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Conception of low-rise earthquake-resistant energy-efficient buildings

Y V Shefer[1], B S Ordobaev[2], S V Romanenko[3], O A Antonevich[4]

[1] Graduate, Tomsk Polytechnic University, Tomsk, Russia
[2] Head of Department, Kyrgyz-Russian Slavic University, Bishkek, Kyrgyzstan
[3] Head of Department, Tomsk Polytechnic University, Tomsk, Russia
[4] Associate Professor, Tomsk Polytechnic University, Tomsk, Russia
E-mail: yuri@shefer.ru

Abstract. The article proposes a new earthquake-resistant technology of low-rise building with increased energy efficiency and long-life operation. The proposed solution allows to build low-rise buildings with increased resistance to natural and man-made disasters. The building is frame (made of tube-concrete) and also completely monolithic, where foundation, all walls, floors and roof are filled of polystirolconcrete (composed of concrete and polystyrene), which forms a monolithic construction.

1. Introduction

There is a need to build buildings and constructions in seismic areas in many regions of the world. The sad experience of the past, devastating earthquakes and analysis of their effects revealed that the problem of reliable seismic protection of citizens and their homes still has not been solved.

It is seen from the analysis of the reports on the effects of strong earthquakes [1] that earthquake-resistant buildings, designed in strict accordance with the local regulations, in many cases were destroyed even under the "non-hazardous" seismic load level, which is lower than the calculated level.

In this case, it is definitely found out that in columns and walls of low-rise buildings all official seismic norms always decreases the real level of seismic stresses it many times, as well as significantly understates the real level of seismic stress and overestimates their actual seismic resistance. For example, according to official standards, these buildings have a wide margin to withstand a 10-point earthquake (by MSK-64 scale). But there are cases of their destruction in reality. This drawback of seismic norms can not be corrected, as it is a direct consequence of the basic postulates of the official theory of the direct dependence of seismic stresses in columns and walls on ranking building mass.

Seismic building codes in some cases increase the level of seismic risk for the population. For example, it is well known that buildings with walls made of bearing materials can not take expending stress (i.e., brick, stone, etc.). As a rule, they are destroyed at 9 magnitude earthquake. However, none of the normative document prohibits construction of such buildings. The main and the only argument is that the "vibrational" doctrine of seismic damage is globally accepted.

2. Experimental part and Discussion

Our research has shown that a devastating earthquake regularly raises a lot of facts and phenomena that can not possibly be caused by low-frequency vibrations and which can not be explained on the basis of the official "vibrational" model of seismic damage to buildings. For example, the low-frequency seismic ground oscillation must cause fractures of reinforced concrete columns near their clamped ends with formation of flexural plastic hinges in frame buildings. However, in reality, instead of it reinforced concrete columns only cut by a skew cracks in the span of the column at a distance from their ends always arises. It should be emphasized that for flexible reinforced concrete columns as for any flexible rod elements on quasi-static loads occurs only bending destruction with their break.

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This is confirmed by numerous experiments on simulating the vibrational seismic impact on the model of frame buildings [2,3].

Earthquake-resistant buildings should not only withstand a major earthquake once, save lives, but to be able to function in the future and continue to withstand new tremors without damaging bearing and life supporting systems. We propose to combine the best native and international construction technology. Such construction technology is based on the construction of framework with tube-concrete and technology of monolithic polystyrene concrete pouring.

First articles on the use of tube-concrete were published in the USSR in 1932 by Professor A.A. Gvozdev on the method of calculation on tube-concrete as construction. However, this technology got a large spread of abroad in the United States, Japan, China, the United Arab Emirates. Tube-concrete columns from steel pipes of rectangular cross-section, filled with concrete are able to withstand considerable horizontal shear stress, which makes them indispensable in earthquake-prone areas.

The essence of the proposed concept is the following: the construction of a 'floating' building frame from tube-concrete with the possibility of nearly any layout and floor height. The building at the same time must consist of at least two frames.

Technical challenge was to increase the energy efficiency of buildings, exceeding the requirements of the regulations; increase structural strength, allowing the construction of multi-storey buildings; reduce the cost of construction.

The solution of this problem is provided by the fact that the building, (Figure1) containing the foundation, walls, building frame, floors overlap, formwork sheets the space between them is filled with light concrete. Walls contain two rigid frames: an inner frame consisting of columns, linked with girth rail with fixed roll-formed profile, which rests on the foundation and is the supporting framework of the building in its lower part. And at a distance of 0.1 to 1 meter from the inner frame light frame of the building is made, fastened, if necessary, with an internal temporal frame locks as filling with light concrete. Interfloor overlaps of building are made of interfloor girth rail fixed to the inner frame with girth rail. All components are equipped with roll-formed profile in such a way that after sheathing with formwork sheets they form a single formwork space of walls and floor overlaps.

Columns, floor girth rail and an outer frame on the upper floor of the inner frame are fixed on a formwork sheets and may be formed as mansard roof. Bearing structures can be used as a foundation of earlier constructed or rehabilitated buildings

Columns, girth rails of inner frame and beams can be made of steel tube of square and / or rectangular cross-section. If it is necessary to increase the load-carrying capacity, fire resistance and seismic resistance steel tubes can also be filled with heavy and / or light concrete.

Industrial applicability of the claimed technical solution can be explained in examples:

- For low-rise buildings (1–3 floor.) Load-bearing structures of building, columns, girth rails and beams are made, for example, of steel pipe cross-section 50 × 100 mm with a 4 mm wall, fastened together by welding.
- Middle-rise buildings (4–5 floor.) Load-bearing structures of building, columns and girth rails are formed, for example, from a steel pipe of 100 mm × 100 mm cross-section with a 4 mm wall, and the beams are made, for example, of steel pipe cross-section 50 × 100 mm with a 4 mm wall, filled with light monolithic concrete of necessary brand strength, fastened together by welding and in addition with screw connections and / or rivets.
- Outer frame is set at such a distance from the inner to provide the required parameters of thermal protection of building.

Inner bearing frame of the building: columns, girth rails and formed floor overlaps are made of metal pipes of rectangular cross-section, fastened to each other by welding and also with rivets or screw connections filled with concrete, where the pipe parameters and concrete brand are determined according to the height of the building and the length of the span.

Outer frame combines the functions of the frame for fastening permanent formwork sheets and at the same time can be used for fastening cleats with the subsequent installation of porcelain stoneware. The distance between frames may be 10 cm above the thickness filling of monolithic polystyrene concrete. In between formwork space necessary utilities are laid. In outer walls ventilation device with heat recovery is set. It serves fresh air into the living room and kitchen. In winter the air is heated and cooled in summer to a comfortable temperature. This can be called air heating in winter and air conditioning in summer. On the top floor of the building walls with thickening are transformed into a roof terrace. To this design (Figure 1) an application for the invention is filled [4] and is currently carrying out the examination on the merits.

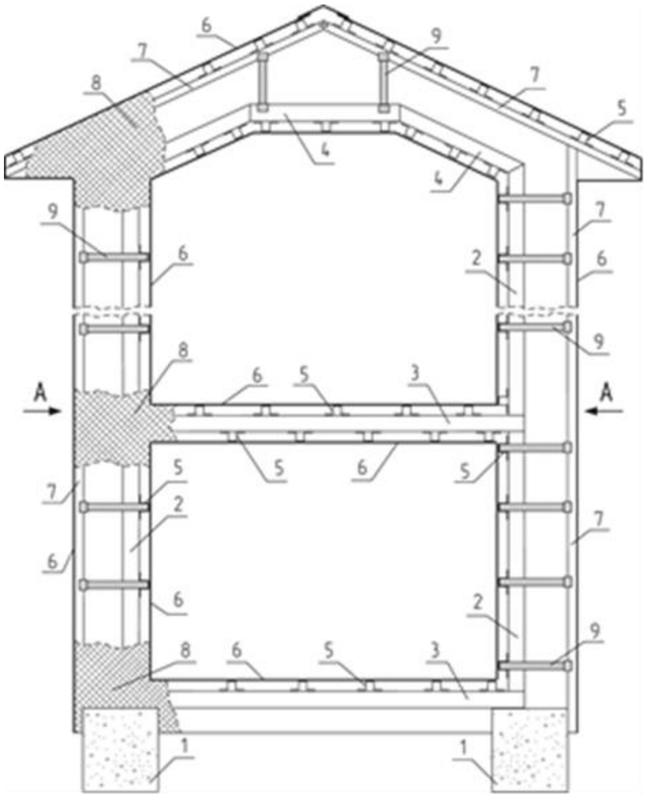

Figure 1. Cross-cross-section of the building
1 – foundation; 2 – inner frame column; 3 – girth rail inner frame; 4 – joisted floor; 5 – roll-formed profile; 6 – formwork sheet; 7 – outer frame; 8 – lightweight concrete; 9 – temporary lock.

We propose to fill constructions with lightweight concrete, for example, polystyrene concrete. Polystyrene technology was patented in Germany in 1952. In Soviet times polystyrene concrete was considered as strategic building material and was used mainly for the construction of large-scale production and storage facilities, as well as military installations. Concrete and Reinforced Concrete Research Institute (CRCRI) gave second life to PSC in our country, spent large scientific work and released All Union State Standards (P 51263-99) on polystyrene in 1999.

The main features of polystyrene. To be more precise, then it would be better to call this material: polystyrene-air-concrete. For the preparation of polystyrene cement, water, foam polystyrene balls and air-entraining resin are used. In the process of cement milk mixing fine bubbles of air are involved. Polystyrene balls are needed for homogeneous distribution of bubbles in the cement matrix. Because of this volumetric weight of polystyrene is homogeneous in whole monolithic poured volume and only slightly different in pouring height. At present, the production of polystyrene, can withstand up to 500 freeze-thaw cycles, then there is no destruction of the material under the design load.

According to our calculations for a comfortable, safe and energy efficient residence one must apply monolithic polystyrene brand D-200 200-600 millimeters thick in boundaring constructions. Thereby, the whole house (foundation, walls, floors, roof) poured monolithically, there are no "cold bridges", and the whole array of polystyrene, in fact, is an effective thermal insulation of its internal space from the environment. In such a house it is warm in winter and cool in summer as in wooden house(Table 1).

Table 1. The dependence of heat flow on the thickness of boundaring constructions

Wall thickness, мм	heat transfer resistance $\frac{м^2 \times °C}{Вт}$	heat flow Вт/м^2
300	4.282	17.50
350	5.000	15,00
400	5.,714	13.12
450	6.428	11.66
500	7.142	10.50
550	7.857	9.54
600	8.571	8.75
650	9.258	8.10
700	10.000	7.50

It is also necessary to consider such characteristics of monolithic polystyrene concrete poured into the permanent formwork as flammability and fire resistance. First of all for the manufacture requires only the use of food self-extinguishing polystyrene brands. So when in contact with open flame polystyrene balls in cement matrix seem to disappear.As polystyrene balls consist by volume of 98% of air, then it is completely combusted in an excess atmosphere oxygen, in contact with air not only from the outside, but also the inside. During the oxidation reaction carbon dioxide and water appear. Carbon dioxide prevents burning and water transforming into vapor at the time of formation, prevents further destruction of the balls within the array.

It should be noted that in the monolithically poured polysterine bearing structures of the building are protected from aggressive environmental factors (moisture, air, heat, vibration, etc.), repeatedly increasing the life of the structure in whole (Figure 2).

As permanent formwork sheets (Figure3) it is useful to apply glass magnesite sheets that have 10 mm thickness, which are non-flammable materials and have fire resistance EI 90. It allows their use in buildings up to 150 meters according to the standards. It protects polystyrene from open flames and additionally protects the bearing structures of the building: columns, girth rails, joisted floors from exposure of high temperatures and destruction.

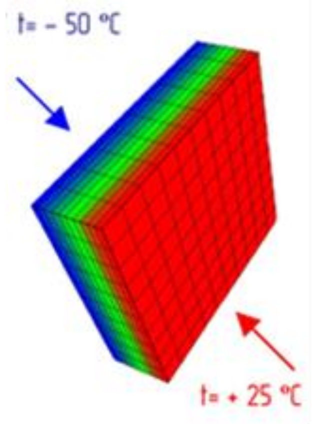

Figure 2. Temperature field.

This design concept allows to combine outside steel frame of the permanent formwork with a suspension system for fixing porcelain. The outer sheets of permanent formwork cleats are attached to the guide profiles with retractable rivets. At the same time it is possible to install windows and balcony doors. Frame of the building enclosed as if in a "shell". For engineering of exterior walls lined with porcelain a patent for utility model is received [5].

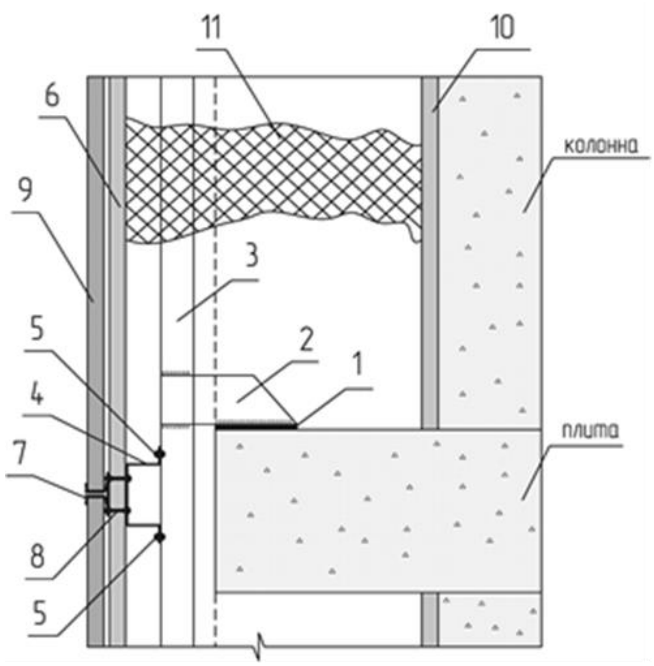

Figure 3. Multi-layer wall

1 – embedded parts; 2 – scarf ; 3 – vertical stand; 4 – horizontal profile; 5 – short rivet ; 6 – outer sheet permanent formwork; 7 – cleat; 8 – long rivet; 9 – covering element; 10 – the inner sheet of non-removable formwork; 11 – polystyrene.

The gap between the porcelain and the formwork is found to be the thickness of cleat. In such a way we get a three-layer instead of five-layer walls construction. Where porcelain and air gap appear apart from two sheets of polystyrene formwork and layer. It plays a very important complementary role in heat and fire protection of walls. In winter heat flow is coming out of the room, heats the air layer, as a result of a small gap and roughness of contacting surfaces. Warm air moves up in the

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laminar regime that leads to the additional thermal insulation effect. In summer, on the contrary, the sun's rays warm porcelain and form airflow in the gap that helps to cool the surface of the wall.

3. Conclusions

So in accordance with the proposed concept of the combined use of technology tube-concrete and monolithic polystyrene allows to design and rapidly build low-rise buildings with increased resistance to earthquakes, fires, which have, in addition, exceptionally high energy efficiency. The concept allows to reduce construction costs and operating costs of maintaining a comfortable temperature indoor air in summer and winter.

References

[1] A sure report for building damages due to the 1995 Hyogo-Ken Nanbu earthquake *Building Research institute. Ministry of Construction (Japan).* 1996 March, 222 p.
[2] Smirnov S.B. Seismic shear buildings - the result of the impact of soil strata slidable deep seismic waves *Housing construction.* 2009. **№9**. P. 32-35.
[3] Smirnov S.B. The reasons for the destruction of earthquake-resistant buildings and principles of effective seismic protection *Concrete and reinforced concrete.* 1994. **№3**. P. 22-25.
[4] Y. Schaefer Prefabricated frame building energy efficient. The application for the invention RU **№ 2012131704;** appl. 24.07.12.
[5] Y. Schaefer The multilayer outer wall lined. Utility model patent RU № 97147 U1; appl. 30.04.10