TECHNOLOGY INTRODUCTION TO FLEX&ROBUST PRODUCTS

The most important thing is, that you give us all relevant information that might attract a building owner to consider installing your product in their building (being newly built or under renovation). Make the best possible selling point and don't spare any images, video, charts…or any other visual aids you might have. The content you will send to us will then be designed by Compaz (project partner) and later uploaded to the website of the project.

FLEX&ROBUST products:

A Flex&Robust line of products is developed from Polymer Flexible Joints (PFJ) and is dedicated to structural and non-structural bonding of elements constructing civil engineering structures, made of various materials (concrete, masonry, wood, metal). The specially designed products are able carry static, dynamic and cyclic loads and simultaneously transfer high deformations. They are resistant to elevated temperatures and reduce stress concentrations by redistributing them for large bonding are. Flex&Robust products can be used many times in seismic areas and strong wind areas. Do not need to be replaced as other connectors after catastrophic events. They protect connected envelope components against damage.

Wide range of Flex&Robust products' properties can be adjusted to various requirements, using special components provided by SIKA Poland, according to license agreement signed with Flex&Robust. The Flex&Robust line of products can construct PUFJ (PolyUrethane Flexible Joints) and FRPU (Fiber Reinforced PolyUrethanes) of good load and deformation capacity, fulfilling vibro-acoustic and thermal comfort requirements, as well as manifesting durability, waterproofing and non-conductive electric properties. It consists of:

1. Flex&Robust Injection – liquid injectable material of fast curing time, suitable for filling gaps and bonding of structural and non-structural envelop components, as well as for repair of damaged elements (Fig. 1a);
2. Flex&Robust Layer – prefabricated or constructed on site flexible layer (PUFJ), which connect structural and non-structural envelop components, can be adjusted to any bonding surface shapes and thicknesses (Fig. 1b);
3. Flex&Robust Composite - prefabricated or constructed on site composite material (FRPU), consisted of strengthening fibers and flexible matrix, fastened to structural and non-structural envelop components by flexible adhesives (Fig. 1c);

a) 

b) 

c) 

Fig. 1.

Examples of PUFJ and FRPU applications are presented on movies at the FLEX&ROBUST website:

http://www.flexandrobust.com/index.php?mod=mod01

Background of FLEX&ROBUST products efficiency – innovation in Civil Engineering

The need for innovation was lack of suitable structural solutions in civil engineering, related to creation of structural connectors based on bonding, having ability to transfer loads and high deformation simultaneously. Majority of civil engineering structures are masonries or concrete with their brittle properties of structural materials. In the past, connectors of brittle structural members were belonging to opposite areas: stiff joints (capable to carry high loads but unable to carry high deformations) and sealants (capable to carry high deformations but unable to carry high loads). The gap between them was empty in the case of construction industry, whereas in motor and marine industries this gap was fulfilled by flexible connectors. Following those branches, a new sort of structural joints was introduced in construction industry, named Polymer Flexible Joints (Fig. 2).

Fig. 2.

The main advantages of the PFJ come from hyperelastic characteristic of special polyurethanes forming flexible joints. They are capable to carry high loads and high deformations simultaneously. They also allow for reducing of stress concentrations and redistributing them over large bonding area.

The need of transferring loads and deformations simultaneously as well as reducing of stress concentrations and redistributing them over a large bonding area is visible in construction industry in macro and micro scale. Lack of these abilities is especially present in structures made of brittle materials (concrete, masonry), located in seismic and settlement areas or places with not stable foundation (e.g. Venice – Fig. 3), on active slops or all places were dynamic (e.g. strong winds) and thermal loads occur.

However, the need of transferring loads and deformations simultaneously is obvious, but the need of reducing stress concentration and redistributing them could be difficult to understand. It is known from many researches that under the peak of stress concentration brittle materials reach easily their limit of elasticity and start forming micro-cracks locally, which link into a main crack after load increase. The stiffer joint between two brittle structural elements is, the higher picks of stress concentrations are, responsible for micro cracks formation and thus weakening of brittle materials. Reduction of stress concentrations assures highly deformable flexible polyurethanes. This idea is schematically presented in Fig. 4.

Fig. 3.

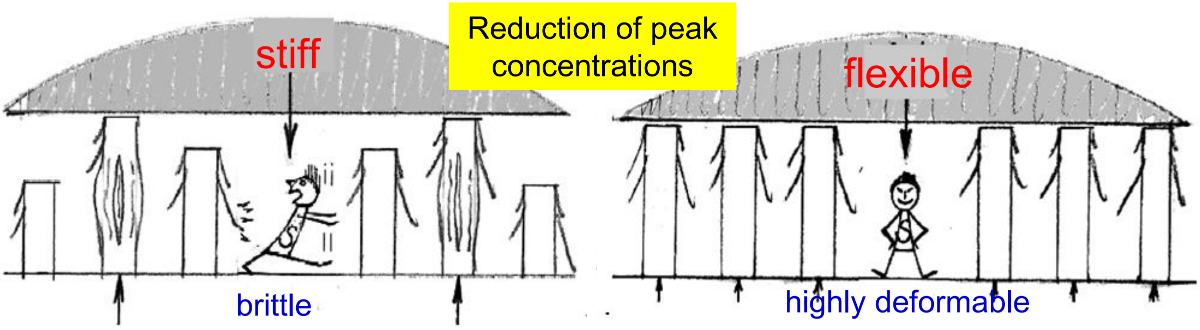

Fig. 4.

Both presented aspects are manifested together in the case of repair cracks in brittle structural elements made of concrete or masonry. In the surrounding of the crack, a weakened zone remains full of micro-cracks. When the crack divides a structural element into two parts, they work separately in the new stress equilibrium and static balance being the consequence of stress redistribution. Separated parts of the cracked structure can draw apart e.g. under cyclic repeated settlements caused by fluctuations of a water level, temperature changes and vibrations (seismic or ambient), of even not very high intensity. Typically, cracks are repaired using stiff and brittle mineral or epoxy grouts, which do not improve significantly the structural capacity (damage energy), because they introduce stress concentrations again and low deformability (disadvantageous in seismic areas, where materials of high ductility are required). The case of a cracked historical masonry building damaged by settlement, repaired by injecting using stiff and strong cementitous mortar is as an example. Large deformations and high stiffness of the repair joint generated stress concentrations in weak and brittle masonry, causing appearance of new cracks in surrounding of the repair (Fig. 5).

Fig. 5.

The other example is the field of strengthening and repair of masonry and concrete structures using externally bonded fiber-reinforced composite systems. Possible advantages of these high-tech materials are not fully utilized because of low tensile and shear surface strength of substrates. Usually, composite strengthening is fixed to masonry substrates using stiff epoxy resins or cementitous mortars of low deformability. Under ultimate loads, failure of brittle substrates are very rapid (no warning) and demolish them (Fig. 6). These failure occur at the relatively low load level (in comparison to composites strength), because of stress concentrations overcoming strength of brittle substrate, caused by stiff and slightly deformable stiff adhesives. This is the reason why other bonding solutions, more compatible with masonry substrate, are sought after.

Fig. 6.

Both presented needs for innovation require construction safety improvement, because brittle and sudden failures occur without ductile behavior. Protection of life and property is the main goal of civil engineering, and this requirement is assured by safety factors in designing (only reducing ultimate load-strength values). However, post failure behavior of structures should be also of great importance. In seismic areas, high amount of ductility and deformation capacity of structures are required. Damaged (cracked) structures manifest low resistance to forced loads, thus protection, repair and strengthening methods should not only recover prior resistance but also introduce new safety structural behavior. It is required from constructions that they will be able to deform safely and largely under extreme loads.

Why the FLEX&ROBUST products are innovative?

The proposed innovative bonding (repair) method uses flexible joints made of special highly deformable polyurethanes of reasonable low stiffness, instead of traditionally using stiff and brittle bonding materials of low deformability (epoxy resin, lime and cement mortars). Flexible joints are constructed from polymers characterized by: low Young's modulus E (from 0.1 MPa up to 800 MPa), high deformability ε (from 2% up to 1000%) and elasto-visco-plastic mechanical behavior, providing a high amount of damping and ductility.

Polyurethanes of various stiffness and deformability, forming PUFJ and FRPU systems, have to be chosen properly to assure compatible work with various substrates under differential loading conditions and can be designed for various requirements. This kind of highly deformable material reduces stress concentrations and more evenly redistribute them along the whole bonding surface (Fig. 4). The new kind of flexible joint introduces greater tensile and shear resistance, deformability and ductility and thus greater bearing capacity (damage energy) in the bonded brittle structural elements, also in the post failure deformation zone - making the structure more safe.

The most popular application of the PFJ are: repair of cracks by injection or filling structural gaps with prefabricated flexible elements to make flexible hinges – system named as PolyUrethane Flexible Joints (PUFJ), as well as bonding of composites using flexible adhesives – system named as Fiber Reinforced PolyUrethanes (FRPU). After repair and strengthening application of PUFJ and FRPU, the significantly higher ratios of tensile, bending and shear strength were obtained by structures having flexible joints, in comparison with the same structures having joints made of brittle bonding materials (epoxy resin, lime and cement mortars). Similar efficiency was observed when detached composites were bonded again by the FRPU repair. These observation were confirmed by scientists from various international universities. Materials using for producing PUFJ and FRPU, designed by Flex&Robust are distributed all-around the world by the well known global chemical company SIKA, producing building materials.

What are the achievements or improvements in terms of measurable outcomes?

Various technologies based on the PFJ were developed in the last decade, manifesting robustness of flexibility. They were investigated in laboratory and in-situ tests, which results were widely published in international journals and conferences. Practical effectiveness of the PFJ was manifested also in civil engineering applications. There were efficiently repaired masonry houses, concrete airport pavements, concrete floors, tram rails and a concrete retaining wall quickly protected on a dynamically developed active slop. All of them protected life and assured save exploitation. Some examples of the achievements and improvements of the PFJ systems are presented below in terms of measurable outcomes.

Comparison of bonding efficiency of PUFJ in the aspect of ultimate loads carried by repair joints, made of various materials of low and high deformability, was presented using specimens made of brick units. The tested units were first broken in a bending test and next repaired by bonding in the place of crack. The results of the tests on specimens with various bonding materials joining disrupted bricks (simulating cracks repair) indicated that repair of cracks in masonries by the use of cement mortar or epoxy resin (stiff materials of low deformability) is less effective (taking into consideration the load level) than using of flexible polymers of high deformability. Example results for the joints made of cement mortar (ZA) and two polyurethanes of various properties (PT and PM) are presented in Fig. 7. The repair joint ZA was unable to recover initial strength of the broken brick (68%), whereas PUFJ flexible repair joints (PT and PM) recovered it significantly (160% and 191%, respectively).

To compare brittle and stiff joints, simple tension and shear tests were carried out on inorganic mortar grout and deformable polyurethane joints. Specimens of small dimension made of typical Polish solid clay bricks (Bonarka) were used. The bed joints between brick elements were made of two kinds of materials of 10 mm thickness in each tested case. As the stiff brittle joint, lime-cement mortar of class M7 was used. As the deformable joint (PUFJ), polyurethane PM injection was applied. In each test, three specimens with mortar – marked (M) and with polymer PM – marked (PM) were investigated. Results in form of stress-strain curves (in comparable scale), obtained during tension and shear tests, are presented in Fig. 8. Tension and shear tests confirmed that PUFJ have much higher load bearing capacity and absorption energy (area under the curves) than brittle joints.

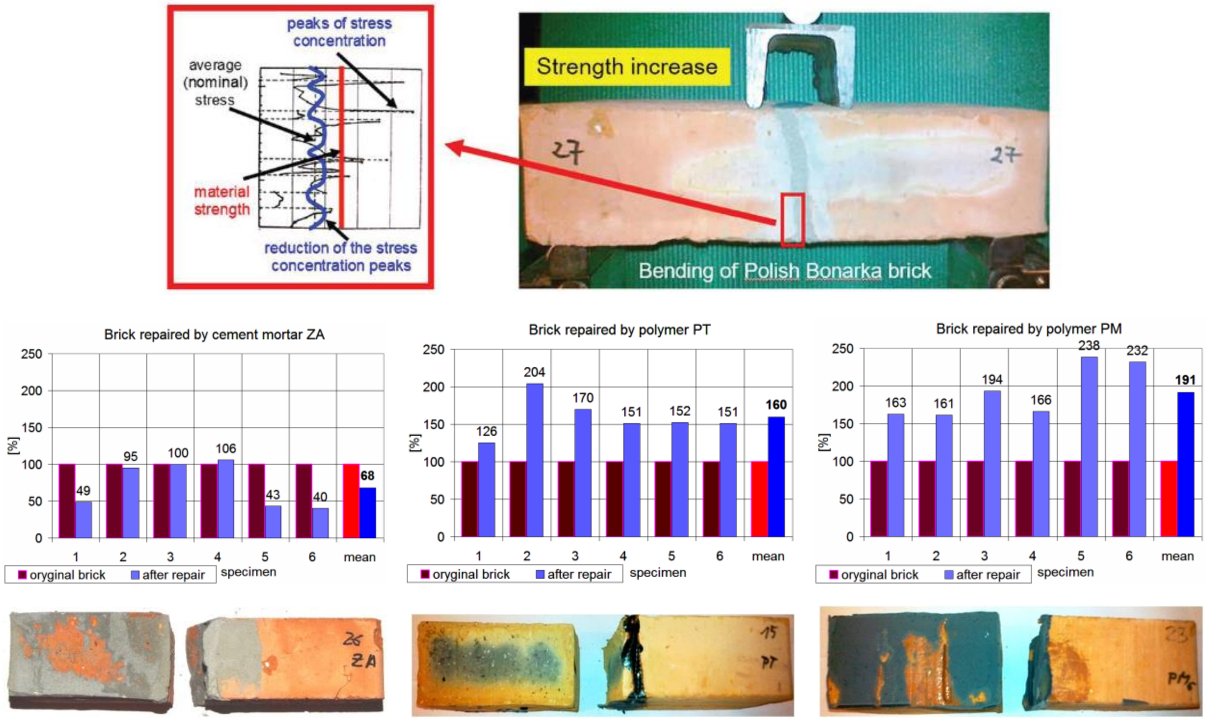

Fig. 7.

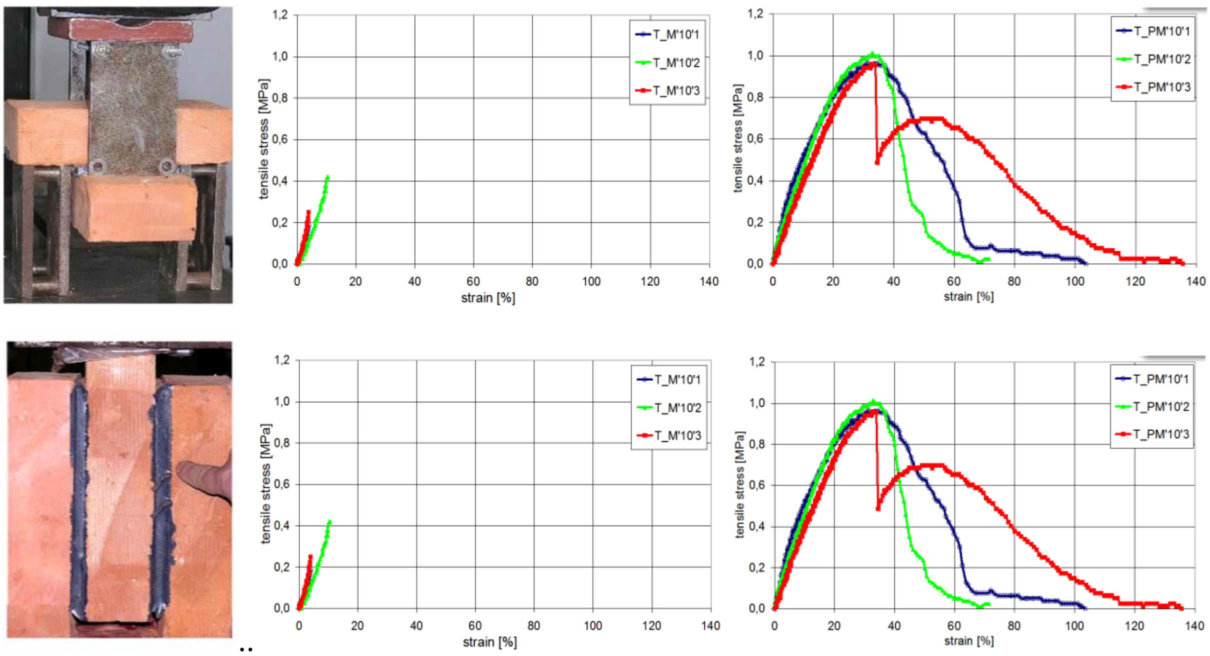

Fig. 8.

Efficiency of highly deformable repair material was checked during laboratory research. A shear test on a cracked masonry wall, repaired using polyurethane PM, was carried out. The wall pre-compressed vertically was subjected to monotonically increasing horizontal shear force in one cycle. The diagonally cracked masonry wall was repaired by polyurethane PM injection (PUFJ), and 24 hours later was again forced horizontally up to failure. The final damage occurred only in the PUFJ. Repaired masonry wall restored the original masonry strength up to 95% (Fig. 9), but ultimate shear strain increased over 10 times and energy dissipation capacity over 14 times. Huge amount of ductility was introduced what increased construction safety significantly.

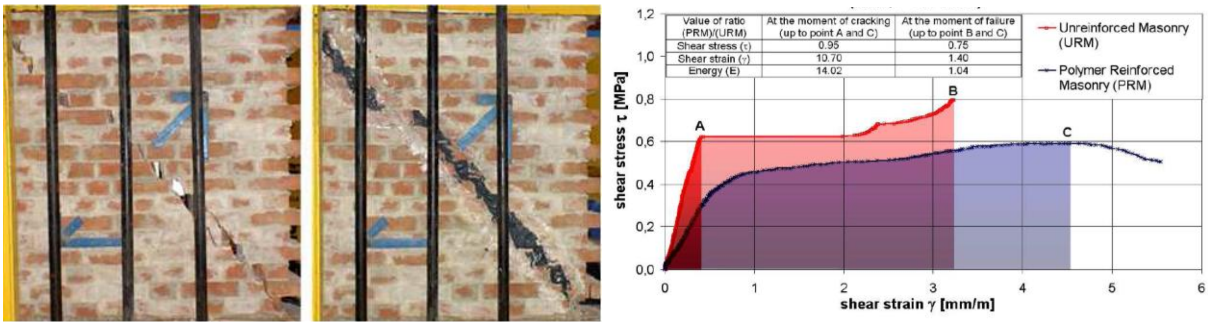

Fig. 9.

Efficiency of injected PUFJ was examined in situ on small masonry building during dynamic tests up to failure. The original structure was damaged by a caterpillar. Ultimate dynamic forces were generated in the corner of the building at the roof level. The structure was about to collapse after the action and had to be rectified what caused appearance of new cracks, looks like after a strong earthquake. The cracked building was repaired by injection using deformable polyurethane PM. Dynamic destructive test using caterpillar showed again that the strength of the PUFJ is higher than the original masonry. After the huge hit of the caterpillar a new crack appeared in a new location, different from the primary damage. Moreover during unloading of the structure, the PUFJ caused closing of the newly appeared cracks. The disrupted part of the wall of triangle shape (protected by PUFJ) was moving during hits, like on the pair of rubber braces. The destructive test showed that the polymer reduces stress concentrations and introduces the huge amount of capacity into the cracked masonry structure absorbing the input energy. New damages went only through new masonry areas, not through the polymer bonded cracks. Finally, the last huge hit collapsed the repaired masonry structure but PUFJ kept fast together pieces of wall during the damage process (Fig. 10).

The tests confirmed efficiency of PUFJ as the repair solution for damaged masonries in cases of static and dynamic loads. The destructive tests showed that PUFJ reduces stress concentrations and introduces huge amount of capacity to the cracked masonry structure to absorb the input energy. The flexible bonded masonry could be able to survive an earthquake and assure construction safety better than an original masonry.

The PUFJ was applied on a masonry family building, constructed from spider-web rubble walls of poor quality. The walls consisted from sand-stones joined with weak lime mortar. Damages in the building appeared in form of cracked wall and were caused by settlement after a flood. The cracks were filled in with PUFJ injection (Fig. 11). Effectiveness of the polymer joint was examined during window exchange. A triangle wall fragment was suspending only on the newly constructed PUFJ for the period of several hours. There were no fissures on a wall plaster and on gypsum markers placed on the joint as well as no cracks have been observed or fissures on structure till now (for 15 years). This case confirms that PUFJ equalize stresses in brittle materials and protects cracked masonries of the weakened structure against appearing of new damages, during movements occurrence of the separated building parts.

Fig. 10.

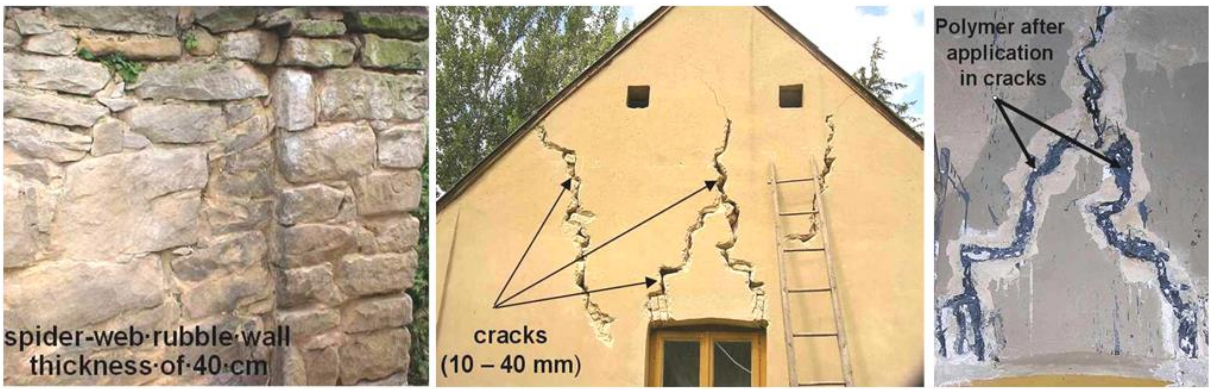

Fig. 11.

The injected and prefabricated PUFJ confirmed their high efficiency during dynamic tests on a shake table (Fig. 12). Many applied strong seismic excitations were unable to cause collapse of infill walls fixed to a reinforce concrete frames by the injected and prefabricated PUFJ. During in-plane excitation, the infill walls protected by injected PUFJ were kept on their position even after serious damage, without out-of-plane collapse. The infill walls protected by prefabricated PUFJ withstood strong out-of-plane excitation without visible damages nor collapse (Fig. 13).

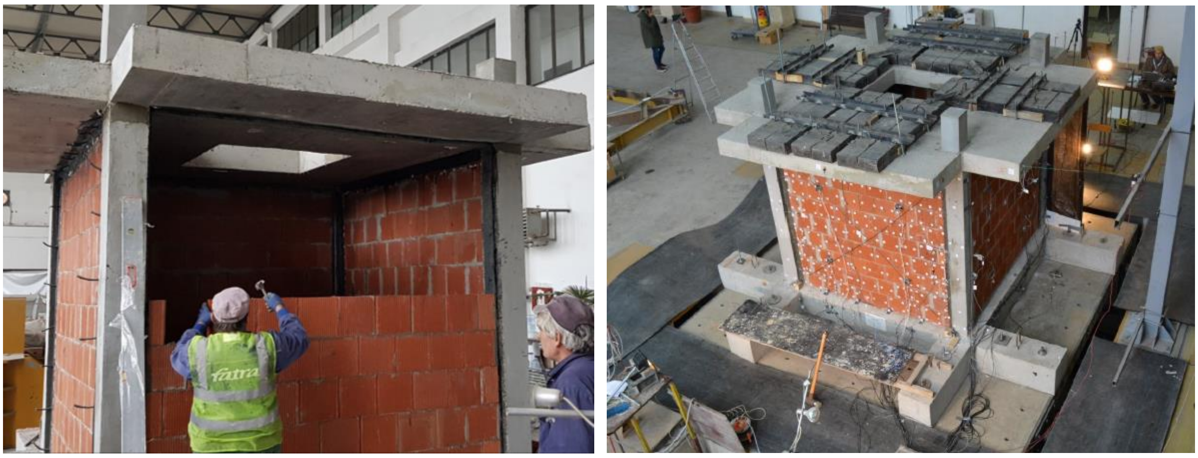

Fig. 11.

Fig. 12.

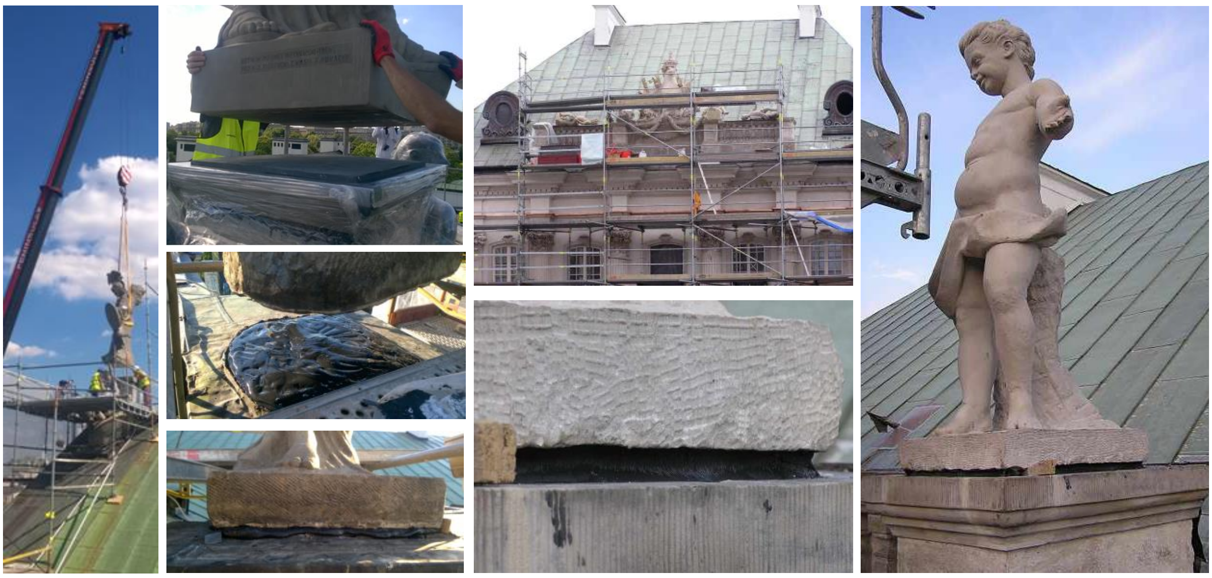

Fig. 13.

The injected and prefabricated PUFJ was examined also practically during fastening of heritage sculptures on palaces roofs in Warsaw. The aim of flexible bonding was protection of stone figures against traffic vibrations destructing them previously. The prefabricated and constructed on side PUFJ have been working properly for 10 years, manifesting their efficiency (Fig. 13).

Composite strengthening systems are effective tools using for improving of structural strength in civil engineering. Typically, stiff adhesives of high strength are used which generates stress concentrations responsible for failure mechanism. The use of more flexible adhesives allows reducing peaks of stress concentrations by redistributing them along the whole bonding area, what results in higher loads carried by the composite strengthening systems. Flexible adhesives allow working even low strength fibers and low strength brittle substrates, introducing larger strength, ductility and bearing capacity, thus making them more safe in exploitation. Digital Image Correlation (DIC) method showed and confirmed that the shear load increase in composite strengthening systems with flexible adhesives (FRPU) is caused by more even stress distribution along the bonding length than in stiff and brittle mineral adhesives (Fig. 14). It was confirmed also by shear tests of composites fixed to weak Italian bricks using epoxy resin and polyurethane PS (FRPU)adhesives. FRPU manifested higher load bearing capacity than the same systems with stiff epoxy adhesives (Fig. 15).

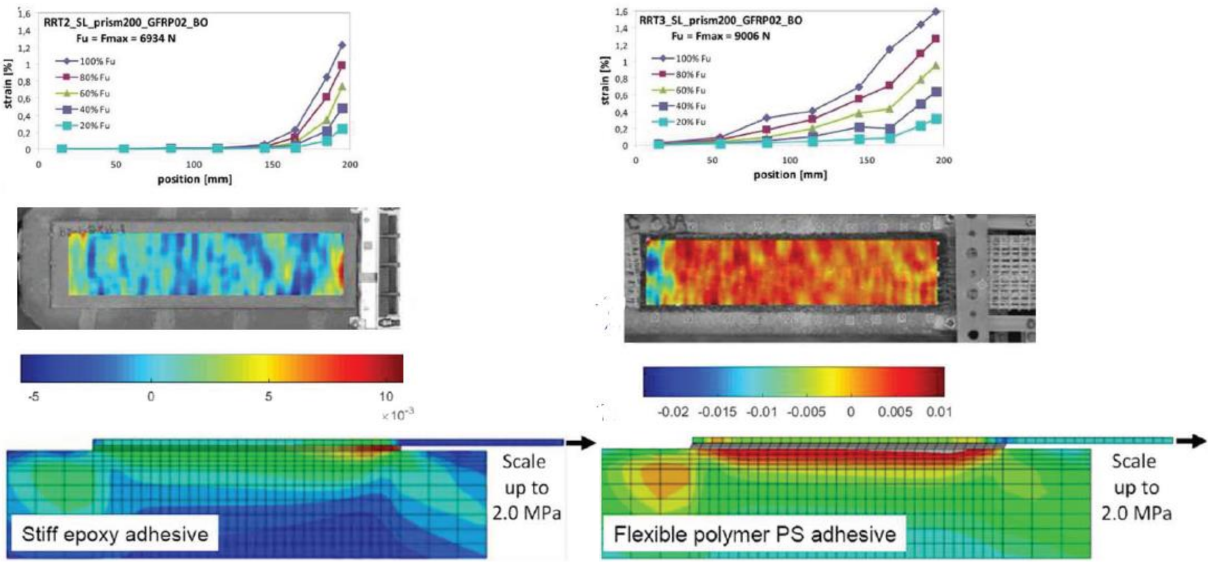

Fig. 14.

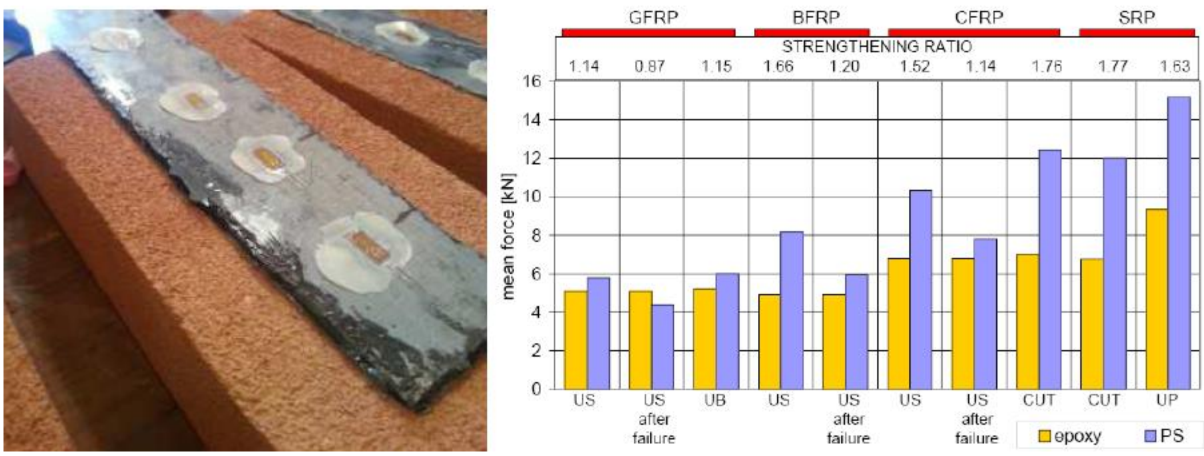

Fig. 15.

Efficiency of FRPU with polyurethane PS adhesive was also examined during laboratory research on large scale masonry specimens. A shear test on a cracked masonry wall (pre-compressed vertically) was carried out using composite strengthening made of four layers of glass fiber grids, fixed to the both surfaces of the masonry (after crack appearance) using polyurethane PS. The composite mats in the form of diagonal bands were fixed without filling the crack, so local destruction of masonry in the crack surrounding (caused by the high level of stress concentrations) was expected. The final damage occurred only in the composite in form of glass fiber rupture, because of very good adhesion of flexible polymer to masonry substrate. Results obtained from the shear tests showed that strength of the repaired masonry specimen exceeds 133% of the original one and increase of the ultimate shear strain was over 12 times and increase of energy dissipation capacity over 16 times (Fig. 16).

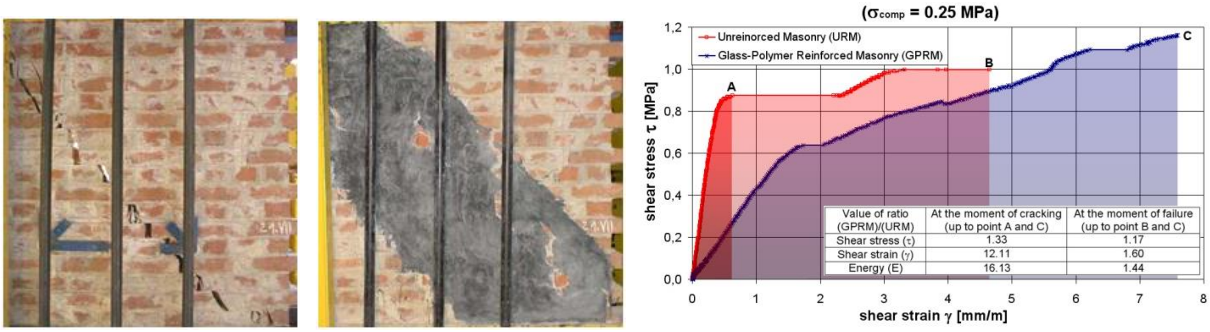

Fig. 16.

Efficiency of FRPU as earthquake protection was tested in laboratory using cyclic shear tests. At the beginning, a masonry wall was damaged by cyclic shear load and then quickly strengthened with a deformable composite system, which consisted of four layers of glass fiber mesh and polyurethane PS adhesive. It was applied on the cracked surfaces of the wall. In this way, a quick emergency repair of a damaged wall during an earthquake was simulated. The strengthened wall was tested up to collapse under shear load increasing cyclically, 23 hours after application of the composite system. Even at collapse, the bond between the coating and the masonry was not lost. The collapse was due to compressive crushing of the masonry, when the bricks were crushed into smaller pieces, and the connection between the outer layers was severed. After repair, the wall's capacity increased with ratios: resistance capacity by 1.29, rotation capacity by 1.61 and hysteretic energy capacity by 1.73. On the contrary, the global stiffness of the wall after quick repair was reduced by about 24% (Fig. 17).

Quick and safe protection of masonry structures just after earthquake, but before aftershock, is a crucial aspect for emergency teams. They require a quick and easy to use strengthening method, which can provide enough strength and ductility properties to the masonry structure weakened by an earthquake. The proposed composite strengthening system fulfils these requirements of earthquake emergency teams.

High efficiency of the FRPU system, consisted of glass mesh and polyurethane PS adhesive was demonstrated during emergency repair of a cracked concrete retaining wall. The soil movement broke this wall, protecting a building founded on an active slope. The applied deformable composite strengthening allowed stopping widely opened and actively increasing cracks in few hours after fastening. Finally, the composite system held back the moving parts of cracked walls, dissipating huge amount of energy – the observed failure mode was in the form of fiber rupture instead of debonding (Fig. 18).

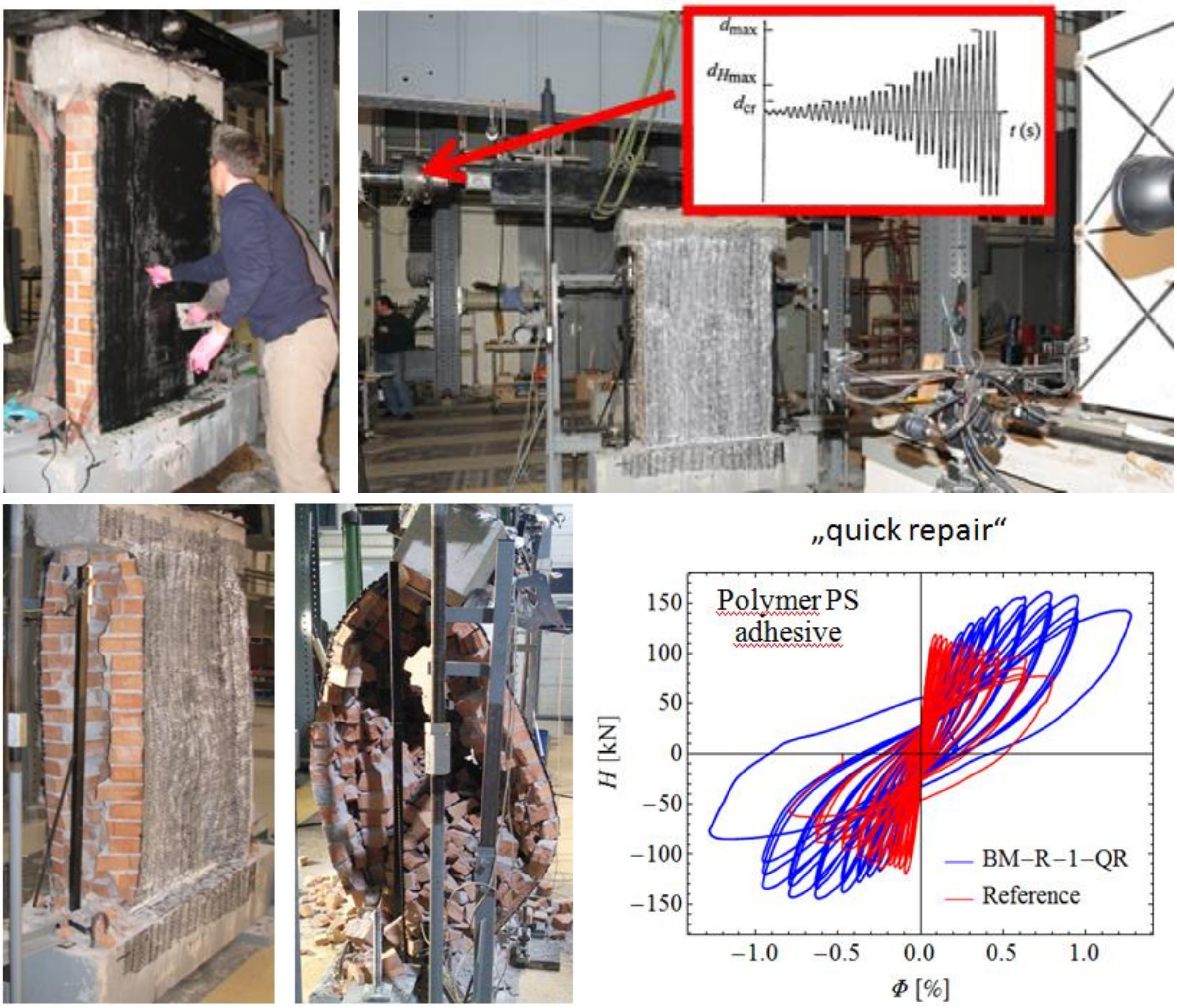
d_{max}
$d_{H\max}$
d_{cr}
t (s)
„quick repair“
Polymer PS adhesive
150
100
50
0
−50
−100
−150
H [kN]
−1.0
−0.5
0.0
0.5
1.0
Φ [%]
BM−R−1−QR
Reference

Fig. 17.

Fig. 18.

FRPU systems were applied also as emergency strengthening of infill walls damaged by seismic vibrations on the shake table. Repeated seismic excitations of high intensity were unable to cause collapse of the infill walls protected by FRPU in in-plane and out-of-plane modes. The building specimen in natural scale with FRPU systems survived many seismic excitations, remaining in good structural shape (Fig. 19).

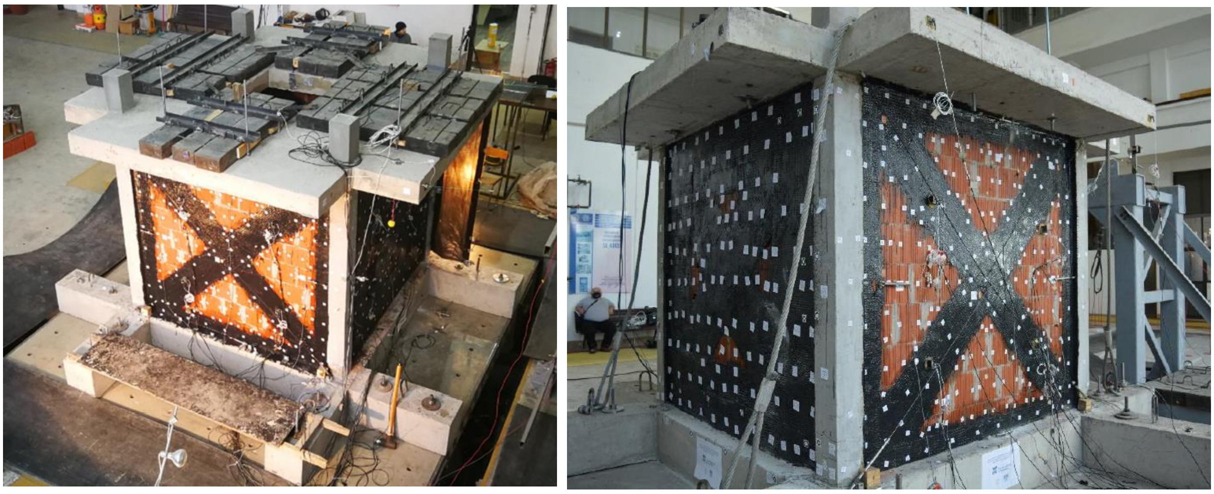

Fig. 19.

What are the overall benefits and/or impacts of using Flex&Robust products?

The PFJ technology (injected and prefabricated PUFJ and FRPU) is a mind braking revolution in construction of envelopes in civil engineering, especially in bonding of structural elements made of concrete, masonry, wood materials and composite strengthening. The carried out tests and practical applications showed that this new joining philosophy can overcome present barriers in civil engineering in frame of construction, repair, strengthening and quick protection of structures. The properly designed PFJ systems can increase structural capacity in the aspects of higher total strength and deformability (ductility). The PFJ systems and their abilities will be used by construction companies in construction of new buildings, retrofitting of damaged buildings and historical structures as well as in other civil engineering structures, where stress concentration occurrence causes reaching capacity limit. Especially, nearly zero energy building (nZEB) market is one of the most promising in cases of envelopes construction. Structural connectors made of PUFJ and FRPU can efficiently join structural and non-structural elements in envelopes, especially, when large deformations are considered caused by seismic and hurricane loads.