VARNOST PASIVNIH HIŠ PRI POTRESU, ZAKLJUČNO POROČILO

SAFETY OF PASSIVE HOUSES SUBJECTED TO EARTHQUAKE, FINAL REPORT

PROJEKT ARRS ŠT. L5-4319, št. pogodbe 1000-11-214319 (2011-2013)

Uvod

Aplikativni raziskovalni projekt ARRS z naslovom "Varnost pasivnih hiš pri potresu" je izhajal iz dveh sicer precej nesorodnih področij, tj. potresna varnost in energijska učinkovitost, ki na evropskih tleh skupaj nastopata precej redko. Ravno v Sloveniji pa se ti dve področji stikujeta, zato prepoznavanje omenjene problematike in začetek raziskav ravno v Sloveniji predstavlja unikatnost oz. specifičnost. Večina Slovenije leži namreč na območju z zmerno potresno ogroženostjo in je za zagotovitev ustrezne mehanske odpornosti in stabilnosti upoštevanje potresnih vplivov zahtevano s predpisi. Število pasivnih hiš oz. energijsko učinkovitih stavb v Sloveniji hitro narašča. Pri tem se za zdaj uporabljajo rešitve konstrukcijskih detajlov za preprečevanje toplotnih mostov, ki so bile razvite in širše uporabljane predvsem na področjih z nizko seizmičnostjo, kjer ni pričakovati močnih potresov in je zato kontrola le-teh samo na statično vertikalno obtežbo zadostna. Na seizmičnih področjih pa je treba zagotoviti tudi ustrezno odpornost na dinamično potresno obtežbo.

Poročilo sestoji iz skupnega dela, ki opisuje potek in dosežke dela na projektu in petih individualnih delov, ki opisujejo delo udeleženca posameznika v zaključni fazi projekta. Poročilo o delu na projektu v prvi fazi je bilo objavljeno v številki 2012/1 revije AR. Individualni prispevki predloženega zaključnega poročila vključujejo:

1) Toplotna izolacija pod temelji (Martina Zbašnik-Senegačnik)
2) Izvedba "seizmične blazine" pod temeljno ploščo (Tomaž Slak)
3) Obnašanje XPS pri tlačni in strižni obremenitvi (Vojko Kilar)
4) Preiskave trenja izbranih sklopov iz XPS (David Koren)
5) Potresni odziv stavb na XPS: parametrična študija (Boris Azinović)

Ključne besede

Pasivna hiša, toplotna izolacija, potresna varnost, konstrukcije, zdrs.

Doseženi cilji in rezultati raziskovalnega projekta

Glavni namen projekta je bil raziskati, do kakšne mere in v katerih primerih je gradnja stavb z znanimi detajli za preprečevanje toplotnih mostov lahko na potresno aktivnih območjih nevarna in kako se tej nevarnosti izogniti z ustreznim arhitekturnim projektiranjem ter uvedbo dodatnih ukrepov za zagotavljanje odpornosti na potresno obtežbo. V ta namen je bila izvedena široka (parametrična) analiza seizmičnega obnašanja stavb s toplotno izolacijo (TI) pod temeljeno ploščo. Analizirani so bili numerični modeli stavb različnih višin, tlorisnih dimenzij, mas, nosilnosti, duktilnosti, z različnim histereznim obnašanjem,

Introduction

The topic researched within the applied project. "Safety of passive houses subjected to earthquake" stemmed from two otherwise quite unrelated fields, i.e. seismic resistance and energy efficiency that in European countries do not frequently appear together. Just in Slovenia these two fields join each other, so identifying the problem and establishment of research right in Slovenia represents uniqueness and specificity. The majority of Slovenia is situated in area of moderate seismic risk. In order to ensure adequate mechanical resistance and stability of structures constructed in such area, the consideration of seismic effects is required by law. In Slovenia the number of passive houses and energy efficient buildings increases rapidly. However, for the time being the structural solutions that have been developed and broadly applied mainly in the areas with low seismicity (where the structural control to vertical static loads is sufficient) are used. In earthquake-prone areas also adequate resistance to dynamic seismic effects have to be assured.

The report contains general part in which the course and achievements of the project are described and five contributions of individual researcher about his/her work in the final stage of the project. Description of the work done in the initial phase of the project has been reported in volume 2012/1 of the journal AR. Individual contributions of the submitted report are as follows:

1) Thermal insulation under foundation (Martina Zbašnik-Senegačnik)
2) Application of "Seismic pillow" under foundation slab (Tomaž Slak)
3) Behaviour of XPS under compressive and shear load (Vojko Kilar)
4) Sliding resistance of XPS foundation sets (David Koren)
5) Parametric seismic study of buildings on XPS (Boris Azinović)

Key words

Passive house, thermal insulation, seismic resistance, structures, sliding.

Achieved project's aims and results

The main aim of the project was to study how and in which cases the construction of low-energy buildings with common details which prevent thermal bridges, might be dangerous in earthquake-prone areas. The question is how to improve their seismic resistance by appropriate architectural design applying energy efficient details with sufficient structural behaviour in the case of earthquake load. For this purpose an extensive parametric study of the seismic response of buildings founded on a thermal insulation (TI) layer was performed. Numerical models of buildings of different height, with different floor plan dimensions, mass, strength, ductility, and

temeljenih na TI slojih različnih trdnosti in debelin (prispevek B. Azinovića).

Dodaten dosežek projekta je priprava in izvedba raziskav obnašanja plošč iz ekstrudiranega polistirena (XPS) proizvajalca Fibran Nord d.o.o. (sofinancer projekta), ki se lahko uporabljajo kot TI pod temeljno ploščo. Teste smo izvedli v Konstrukcijsko-prometnem laboratoriju na Fakulteti za gradbeništvo in geodezijo v Ljubljani pod vodstvom izr. prof. dr. Violete Bokan-Bosiljkov. Na osnovi monotonih in cikličnih ter strižnih in tlačnih preiskav smo pridobili osnovne podatke (prispevek V. Kilarja), s katerimi smo lahko izvajali računalniške simulacije obnašanja pasivnih hiš med potresi. Dodatno so bile opravljene tudi nestandardizirane preiskave trenja na sklopih sestavljenih iz XPS plošč in betonske plošče, v izbranih primerih pa še iz hidroizolacije ali polietilenske folije (prispevek D. Korena).

Izvedene numerične analize seizmičnega odziva stavb so pokazale, da pri manjših (npr. enodružinskih) hišah temeljenje na TI pod ploščo konstrukcijsko ni vprašljivo, še posebej, če je stavba podkletena in zasuta z zemljo. Drugače pa je lahko pri višjih/težjih/vitkejših nepodkletenih ali od kleti ločenih objektih, grajenih na potresnih območjih, na katere lahko ima potres večji vpliv. Z vgradnjo mehkih slojev TI pod temeljno ploščo spremenimo dinamične karakteristike stavbe in je zato potrebno paziti predvsem na naslednje:

- Pri močnem potresu lahko pride do poškodb (stiskanja) TI pod ploščo in posledično do zmanjšanja toplotnih karakteristik izolacije in nagibanja objekta. S statičnim računom je potrebno zagotoviti, da zaradi nihanja stavbe med potresom niso prekoračene projektne tlačne in projektne strižne napetosti in/ali deformacije v TI pod temeljno ploščo.
- *Pri močnem potresu lahko zaradi drugačnega nihanja stavbe na mehki toplotnoizolacijski podlagi v nekaterih primerih pride do povečanja potresnih vplivov na zgornjo konstrukcijo. S statičnim računom je potrebno preveriti, kakšna so mogoča povečanja obremenitev, in zgornjo konstrukcijo projektirati z zadostno nosilnostjo. Paziti je treba tudi, da ni prekoračen največji dopustni horizontalni pomik na vrhu stavbe, saj je lahko ta zaradi zibanja objekta na TI precej večji kot pa pri stavbi, temeljeni na togih tleh.*

Za obnašanje stavbe so najbolj pomembni togost, nosilnost in duktilnost zgornje konstrukcije ter materialne karakteristike TI podlage (tlačna in strižna nosilnost/togost).

Najpomembnejše ugotovitve ZA KONSTRUKCIJO so:

- Nihajni čas konstrukcije se z vgradnjo toplotnoizolacijske podlage pod temeljno ploščo podaljša in se lahko premakne v resonančni del spektra, kjer so potresne sile največje. Posledično so lahko presežene projektne vrednosti napetosti v konstrukcijskih elementih (stebri, grede, stene, spoji) ali etažnih zamikov zgornje konstrukcije.
- V primerih močnega potresnega vzbujanja so lahko preseženi tudi največji dopustni horizontalni pomiki vrha stavbe, ki nastanejo kot posledica zasuka objekta (zibanja) na podajni TI.
- Ozke in visoke stavbe ali stavbe z večjimi nepravilnostmi po višini niso primerne za temeljenje na TI podlagi, saj lahko pride do globalnih nestabilnosti, nagibanja ali prevrnitve objekta.

with different hysteretic behaviour, founded on TI layers of different strength and thickness have been analysed (contribution of B. Azinović).

An important project's achievement is also the design and execution of the experimental tests on the behaviour of the extruded polystyrene (XPS) boards for the application beneath the foundations. The specimens produced by the project's co-funder company Fibran Nord d.o.o. were tested. The tests were carried out in the testing Laboratory of Civil and Geodetic Engineering Faculty at the University of Ljubljana and conducted by assoc. prof. dr. Violeta Bokan-Bosiljkov (UL FGG). Based on the XPS characteristics evaluated by static monotonic or cyclic shear and compressive tests (contribution of V. Kilar) the data necessary to perform numerical simulations of the passive buildings' seismic response were obtained. Additionally, non-standardised tests were carried out in order to estimate the coefficients of friction between the different constituent elements (XPS, concrete, waterproofing or polyethylene sheet) in TI foundation set (contribution of D. Koren).

The results of the performed seismic analyses have shown that in the case of smaller (e.g. single-family) houses the insertion of a layer of TI beneath the foundation slab is not of critical concern from the structural point of view, especially if the house has embedded basement. Oppositely, in the case of higher/heavier/slenderer buildings without basement built in earthquake-prone areas the negative effects of creating foundations on a TI layer might be expected during earthquakes.

Since the insertion of a layer of TI beneath the foundation slab of buildings could change the latter's dynamic characteristics, the following issues should be appropriately addressed:

- *In the case of stronger seismic excitation the TI layer under foundation slab might suffer undesirable damage (compressive deformations) and consequently its thermal efficiency could deteriorate and the building might sway. Thus, the designers of multi-storey buildings founded on the TI layer have to pay additional attention to the compressive and shear stresses and/or deformations in the TI in order to ensure that their design values are not exceeded.*
- *As a consequence of changed fundamental mode/period of vibration the stronger seismic excitation in some cases might cause increased seismic effects on the upper structure building, leading to undesirable damage of the structure or its non-structural elements. Thus, the designers of multi-storey buildings founded on the TI layer have to ensure sufficient strength of the superstructure. Additional control should be made to the horizontal top (roof) displacement of the building which is a consequence of the vertical deformability of the TI and the building's rotations and could be substantially larger than in the case of the fixed based structure (without TI beneath foundations).*

The essential parameters for the seismic behaviour of the buildings on TI are stiffness, strength and ductility of the superstructure and the material characteristics of the TI layer (compressive and shear strength/stiffness).

The main findings related to the SUPERSTRUCTURE are:

- *By inserting the flexible layers of TI between the reinforced concrete (RC) foundation slab and the layer of blinding concrete on the ground, the fundamental period of the structure will be prolonged and might be moved into the resonance part of the design response spectrum (into the period range of constant accelerations) where the seismic*

Najpomembnejše ugotovitve ZA TOPLOTNO IZOLACIJO POD TEMELJNO PLOŠČO so:

- Pri stavbah na TI pod temeljno ploščo lahko pri močnejšem potresnem vzbujanju pride do prekoračitve tlačnih trdnosti v TI. Do tega lahko pride že pri trietažnih stavbah (t. j. P + 2E ali P + E + M na XPS 400). Pri stavbah z dvema etažama do tega ni prišlo v nobenem od analiziranih primerov. V primeru težjih, vitkejših in višjih stavb je torej bolj priporočljivo uporabljati TI višjega tlačnega razreda.
- Kontrola največjih strižnih napetosti in največjih horizontalnih pomikov TI ni bila problematična.
- V določenih primerih lahko pride tudi do horizontalnega zdrsa na stiku temeljna plošča – TI ali pa na stiku med posameznimi sloji TI (če je ta dvo- ali več-slojna). Nastop zdrsa je odvisen od koeficienta lepenja, ki po rezultatih meritev znaša približno 0.6 za stik XPS – XPS, 0.5 za stik XPS – beton in približno 0.3 za stik XPS – hidroizolacija (nelepljiva).

Sodelavci/ Participants

Vojko Kilar (vodja projekta), Martina Zbašnik-Senegačnik, David Koren, Tomaž Slak, Tadeja Zupančič, Lucija Ažman-Momirski, Simon Petrovčič, Srečko Vratuša, Edo Wallner, Boris Azinović – mladi raziskovalec (vsi UL-FA) / young researchers (UL-FA)

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forces acting on the structure are the largest. Such an increase could lead to exceedance of the superstructure's design strength or deformation capacity values.

- *In the case of stronger seismic excitation the allowable value of the building's horizontal top (roof) displacement which is a consequence of the building's rotations could be exceeded.*
- *Narrow and high buildings and/or buildings with irregularities in height should not be founded on TI layers otherwise it might cause structure's global instabilities, inclinations or even overturning problems.*

The main findings related to the THERMAL INSULATION LAYER BENEATH THE FOUNDATINON SLAB are:

- *In the case of stronger seismic excitation the maximum compressive stresses in the TI layer could exceed the TI nominal compressive strengths. In the investigated cases such occurrences were detected already in the cases of buildings (founded on XPS400) with more than two or three storeys. In all analysed two-storeyed building models the compressive strength in the XPS was never reached. In the case of heavier, slenderer and higher buildings the use of TI of higher compressive strength class is recommended.*
- *The control of maximum shear stresses and maximum horizontal displacements of the TI has not revealed to be of critical concern.*
- *In some cases the friction capacity between the TI layers (if TI is two- or multi-layered) could be exceeded and sliding might occur. The capacity depends on the coefficient of friction of the used contact surfaces. Experimentally evaluated values are equal to approximately 0.6 for the contact XPS – XPS, 0.5 for the contact XPS – concrete and 0.3 for the contact XPS – waterproofing layer (without adhesive).*

Rezultati / Results

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