Monitoring Complex Junctions of the Load-Bearing Structures of Buildings

Khamidulla Sagdiev, Victor Galiaskarov, Zohidjon Teshaboev and Anvar Yuvmitov

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Kh S Sagdiev[1], **V A Galiaskarov**[1], **Z R Teshabaev**, **and A S Yuvmitov**[1]

[1]Institute of Mechanics and Seismic Stability of Structures of the Academy of Sciences of the Republic of Uzbekistan, 100125 Tashkent, Uzbekistan

[1]anvar.sayfullaevich@mail.ru

Abstract. A new technique of the monitoring of the complex junctions in the load-bearing structures of the buildings and structure facilities at the aftermath of earthquakes is proposed in the paper. The proposed method is based on the tensometric measurement of the deformation of the load-bearing structures.

Keywords. structure, complex junction, earthquake-resistant construction, strain gauges, permanent strain.

1. Introduction

As is well known, severe and destructive earthquakes cause great damage to the national economy, and their unexpectedness might cost the people life, since the methods of the prediction are yet not developed and require further research in this area. A study of severe earthquake consequences shows that the global scientific and technological potential is not able to prevent, and to predict the exact time, place and intensity of strong earthquakes occurring on the planet. Analysis of the consequences of the strong ground motion, damage and destruction to buildings and structures of cities show the shortcomings of existing technology of earthquake-resistant construction.

It should be noted that to protect the population in such an event is of particular importance, since a great number of cities and towns of our Republic (more than 80%) are located in the highly seismic areas with an intensity rate of 7 points or more. Obviously, the problem of the ensuring seismic safety of the population and the preservation of the material and technical values in case of the strong earthquakes is relevant and requires its solution.

The solution to the problem of earthquake resistance of structures is closely related to the results of studying the effects of the earthquakes, structure and soil oscillations during the earthquakes; it also depends on the results of field-model tests of structures under dynamic type of seismic effects. In the process of designing and construction, the consideration of seismic effects is mainly taken into account in the most vulnerable transverse (shear or bending) directions of the building structures.

In this connection, the results of instrumental observations for structures and soil oscillations and the analysis of the effect of the earthquakes are directly related not only to regulatory documents, but also to improving design models and schemes when evaluating the calculation methods for earthquake resistance,

2. Research Methodology

The results of field measurements are the initial information for the model substantiation and theoretical preconditions in calculating buildings and structures. According to the records of oscillation of the soil base and the building, the calculated values of seismic effect are formed; among them of great importance is the amplitude-frequency spectrum of external load. Depending on the frequency spectrum and the rigidity, different structures behave differently during the earthquakes.

It is known, that during the earthquakes, the main load-bearing structures are destroyed in the complex junctions of the buildings due to occurrence of additional internal forces. Besides, in the complex stress state of the bearing structures there are such strains that are not taken into account in design due to chaotic nature of earthquakes [1-7].

To study the processes in the complex junctions of the bearing structures of buildings after earthquakes, the authors of this paper have proposed a method for monitoring the complex junctions of structures in the points under high loads. As an example the arrangement of strain gauges in complex junctions of the bearing structures of frame buildings, columns with beams (Fig.1), as well as the junctions of transverse and longitudinal bearing walls with fixing in buildings built of bricks were considered (Fig. 2).

To identify seismic effect on this junction, a strain gauge, made in the form of a clip from an elastic steel strip was attached to the column, to the beam and load-bearing walls [8-9]. The design of the strain gauge is shown in figure 3. After manufacturing the strain gauge is calibrated using a special stand and the calibration graph is built. A numerical value of the displacement at the studied point is determined after each subsequent measurement using the calibration curve.

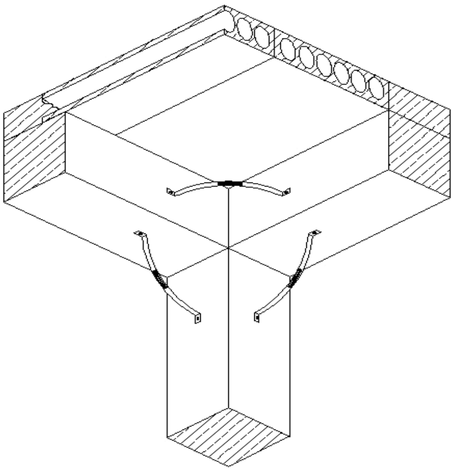

Figure 1. Mounting displacement gauges on the complex junction of the frame building

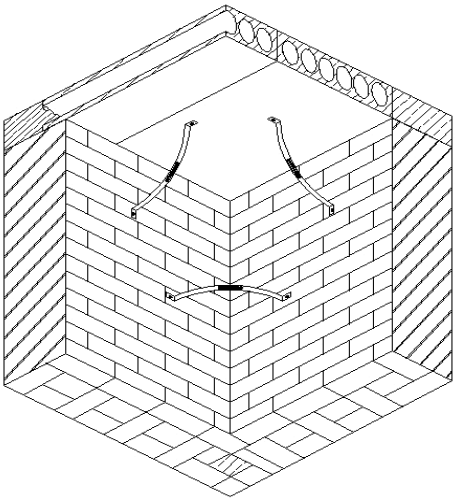

Figure 2. Mounting displacement gauges on the interface junction of the bearing walls of buildings made of bricks

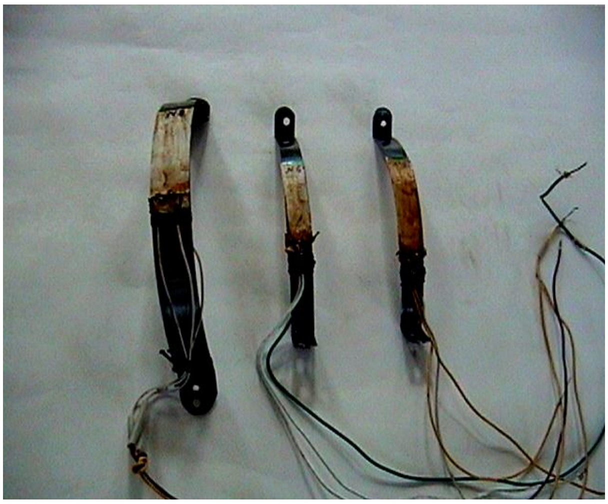

Figure 3. Displacement gauges, plates with glued strain gauges and connecting wires

For register the strain, the gauge is connected to the measuring complex, consisting of the measuring bridge, an amplifier, an analog-to-digital converter (ADC), and a laptop with software. The measuring bridge, amplifier and ADC are located in one body (figure 4).

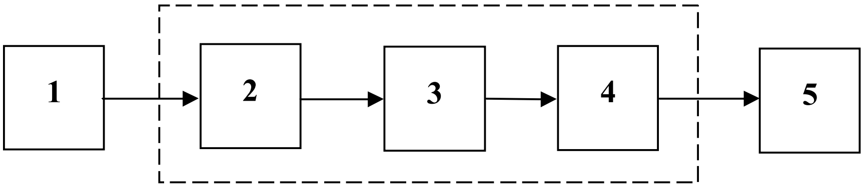

Figure 4. Block diagram of the measuring channel:
1- strain gauge, 2- measuring bridge, 3- amplifier,
4 - Analog-to-digital converter (ADC), 5- laptop.

The strain gauge measuring channel consists of the strain gauge and the measuring complex. The principle of the operation of the strain gauge measuring channel is as follows: the analog signal from the strain gauge is transmitted to the measuring bridge, then to the amplifier, where the signal is amplified. The amplified analog signal is converted by the ADC to the digital signal, transmitted to the USB port of the laptop. The software installed in the laptop processes the received data, displays the information in the form of a graph on the monitor and saves it in the file.

Before measurements, the strain gauge was calibrated on a special calibration stand (Fig. 5). For this, the strain gauge was fixed in the movable racks 2 at a certain distance (sensor base), the indicator needles 4 were set to zero, which corresponds to the beginning of the measurement. The position of one movable racks 2 was changed by rotating the regulator 3, changing the sensor base and the bending of the steel clip with glued strain gauges. In this case, the resistance of the strain gauges changed, causing a change in the signal. The greater the bending of the steel clip from the initial position, the greater the magnitude of the signal and beam displacement on the monitor.

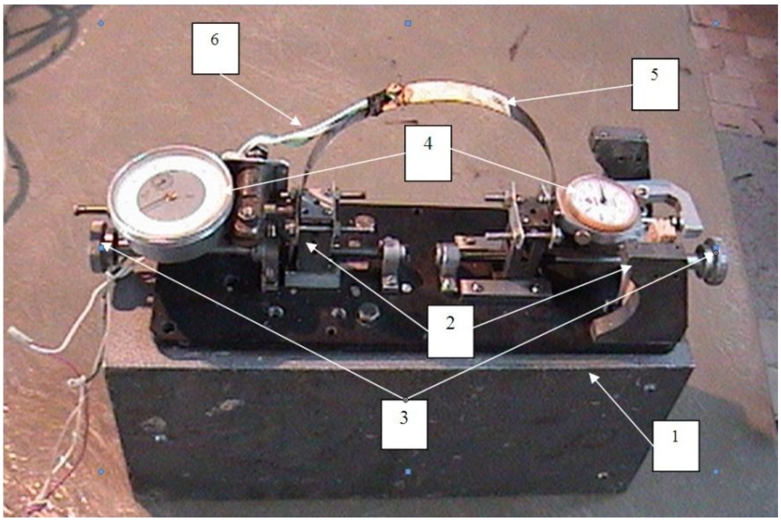

Figure 5. Stand for strain gauge calibration:
1 - installation base, 2 - racks, 3 - moving shoulders, 4 - indicators of ИЧ10МН type,
5 - calibrated displacement gauge, 6 - connecting wires to the measuring channel.

3. Research results

Figure 6 shows the curve, recorded during the calibration of the strain gauge with the measuring complex and displayed on the laptop monitor when the movable rack is displaced by 0.3 mm.

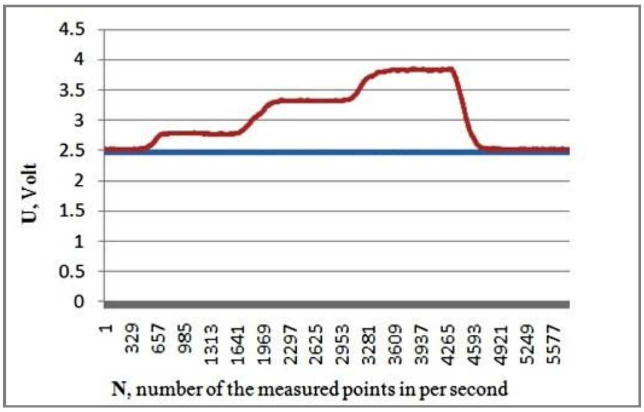

Figure 6. Calibration curve of the strain gauge channel, 0.3 mm displacement of the movable rack

At computer calibrating the strain gauge channel, 9600 measurements in 40 seconds were performed, shown on the graph horizontal axis. That is, 240 measurements per 1 second. This recording mode allows recording low-frequency oscillatory processes without loss of information. Displacements of the mobile racks of the stand in millimeters cause a change of signal in Volts, shown on the vertical scale.

The results of measurement according to the readings of the ИЧ10МН indicator in millimeters are given in table 1 as well as the corresponding readings in Volts on the laptop screen, and their average values in Volts. These results were obtained by 5 times reduction of the sensitivity of the strain gauge channel amplifier ($\beta_t = 5$).

Table 1 - Measurement results by strain gauge channel

Indicator of ИЧ10МН, mm	1st series, Base increase, U, Volt	2nd series, base reduction U, Volt	1st series, Base increase, U, Volt	2nd series, base reduction U, Volt	U_{aver}, Volt	U_{aver}/A_u, Volt/mm
0	0	0	0	0	0	0
0.1	0.31	0.31	0.26	0.26	0.29	2.9
0.3	0.82	0.84	0.79	0.81	0.82	2.7
0.5	1.35	1.39	1.3	1.3	1.34	2.7
						$\approx 2.8_{\text{aver}}$

Calculating the coefficient of the increase of the strain gauge channel according to the formula (1), we obtain:

$$f_t = \beta_t \cdot U_t / / A_u \quad , \tag{1}$$

where A_u is the displacement of the movable racks along ИЧ10МН indicator, in mm; U_t is the magnitude of the channel voltage, in Volt; β_t is the coefficient of sensitivity reduction of the amplifier of the strain gauge measuring channel along the amplifier; f_t is the coefficient of increase of the strain gauge measuring channel, Volt/mm.

According to the data obtained, the coefficient of strain gauge channel increase, with account for 10 times decrease in the amplifier sensitivity, is $f_t = 14$ Volt/mm.

Further, the coefficient of the increase of the strain gauge channel f_t is used for the calibration of the seismometric channels of mobile station and strain measurements.

4. Discussion of results

Consider a behavior of a complex junction of the brick four-story building of the Chemical and Pharmaceutical Research Institute "Uzfarmsanoat" after the earthquake occurred on the border between Uzbekistan and Kazakhstan on the night of March 14, 2019 at 02:32 a.m. Tashkent time. The epicenter was located at a distance of 28 km from Tashkent to the north-west. Earthquake coordinates are: 41.40 degrees north latitude, 68.94 degrees east longitude. Magnitude is M = 4.3, depth is h = 10 km. (Data presented by the Republican Center for Seismic-Prediction Monitoring of the Ministry of Emergencies of the Republic of Uzbekistan). The strength of tremors in Tashkent was 4 points. The seismogram of this earthquake recorded for 15 minutes by Engineering - Seismometric Observation Station (ESOS) is shown in figure 7. Measuring seismometers SM-3 were located on the concrete floor in the basement of the building and were oriented in longitudinal, transverse and vertical directions to the institute building.

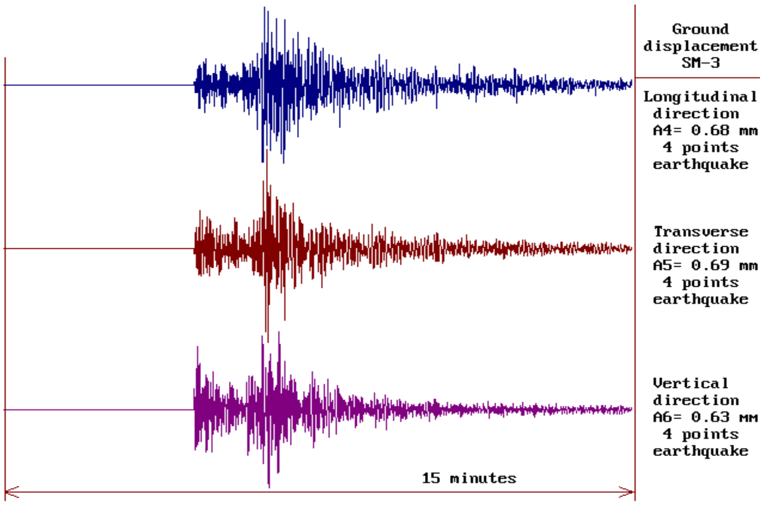

Figure 7. An earthquake in Kazakhstan,
recorded by the Engineering - Seismometric Observation Station (ESOS)
on March 14, 2019, at 2:32 a.m.

The seismogram shows the displacement in millimeters to which the oscillation intensity in points corresponds according to the MSK-64 seismic scale.

The analysis of the seismograms must begin with the determination of the periods of oscillations T of the seismometers. To do this, in figure 7, we select a fragment with maximum amplitudes, and stretch it horizontally (figure 8). The velocity and frequency of oscillations in the longitudinal, transverse and vertical directions that affect the building can be calculated by the seismogram. The interval between the dashed lines is 1 second.

According to the calibration values of the magnification factor and the periods of oscillations (frequency) for the SM-3 seismometer, a period close to the values obtained during the earthquakes is determined. For the soil and floor of the basement, the periods of the oscillations are: $T_{long} = 0.105$ s for longitudinal, $T_{trans} = 0.09$ s for the transverse and $T_{vert} = 0.125$ s for the vertical components, where the corresponding frequencies of soil oscillations in the longitudinal, transverse and vertical directions are:

$$T = 1/\omega, \tag{2}$$

where: T is the oscillation period;

ω is the oscillation frequency.

$$T_{long} = 0.105 \text{ s}, \quad \omega_{long} = 9.5 \text{ Hz};$$

$$T_{trans} = 0.09 \text{ s}, \quad \omega_{trans} = 11.1 \text{ Hz}.$$

$$T_{vert} = 0.125 \text{ сек}, \quad \omega_{vert} = 8 \text{ Hz}.$$

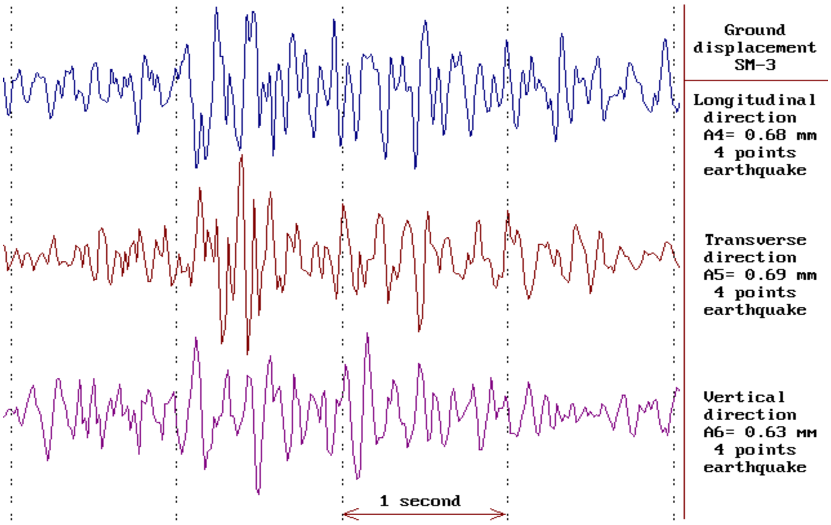

Figure 8. Fragment of the seismogram record with maximum oscillations within 4 seconds

Using formula (1), the maximum values of the displacements of soil oscillations along the longitudinal and transverse directions for the seismometric channel are found

$$A_{true} = \beta \cdot U/f \qquad (3)$$

where: $\beta = 10$ is the coefficient of sensitivity reduction of seismometric channels amplifiers; $U_1 = 0.28$ V, $U_2 = 0.29$ V and $U_3 = 0.25$ V are the recorded voltages in volts corresponding to the maximum values of the amplitude of soil oscillations into longitudinal, transverse and vertical directions.

To define the displacement of concrete floor of the building basement in the horizontal direction during an earthquake, the maximum value of soil displacement was calculate according to the mean-square values of the oscillations components:

$$A = \sqrt{(0.682 + 0.692)} = 0.97\,mm$$

When calculating the seismic wave velocity, f takes the form of

$$f_1 = f_t \cdot T/\,2\pi \qquad (4)$$

The displacement rate during an earthquake is calculated by the formula

$$V = \beta \cdot U/f_1 = \beta \cdot U/\,(f_t \cdot T)/2\pi \qquad (5)$$

Substituting the obtained values into formula (5), we can calculate the velocity of seismic wave at the point of seismometers location

$$V_{soil} = 10 \cdot 0.28\text{ V} / (14\text{ V/mm} \cdot 0.105\text{ s}) / 6.28 \approx 1.2\text{ cm/s}$$

Similarly, the velocities are calculated in horizontal and vertical directions.

The calculated velocity according to the displacement data obtained by seismometers on the MSK-64 seismic scale corresponds to 4 points oscillation of concrete floor of the basement, where they were installed.

The measuring bridge with the strain gauge, was adjusted so that when the measuring bridge was in equilibrium, the signal from the output of the measuring bridge was zero, and the signal on the laptop monitor was in the form of a vertical straight line in the middle of the screen. This is done so that when the beam is shifted to the right or left side, in case of permanent strain, the straight line on the monitor will shift to the right or left of its original position. The difference between the recorded data determines the displacement that occurred in the studied junction.

At the initial measurement, taken 4 months before the earthquake, a straight line 1 (Fig. 9), corresponding to zero displacement, was set on the laptop monitor in the middle of the screen at 0.0 mm. After the earthquake, the repeated measurements of this unit were carried out, which showed on the monitor a line shift to the 0.11 mm mark. When the beam is displaced, the strain gauge changes its spatial position by changing the resistance of the strain gauges, which leads to the appearance of a signal from the measuring bridge and the line on the monitor shifts from position 1 to position 2, which corresponds to a 0.11 mm shift of the beam to the right.

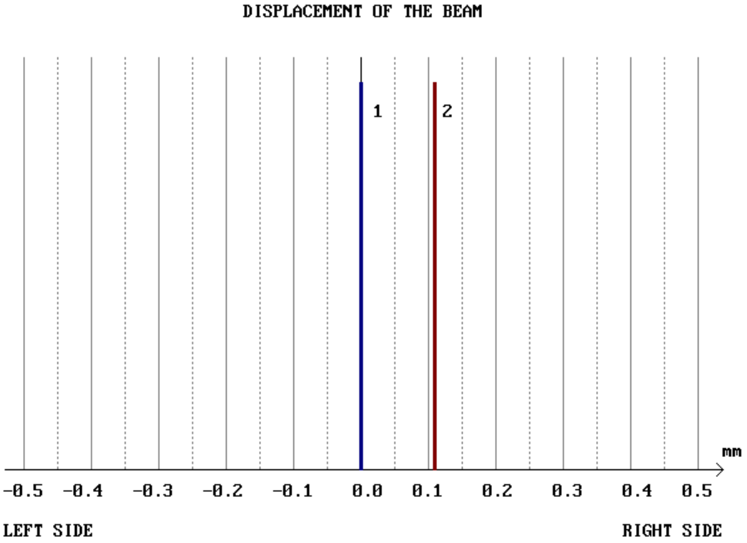

Figure 9. 0.11 mm displacement of the beam after earthquakes

5. Conclusion

The article discusses the method for determining of the possible permanent strain in the complex building structures after the earthquakes. The availability of this method lies in the fact that the applied strain gauge is an elementary design, technologically easy to manufacture and has a low cost. The calibrated strain gauge is attached to the test object, an initial measurement with the measuring complex is carried out, and then, the strain gauge remains at the test object without the measuring complex. For the monitoring, the measuring complex is regularly (once every three months) and each time after an earthquake is connected to the strain gauge. The measurement results are observed on a laptop monitor and compared with previous measurements. This method allows quick monitoring a great number of objects, where similar strain gauges are installed, without wasting time on their installation.

Carrying out monitoring of the micro seismic oscillations of the building provides information on the state of a given object during long-term operation period. When several microseisms records were made over a long time, then when comparing the calculated values of the building's own oscillations in longitudinal and transverse directions, we can draw a conclusion about the state of a structure. An increase in the period of natural frequency oscillations of a building leads to a decrease in the strength characteristics of the building materials and the structure itself. The constancy of the values of the natural oscillations of the microseisms in two directions indicates the good state of the building. In addition, if it is possible to calculate the damping decrement from the obtained records, it is also possible to compare their values and determine the state of the building at the moment.

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