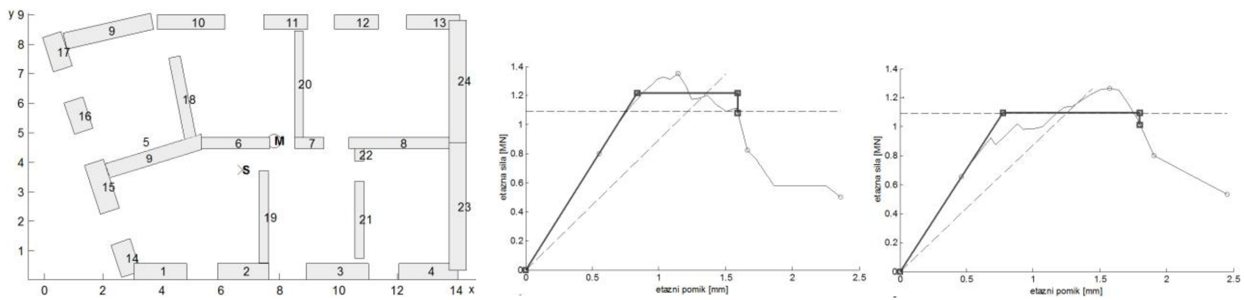

Figure 2: Analysis of a house in the Posočje region: a) Ground floor layout; b) and c) Seismic resistance envelopes of the ground floor storey in the X and Y directions

The results of a seismic resistance analysis of a house in its existing state are compared with the requirements of Eurocode 8 in order to select the most appropriate combination of measures to increase its seismic resistance:

- systematic injecting of stone-masonry with cement grout (Fig. 3a),
- application of bilateral reinforced cement coatings to walls (Fig. 3b),
- replacing light partition walls with load-bearing walls,
- building new walls or RC frames.

If not applied after previous earthquakes, the following measures are prescribed in order to achieve structural integrity and thus exploit the calculated seismic capacity of the building:

- tying structural walls at each floor level with steel ties on both sides of walls (Fig. 6b),
- anchoring floor structures to the supporting walls (Figs. 6a, 6b),
- systematic cement-grouting and jacketing of foundation walls.

The sufficiency of the selected chosen measures has to be proven by the analysis of the building in its strengthened state.

So far reviews of projects have shown significant and persistent mistakes. Field investigations of masonry, floor structures, foundations and verification of the presence of wall ties are frequently not carried out. If systematic grouting was prescribed after previous earthquakes, as evident from archival documents, the realization and effectiveness of this measure should be verified before designing, and according to the findings grouting or repeated grouting should be prescribed. Insufficient examination of the structure and its details usually leads to changes in the measures and additional measures when the works are already taking place. Some mistakes are made in the selection of the mechanical properties of masonry and structural modelling. Inadequate evaluation of the stiffness of structural walls strengthened by bilateral RC coatings causes incorrect differences between the strengthened walls and the non-strengthened walls, and thus incorrect progression of the limit states of the analysed storey. Designers sometimes perform a verification of the ductility capacity, as required for the selected value of the behaviour factor, or take into account the value q = 2.0, although the building has only few vertical ties and most of its walls are not confined.

Figure 3: a) Systematic cement-grouting of masonry b) Reinforced cement coating: steel mesh is placed after steel anchors are fixed through the floor structures and adjacent walls.

A very common mistake when analysing churches is the inappropriate modelling of the load-bearing structure. The storey mechanism is not suitable for churches, as cracks in the walls develop above the openings and not between them as is the case for the storey mechanism.

SUPERVISION OF THE IMPLEMENTATION OF STRENGTHENING MEASURES

Since anomalies and discrepancies between the prescribed and actually executed strengthening measures after the earthquake in 1998 were found out on the basis of systematic investigation of some of the most heavily damaged buildings after the earthquake in 2004, additional supervision of the execution of the vitally important strengthening measures has been introduced. This supervision involves verification of the systematic cement-grouting of stone masonry, repair of cracks in masonry, tying walls and connecting floors to walls.

Due to differences in the quality of the stone-masonry, verification of the systematic filling of voids with injected cement grout always needs to be performed. Verification of the presence of grout and its effectiveness is carried out also in all cases when the designer considered that the walls were injected after previous earthquakes, but did not perform any trial boreholes.

The effectiveness of cement grouting is verified after it is finished by coring the injected masonry at three to five characteristic positions. Control boreholes, 100 mm in diameter, are made at the side from which the grout was previously injected. Each control hole is made between the injection holes and through the whole thickness of the wall. Afterwards, the results of grouting are inspected and evaluated visually from the appearance of the core and the surface of the drilling hole. Grouting effectiveness depends primarily on the presence and the quantity of grout in voids, whose task it is to connect together the stones and the existing mortar into a monolithic structure, and so to prevent delamination of the walls. The primary purpose of the supervision is thus to evaluate these properties. Among the inspections so far carried out, very different results have been obtained (Figs. 4 and 5). In some cases, the masonry is proved to be less suitable or even unsuitable for grouting, since all the gaps between stones are well filled with mortar. It is very unfavourable if the mortar is weak and dusty, and thus prevents the flow of cement grout and the filling of the gaps between the stones.

Figure 4: Very effective grouting - the grout has filled the voids and connected together the stones and mortar

Figure 5: Less effective grouting - the grout is present but didn't connect together the stones and mortar

An unfavourable outcome of grouting as prescribed in a project does not always originate in the lack of a pre-design inspection or the unsuitable structure of the masonry, but can also be due to limitations or interventions on behalf of the protection of the cultural heritage. This can be illustrated by a typical example of a church, where the presbytery walls were more damaged than the walls of the nave. In order to protect the frescoes in the presbytery, which were not uncovered before the masonry of the nave had been grouted, the presbytery walls were left ungrouted, even though this measure was prescribed for all the walls. The structure of the church therefore became even more irregular than it was before the intervention.

The success of repair of cracks in brick masonry depends a great deal on the technology used. According to a common instruction in projects, a V-shaped groove should be cut along the crack and filled with mortar. In one such case it was found that the repair had been carried out on one side only and that the groove had been cut by a rotary hammer. The webs of the hollow brick cracked, as seen on the right side of the core (Fig. 5b). Since then, it has been recommended that such cracks are always repaired on both sides, whereas the repair technique depends on where the crack runs. If it runs along the mortar joint, the existing mortar that is crushed must be replaced with new mortar without cutting the bricks. After the mortar has been removed the surface of the masonry must be cleaned and wetted, and afterwards the joints are repointed with cement mortar. If the crack runs through the bricks, the groove should be made by sawing in order to prevent cracks.

Figure 5: A retrofitted brick masonry wall: a) the surface of the borehole, b) the core

The usual difficulties with the application of reinforced-cement coatings are associated with the unevenness of wall surfaces. Reinforcing mesh is placed on the first layer of cement mortar. The mesh is then placed on both sides of the wall, and connected together with steel anchors placed through the masonry. Finally, the second layer of cement coating is applied. The total thickness of the coating is supposed to be about 5 cm, which is difficult to achieve in practice, especially at overlaps of the reinforcing mesh. The design thickness is therefore often exceeded. Significantly greater thickness represents additional weight, which could in extreme cases require redesign.

Connecting walls together with steel bars, which are threaded at their ends and bolted at the ends of walls onto steel anchor plates, is a mandatory measure for all buildings that either have wooden floors, or newer RC slabs with bearing areas which were not implemented across the entire thickness of the wall. According to the recommendation of DTP, the depth of the grooves for placing steel bars should be equal to the thickness of the plaster, so the bars are placed on the wall surface. Nevertheless, in practice these grooves can be up to 20 cm deep, if hammers are used carelessly.

The continuity of steel ties along the whole length of a house is also of vital importance. In practice, there are some difficulties next to balcony slabs or vestibules. The level of the ties must therefore be adapted to these barriers, and in no case should ties be interrupted or even foreshortened.

If the pre-design inspection of the structure is omitted or inadequate, additional actions are often needed during the construction works. Where RC slabs over adjacent rooms have not been constructed at the same level, the method for the connection of these slabs should be suitably adapted. If the top or the bottom surface of the slab on one side of the wall is approximately at the level of the mid-thickness of the RC slab on the other side of the wall, a flat steel element should be affixed to the surface of the RC on the first side, a steel bar is then welded onto the steel plate and anchored into the hole, which has been drilled into the RC slab on the other side of the wall. Such a combination of a flat steel element and a steel bar is usually used in case of thinner RC slabs made of weak concrete (Fig. 6a). For the connection to the outer walls, the steel bars are threaded and anchored to the outer surface of the wall by means of nuts and steel anchor plates (Fig. 6b). In the case of significant differences in the levels of the RC slabs, steel elements can be used to compensate for differences in height.

Figure 6: Connecting RC slabs and exterior walls: a) Steel bars welded to flat steel elements that are screwed into the RC slab, b) Steel anchor plate and steel tie along the wall

In some rare cases, the project needs significant changes during the construction itself. Such is the case of a building for which the designer didn't treat bricks with horizontally-oriented holes as unsuitable for load-bearing walls. In fact he didn't take into account the results of previous tests, which showed that the compressive strength of these bricks is significantly lower than the minimum allowed according to the National Annex for the use of Eurocode 8 in Slovenia ($f_{b\text{-avg}} = 4.3$ MPa $< f_{b,\ min} = 10$ MPa). A thorough reconstruction of the building was consequently needed. Part of the existing walls was replaced with RC walls.

CONCLUSIONS

The described experience obtained in the repair and strengthening of stone-masonry buildings was very diverse. In order to achieve effective rehabilitation of a damaged area it is very important to have a strategy that is agreed to by all the involved disciplines. In the case of heritage buildings it is important to design such measures that will be effective for the needed strengthening but will also affect their appearance within acceptable limits. Any changes during the execution phase should be avoided as much as possible.

The houses and buildings of the Posočje area, which, over 28 years, was hit by so many destructive earthquakes, are very varied and irregular. Several structural interventions into the masonry and replacements of individual floor structures have been carried out after they were built. The pre-design inspection of a building and its structure in order to determine its specificity is therefore of crucial importance. After the last strong earthquake, the use of Eurocode 8 for seismic design has become mandatory. Due to difficulties with the introduction of the new code and prescribed methods, additional revision of projects proved to be very useful in that they enabled the timely elimination of mistakes, and provided a better basis for the execution of repair and strengthening measures.

The implementation of supervision over the execution of works was basically aimed at those measures which are more difficult to check regularly, but have an important influence on the effectiveness of the rehabilitation. As was found out after the earthquake of 2004, systematic cement-grouting of masonry and the tying of walls with steel ties were, in some cases, not implemented properly. Besides these two measures, the repair of cracks, the strengthening of foundations, and the anchoring of floor and roof structures to structural walls are subject to supervision during their execution. During the implementation of supervision it was also found that the structure of masonry is not the same in all buildings, and masonry with a very full structure cannot be grouted. It is therefore very important to carry out a pre-design inspection of the masonry and to choose adequate mechanical properties for the analysis of seismic resistance.

This supervision represents not only an additional control over the execution of strengthening measures, but also helps to provide advice to designers and contractors, and regular monitoring and assistance in choosing the most appropriate implementation of each action.

REFERENCES

1. Vidrih, R. (2008) “Seismic Activity of the Upper Posočje Area”, Environmental Agency of the Republic of Slovenia”, Seismology and Geology Office, Ljubljana, Slovenia.
2. Boštjančič, J., Sheppard, P., Terčelj, S., Turnšek, V. (1976) “Use of a modeling approach in the analysis of the effects of repairs to earthquake-damaged stone-masonry buildings”, Bolletino di Geofisica Teorica ed Applicata, Udine, Italy, Part 2, 1091-1116.
3. Turnšek, V., Terčelj, S., Sheppard, P., Tomaževič, M. (1978) “The Seismic Resistance of Stone-Masonry Walls and Buildings”, 6th European Conference on Earthquake Engineering, Vol. 3, Dubrovnik, Croatia, 275-282.
4. Tomaževič, M., Klemenc, I., Lutman, M. (2000) “Strengthening of Existing Stone-masonry Houses: Lessons from the Earthquake of Bovec of April 12, 1998”. European Earthquake Engineering, Vol. 14, No. 1, 13-22.
5. Tomaževič, M., Lutman, M., Klemenc, I., Weiss, P. (2005) “Behaviour of Masonry Buildings during the Earthquake of Bovec of July 12, 2004” European Earthquake Engineering, Vol. 19, No. 1, 3-14.
6. Eurocode 8 (2004) “Design of structures for earthquake resistance, Part 1: General rules, seismic actions and rules for buildings. EN 1998-1”. Brussels: CEN.
7. Eurocode 8 (1996) “Design of structures for earthquake resistance, Part 3: Assessment and retrofitting of buildings. prEN 1998-3”. Brussels: CEN.
8. Tomaževič, M., and Lutman, M. (2007) “Heritage Masonry Buildings in Urban Settlements and the Requirements of Eurocodes: The Experience of Slovenia” International Journal of Architectural Heritage, 108-130.
9. Eurocode 8: Design of structures for earthquake resistance, Part 3: Assessment and retrofitting of buildings. prEN 1998-3. 2004. Brussels: CEN.