Structural Solutions for Buildings with "Sinch" Frames

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Abstract. Individual traditional buildings are widespread in the Central Asian region up to day. There are special building methods and guidelines are developed. The total number of individual buildings intended for housing is more than 2 mln. One type of traditional housing is “sinch”. More than 30% of structures in rural areas are of “sinch” frame shape. Briefly “sinch” is wooden-panel houses with a double wooden frame filled with soil materials (adobe). Because our region is a seismic prone zone a key aspect here is assessment of vulnerability to structures due to earthquakes. Methodology for aseismic design for reducing seismic risk is a vital problem for us. There are several technical solutions for this structure to exist. In this paper, the structural solutions of buildings with “sinch” frames are examined to address issues: seismic stability and the validity of using a widespread and characteristic solution in the region under study - a “sinch” frame without anchor ties of the lower strapping beam with the foundation;

Keywords: Structure, vulnerability, support, span, utility model

1. Introduction

The urgency of global climate change, due to long-term natural degradation, natural disasters the surface morphology of traditional buildings differs significantly from that of modern ones. Research and monitoring of structures of this type are carried out in regions around the world [1-4].

Special measures for strengthening and assessment of possible damages due natural hazards are developed also [5-10]. However, we are considering here a traditional construction unique to the Central Asian region

The absence of anchor ties of the lower strapping beam with the foundations of the “sinch” frame (Fig.1) takes place in all the surveyed buildings, as well as in the buildings that were not covered by the field survey. Moreover, the noted ties are absent both in old buildings, where rubble concrete and rubble foundations were used, and in buildings of recent and modern construction, where monolithic concrete foundations are used.

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The presence of anchor ties for connecting the lower strapping beams with the foundations is regulated by the requirements of the standards (item 3.7.11, KMK 2.01.03-96 "Construction in seismic areas") [11], but causes a lot of controversy among practicing construction specialists, engineers, and designers in the field of earthquake-resistant construction. In particular, there is an opinion that the absence of anchor ties can ensure the "slippage" of the "sinch" frame relative to the foundation and absorb part of the energy of the horizontal seismic shock, by analogy with the effect of seismic isolation in the well-known solution of a seismic isolating sliding belt.

As for the second of the above issues, concerning seismic resistance and the validity of the solution of the "sinch" frame using a hinged post-and-beam system in its upper part, there also exist alternative opions. In particular, there is an opinion that the presence of such a system reduces the rigidity of the frame and, consequently, the period of natural oscillations, as well as the forces in its elements from seismic impacts.

The above provisions served as the basis for the need to conduct a series of calculations for various options of the problem.

1- brace beam, 2- adobe 3- frame strapping beam

Fig. 1. Traditional "sinch" frame structure.

In total, three options of the problem were considered. Their description and characteristics are given in Table 1.

Table 1. Description of the problem options

No. of problem option	Estimated seismicity by MSK-64	Description of option characteristics

1	7 points	Conventional solution of the frame lattice (without using a post-and-beam system in the upper part of the frame) and modeling the presence of anchor ties of the lower strapping beam with the foundation
2	8 points	
3	9 points	

A conventional solution of the frame lattice without using a post-and-beam system in the upper part is considered. The marked groups of options are designed for seismic impacts with an intensity of 7, 8, and 9 points on the MSK-64 scale in a spatial setting.

2. Modeling the system

As a basis for the calculation model, one of the most typical (in the studied region) volumetric-planning and design solutions for an individual residential building of private development using a double “sinch” frame was accepted (however, the outbuilding or annex attached to the house was not modeled). Figure 2 shows the wall plan, wall elevation along various axes, section, and schematic plan of the roof elements (according to options No. 1, No. 2, and No. 3).

The following types of finite elements (FE) of the PC "Lira 9.4" software were used to model the system:

FE No.7 – beam grillage rod on elastic foundation. This FE modeled elements of monolithic concrete foundation. One type of rigidity was used;

FE No. 5 – spatial frame rod. This FE modeled wooden elements of the “sinch” frame lattice (lower and upper strapping beams, posts, diagonals, elements of the hinged post-and-beam system in the upper part of the “sinch” frame), and purlin roofing and roof beams. In this case, to consider the real geometric characteristics of the cross-section of the elements, 10 types of rigidity were used for their modeling;

FE No. 23 – rectangular finite element of wall beams of general provision. This FE modeled filling of the “sinch” frame lattice with earth materials. One type of rigidity was used;

FE No. 24 is a triangular finite element of a wall beam of general provision. This FE also simulated the filling of the “sinch” frame lattice with earth materials. One type of rigidity was used;

FE No. 41 is a rectangular finite element of a shell slab. This FE simulated the elements of the "black" ceiling. One type of rigidity was used;

FE No. 51 is an element that modelled the connection of finite rigidity in the general coordinate system. This FE was used in the problem options with the absence of anchor ties of the lower strapping beam with the foundation. In this case, the value of the finite rigidity of this FE was determined as a function of the friction forces arising in the contact zone of the lower strapping beam of the “sinch” frame with the foundation surface (considering the presence of a waterproofing layer made of roofing felt).

Figure 3 shows a general view of the modelled system for options of problems No. 1, No. 2, and No. 3 (for characteristics of options, see Table 1), described by 274 nodes, 424 elements, and 10 types of rigidity. The numbering is shown below (Fig. 3). In this case, the geometric characteristics of the sections of the elements of the corresponding rigidity types were taken based on the measurements during field surveys, namely:

rigidity type 1 – ordinary posts and diagonals of a wooden “sinch” frame of circular cross-section with a diameter of 80 mm;

rigidity type 2 are corner posts and posts at the intersection of longitudinal and transverse walls of circular cross-section with a diameter of 100 mm;

rigidity type 3 are elements of the upper strapping beam with cross-sectional dimensions of 150x150 mm;

rigidity type 4 are elements of lintels of window and door openings, as well as niches; of circular cross-section with a diameter of 80 mm;

rigidity type 5 are elements of roof beams with cross-sectional dimensions of 150x150 mm;

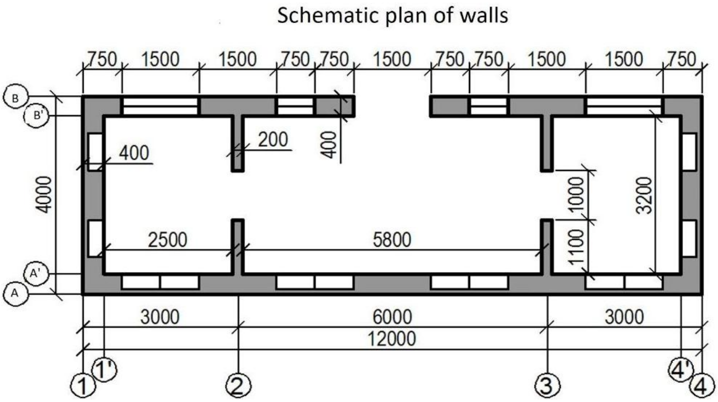
rigidity type 6 are elements of the lower strapping beam with cross-sectional dimensions of 150x100 mm.

At calculation elements simulating a reinforced concrete foundation were with cross-sectional dimensions of 400x400 mm;

There are rectangular and triangular elements simulating the filling of the lattice of the “sinch” frame with earth materials 120 mm thick.

The rectangular elements of the shell slab simulated the wooden covering of the “black” ceiling 30 mm thick.

The following parameters accepted for beams: Young modulus is E=10000 MPa, specific gravity is ρ=600kg/m3.



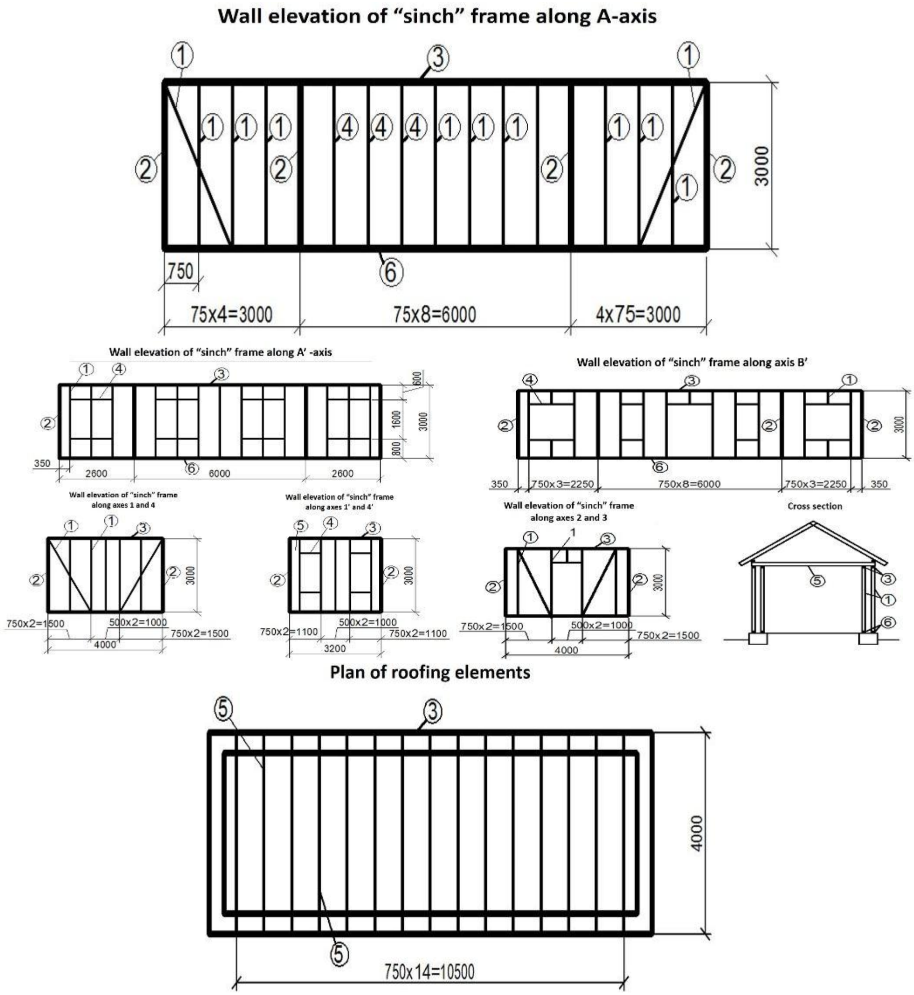


Figure 2. Wall plan, wall frame elevation along various axes and a schematic plan of roofing elements for options of problems No. 1, No. 2, and No. 3.

Figure 3. General view of the simulated system for options of problems No. 1, No. 2, and No. 3 (elements of the foundation, filling of the “sinch” frame and elements of the ceiling are not shown).

The following types of loading were taken in the calculations:

the constant uniformly distributed load from the dead weight of structures;

the temporary snow load applied to the nodes of the upper strapping beam of the external frames of the longitudinal and end walls;

the sign-alternating wind load;

the sign-alternating seismic load in the longitudinal direction (along the global X-axis or along the global Y-axis), applied to the nodes with the corresponding concentrated masses;

The following load values were taken in the calculations:

the dead weight of the supporting structures of the frame, roof beams, and frame filling elements was set automatically by the system in accordance with the assigned rigidity types (according to the geometric characteristics of the cross-sections and material density);

constant uniformly distributed linear load of 0.225 t/m on the roof beams from the roof itself (elements of the "black" ceiling, insulation, trusses);

temporary uniformly distributed snow linear load of 0.14 t/m on the upper frame strapping beams;

temporary useful uniformly distributed linear load of 0.063 t/m on the roof beams (load on the attic in use);

temporary wind sign-alternating uniformly distributed linear load of 0.024 t/m, applied to the posts of the external wall frames;

seismic sign-alternating load applied to the corresponding nodes of the system at the roof level with concentrated masses of 0.42 t (including the dead weight of the structures, frame filling elements, temporary and snow loads with the corresponding load combination factors), recorded in the loaded areas.

3. Calculation results and their analysis

As a result of the calculation of the system by problem options, data were obtained on the processing of dynamic (seismic) impacts, displacement of nodes, force (stress) in the elements of the system, calculated combinations of forces in the elements by sections, according to the adopted geometric dimensions of the cross-section and types of rigidity.

Figures 4 and 5 show mosaics of longitudinal forces N (kN) in the elements of the system (according to the option of problem No. 3; see Table 1) under the action of a seismic load (of 9-point intensity) for loadings No. 4 and No. 5, respectively, along the building (in the direction of the global X-axis) and across the building (in the direction of the global Y-axis).

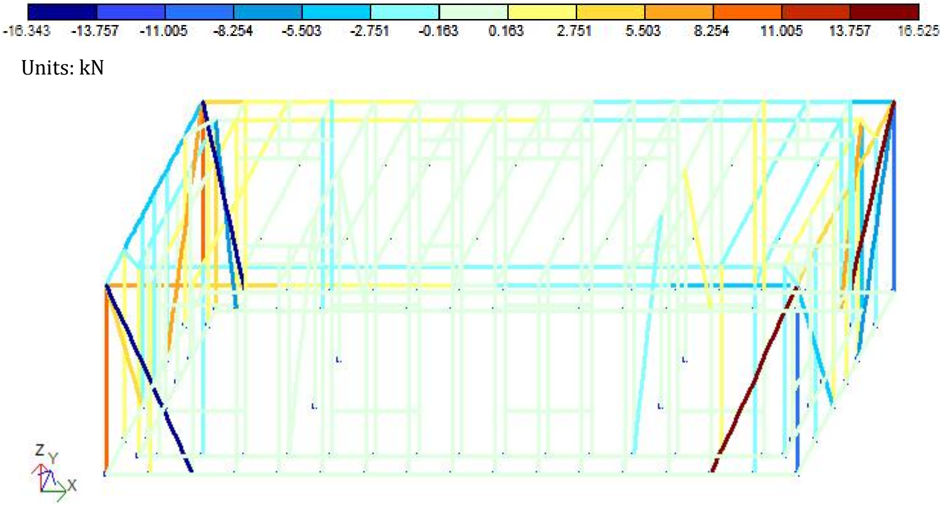
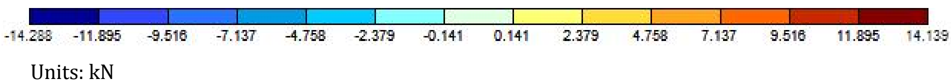


Figure 4. Mosaic of longitudinal forces N (kN) in the elements of the system under seismic load (along the building in the direction of the global X-axis).

The calculation results are analyzed in Figs. 3 and 4; they allow us to state the following.

The most loaded elements of the system in CCF under seismic impacts are the diagonals of the frames of longitudinal, end, and internal transverse walls. The next less loaded are the elements of the upper strapping beams, and vertical posts of the frame (which mainly bear the load from the dead weight of the structures and the snow load). For example, the stresses in the most loaded diagonal of the transverse wall frame under a 9-point seismic impact (with the most unfavorable combination of forces) are ≈ 3.6 MPa, which does not exceed the value of the calculated resistance of wood (for poplar species).



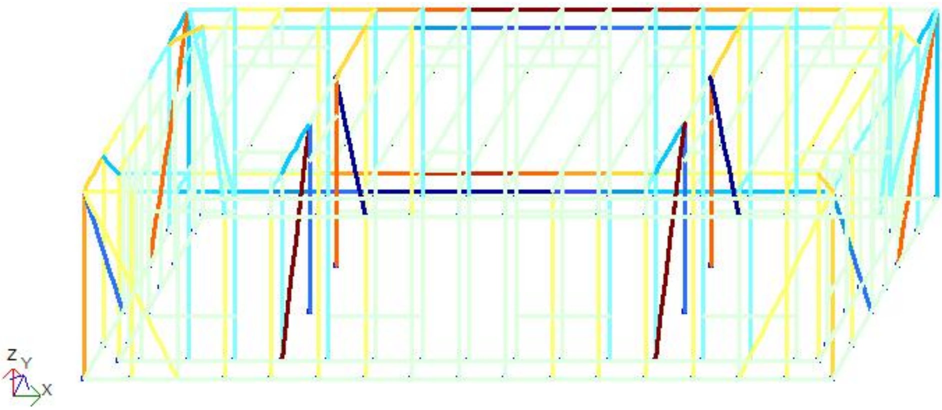


Figure 5. Mosaic of longitudinal forces N (kN) in the elements of the system under seismic load (across the building in the direction of the global Y-axis).

Below are the results of the structural calculation for checking the strength and stability of the most loaded diagonal of the system under seismic impacts with an intensity of 9 points (the option of problem No. 3), performed in the environment of the subsystem PC Lira 9.4 "Wooden structures".

4. Conclusion

By calculation results, the following conclusions were made:

The conventional "sinch" frame solution provides sufficient strength and stability for its elements, based on their established geometric characteristics from field surveys, even under the most unfavorable combinations of forces during seismic events with an intensity of 9 points.

The relative bias values (which indicate the relative displacement of the top of the building) under seismic impacts with an intensity of 7 and 8 points for this design solution meet the requirements of paragraph 2.12 and Table 2.6 of the KMK [11].

However, under a 9-point seismic impact, the largest relative displacements of the top of the building exceed the maximum permissible values according to the KMK by 22%. This is in line with KMK requirements, which do not regulate the use of such frames in regions with seismicity of 9 points and higher.

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