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First Implementation of the Original Concept for Base Isolation of Residential Houses Unified by One Reinforced Concrete Slab

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ABSTRACT

In 2018 the original concept for base isolation of four residential houses unified by one reinforced concrete slab was proposed by the author of this paper [1]. It was shown that proposed new solution gives a possibility to significantly (about two times) reduce the number of seismic isolation laminated rubber-steel bearings (SILRSBs) in comparison with the known ways of creation of base isolation systems. The given paper presents the first practical implementation of the proposed original concept for base isolation of two 3-story residential private houses unified by one rigid reinforced concrete (R/C) slab. Details of the developed structural solution are described, as well as stages of implementation of this new concept in construction site are illustrated. The paper also briefly describes an architectural solution developed based on the proposed concept, but mainly it focused on the construction process of two residential houses with load-bearing walls located on mentioned R/C rigid slab supported by SILRSBs. The space below this slab is used as the basement/parking/technical floors. All the structural elements under the level of SILRSBs are designed as the R/C lower pedestals and shear walls. Thanks to the proposed new solution only 12 SILRSBs were used in construction of two base isolated houses.

INTRODUCTION

Seismic isolation technologies are well developed and widely implemented in Armenia due to research and design works of the author of this paper, who had started his activities on these systems in 1993. Due to his efforts 56 buildings and structures have been designed with application of base or roof isolation systems. Of these designed buildings, the total number of already constructed and retrofitted buildings has reached 48 (Fig. 1).

Seismic isolation of structures should be currently considered as common and most effective method of providing protection from earthquake damage, high reliability of buildings and increasing of the quality of human lives. Some of the already implemented projects are shown in Table 1. The fact deserving attention is that number of seismically isolated buildings per capita in Armenia is one of the highest in the world. This is also confirmed in [16]: "Armenia … remains second, at worldwide level, for the number of applications of such devices per number of residents, in spite of the fact that it is a still developing country".

Usually for each of seismic isolated buildings their structures of base isolation are located exactly within the limits of the buildings' plans. In the case described in [1] for the first time a new and original concept for base isolation of four residential houses unified by one rigid R/C slab was suggested and developed (Fig. 2), and the rigid slab in its turn provided with the base isolation system. In this case there is no need to locate the SILRSBs exactly under the load-bearing walls of each building.

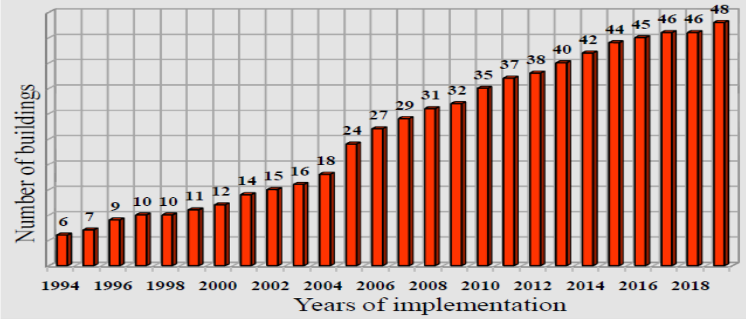
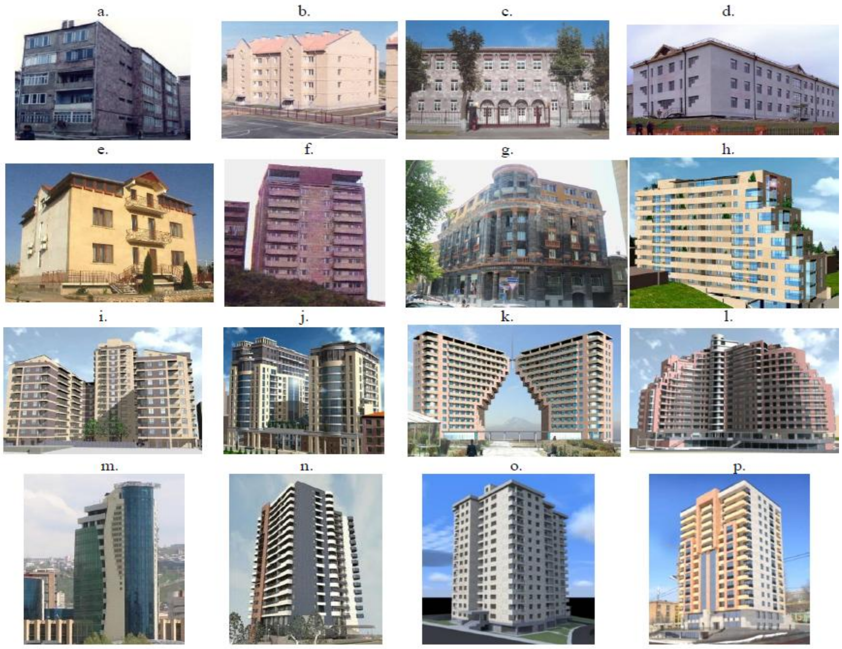


Figure1. *Number of seismic (base and roof) isolated buildings, newly constructed or retrofitted in Armenia by years*

Figure2. *Design views of four 3-story private houses with stone load-bearing walls to be constructed on one large base isolated rigid R/C slab*

Table1. *Views of some retrofitted and newly constructed buildings in Armenia using seismic isolation systems*



a - 5-story existing stone apartment building retrofitted by base isolation for the first time in the world without interruption of the use of the building [2,3],

b - 4-story base isolated apartment building with reinforced masonry bearing walls in Huntsman Village [4],

c - 3-story existing stone school building retrofitted by base isolation without interruption of the use of the building [5],

d - 3-story base isolated clinic building [5],

e - 3-story base isolated private house with stone bearing walls and dynamic damper at the level of isolation system [7], *f* - *9-story existing roof isolated apartment building protected by means of an isolated upper floor [8],*

g - *6-story base isolated hotel/commercial centre building [4],*

h - *11-story base isolated building of the multifunctional residential complex "Cascade" [9],*

i - *16- and 10-story base isolated buildings of the multifunctional residential complex "Our Yard" [10],*

j - *16- and 14-story base isolated buildings of the multifunctional residential complex "Arami" [4],*

k - *18-story base isolated buildings of the multifunctional residential complex "Northern Ray" [11],*

l - *16- and 13-story base isolated buildings of the multifunctional residential complex "Dzorap"[4],*

m - *20-story base isolated business centre "Elite Plaza" [12],*

n - *17-story base isolated building of the multifunctional residential complex "Baghramian" [13],*

o - *17-story base isolated building of the multifunctional residential complex "Avan" [14],*

p - *15-story base isolated building of the multifunctional residential complex "Sevak"[15],*

Buildings "d", and from "f" to "p" have the structural system with R/C bearing frames and shear walls

Similar concept was suggested earlier in [4] (see Table 1 item "j") and in [17]. But in those structural solutions each of the SILRSBs in the seismic isolation systems is located right between the bearing structures below and above it. In contrast to this approach the author proposed an idea when a large R/C rigid slab is supported by SILRSBs and the distance between them in longitudinal and transverse directions may differ (can be much bigger) than the distance between the bearing structures of the buildings to be constructed on this slab. The designed buildings are the private houses and besides the ground (parking/basement/technical) floor each of them has two living floors and an attic. In fact, this proposal/idea has a far going purpose of its application in considerably bigger complexes.

Architectural Solution Developed Based on the Proposed Concept

To initiate the practical implementation of the proposed original concept first of all an architectural solution was developed in the form of a 3-story structure, which include two houses unified by one R/C seismically isolated rigid slab. Overall dimensions of the designed structure are 19.5×11.0 m. There is only one mutual wall along the height of this structure, which is dividing it in two separate private houses. Each of them has its separate entrance to the ground floor (Fig. 3), as well as to the living areas (Fig. 4 and 5).

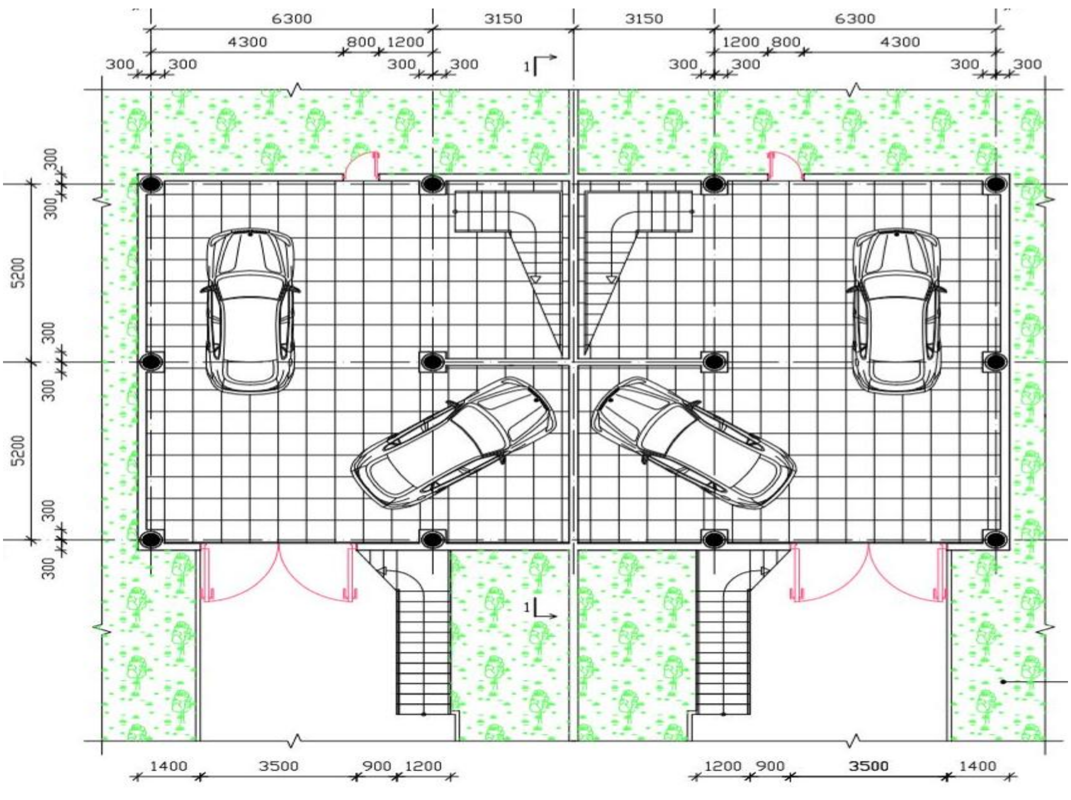


Figure3. *Plan of the ground (parking/basement/technical) floor*

From the given figures one can see that people can enter the living areas using provided outside stairs, as well as the stairs envisaged inside of the ground floors. There are doors in these ground floors leading directly to the gardens. From the level of the first (living) floors there are stairs to the second (living) floors and then from these floors the provided stairs allow to reach the attic. The total area of each house in this project equals to 447 sq. m. Designed architectural view of the two base isolated 3-story residential private houses unified by one rigid R/C slab is shown in Figure 6.

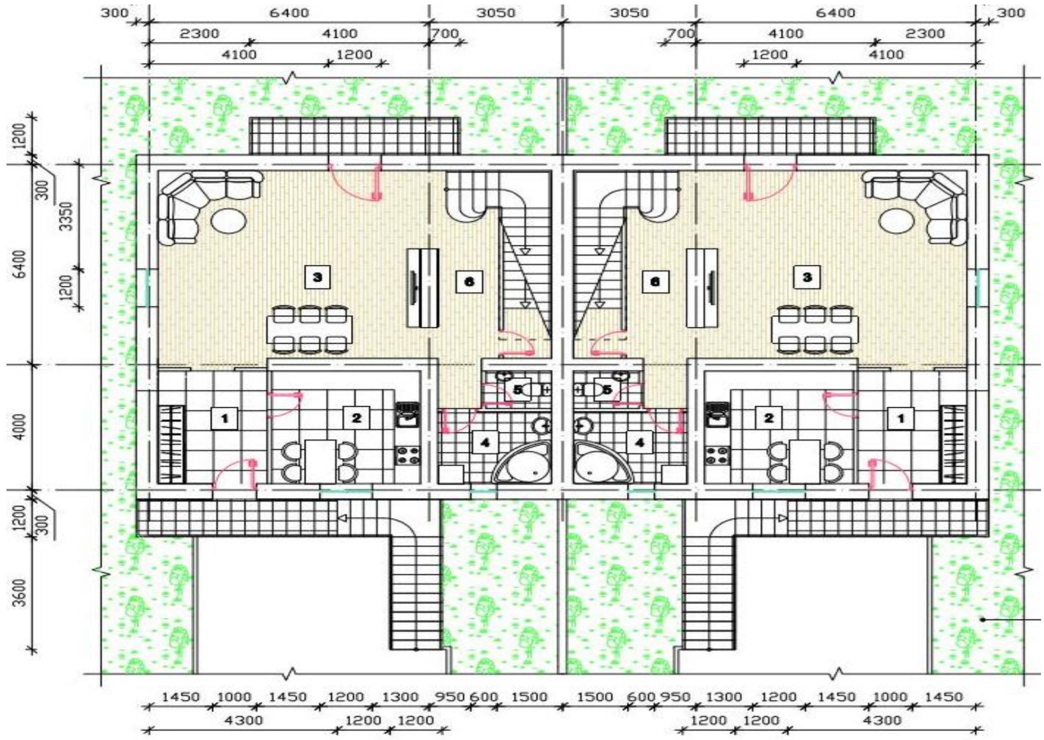


Figure4. *Plan of the first floor with living room and the kitchen in each house*

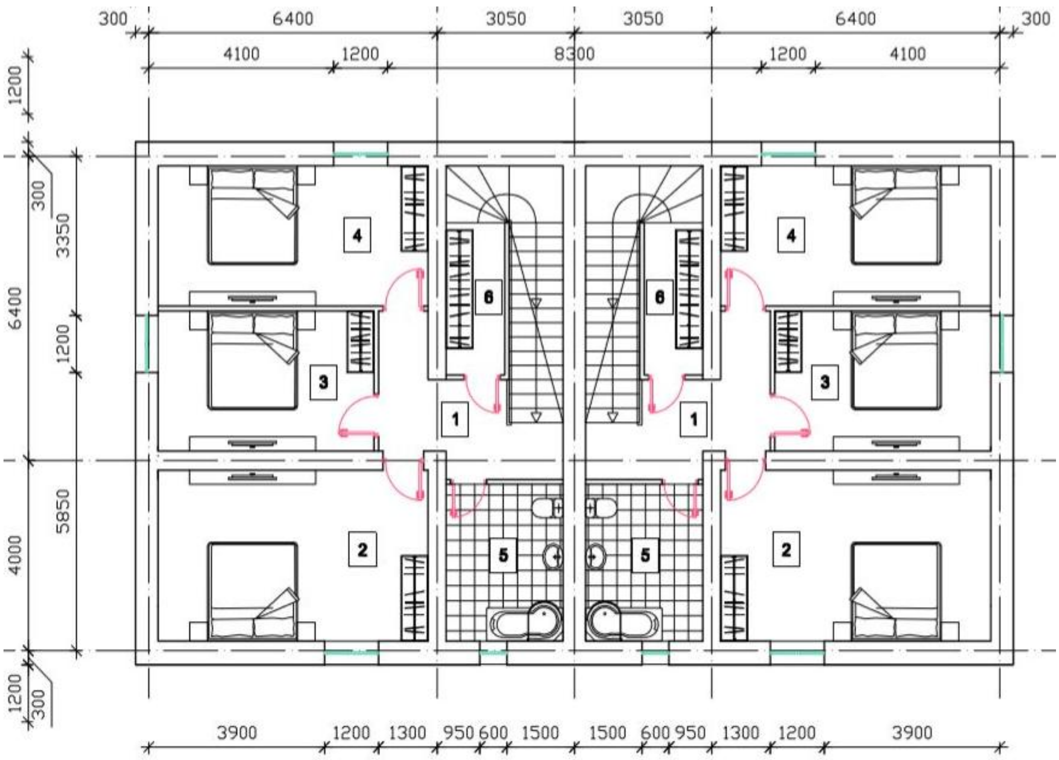


Figure5. *Plan of the second floor with three bedrooms in each house*

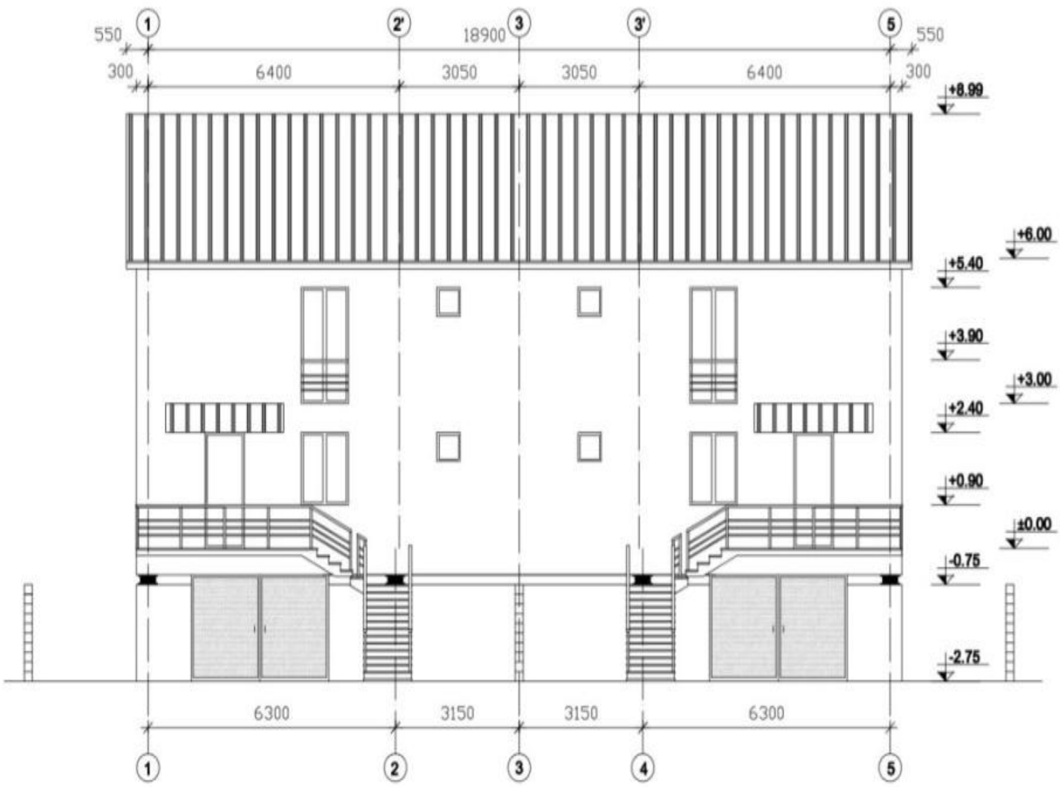


Figure6. *Designed architectural view of the two base isolated 3-story residential private houses unified by one rigid R/C slab*

STRUCTURAL SOLUTION DEVELOPED BASED ON THE PROPOSED CONCEPT

Foundations in the considered complex are designed as R/C spread footings with dimensions in plan equal to 800×800 mm and the height – 400 mm connected to each other by the R/C continuous beams with the cross-section of 500×400(h) mm. Above all spread footings the seismic isolators' lower pedestals are envisaged with the cross-section of 600×600 mm and the height – 2.1 m and they connected by the 200 mm thick shear walls as shown in Figure 3. Consequently, the given structural concept provides the possibility to create a needed rigid system below the seismic isolation interface. Figure 7 shows reinforcement frames of the lower pedestals and the continuous beams.

Figure7. *Reinforcement frames of the lower pedestals and the continuous beams before installation of the shearwalls' reinforcement*

Before casting the concrete of these beams the installation of the shear walls' reinforcement frames should be finished. Then the foundation beams can be concreted forming a horizontal system with the required stiffness (Fig. 8).

Figure8. *View of the concreted foundation and the reinforcement frames of the lower pedestals and the shear walls*

On the top of each lower pedestal the installation of the SILRSBs' lower sockets is envisaged (Fig. 9). Generally, the SILRSBs are located by upper and lower recesses provided by annular steel rings bolted to outer steel plates which are connected to the reinforcement in the lower and upper pedestal; the isolators themselves are not bolted to the structure [2, 3, 4]. This method of connection helps to minimize the cost of the SILRSBs themselves and simplifies their installation on site. Characteristics of the SILRSBs used in this project can be found in [1]. It is very important to provide strictly horizontal position of every lower socket and to make sure that all the 12 sockets are in the same horizontal plane. This stage of the construction works is finished when all the lower pedestals and shear walls are concreted (Fig.10).

Figure9. *View of the lower socket on top of the lower pedestal for location of SILRSB*

Figure10. *Views of the concreted shear walls, lower pedestal and of SILRSBs' lower sockets on top of them*

The next stage starts with installation the SILRSBs in their lower sockets and then placement of the upper sockets on them (Fig. 11). Together with the placement of the upper sockets the reinforcement frames of upper pedestals must be prepared and installed as shown in Figure 12. The upper pedestals are envisaged with the cross-section of 600×600 mm and the height – 500 mm. When the reinforcement frames of upper pedestals are placed on all the 12 SILRSBs, then the rigid structure between the marks -0.55 m and -0.05 m is going to be constructed. This structure consists of R/C beams and a slab. Beams have cross-section 350×500(h) mm and the thickness of slab equals to 120 mm. Figure 13 shows a fragment of reinforcement frames of beams; their reinforcing bars are passing through the reinforcement frames of upper pedestals.

Figure11. *SILRSBs are installed in lower sockets and then the upper sockets are placed*

Figure12. *View of the reinforcement frames of upper pedestals*

Figure13. *Reinforcement frames of beams are installed and passing through the reinforcement frames of upper pedestals*

Thus, thanks to the anchor rods to which the steel rings of the lower and upper sockets are bolted, these elements are reliably connected to the lower and upper pedestals, respectively (Fig. 14). Geometrical dimensions of the SILRSBs are given in Figure 15, from which it can be noticed that their height is equal to 202.5 mm. This means that installed SILRSBs are forming the gap of the seismic isolation interface which is needed for its free movement during the earthquake impact. As the thickness of the recess rings of the lower and upper sockets is equal to 20 mm, then the total height of each SILRSB between the rings of the sockets will be equal to 162-163 mm. Exactly this height is conditioning the shear deformations of SILRSBs under the action of the horizontal seismic forces.

Figure14. *View of the SILRSB installed in the lower and upper sockets between the lower and upper pedestals at the corner of the building*

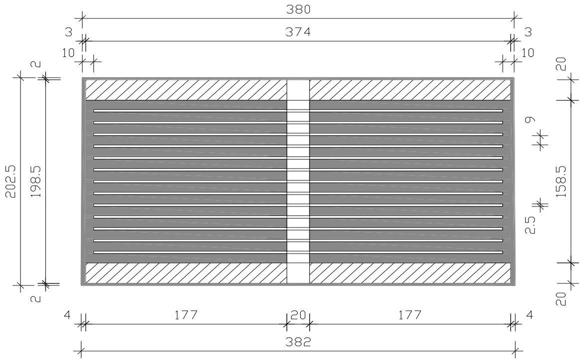


Figure15. *Geometrical dimensions of the SILRSBs used in the described project*

Then above the mentioned interface the rigid R/C slab, which unifies the two 3-story residential houses is going to be constructed at the upper level of the described beams. Some fragments of its construction process before and after casting the concrete are shown in Figure16.

Figure16. *Fragments of the reinforcement of R/C slab and their views after casting the concrete*

From the above given information, it is easy to notice that the distance between the SILRSBs in longitudinal and transverse directions is bigger than the distance between the load-bearing walls of the residential floors. Two houses have only one mutual interior wall with the thickness of 500 mm, and each of the houses has three exterior walls also 500 mm thick. Interior load-bearing walls are 400 mm thick. All walls are made of tuff stones. The second and third floors' R/C slabs also have thickness equal to 120 mm and the height of these floors is equal to 3.0 m.

At the design stage special attention needs to be paid to the stairs leading from the ground floors to the first (living) floors of each building. These are inside and outside double-flight stairs which have the gaps within their structure permitting to separate them at the level of seismic isolation interface (in fact the gaps between the substructure and superstructure). Thus, like the main gap of seismic isolation system, provided gaps within the stairs are also giving the possibility for free movement of superstructure related to the substructure without causing any damage to the stairs. As an example, the already constructed outside stairs with the provided gap are shown in Figure 17.

It is obvious that if each of the buildings in this complex would be constructed separately then at least nine SILRSBs would be needed to create its seismic isolation system. This means that for two of such separate buildings the total number of the needed SILRSBs will be equal to 18. But in the proposed solution only 12 SILRSBs are used.

Figure17. *Views of the outside double-flight stairs leading from ground level to the first living floor of one of the residential houses; the seismic isolation system, the main gap around the perimeter of the ground floor and the gap in the double-flight stairs*

Conclusions

- First practical implementation of the earlier suggested and developed new and original concept for base isolation of residential houses unified by one rigid R/C slab, which rests on the SILRSBs, is described.
- Architectural and structural solutions of two 3-story buildings currently under construction are illustrated by drawings and photos explaining details of the proposed idea.
- Using the feature of the proposed approach that allows increasing the distance between the SILRSBs under the rigid R/C slab in longitudinal and transverse directions in comparison with the distance between the bearing elements of the superstructure, the number of SILRSBs could be significantly reduced.
- In comparison with the usual way of creation of base isolation systems the proposed idea leads to the more flexible architectural solutions and to obtaining of the larger spaces in the ground floors, which can be used as the basement/parking/technical floors.

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