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EVALUATION OF STABILITY OF MASONRY MINARET IN HIGH SEISMICITY REGION

OCENJEVANJE STABILNOSTI ZIDANEGA MINARETA NA IZRAZITO POTRESNEM OBMOČJU

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EVALUATION OF STABILITY OF MASONRY MINARET IN HIGH SEISMICITY REGION

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izvleček

Pričujoča študija je rezultat avtorjevega sodelovanja v projektu prenove Ferhad-pašine mošeje. Cilj projekta je izgradnja avtentične zgradbe z uporabo avtentičnih materialov, pri čemer bi bila spoštovana estetska načela in pristopi starodavnih graditeljev. Stavba bo na novo zgrajena v isti obliki kot je bila pred porušitvijo, pri čemer bodo uporabljani tudi podobni načini gradnje. Predvidevanja so, da se bo zaradi pomembnih razvojnih sprememb v arhitekturi, ki so se zgodile od časa prvotne gradnje, težko ravnati po tem načelu. Spomeniki so dragocenosti, ki jih je potrebno spoštovati in jih kolikor se le dà malo spreminjati. Takšna zapažanja bi lahko privedla do protislovnih odločitev, zaradi katerih bi bila včasih sprejeta večja tveganja zato, da bi se izognili spremembam prvotne zamisli ali jih vsaj omejili. Ferhad-pašina mošeja je delo visoko usposobljenega mimarja (graditelja) in muhendisa (inženirja). Je izdelek Sinanove šole.

7. maja 1993 je bila mošeja razstreljena in zravnana z zemljo, gradbeni material pa odpeljani na odlagališče odpadkov v Ramiće. Za analizo lupinastih elementov minaretov je bil uporabljen računalniški program SAP2000. Ob predpostavki neobstoječe napetosti je bilo ugotovljeno, da je bila pod potresno obremenitvijo obtežitev znatno presežena. Deformacije, ki jih povzročajo strižne sile nepomembno vplivajo na trdnost visokih, vitkih objektov, zato jih pri praktičnih izračunih lahko zanemarimo. Da bi zmanjšali raztezno silo, ki se pojavi zaradi seizmičnih premikov, smo predlagali dvoje rešitev.

ključne besede

minaret, objekt, kulturna dediščina, gradnja, seizmično delovanje, lupinasti elementi

abstract

This paper is a result of authors' involvement in the Project of Rehabilitation of the Ferhad-Pasha's Mosque.

The aim of the project was to construct an authentic building using authentic materials, while respecting the principles of aesthetics and the approaches of ancient builders. The building will be reconstructed to the same condition as it was before destruction using similar construction methods. It is foreseen that it will be difficult to comply with this principle, due to significant developments in architecture since the initial construction. Monuments are precious things that must be respected, and altered as little as possible. These observations could lead to contradictory decisions, at times accepting a higher degree of risk in order to avoid or limit changes to the original concept. The Ferhad-Pasha's Mosque is the work of a highly-qualified mimar (builder) and muhendis (engineer), a product of Sinan's school.

On 7 May 1993 the mosque was dynamited and razed to the ground, and the material removed to the city landfill site in Ramiće. The computer program SAP 2000 was used to analyze the minarets with shell elements. Assuming no tension, it was found that the stress was exceeded to a greater extent under the earthquake load. Deformations caused by shear forces have an insignificant influence upon the rigidity of tall slender structures, thus they can be neglected in practical calculations. To reduce the tensile stress, which appears due to seismic movements, we recommended two solutions.

key words

minaret, structure, cultural heritage, construction, seismic action, shell elements

The Ferhad-Pasha's Mosque was built on a site between the Crkvina (Crkvena) brook and the Vrbas River, in the former Donji Šeher quarter of Banja Luka. The Ferhadija, as it is also known, was one of the many properties endowed by Ferhad Pasha Sokolović. The way it was built suggests a pupil of Sinan's, who was keen to test a new structural solution and create a prototype for a mosque to be endowed by Sultan Murat III in Manisa, the Muradija Mosque. The Ferhadija Mosque is the work of a highly-qualified mimar (builder) and muhendis (engineer), a product of Sinan's school.

The features that make the Ferhadija one of the most important monuments of the Ottoman architectural heritage in Bosnia and Herzegovina are:

- The tetimas (rooms to the sides of the main prayer area), with their distinctive vaulting;
- The combination of semi-domes over the mihrab area, the main dome and side semi-vaults, a unique structural solution for the load-bearing system;

The two staircases leading from the mahvil – prior to the Ferhadija. The only other use of this in south-eastern Europe has been registered in the Jahja Pasha Mosque in Skoplje, 1503-04.

Minarets as load-bearing structures in architecture

Vertical architectural structures attest to the aspiration to a higher reality, beyond the mundane, the commonplace, the earthbound; they direct us somewhere (for instance, to a Renaissance square), and enable us more clearly to hear voices and sounds (bells, the azaan or call to prayer) or to see (the time on a clock tower). Verticality in architecture does not solely relate to religion; it is also, plainly, a demonstration of power. With the passage of time, tall vertical forms became a key element in the repertoire of forms, serving both as a point of reference and as a means of identification, a marker of space and aura at the centre of an urban ensemble.

The statics model of such a structure is the cantilever, fixed at the lowest point, bearing the vertical central self weight load of and the continuous horizontal stresses over the entire height of the building (usually caused by earthquakes and wind).

As regards the earthquake stress, it is typical of this structure that the critical points at which the greatest damage and possible collapse occur are in the lower parts of the structure.

The effect on the building lies in the relation and proximity to the building's own oscillation frequency and the frequency magnitude and energy, which explains why minarets and tall towers sometimes survive earthquakes better than solid but extremely rigid buildings, where resonance oscillations may arise, in addition to poor-quality materials and other factors that may render such a structure highly vulnerable.

Masonry minarets are characterized by two striking features. On the one hand, their height and slenderness necessarily result in a shortfall in the corresponding absorption of the distribution of stresses (tensions), a shortfall in the dissipation of energy along the structure with a concentration of stresses in plan and weakness resulting from the predominant vertical actions, and weakness of the damaged masonry. On the other hand, as regards the dynamic behaviour of masonry minarets, their longish fundamental vibration period is a positive feature. For this reason, the dynamic behaviour of the tower is limited by the falling curve of the response spectrum. Whether this will be favourable depends above all on the seismic risk of the area under investigation, as well as on the actual condition of the structure and the materials from which it was built. Combining these two contrasting properties generates the corresponding (accurate) prescribed seismic assessment of a masonry minaret.

Rehabilitation of the Ferhad-Pasha's Mosque

The computer program SAP 2000 V12 was used to analyze the minarets with shell elements. The finite element model of the minaret is shown in Figure 2.

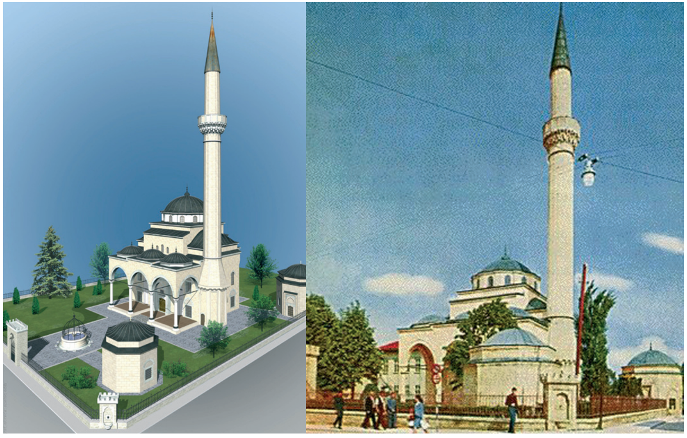
The major part of the building is built of carved stone blocks made of crystal travertine.The chief load combinations to be considered are dead load plus seismic load, and for tall structures on exposed sites dead load plus wind load.

A linear dynamic analysis was recommended in section for determination of internal forces due to seismic loading in tall slender structures of this type. A dynamic analysis of this kind was recommended for the slender minaret-like structure, which is easily modelled as tube. Once the loading had been determined, stresses were calculated statically, again assuming linear elasticity.

Static analyses of internal forces and moments were made for both wind and earthquake loading.

The response of the minaret was analysed in the event of different levels of seismicity in the area, i.e. levels VIII and IX according to EC 8.

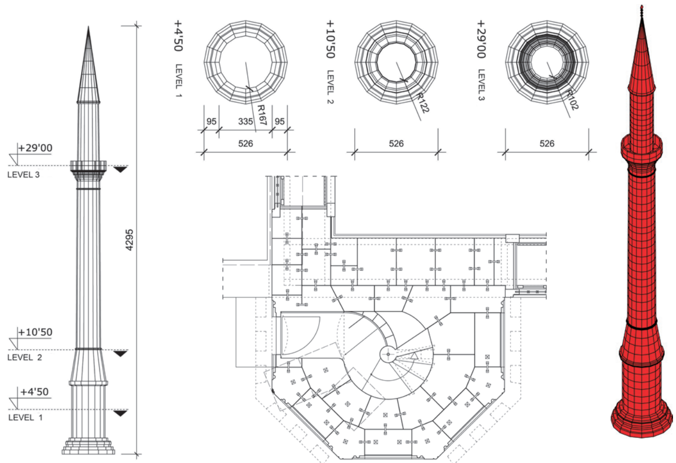
The internal forces and moments were recalculated using computer facilities. Taking into consideration the fact that the Banja Luka area is nowadays a part of the seismic zone IX, seismic influences are dominant in the construction of the minaret. Seismic action is the largest action that affects the minaret and endangers it, not only because of the intensity of the forces, but especially because masonry structures are not designed to deal with tensions.



Slika 1: Ferhad-pašina mošeja - 3D maketa ter mošeja pred razstrelitvijo.
Figure 1: The Ferhad-Pasha's Mosque – 3D model and the Mosque before mining.

A sixteen-sided, 41.7 meters high minaret with no alem is abutting onto the front right corner of the prayer area and leaning, in part, against the side wall of the mosque. The minaret is, in effect, structurally attached to the mosque wall at the height of 10.50 m, while above the upper level of the mosque wall it forms an independent slender structure with circular, ring-shaped horizontal sections. The diameter of the minaret up to the height of 5.80 m is 3.50 m. Then it gets linearly reduced to 2.56 m up to the height of 9.30 m and remains constant up to the šerefet (balcony). Above the šerefet the diameter reduces to 2.12 m and remains as such up to the height of 35.20 m.

The wall thickness beneath the šerefet is 0.50 m, and above it 0.31 m. The minaret is made of dressed stone blocks of crystal tuff. The plinth of the minaret is five-sided and can be accessed from the outside, next to the porch. A minaret can be divided into foundation and tubular part. The tubular part is made of plinth, base, minaret, šerefet, barrel and roof. All these elements, except for the šerefet, are made of tuff stone joined by overlapping, with joints filled with lime mortar, iron cramps immersed in lead and vertical anchors for the šerefet. The plinth, the base and the minaret form a closed, hollow "tube". Inside the minaret there is a stone staircase leaning against the minaret walls along the peripheral part. The opening inside the minaret is constant and measures 1.5 m. The minaret terminates in a cone-shaped barrel measuring 7.50 m in height. The roof structure of the barrel is made of wood and has sheet lead cladding, just as the domes do. The structure of the šerefet or gallery, intended for the muezzin, is made of limestone and has a stalactite-like appearance when observed from the outside. This shape of the šerefet is achieved by way of projecting horizontal stone courses in form of a console in relation to lower layers, which the gallery and fence are leaning against. The šerefet floor lies at the level of 27.95 m. The walls of the mosque and minaret are made of white-beige coloured crystal tuff ("bigar", travertine). Tuff is a porous, calcium carbonate rock, produced through sedimentation in cold water, which has a very important property of being resistant to the effects of frost.



Slika 2: Minaret – 3D AutoCAD maketa, SAP2000 V12 maketa in prerez.
Figure 2: Minaret – 3D AutoCAD model, SAP2000 V12 model and cross section.

Investigations carried out

The known mechanical characteristics of the materials that the minaret was made of were used in the models. According to the information used by the investor, the Islamic Community in Bosnia and Herzegovina (in 2002), in the Project of Reconstruction of the Ferhadija Mosque minaret: modulus of elasticity, Poisson's ratio and specific weight of stone material are 5,000,000 MN/m^2, 0.22 and 0.020 MN/m^3 respectively, all used in the variants in which the minaret is either attached to the building or not. Linear elastic behaviour of the material was assumed, while reduction in rigidity was neglected. Second rank geometric effects were also neglected in the analyses. The damping with a viscous damping coefficient of 5% was used in all dynamic analyses of the area. It is known that the minaret is located in the region of high seismic activity; zone IX according to the Euro code provisions for earthquakes and the seismic maps with a return period of 500 years.

- The dynamic modulus of the material is Ed = 184•104 MN/cm^2.
- Permissible compressive strain of the stone – $\sigma c = 1.4$ MN/m^2;
- Permissible tensile strain – $\sigma t = 0.15$ MN/m^2;
- Permissible shear strain of the stone – $\tau = 0.10$ MN/m^2;

Other models were also produced with a view to determining the dynamic properties of the minaret and analyzing its response in the event of different levels of seismicity in the area, i.e. levels VII and VIII according to EC 8 in order to check the process of designing and constructing the minaret.

EC 8 – VII level of seismicity	coefficients
Category of soil B	S=1; β0=2,5; K1=1; K2=2; TB=0,15; Tc=0,6; Td=3
q –Factor of behaviour	
System of reversed pendulum	2
Low ductility	1,5
Proper structure	Kr=1
Dominating mode of aberration	Kw=1
Factor of behaviour	q=1,50
Category and factors of importance	γ=1,20 (cultural institutions)

Tabela 1a: Uporabljeni projektni spekter.
Table 1a: Used design spectrum.

	EC 8 – VII zone of seismicity (m/s2)	EC 8 – VIII zone of seismicity (m/s2)	EC 8 – IX zone of seismicity (m/s2)
0.0	1.18	2.35	3.53
0.1	1.70	3.40	5.10
0.15	1.96	3.92	5.89
0.2	1.96	3.92	5.89
0.4	1.96	3.92	5.89
0.6	1.96	3.92	5.89
0.8	1.62	3.24	4.86
1.00	1.40	2.79	4.19
1.5	1.07	2.13	3.20
2.00	0.88	1.76	2.64
2.5	0.76	1.52	2.27
3.0	0.67	1.34	2.01
4.0	0.42	0.83	1.25
5.0	0.29	0.57	0.86
6.0	0.21	0.42	0.63
8.0	0.13	0.26	0.39
10.00	0.09	0.18	0.27

Tabela 1b: Uporabljeni projektni spekter.
Table 1b: Used design spectrum.

Further on, the analysis of the minaret revealed only a difference in the height of the circular body of the minaret, while the geometric properties of the base or the joining part, of the transitional part and of the roof were identical in all models. Variants were also produced, in which the height of the minaret was increased or reduced by approximately 12% (5 m).

Another type of analyses performed dealt with altered mechanical properties of the materials that the minaret was made of, as follows: modulus of elasticity =7500 MN/m^2, Poisson's ratio=0.26 and specific weight of stone material = 0.023 MN/m^3 to replicate the case of better material properties, then modulus of elasticity of sections with no cracks = 3500 MN/m^2, Poisson's ratio =0.20 and specific weight of stone material = 0.018 MN/m^3 in the case of poor material properties.

In the end, models were analyzed, in which the geometric properties of masonry elements of the minaret were changed by increasing and reducing the thickness of the elements by approximately 10-15 %.

Other types of analyses and calculations were also undertaken. These primarily considered the results of in situ investigations, which revealed values of the dynamic properties of certain minarets, deformations of the investigated minarets, stress distribution in the structure of the minarets and similar. They also utilised the results of "traditional" calculation, which is common in the engineering work as a control calculation of the static system of a structure, recognizing the known properties of the installed material and the known dimensions of the elements, with a view to determining the stability and safety of the structure.

Results of investigations

The height of the minaret influences periods of oscillation to a large extent. The first and basic periods, calculated individually for minaret model I (41.65 m – real height), II (46.65 m – minaret height increased by approximately 12%) and III (36.65 m – minaret height reduced by approximately 12%), were 1.000, 1.359 and 0.683 s respectively.

Minaret shapes produce reaction dominated by torsion, with the greatest displacements registered on the top. The displacements start to increase above the transitional part of the minaret structure (contact between the building and the minaret).

A state regulation for the displacement index does not exist, however, the value of H/400 is a traditionally accepted limit.

If this requirement is applied to the analyzed towers, whose height is 46.65, 41.65 and 36.65 m, the corresponding, maximum permissible displacements on the top will be 0.1168, 0.1041 and 0.0916 m. The specified displacement limit was exceeded in all cases of the analyzed minarets, ranging from 0.1027 m (12%) to 0.2015 m (172%).

In minaret models with better mechanical properties of the material the critical displacements of the top of the minaret decreased by 15% in comparison with the displacements observed in the existing minaret, whereas extreme tensile stresses decreased by 17%. It was revealed that it would be insufficient to intervene solely by means of injecting the joints of the elements of the masonry structure, thus influencing the modulus of elasticity of the masonry, providing better mechanical properties of the masonry structure material, and also significantly reducing the displacements of the top of the minaret and the extreme tensile stresses.

Increasing and decreasing the thickness of elements results in an insignificant decrease or increase in the displacements of the minaret top and in tensile stresses.

Dynamic analyses revealed that the maximum stresses will appear near the lower part of the minaret, above the contact point between the minaret and the building. It should be mentioned that the models of minarets used in this investigation were laterally reinforced throughout their heights.

The highest calculated normal compressive stresses and tensile stresses were 4.6 MN/m^2 and 1.53 MN/m^2. These results show that normal compressive stresses were somewhat higher than the compressive strength of the masonry structure, whereas the obtained tensile stresses were too high.

The research revealed that, in the majority of tested variants, the influences of the wind are neither relevant in maximum displacements, nor in the obtained extreme strain values, except in the case of the minaret variant in zone VII.

The slenderness parameter of the minaret, which represents the relation between the minaret height and the cross section diameter, was considered = H/d. Taking into account the calculated stresses and horizontal displacements, the approximate value of H/d =10.0 (the real value is H/d = 12.91) is the recommended minaret slenderness (H/d), determined by the investigations conducted on models of the Ferhad-Pasha's Mosque minaret.

DETERMINING THE OPTIMUM SLENDERNESS				
attached to the main building	Name of the minaret Ferhad-Pasha's Mosque in Banja Luka	displacements (m)	H/400	slenderness = H/d
level of seismicity	zone IX			
total height (m)	46.65	0.2015	0.0881	0.1438
total height (m)	41.65	0.1371	0.0791	0.1291
total height (m)	36.65	0.1027	0.0666	0.1087

Tabela 2: Določanje optimalne vitkosti minareta Ferhad-pašine mošeje.

Table 2: Determining the optimum slenderness of the Ferhad-Pasha's Mosque minaret.

Strengthening proposals

To reuduce the tensile stress, large due to seismic movements, it is recommended to install vertical carbon, reinforced fibre composite NSM CFRP sheets, sealed with appropriate plaster.

It is necessary to perform this intervention over a major part of the minaret from the base, and to pay special attention to sections with high decreases of cross-sections at the place of the šerefet and immediately after it. For vertical individual constructions, such as clock towers, towers and minarets, the stiffening capacity is increased via installation of vertical iron elements or some synthetic fibres. It is proposed here to achieve sufficient tensioning capacity using the carbon composite.

Analysis indicated this prevents further damaging of the building, and provides a satisfactory capacity level.

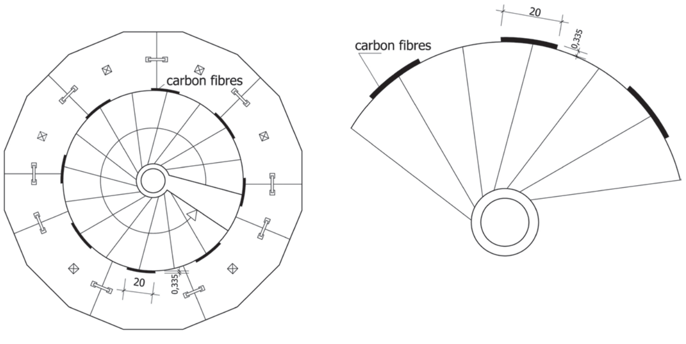
The fibre model assumes that the structure has a certain number of axial fibre sheets to reduce tension stresses. The use of tested materials of good quality and high tensile strength, which ensure fast, cost-effective and efficient installation, is desirable.

Using modern structural conservation techniques allows us to intervene respecting the original concept and achieving a skilled balance between safety and the necessary permanence, in line with the philosophy of minimum intervention and a careful assessment of the possibilities offered by old and new technologies. The proposed intervention aims to apply, by appropriate techniques, a reticular system made of vertical and horizontal FRP sheets glued to the masonry. Figure 3. shows the FRP system as it appears on the inner walls of the structures.

Carbon fibres with a specific weight of γ = 6•10-5 MN/m^2, t =0.000335 m in thickness and w = 0.20 m in width, are to be employed. With a view to preventing possible cracks on the outer side of the minaret, extra reinforcement in form of additional CFRP rods installed into stone block joints at every four meters of the minaret height. The rods are to be bonded using appropriate plaster.

The ultimate tensile strength of the fibres is 4.800 MN/m^2. The FRP system ensures a monolithic behaviour of the masonry in the case of high-intensity earthquakes.

An FRP tie system is to be applied to the inner walls and anchored at the base by a reinforced concrete slab, independent of the tower's foundation. The intervention enhances the seismic capacity of the structure and is fully provisional as it may be removed by heating the FRP with a hot air jet.



Slika 3: Vertikalne in horizontalne plošče iz plastike ojačane s steklenimi vlakni (FRP).

Figure 3: FRP system - vertical and horizontal FRP sheets.

This would not constitute a permanent intervention to the minaret, as replacing the concept would not be hard if a more elegant solution to the stability of the minaret was to be found at some future date.

Advantages of this type of interventions are: Easy to handle and transport; ability of real-time monitoring; excellent fatigue and fracture resistance; high specific strength properties (20-40% weight savings); lower thermal expansion properties; resistance to chemical agents and impermeability to water; tailor made solution; outstanding corrosion resistance; lower tooling cost alternatives; in comparison with conventional material very good ratio rigidity / self weight.

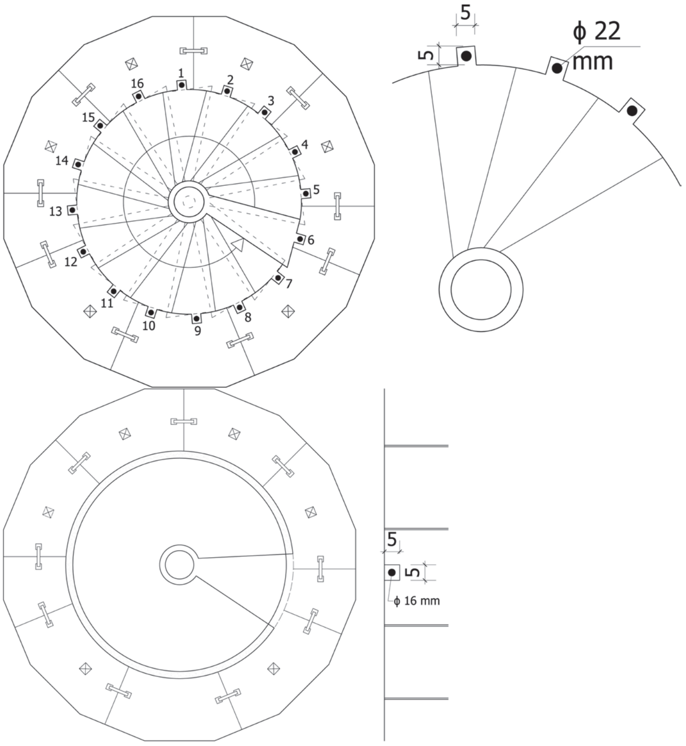
The Venice Charter (and the Charter of Krakow in addition) regards historic monuments as architectural works that attest to the culture and tradition of peoples over the centuries. It is incumbent upon us to preserve and safeguard them intact for future generations. Interventions should have respect for the original materials; required replacements need to be harmoniously integrated with the whole, but easily identified; and additions are acceptable only if their influences on the other parts of the monument and/or its surroundings are negligible.

A special problem is the implementation of effective laws and recommendations, very often leading to complex and unwarrantable solutions.

The truth is that they were not designed to be implemented in cultural heritage. When traditional techniques are shown to be inadequate, historic properties may be consolidated using modern structural conservation techniques that have been proven by scientific research and are already empirically tried and tested. Structural codes for new buildings, much less older ones, are not written to ensure that buildings are strong enough to survive a large earthquake without major damage. We should not forget that the objective of the code requirements is to avoid collapse. This is a technique extensively used for western European historic structures and seems very appropriate for reversible interventions.

The second proposal includes traditional retrofit strategies based on steel.

The structure of the Ferhad-Pasha's Mosque minaret was already strengthened in 1986. After the earthquake (magnitude was 6.0) the minaret was affected by decay and cracks that were visible. At that time the Banja Luka area was a part of the seismic zone VIII. To take off the tensile stress, which appears due to seismic movements, vertical and horizontal reinforcing bars Φ22 and Φ16 were proposed to be installed (16 vertical and 8 horizontal bars). Figure 4. shows this intervention.



Slika 4: Tradicionalen poseg – vertikalne in horizontalne armaturne palice.
Figure 4: Traditional intervention - vertical and horizontal reinforcing bars.

In order to avoid disturbance of minaret's architecture, vertical and horizontal bars would be installed into previously prepared openings at the inner side of the minaret. It would have been much more effective if the bars had been installed at the outer side of the minaret.

In addition, injecting the joints of the elements of the masonry structure, thus influencing the modulus of elasticity of the minaret and providing better mechanical properties of the masonry structure material, and also significantly reducing the displacements of the top of the tower (minaret) and the extreme tensile stresses, could be undertaken.

We are of the opinion that one should not go beyond the 1986 intervention and further modify the structural solution, which, in any case, does not comply with heritage protection principles. Final decisions are steel going to be decided.

Conclusions

The calculations made have clearly shown that the loads caused by seismic activity were not taken into account sufficiently in the process of designing and constructing the minaret, a property of historical and cultural heritage, i.e. that much more significant tensile stresses appeared in the analysis of the minaret, which should be reduced in order to ensure the appropriate level of safety.

It is our intention to encourage once again the possibilities of passing special laws and recommendations for historical heritage buildings and imposing a special status of these buildings in structural treatments. A significant number of church towers and minarets belonging to the cultural heritage should be reinforced against possible seismic influences.

A special problem is the harmonisation of required structural measures with the requirements of cultural heritage protection.

The problem is the use of current laws and recommendations, which were not designed to be implemented in cultural heritage and which, if applied strictly, very often result in complex and unwarrantable solutions. Needless to say efforts should be made to respect heritage preservation requirements with regard to the selection of materials and preservation of the traditional details of the original structure. The choice of the criteria and technology of intervention is a technical and cultural issue.

Every intervention results in some changes, which further cause the loss of a part of building's authenticity. One should, therefore, be very careful when making decisions on preventive interventions. The risk of possible effects (mostly seismic forces) upon a building under investigation needs to be taken into account, which should be followed by the decision whether to intervene or not.

It is not possible to provide a rule for the selection of an intervention, although some guidelines can be offered, such as: respecting the original concept and achieving a skilled balance between safety and the necessary permanence, in line with the philosophy of minimum intervention and a careful assessment of the possibilities offered by old and new technologies. The use of tested materials of good quality and high tensile strength (carbon fibres, epoxies, SMA, STU, etc.), which ensure fast, cost-effective and efficient installation, is desirable.

Bibliography

Čaušević A., Hadžirović M. (2007): Protection of and Interventions on The Towers of Religious Buildings, Proceedings of II Congreso International de Patrimonio e Historia de la Ingenieria : Las Palmas de Gran Canaria, Centro International de Conservation de Patrimonio (CICOP), pages 163-183.

Čaušević A., Rustempašić N. (2005): Ferhad-Pasha's Mosque - Rehabilitation of historic masonry buildings in seismic areas, Proceedings of 2nd H&mH International Conference on Vulnerability of 20th Centuri Cultural Heritage to Hazards and Prevention Measures, CICOP Federation, pages 50-59.

Čaušević A., Rustempašić N. (2010): Dealing with masonry minaret stability problem in the case of the Ferhad-Pasha's Mosque Minaret, Proceedings of 8th International Masonry Conference, Dresden, Germany, pages 1841-1849.

Explanation of lesser-known terms

Ferhadija – sth. related to Ferhad-Pasha
Mimar – constructor
Muhendis – engineer for civil works
Turbe – a mausoleum
Tetima – apse
Mihrab – imam's room
Mahvil – a sort of portico, part of mosques
Tugla – specific clay bricks used in Roman and Turkish architecture
Šerefet – widened section of minaret, a kind of gallery
Mujezin – muezzin
Abdest – the act of preparation for praying

Notation

Am	Cross section
σt	Permissible tensile strain
σc	Permissible compressive strain of the stone
τ	Permissible shear strain of the stone
E	Modulus of elasticity

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