Monitoring of a Seismic Isolation Object on Fluoroplastic Gaskets

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Abstract. A special testing ground is used to study the seismic insulating properties of buildings in Almaty. It includes buildings with conventional tape foundations with a cross-tape system, seismic-insulating kinematic and supports with fluoroplastic gaskets. The buildings are equipped with engineering-seismometric service stations (stations 20, 21, 22). The results of experimental studies of the house on fluoroplastic gaskets, performed in the late 80s, are analyzed. The results are compared with instrumental records during the earthquakes of May 31, 2012 and August 16, 2014. The period of the maximum of the spectrum coincides with the resonance at the initial stages of vibration tests 0.44-0.47 sec. Using a single-mass calculation scheme, taking into account the presence of dry friction forces, the calculation of the dynamic model of the building on the impact of an unsteady random process is performed. The median acceleration values at the base correspond to the data of the “Seismic Zoning Map of the Republic of Kazakhstan” for earthquakes with a recurrence of 475 years and 2475 years. Probabilistic estimates of displacement values at the support level are obtained.

1. Introduction

In the 80s of the last century, the works of Mikhailov G.M., Pavlyk V.S., Polyakov V.S., Kilimnik L.Sh., Aubakirova A.T., Belash T.A., Soldatova L.L., Chudnetsova V.P. developed intensively the seismic isolation systems based on the use of various dry friction elements. Numerous copyright certificates and patents have been obtained.

In addition to seismic insulating kinematic foundations [1-5], KazRDICA JSC also developed several seismic insulating systems with dry friction elements [6-9]. One of such buildings was built with the use of fluoroplastic gaskets, tested by an inertial vibration machine, and for the purpose of further monitoring was equipped with an engineering-seismometric service station. The magnitude of the decrease in seismic forces on the seismically insulated building was estimated relative to the building-analogue.

In the city of Almaty, there is a special training ground on which three buildings with different construction of foundations are built, one of which consists of dry friction elements with fluoroplastic gaskets. These houses are monitored in real time.

Two tasks are being solved:
- Definition of reduction of seismic forces on the building;
- Evaluation of the durability of fluoroplastic gaskets.
2. Research methods and special training site

In 1989, on three buildings built with the same base part (9-floor large-panel building of the 158 series), but with different foundations: ordinary tape with a system of cross tapes, seismically insulating kinematic [1-6] and supports with gaskets made of fluoroplastic, seismometric engineering service stations were installed. Below are the results of a study of a building with supports on fluoroplastic gaskets, on which the ISS station operates and there are results of vibration tests of this building.

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, their comparison with experimental data and the calculation of a seismically insulated building for a seismic effect represented by a random process.

3. Results and discussion

On August 16, 2014 at 03 a.m. 42 minutes an earthquake was registered by a network of seismic stations of the State Institution “Seismological Experimental and Methodical Expedition of the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan”. The epicenter was located 41 km east of Almaty with coordinates 43 ° 30 ′ N and 77 ° 40 ′ E, energy class K = 12.0, magnitude MPV-5.2, depth 5 km. Tremors were felt in Almaty, 4-5 points on the MSK-64 scale.

The earthquake was recorded by stations of the engineering-seismometric service, which are installed in the buildings of the seismic isolation site. The greatest interest for analysis is instrumental records of accelerations - accelerograms.

The earthquake is not very strong. However, it is possible to compare the results of the analysis of accelerograms on an analog building and a seismically insulated building with dry friction elements.

![Figure 1. Sliding support with fluoroplastic gaskets-4.](image-url)
Table 1 and Figure 2 show the values of spectral accelerations during a given earthquake (seismic station No. 22 “House on fluoroplastic gaskets”), and figure 2 shows a graph of spectral accelerations. The same figure 1 shows the graphs of spectral accelerations recorded on the building-analogue. The ratio of the values of spectral accelerations at the level of the 9th floor allows us to estimate the magnitude of the effect of seismic isolation in a given earthquake. The magnitude of the ratio of spectral accelerations is 1.61.

The value of 0.41 sec is the initial period of free oscillations of the building.

**Table 1. Maximum values of accelerations and accelerogram parameters dated 08.16.2014.**

| Record         | Acceleration, cm/s² | Effective duration, s | Spectral acceleration, cm/s² | Spectrum maximum period, s |
|----------------|---------------------|-----------------------|-----------------------------|----------------------------|
| 89-FT-1-1x     | 6.48                | 8.57                  | 22.95                       | 0.14                       |
| basement       |                     |                       |                             |                            |
| 89-FT-9-9x     | 16.41               | 7.81                  | 117.34                      | 0.41                       |
| 9th floor      |                     |                       |                             |                            |

**Figure 2. Spectral Acceleration for the earthquake of August 16, 2014.**

On May 31, 2012, almost all seismic stations of the ISS service recorded a seismic event. The strength of the tremors during the earthquake in Almaty was about 4-5 points. At the epicenter, the magnitude of the earthquake was 5.7 points, according to the Euro-Mediterranean Seismic Center. The coordinates of the epicenter are 43.388 ° N, 78.773 ° E (148 km from Almaty, 183 km from Taldykorgan, 1028 km from Astana), the epicenter depth is 25 kilometers.

Table 2 shows the maximum acceleration values for each of the registration points. Lines 1-3 correspond to the accelerations recorded by the OSB sensors, 4-6 correspond to the accelerations obtained by double differentiation of the displacements. The axis OX corresponds to the direction across the building, OY - along. Figure 3 shows the spectral curves.

According to the current MSK-64 (K) scale, a 5-point earthquake corresponds to an interval of acceleration values of 16-35 cm / s² with a median value of 25 cm / s². The magnitude of the acceleration in the foundation level, the intensity of the earthquake can be estimated as 4-5-point.
Table 2. Maximum values of accelerations and accelerogram parameters, dated 31.05.2012.

| №  | record | acceleration, cm/s² | Effective duration, s | Spectral acceleration, cm/s² | Spectrum maximum period, s |
|----|--------|----------------------|-----------------------|-----------------------------|--------------------------|
| 1  | 86-22-1-14x basement | 6,43                 | 4,96                  | 4,52                        | 0,47                     |
| 2  | 86-22-9-17x-9th floor | 16,05                | 7,20                  | 7,51                        | 0,44                     |
| 3  | 86-22-9-18y 9th floor | 0,52                 | 11,60                 | 5,55                        | 0,44                     |
| 4  | 86-22-1-10y - basement | 13,41                | 13,41                 | 4,78                        | 0,44                     |

Figure 3. Spectral curves of seismic events on May 31, 2012
(the picture on the left is the OX axis, the picture on the right is the OY axis).

On the graphs of the spectral curves, some regularities are clearly expressed. On the spectral curves corresponding to the foundations, 2 peaks appear - at periods of 0.13-0.14 sec and 0.44-0.47 sec. This may be due to the design features of this building - the presence of seismically insulating foundations of a sliding type. One of the peaks may be associated with the work of the supra-foundation part of the building, the second - seismic isolation systems. Moreover, for the case of direction across the building, all 3 spectral curves are embedded in each other for a period of 0.44 seconds. To clarify the assumptions made, it is necessary to process instrumental records of the same or greater intensity.

The maximum values of the spectral coefficient β take place on the last ninth floor in both axes of the building. Perhaps this is also due to the features of the building.

It should be noted that the periods of the maximum of the spectrum obtained from two earthquakes on August 16, 2014 and May 31, 2012 differ by only 7%.

For comparison purposes, below are the data of static and dynamic (vibration) tests of a building with fluoroplastic gaskets, performed in 1988 [6-8]. The results of the studies, considering their importance, are given in sufficient detail.

The main results:
1. To obtain a diagram of the movement of supports during static tests, we used a system of hydraulic jacks located in the basement of the building. The building was displaced in the direction of the longitudinal axis by 3-72 mm in each direction from the equilibrium position. In extreme positions, pressure was released in the hydraulic system of the jacks and the building slid in the opposite direction under the influence of gravitational restoring force. Residual displacements were of 10-20 mm. The average value of the coefficient of friction is 0.035. It was found that as a result of the movements the fluoroplastic film was not damaged.

2. Under vibration loading, the sliding of the support began with the inertial forces developed in the structure - 900-1000 kN, which corresponds to the static threshold of operation. With increasing loads at each stage, an increase in inertial forces in the system was observed. In this case, the level of the amplitude of displacement increased. However, with an increase in the intensity of the external disturbing load from 124 to 514 kN, the inertial force did not exceed 1650 kN. Thus, the reaction value of the structure was determined by a dynamic coefficient of friction equal to 0.05-0.06.

3. When testing a building-analogue, the maximum reaction value was 4880 kN. Therefore, the effect of seismic isolation relative to the reaction of a building-analogue is approximately three times (Fig. 4).

We will calculate the seismically insulated building taking into account regional features of the seismic impact for the city of Almaty - a metropolis with a population of over 2 million people. According to the current Seismic Zoning Map of the Republic of Kazakhstan, the median acceleration values in the city are equal at a repeatability of once every 475 years, 0.38g, and at a time of 2475 years, 0.73g. Here g is the acceleration due to gravity.

The two indicated acceleration values are most closely associated with two accelerograms of the 1990 Baysorun earthquake with acceleration peaks of 699.2 cm / s² and 436.9 cm / s². The differences between the peak values of acceleration from the values normalized by the Seismic Zoning Card are 2-8% here. Therefore, these accelerograms can be taken as starting points for modeling the seismic impact by a random process.

One of the fastest and most convenient is an algorithm based on recursive filtering (autoregression) [10]. The basic calculation formula for autoregression (moving average) is:
\[ y_k = \sum_{i=0}^{m} a_i x_{k-i} - \sum_{i=1}^{n} b_i y_{k-i}, \]  
\[ \text{where} \]
\[ x_{k-i} - \text{discrete implementations of a random process at the input of the system,} \]
\[ y_k - \text{discrete implementations of a random process at the output (in this case, accelerograms);} \]
\[ a_i, b_i - \text{moving average autoregressive model coefficients;} \]
\[ m \text{ and } n - \text{positive numbers (} m \leq n). \]

This method does not have a methodological error, and the parameters of the modeling algorithm are expressed explicitly through the parameters of the correlation function. If the form of the correlation function is complicated (for example, the continuous transfer function of the forming filter has multiple poles), then the recurrence algorithms become approximate.

The seismic effect was modeled by a stationary random process, which is obtained by multiplying the realizations of the stationary process by a deterministic envelope. The correlation function of a stationary random process is assumed to be cosine-exponential. The determinate envelope is adopted in the form of a fractional rational function Aptikaeva F.F. [11]

\[ A = A_{\text{max}} \frac{3td}{9t^2 - 9td + 4d^2}. \]  
\[ \text{The value of } d \text{ is the effective duration of the seismic impact (duration of exposure with an intensity of at least half the maximum – pulse width).} \]

For the analysis of possible displacements under the influence of reactive powers at the level of seismic insulating foundations (fluoroplastic gaskets) under seismic loads and also for assessing the reliability of such buildings, a single-mass cantilever system with a concentrated mass and an element of dry friction can serve as an acceptable design model. From the above test results of the facility, the dry friction values of the fluoroplastic are used, which are necessary for evaluating the seismic reaction and reliability.

Integrates a nonlinear differential equation

\[ m \ddot{x} + \mu \dot{x} + mg \cdot f_{mp} \text{sign} \dot{x} = -m \ddot{x}_{0i}, \]  
\[ \text{where} \]
\[ \ddot{x}_{0i} - \text{i-th accelerogram,} \]
\[ \mu - \text{inelastic drag coefficient (Feucht hypothesis),} \]
\[ m - \text{building mass, } g - \text{acceleration of gravity, } f_{mp} - \text{dry friction coefficient, } x - \text{horizontal movement} \]

Integration of the nonlinear differential equation was carried out using the integrators of the computer mathematics system MATLAB.

The design model of the building has the following inertial and dissipative characteristics (Q=mg):

\[ Q = 24300 \text{ kH;} \]
\[ \mu = 44 \text{ kH-sec/cm.} \]
Here, the criterion for failure is the achievement of maximum permissible displacements $[x_{\text{max}}]$. According to the data of static tests [3] and the magnitude of the free-wheeling of foundation structures, it is accepted $[x_{\text{max}}] = 15$ cm. Reliability (uptime probability) $W = W(|x| < [x_{\text{max}}])$. The value $f_{\text{imp}}$ is taken from experimental studies. Calculations are performed by the method of statistical tests (Monte Carlo method) using the capabilities of the licensed computer mathematics system MATLAB [12].

To assess the quality of the seismic isolation system and the selected seismic impact model, we will calculate the probabilistic characteristics of the displacement parameters at the level of support and reliability (probability of failure-free operation) of the seismically insulated building on fluoroplastic gaskets at different values of the friction coefficient (tables 3-4). The scheme of the classical Monte Carlo method is implemented. In the calculations, 1000 realizations of the random process are used.

**Table 3.** The values of the probabilistic characteristics of displacement and the reliability value $W$ of a seismically insulated building, $f_{\text{imp}} = 0.035$.

| Parameters                  | For repeatability 475 years | For repeatability 2475 years |
|-----------------------------|----------------------------|----------------------------|
| Average value, cm           | 5.79                       | 14.06                      |
| Median value, cm            | 4.93                       | 12.36                      |
| Standard deviation, cm      | 3.37                       | 7.59                       |
| The coefficient of variation| 0.58                       | 0.54                       |
| Reliability $W$             | 0.985                      | 0.63                       |
| Probability of failure $Q$  | 0.015                      | 0.37                       |

**Table 4.** The values of the probabilistic characteristics of the displacement and reliability values $W$ of seismically insulated building, $f_{\text{imp}} = 0.05$.

| Parameters                  | For repeatability 475 years | For repeatability 2475 years |
|-----------------------------|----------------------------|----------------------------|
| Average value, cm           | 4.20                       | 11.41                      |
| Median value, cm            | 3.60                       | 9.74                       |
| Standard deviation, cm      | 2.41                       | 6.53                       |
| The coefficient of variation| 0.57                       | 0.57                       |
| Reliability $W$             | 0.998                      | 0.76                       |
| Probability of failure $Q$  | 0.002                      | 0.24                       |

The displacement values at the basement level with $f_{\text{imp}} = 0.05$ are within the range of 4.20-11.41 cm on average and 3.6-9.74 cm on median values.

The reliability value $W$ with a repeatability of 475 years within the indicated values of the dry friction coefficient is 0.985-0.998, and with a repeatability of 2475 years it is much less than 0.63-0.76. Estimates of reliability appear to be accurate since obtained with a large number of implementations. With further refinement of seismic impact models, reliability estimates will be updated.
Thus, for a 9-floor large-panel building, whose seismic isolation is based on fluoroplastic gaskets (Figure 1), there is an experimental information on the behavior under vibration influences, the characteristics of the fluoroplastic layer at the level of the seismically insulating foundation, and instrumental information on 3 points of registration of accelerations in local earthquakes. All this creates the prerequisites for further study of the behavior of this building with predicted real earthquakes.

It should be noted that seismic isolation systems based on dry friction elements are quite simple. The effectiveness of reducing seismic loads here does not cause co-opinion. Settlement schemes are quite simple. Therefore, the use of a seismic isolation system based on dry friction elements remains very promising. The purpose of this article is to show that there are enough experimental data and theoretical prerequisites for the mass application of such systems. The engineering-seismometric service of KazNIISA JSC in Almaty organized constant monitoring of such a system - a 9-floor seismically insulated building on fluoroplastic gaskets.

Despite the guaranteed decrease in seismic forces as a result of the use of dry friction elements, there are few cases of mass application of such systems. This is the micro-district “Alamedin” in Bishkek, where about 40 buildings were built using the “sliding belt” system. Apparently, the designers are afraid of large movements in the level of the seismic insulating layer and the problem of returning the building to its original position.

This article completes the first cycle of work on the behavior of an analog building and buildings with seismic isolating supports of two types at a seismic isolation test site in Almaty. In the future, upon receipt of new instrumental information on the behavior of buildings during local earthquakes, research will continue. New structural seismic isolation systems are being developed in Almaty [13-17].

4. Conclusion
1. A set of experimental studies was carried out on the object of a seismic isolation test site in Almaty for a fluoroplastic gaskets building equipped with an engineering-seismometric service station (seismic station No. 22), including dynamic vibration tests, static studies and standby observations using stations of engineering-seismometric service.
2. According to the data of the engineering-seismometric service of KazRDICA JSC and the results of vibration tests, there is a decrease in seismic forces from 1.6 to 3 times.
3. The magnitude of the period of the maximum spectrum of the building according to the engineering-seismometric service 0.41-0.47 sec.
4. The fluoroplastic film retains its properties - after 30 years of operation of the building, according to instrumental records of ISS station No. 22 “Building on fluoroplastic gaskets”, there is a decrease in seismic forces on the seismically insulated building compared to the analogue building.
5. Statistical modeling of the reliability of a seismically insulated building was carried out taking into account the data of the “Map of seismic zoning of the Republic of Kazakhstan” and the probabilistic characteristics of the displacement values of the building at the level of seismic insulating supports were calculated. It is shown that at $f_{mp} = 0.05$ the median displacement does not exceed 9.74 cm.

5. References
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