Reduction of seismic loads for transport construction facilities using dry friction elements

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Abstract. In the city of Almaty, a seismically insulated building using dry friction elements was built at a special training ground. An engineering-seismometric service station is installed on the building. The dynamics of the building under the influence of accelerograms of real earthquakes in the city of Almaty is being studied. Accelerograms of the Baysorus earthquake recorded on solid soils and the Zhalanash-Tyup earthquake recorded on clay soils are used. Spectral coefficients are obtained for various values of the dry friction coefficient. It is shown that on solid soils the use of seismic isolation with dry friction elements based on fluoroplastic gaskets reduces seismic loads by half. On clay soils, the use of such a system of seismic isolation seems inappropriate. The results of the work can be used for seismic isolation of transport infrastructure facilities.

1. Introduction

One of the effective systems of active seismic protection with increased dissipative properties is reduction of the inertia loading over foundation part of building by means of dry friction dampers, located between the elements of building. General principles of such systems are expounded in the works of Mikhailov G.M. [1] and Pavlyk V.S. [2].

It is necessary to note the work of Belash T.A [3], devoted to the optimization of energy absorption in buildings and structures on seismic insulating foundations. History of application of dry friction systems in seismic insulation tasks is given in [4]. In general, seismic isolation systems with elements of dry friction are a dynamically developing area with great prospects.

The damping of seismic insulating pile foundations of buildings with a rigid structural scheme is physically based on the fact that part of the seismic energy transmitted by the foundation will be spent on overcoming the dry friction forces in the damper, going down.

It should be noted a review of all seismic insulating structural systems used in the Republic of Kazakhstan to date, Yerzhanov S.Ye., Lapin V.A. [5].

Some new methods of using dry friction elements are given in [6-15].

A seismic isolated building using dry friction elements was built on a special test site in Almaty [16].

The sliding support is a seismic insulating structure with supporting surfaces in the form of a part of a sphere with a radius of 2 m (Fig. 1). The supporting parts are glued with a fluoroplastic film. Fluoroplastic is not thermally conductive; it remains operational in the temperature range from -269 to +269 degrees Celsius, does not absorb water, is chemically resistant to acids, has a high electrical resistance, and practically does not age.
The typical building is a large-panel residential building of the 158 series, a single-access block section. Building dimensions: length - 17.4 m, width - 12.9 m, height - 31.5 m. The building has 9 floors with a height of 3 m each with an additional technical underground and a semi-aisle attic. The sliding supports of the house are located at the intersection of the center axes on the special foundation racks, which are elements of cross reinforced concrete strip foundations (Fig. 1). The sliding plane of the supports is located above the planning mark of the surrounding soil.

The building with fluoroplastic is located at the intersection of Rozybakiev and Bolotnikov Streets in Almaty. The soil conditions at the construction site are boulder pebbles, 2nd category for seismic properties. Groundwater level - 20 m.

The main method is the analysis of accelerograms of recorded earthquakes and the calculation of a seismically insulated building for seismic impact, represented by instrumental records.

Figure 1. Sliding support with fluoroplastic gaskets-4.

2. Mathematical model
It is of interest to perform an assessment of the effectiveness of systems with dry friction, taking into account local features of the Almaty region.

The equation of the dynamics of a single-mass elastic system, taking into account the forces of dry friction, has the form:

\[ \ddot{y} + \frac{2\delta}{T} \dot{y} + \left( \frac{2\pi}{T} \right)^2 y + H \text{sign} \dot{y} = -\dot{Y}_0, \tag{1} \]

where \( y \) - is the relative displacement of the system; \( \delta \) - decrement of vibrations, taken in further calculations on the basis of a series of experimental works equal to 0.5; \( T \) - period of own oscillations of the system; \( \dot{Y}_0 \) - base acceleration represented in the form of digital accelerograms of real earthquakes; \( m \dot{H} \text{sign} \dot{y} \) - dry friction force, constant in absolute value and changing direction.
depending on the sign of the speed of oscillations \( H = fg \); \( f \) - coefficient of dry friction; \( g = 981 \text{ cm/s}^2 \) - acceleration of free fall.

The dry friction element is adopted here without inertia.

It is proposed to use the well-known approximation of the hyperbolic tangent function of Sigal F. R. [16] to describe the forces of dry friction. Then equation (1) takes the form

\[
\ddot{y} + \frac{2\delta}{T} \dot{y} + \left( \frac{2\pi}{T} \right)^2 \cdot y + H \text{th} (\bar{n} \dot{y}) = -\bar{Y}_0,
\]

(2)

where \( \bar{n} \) - is the coefficient selected depending on the problem to be solved. When properly selected, the stops are replaced by a very “slow motion”, which greatly simplifies the numerical solution of the problem, since there is no need to record and analyze the conditions for stopping the motion. Numerical experiments show that the more \( \bar{n} \dot{y}_{\text{max}} \), the closer \( \text{th} (\bar{n} \dot{y}) \) to \( \text{sign} \dot{y} \). For the case of harmonic motion of the base, we compared the exact and approximate solutions. The results indicate a slight difference between exact and approximate solutions. It is established that the coefficient should be chosen from the condition \( \text{th} (\bar{n} \dot{y}) \approx 40 \).

3. Results and discussion

3.1 Hard soil

The most noticeable seismic event of the 90s of the last century for the region of Almaty is the Baisorun earthquake on November 12, 1990.

The earthquake occurred in the Northern Tien Shan within the highly active seismic and very dangerous for the city of Almaty Kungei Zaili zone. The vast territory, including Alma-Ata, Taldy-Kurgan and Dzhambul regions of Kazakhstan, as well as the Issyk-Kul region of the Kyrgyz Republic, was covered by shocks. The earthquake manifested itself with the greatest force in the village of Kuturgan, located 20 km east of the epicenter. In Alma-Ata, an earthquake manifested itself with an intensity of 5-6 points. Magnitude of earthquakes: \( M = 6.3 \). Focal depth: \( H = 15-20 \text{ km} \).

The maximum force at the epicenter is 8 points.

There is a two-component recording of the earthquake recorded by Kurmunity station at a distance of 35 km from the earthquake source (Figures 2–3). Digital step 0,008 sec.

This record can be used to develop a seismic model for the Almaty region.

Figure 2. Accelerogram of the Baisorun earthquake on November 12, 1990 (component N-S).
Table 1 shows some parameters of instrumental recordings - accelerograms. A quick analysis of table 1 shows that accelerograms are well centered. Instrumental recordings are of high frequency. The predominant periods and carrier frequencies are determined by spectral density using the SCM MATLAB Signal Processing Toolbox. With a total duration of exposure over 8 seconds, the effective duration (duration of oscillations with an amplitude of more than half of the maximum) is 2.5 seconds, i.e. approximately 30% of the total duration. Thus, there is the impact of the pulse type.

The ratio of the maximum values of the component accelerations is 1.6. This ratio is very different from the results of the statistical analysis of strong European earthquakes. It was found that with a probability of 0.5, the maximum horizontal accelerations differ by less than 40%. Perhaps the differences are due to some regional effects. Interesting, the ratio of the sweeps is about the same - 1.59.

Table 1. Accelerogram Parameters.

| Parameters                              | Component 1 (N-S) | Component 2 (E-W) |
|-----------------------------------------|-------------------|-------------------|
| A maximum of accelerogram. cm/of c2    | 699.2             | 436.92            |
| A minimum of accelerogram. cm/of c2    | -589.85           | -375.53           |
| Dispersion. cm2/c4                     | 69.64             | 72.05             |
| Root-mean-square. cm/of c2             | 8.34              | 8.49              |
| Scope. cm/of c2                        | 1289.05           | 812.450           |
| Mean value. cm/of c2                   | 4.193             | 6.098             |
| Median value. cm/of c2                 | 1.600             | 9.845             |
| A maximum of spectral closeness        | 42.20; 36.58      | 39.69             |
| Frequency. 1/c                         | 3.66; 4.76        | 4.88              |
| Period. c                              | 0.27; 0.21        | 0.20              |
| Duration of vibrations with amplitude of greater half of maximum (effective duration). c | 2.52 | 2.50 |
Figures 4 and 5 show the spectral curves $\beta$, obtained by solving equation (2) for different values of the dry friction coefficient $f$. The value of the logarithmic coefficient $\delta = 0.314$ (5% of the critical value). The calculations were performed using the MATLAB computer math system.

Note that the values of the dry friction coefficient $f$ equal to 0.05-0.1 correspond to the parameters of fluoroplast-4. Due to the low coefficient of sliding friction when the inertial loads exceed the threshold, the building begins to slip relative to the foundation. From this point on, the seismic loads on the building do not increase. All the energy of the seismic impact is spent on the movement of the supra-foundation structures of the building.

When seismic effects are typical for the Almaty region, the effect of reducing seismic forces can be very significant - up to 2 times.

3.2 Soft soil
It is also necessary to evaluate the behavior of a seismically insulated house on soft soils. There are instrumental records of engineering-seismometric stations on clay soils.

The Zhalanash-Tyup earthquake on March 25, 1978 occurred 140 km southeast of Almaty in the area of the village of Zhalanash in the Almaty region (near the border of Kazakhstan and Kyrgyzstan).
Its focus was in the zone of eastern immersion of the Kungei anticlinorium. The earthquake was felt from the northern coast of Lake Balkhash in the north, Ferghana and Talas ridges in the west to the state border in the south and east. In Almaty, an earthquake appeared with an intensity of 5-6 points. Earthquake magnitude: $M = 6.6$. Depth of the outbreak: $N = 15$ km. The maximum strength at the epicenter is 8-9 points.

Figures 6-7 shows instrumental records (accelerograms) in case of specified earthquake on clay soils. These are instrumental records of the network of stations of "KazRDIKA" JSC in Almaty.

![Figure 6. Accelerogram of the Jalanash-Tyip earthquake of 25 March 1978, Aremz seismic station.](image)

![Figure 7. Accelerogram of the Jalanash-Tyip earthquake of 25 March 1978, 70 station.](image)

Figures 8-9 shows the spectral curves of $\beta$ constructed for the above accelerograms. The analysis shows that the decrease in seismic loads does not exceed 10%. Therefore, the use of dry friction elements on clay soils is not very advisable.
4. Conclusion
1. With the expected earthquakes taking into account local features of the seismic impact, there is a twofold decrease in seismic loads. Reduction of both inertial seismic loads and internal forces is provided at the level of the floors of each building.

2. The use of seismic insulating foundations on construction sites near tectonic faults is recommended. There are over 300 hectares of such sites near tectonic faults on the territory of Almaty. Construction of low-rise rigid buildings (up to 4-5 floors) in such areas will contribute to improving the efficiency of earthquake-resistant construction in Almaty and its surroundings.

3. Mass application of seismic insulating foundations with dry friction elements at sites of the city of Shymkent is recommended. The territory of the city has a 7-point background seismicity and a population of over 1 million people. The use of such foundations will make it possible to reliably reduce the seismic load by 1 point and, therefore, use standard series for the construction of residential buildings for non-seismic areas.

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References

[1] Mikhailov G M 1974 Earthquake resisting building (M.: TsINIS of Gosstroi of the USSR)

[2] Pavlyk V S 1971 Materials to the All-union conference on planning and building of earthquake resisting building and building. Basic directions of research on earthquake resisting building (M.: TsINIS of Gosstroi of the USSR) p 210

[3] Belash T A 1996 Optimization of parameters of energyabsorption in building on seismic isolation foundations. Dissertation on the competition of graduate degree of doctor of engineering sciences p 458

[4] Calvi Paolo M, Calvi Gian Michele 2018 Soil Dynamics & Earthquake 106 14 DOI:10.1016/j.soildyn.2017.12.003

[5] Yerzhanov S Y, Lapin V A 2017 Researches of earthquake resisting of building and constructions (Almaty: Kazakhstan)

[6] Ahmad Shakeel, Ghani Farrukh, Raghib Adil Md 2009 Construction & Building Materials 23(1) 146 DOI:10.1016/j.conbuildmat.2008.01.012

[7] Wei Biao, Wang Peng, He Xuhui, Jiang Lizhong 2018 Journal of Testing & Evaluation 46(4) 1 DOI:10.1520/JTE20160598

[8] Bulat A F, Dyrdaz I, Lysytsya M I, Grebenyuk S M 2018 Strength of Materials 50(3) 387 http://doi.org/10.1007/s11223-018-9982-9

[9] Wei Biao, Wang Peng, He Xuhui, Jiang Lizhong 2018 Journal of Testing & Evaluation 46(4) 1 DOI:10.1520/JTE20160598

[10] Wei Biao, Wang Peng, Liu Weian, Yang Menggang, Jiang Lizhong Seismic 2016 International Journal of Non-Linear Mechanics 83 65 Doi:10.1016/j.ijnonlinmec.2016.04.001

[11] Shakeel Ahmad, Farrukh Ghani, Adil Md Raghib 2009 Construction & Building 23(1) 146 DOI:10.1016/j.conbuildmat.2008.01.012

[12] Li Shan-stan L, Wei Biao, Li Chaobin, Wang Weihao, Fu Yunji 2020 Journal of Vibroengineering 22(1) 120 DOI:10.21595/jve.2019.20739

[13] Wei Biao, Wang Peng, Yan Bin, Jiang Lizhong, He Xuhue 2016 Journal of Vibroengineering 18(3) 1668 DOI:10.21595/jve.2016.16114

[14] Kovaleva N V, Rutman Yu L, Davydova G V 2013 Magazine of Civil Engineering 5 137 DOI:10.5862/MCE.40.12

[15] Alpatov V 2019 Results of Studying the Yield Strength of the Spatial Structure Joint Using CAE Systems IOP Conference Series: Materials Science and Engineering 661 012021 doi:10.1088/1757-899X/661/1/012021

[16] Alpatov V, Saharov A 2019 Variant Design of Metal Dome Frame IOP Conference Series: Materials Science and Engineering 661 012086 doi:10.1088/1757-899X/661/1/012086