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Professional paper

MEASURES OF REHABILITATION OF UNREINFORCED MASONRY SPORTS FACILITY WITH IRREGULARITIES

Festim Ademi[1], Enis Jakupi[2], Rezona Fetahu[3]

1 Ass. MSc Faculty of Applied Sciences, University of Tetova, Tetovo, Republic of North Macedonia,*
2 Prof. PhD Faculty of Applied Sciences, University of Tetova, Tetovo, Republic of North Macedonia
3 Master Degree Student, Faculty of Applied Sciences, Universty of Tetova, Republic of North Macedonia
**festim.ademi@unite.edu.mk ; enis.jakupi@unite.edu.mk ; r.fetahu211548@unite.edu.mk*

Abstract

Considering the seismicity of the territory of North Macedonia, as well as the significant number of existing masonry buildings, it became necessary to establish a procedure for assessing the seismic resistance of these buildings, as well as the need to improve their carrying capacity by applying various strengthening measures.

The sports halls as accompanying structures were built of unreinforced masonry. The literature in this area was investigated, regarding the estimation of the seismic capacity of this type of building, the characteristics of URM buildings, and the types of damages as well as strengthening measures.

For the selected building, the sports hall "Partizani" in Debar, the seismic load capacity of the walls was controlled according to the valid rules for seismic design of masonry buildings. A numerical analysis was carried out and the structural response was determined. The methods for strengthening by applying steel ties and steel beams on the upper part of the walls were selected, as techniques for improving the global seismic behavior of the building with vertical irregularity. A model of the structures reinforced with steel elements was made and an analysis was carried out. Using the obtained results from the analysis, appropriate comments and conclusions were given regarding the behavior of the masonry structures, their seismic capacity, and the effectiveness of the selected strengthening procedure.

Keywords: Seismic capacity, Masonry Structures, Unreinforced Masonry, Strengthening procedure.

1 Introduction

Predicting the seismic behavior of masonry buildings is an extremely complex task, due to the heterogeneous structure and difficulties in determining the mechanical characteristics of masonry as a building material.

The assessment of the vulnerability of masonry structures in the past was mainly carried out using empirical methods based on data from earthquakes. With the development of computer technology and numerical methods, such as the finite element method, as well as non-linear analysis procedures, it is possible to apply analytical procedures for the determination of seismic vulnerability to masonry structures more often.

Although there is a certain scientific experimental and analytical level of research, the process of strengthening masonry structures, especially in North Macedonia, is mainly based on the experiences of engineers and contractors. Several masonry structures have been strengthened using traditional strengthening techniques such as crack repair, injection, and jacketing. Some of these techniques are based on earthquake damage analysis and engineering assessments, but for some of them, there are also laboratory tests.

In this master's work, the method of strengthening with the application of steel braces placed on the upper part of the walls, as a technique for improving the global seismic behavior of masonry buildings made of unreinforced masonry, was studied. This technique has been investigated in a small number of cases available in literature.

To determine recommendations for the application of this strengthening technique, as well as to obtain adequate knowledge about the behavior of masonry structures reinforced in this way exposed to seismic actions, there is a need for its experimental and analytical research. The motivation for the research arose from the need to analyze the load-bearing condition of existing masonry buildings, analysis of strengthening methods as well as analysis and comparison of the response of the existing and strengthened construction. To answer these questions, this study investigates this traditional strengthening technique by comparing the results experimentally and analytically with the response of unreinforced masonry walls.

Considering the significant number of existing buildings built before the existence of aseismic design regulations, seismic risk mitigation is only possible if information about their vulnerability is provided. Within the framework of existing buildings built before the existence of regulation, masonry structures dominate. Thus, in our country, a large part of public institutions is housed in brick structures, namely:

- Educational institutions - kindergartens, primary and secondary schools, higher education institutions,
- Administration - ministries, local government, courts, etc.
- Cultural institutions - museums, archives, etc.

In the framework of this paper, the research is focused on educational institutions, namely old school buildings and within the same, the gymnasiums as accompanying buildings, built of non-reinforced masonry.

2 Analysis of the seismic vulnerability of an existing building "PARTIZANI" Sports Hall, Debar

The building was built in 1930 and has a basement + ground floor + 1 floor and is located in Debar. There is no project documentation for the construction of the building and all data regarding the existing geometry of the building, as well as possible previous reconstructions, have been determined by recording and measuring the building on-site and by talking to adults working in the gym.

The goal was to define the geometric characteristics of the construction, to create a calculation model, and to estimate the load capacity according to PIOVSP'81.

After the detailed geometrical recording on the spot, graphic attachments of foundations and cross-sections for the construction of the building were made. The construction consists of a basement (on one part of the building), ground floor, and first floor, and a sports hall is in one part. The floor heights are: basement (-3.40), ground floor (+0.00), floor (3.60) roof of the hall (+6.00), and roof of the building (+7.20). The building has a rectangular shape with one section indented by 4.20 m in the middle of the building. The basics of the facility are shown in Figures 1, 2, and 3. All geometric parameters, arrangement, position, and dimensions of the structural elements are additionally shown in the following figures.

The construction system of the building is load-bearing masonry, stone blocks in the basement, and solid brick on the ground floor and first floor. The determined thickness of the walls is 52 cm in the basement on the ground floor and first floor. The mezzanine construction is wooden and flexible. The roof structure is wooden, composed of wooden elements on which the horns and the roof covering (tile) rest. It was difficult to determine the type and dimensions of the foundation construction, so it was assumed that strip masonry foundations were constructed under the load-bearing walls.

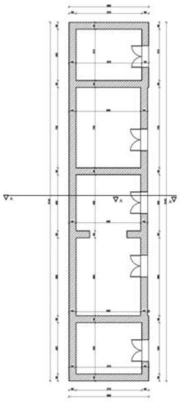

Figure 1: Basement

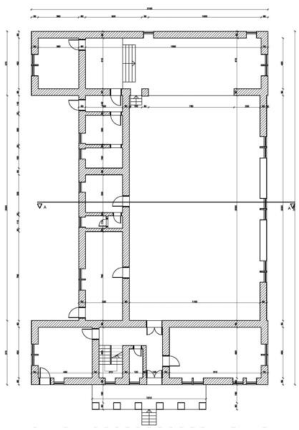

Figure 2: Ground Floor

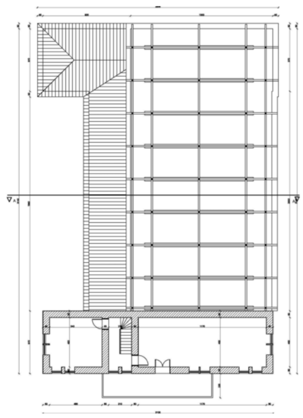

Figure 3: First Floor

Geometry and Materials:

In the mathematical model of the construction, all load-bearing elements determined by on-site recording are taken into account. In the absence of information regarding the values of the mechanical characteristics of the materials in the analysis, the parameters of the materials were taken according to the recommendations of Eurocode 6:

$$f_k = K \cdot f_b^{0,7} \cdot f_m^{0,3} = 0,55 \cdot 9,32^{0,7} \cdot 2,0^{0,3} = 3,23\ MPa$$

- Characteristic Compressive strength of masonry:
- Modul of Elasticity: $200 f_k \le E \le 2000 f_k \quad 646,09 \le E \le 6460,9 MPa$
  $E = 1000 \cdot f_k = 3232\ MPa$
- Shear modulus of masonry: $G = 0,4 \cdot E = 1292,8$ MPa
- Volumetric weight: $\gamma = 16,0\ kN / m^3$

3 Mathematical model

Based on the data recorded on site, a detailed analysis of the structure was made and it was determined that the structure is masonry, made of load-bearing masonry walls, placed in two main directions.

The location and all geometric characteristics (thickness, length, height) of all structural elements bearing walls in the building in the direction "X" and in the direction "Y" are defined.

The load-bearing walls of all floors are marked separately. In addition to the load-bearing walls, the building also consists of cerclage beams at the level of the mezzanine structure. The defined bearing walls in the "X" direction and in the "Y" direction are shown in Figures 4, 5, 6, and 7.

The mathematical model of the construction of the object and the analysis with the method of finite elements was carried out with the computer program SAP2000.

A spatial mathematical model with finite elements is defined for the object, which is made based on the available data on the geometric and material characteristics.

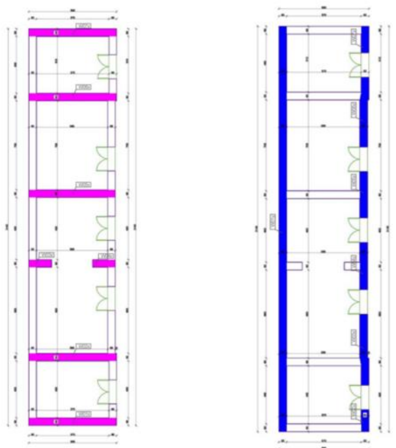

Figure 4: *Bearing walls in both directions on the basement*

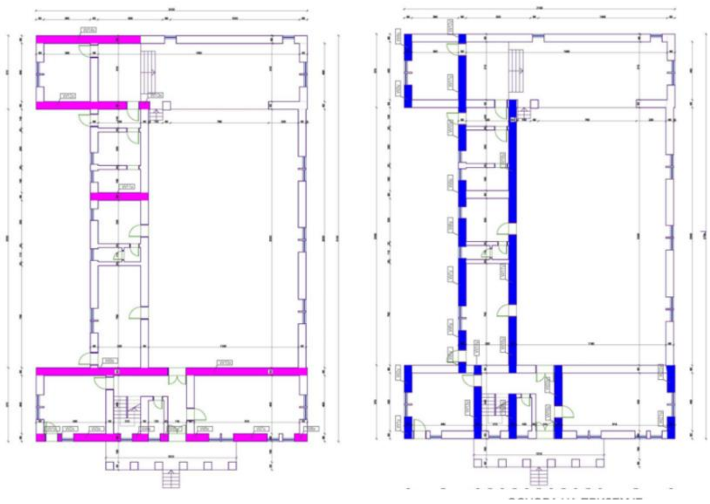

Figure 5: *Bearing walls in both directions on the ground floor*

Figure 6: *Bearing walls in both directions on the ground floor*

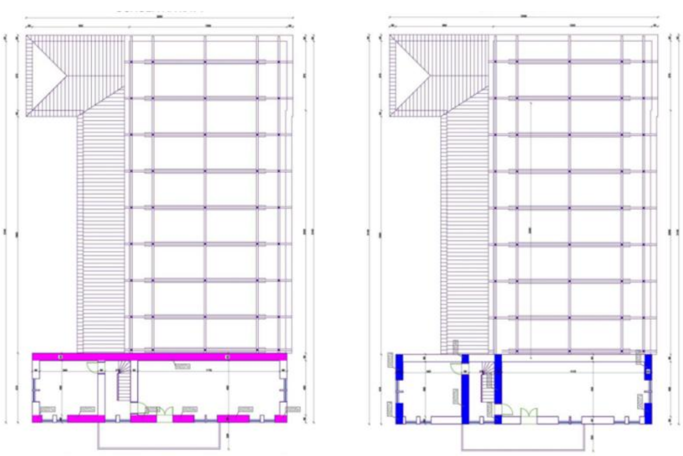

Figure 7: *Bearing walls in both directions on the first floor*

Columns and beams are modeled with beam finite elements with assumed isotropic characteristics:

- Slabs and walls are modeled with 4-node plate finite elements with isotropic characteristics.
- The boundary conditions of the construction with the bearing are modeled in the form of pinches, that is, a rigid foundation is considered.

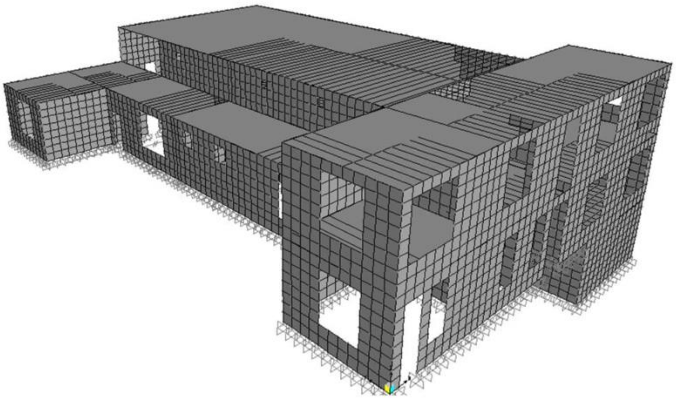

Figure 8: Mathematical model of the object

Determination of dynamic characteristics of the construction

To determine the dynamic characteristics of the structure, the dynamic mass of the structure is calculated by including 100% of the value of permanent loads, 100% of the value of useful loads with long-term effects and 50% of the value of useful loads.

With this analysis, the periods and tonal forms of self-oscillations, as well as the participation of the masses according to the individual tonal forms and have been determined.

The period of the basic tone of the construction is T1 = 0.21s. In the I tone form, the direction of oscillations of the construction is with a translational shift in the direction of the global axis "X". In the III tone form (T=0.16s) the construction oscillates with translational displacement in the direction of the global axis "Y". Table 1 shows the values of the first 12 periods, as well as the participation of masses by routes.

TABLE 1: MODAL PERIODS AND FREQUENCIES

TABLE: Modal Periods And Frequencies						
OutputCase	StepType	StepNum	Period	Frequency	CircFreq	Eigenvalue
Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
MODAL	Mode	1	0.213743399	4.678507064	29.39592684	864.120515
MODAL	Mode	2	0.186635762	5.358029938	33.66549498	1133.365553
MODAL	Mode	3	0.171238517	5.839807626	36.69259347	1346.346416
MODAL	Mode	4	0.16071422	6.222224775	39.09539129	1528.44962
MODAL	Mode	5	0.146929068	6.806005202	42.76339189	1828.707686
MODAL	Mode	6	0.142339719	7.025445919	44.14217857	1948.531929
MODAL	Mode	7	0.12245538	8.166239796	51.3099979	2632.715885
MODAL	Mode	8	9.88E-02	10.12326952	63.60637833	4045.771365
MODAL	Mode	9	0.095510782	10.47002207	65.78508884	4327.677914
MODAL	Mode	10	8.60E-02	11.62955025	73.07061924	5339.315397
MODAL	Mode	11	8.04E-02	12.43844636	78.15306344	6107.901325
MODAL	Mode	12	7.68E-02	13.024095	81.83280237	6696.607543
MODAL	Mode	13	7.67E-02	13.03515431	81.90229006	6707.985117
MODAL	Mode	14	0.074511545	13.42073903	84.32499031	7110.703991
MODAL	Mode	15	7.33E-02	13.64981634	85.76432546	7355.519521
MODAL	Mode	16	7.28E-02	13.73313416	86.28782676	7445.589046
MODAL	Mode	17	7.24E-02	13.80824416	86.75975681	7527.255402
MODAL	Mode	18	7.08E-02	14.13104611	88.78798128	7883.305619
MODAL	Mode	19	7.01E-02	14.27169385	89.67169713	8041.013267
MODAL	Mode	20	0.068519926	14.59429489	91.69865921	8408.644101
MODAL	Mode	21	6.58E-02	15.19063802	95.44559362	9109.861341
MODAL	Mode	22	0.06338629	15.77628222	99.12530465	9825.826021
MODAL	Mode	23	6.23E-02	16.05725254	100.8906933	10178.93199
MODAL	Mode	24	6.11E-02	16.37233306	102.8704025	10582.31971
MODAL	Mode	25	6.06E-02	16.50555813	103.7074803	10755.24147
MODAL	Mode	26	5.89E-02	16.98651577	106.7294263	11391.17044
MODAL	Mode	27	5.84E-02	17.11306512	107.5245593	11561.53086
MODAL	Mode	28	5.79E-02	17.26397987	108.4727847	11766.34501
MODAL	Mode	29	5.74E-02	17.42307966	109.4724382	11984.21472
MODAL	Mode	30	5.71E-02	17.50564033	109.9911821	12098.06014

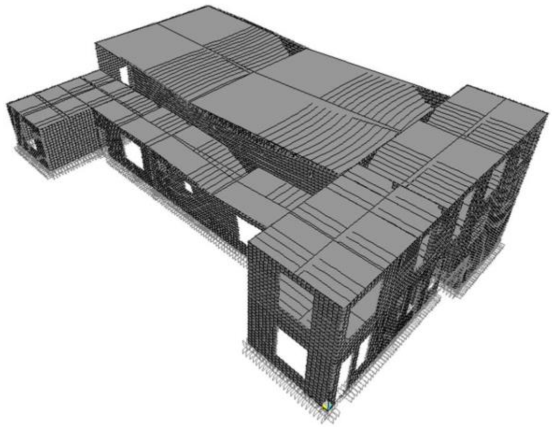

Figure 9: *Display of tone form in ''Y '' direction, T = 0.21 s*

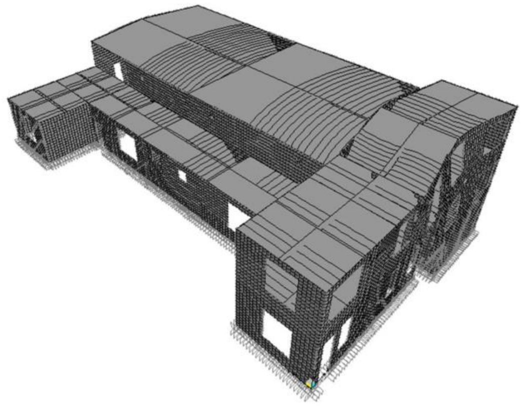

Figure 10: *Display of tone form in ''Y'' direction, T = 0.16 s*

Seismic analysis according to PIOVSP'81

The seismic calculation, by the Rulebook on technical standards for the construction of high-rise buildings in seismically active areas, is carried out according to the method of equivalent horizontal load.

The object is treated as an object of category II, which is in a location corresponding to category II soil. The construction has been analyzed for the effect of an earthquake in a zone of IX degree according to the MKZ seismic scale.

$$S = K_0 \cdot K_s \cdot K_d \cdot K_p \cdot G = 0{,}1 \cdot 1{,}5 \cdot 1{,}0 \cdot 2 \cdot G = 0.3G = 3072.5kN$$

The total seismic force is distributed along the height of the building according to the form given in PIOVSP'81:

$$S_i = S \frac{G_i \cdot H_i}{\sum_{i=1}^{n} G_i \cdot H_i}.$$

The calculated seismic forces per floor are given in a table:

TABLE 2: SEISMIC FORCES PER FLOOR

i	Si
0	619.1
1	1115.2
2	1338.2

Considering that the current Rulebook does not define a procedure for analyzing masonry structures from the action of seismic load, in the case when the calculation is performed on a three-dimensional mathematical model with finite elements, the analysis is performed in the following way (for each direction separately):

- A division of belonging areas from the mezzanine construction has been made the walls. Each field of the mezzanine construction as a surface is divided on the load-bearing walls that "support" that field.

- The load from the inter-floor construction is calculated for each load-bearing wall separately, in proportion to the area concerned.
- The own weight of each wall is calculated separately.
- The load from the walls in the direction that is not is subject to consideration calculates and applies accordingly, according to the location of the load-bearing walls in the analyzed direction.
- The total load on each wall is calculated separately.
- The total calculated seismic force on each wall is applied in the mathematical model as a horizontal line load at the upper end of the wall.

According to the procedure defined above, the calculated seismic forces for the individual walls are shown in the following tables:

TABLE 3: SEISMIC FORCES IN BOTH DIRECTIONS ON THE BASEMENT

Floor 0

X Direction

W01	196.6016	69.12
W02	196.6016	134.21
W03	50.9184	39.77
W04	50.9184	45.17
W05	196.6016	102.23
W06	196.6016	125.55
W07	196.6016	102.99

Y Direction

W01	888.2432	286.83
W02	50.856	25.72
W03	161.1168	89.08
W04	108.784	43.56
W05	107.3696	53.81
W06	158.288	80.60
W07	60.7568	39.45

TABLE 4: SEISMIC FORCES IN BOTH DIRECTIONS ON THE FIRST FLOOR

Floor 1

X Direction

W1	22.8384	31.27
W2	16.0992	4.80
W3	119.808	87.69
W4	50.01984	91.95
W5	27.5184	7.57
W6	66.88864	37.41
W7	100.905	41.34
W8	41.0176	38.66
W9	314.2464	279.42
W10	290.2848	157.18
W11	134.784	107.39
W12	215.904	102.08
W13	30.2016	55.79
W14	242.6112	72.66

Y Direction

W1	61.984	36.33
W2	73.9648	58.58
W3	63.4816	25.55
W4	72.4672	35.51
W5	30.2016	41.19
W6	62.2336	14.16
W7	123.76	27.13
W8	69.6384	15.58
W9	76.6688	23.54
W10	79.5392	17.94
W11	142.7712	54.49
W12	27.2064	28.05
W13	126.048	94.64
W14	27.2064	40.79
W15	104.233	66.22
W16	136.5312	94.26
W17	172.7232	59.55
W18	290.784	117.88
W19	53.86368	60.51
W20	99.39072	71.17
W21	61.984	59.84
W22	66.4768	72.29

TABLE 5: SEISMIC FORCES IN BOTH DIRECTIONS ON THE SECOND AND THIRD FLOOR

Floor 3

X Direction

W201	36.192	26.86
W202	119.4086	70.28
W203	85.0512	35.69
W204	73.0704	25.22
W205	103.8336	35.51
W206	54.4128	31.40
W207	628.992	239.95

Y Direction

201	61.984	25.91
W202	73.9648	56.85
W203	126.048	77.13
W204	27.2064	46.59
W205	27.2064	32.13
W206	126.048	95.11
W207	61.984	40.54
W208	73.9648	69.10

Floor 2

X Direction

W101	209.664	326.45
W102	149.76	285.07
W103	97.5936	61.36
W104	422.3232	157.49
W105	55.1616	42.95

Y Direction

W101	417.3312	384.93
W102	193.2736	105.69
W103	204.3392	79.39
W104	201.8432	78.53
W105	291.6992	143.80
W106	113.4016	102.53

Assessment of the carrying capacity according to PIOVSP'81

In this paper, the control of the stresses in the walls was carried out according to the method of permissible stresses as well as according to the method of limit states as recommended according to the current Rulebook for the design of masonry buildings in seismically active areas.

Control according to the method of permissible stresses.

According to PIOVSP'81, the main tensile stresses in the individual elements (walls) are controlled, and their values must not exceed the values given in Table 4 of the same Rulebook.

According to this table, for a wall made of solid clay brick with dimensions 6x12x24 cm and brand MO 10.0 and mortar with brand MM 2.5, the allowable main tensile stress is 0.09 MPa. The principal tensile stress in the individual elements is calculated according to the relation:

$$\sigma_n = \sqrt{\frac{\sigma_0^2}{4} + \left(1{,}5 \cdot \tau_0\right)^2} - \frac{\sigma_0}{2} \geq \sigma_{n,doz} = 0{,}09\ MPa$$

A check was made in three sections of each load-bearing wall, as shown in figure 11:

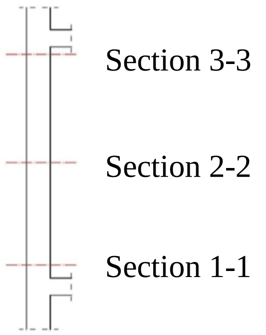

Figure 11: Mathematical model of the object

Control according to the method of limit stresses

According to this control, the bearing capacity of the object is compared with the total seismic force, whereby the reliability factor should be taken at least 1.5 (PIOVSP'81). The shear stress of an individual element, a wall, is calculated according to the following relation:

where: $\sigma_{0,rus}$ is the main tensile stress in the wall during collapse. The values for this stress are given in Table 5 of the Rulebook. According to this table, for a wall made of solid clay brick with dimensions 6x12x24 cm and brand MO 10.0 and plaster with brand MM 2.5, the main tensile stress at failure is 0.18 MPa. The transverse force in the wall is calculated as the product of the shear stress at the top of the wall and the shear area of the wall (length x thickness).

This can be represented by the following relation:

$$R_{w,x} = \sum_{i=1}^{n_x} A_w \left(\frac{\sigma_{0,rus}}{1.5} \sqrt{1 + \frac{\sigma_0}{\sigma_{0,rus}}} \right)$$

$$R_{w,y} = \sum_{i=1}^{n_y} A_w \left(\frac{\sigma_{0,rus}}{1.5} \sqrt{1 + \frac{\sigma_0}{\sigma_{0,rus}}} \right)$$

The following table shows the results of the analysis performed according to the X-direction limit load method:

Tensile stress 180

Floor 0 direction
X Правец

Wall ID	Length (m)	Depth (m)	Area of the wall	Section	Force (kN)	Stress (σ_0) Kn/m^2	Stress , kN/m^2	Shear Force (kN)
W01	6.95	0.52	3.614	rope	357.18	98.83232	149.3539	539.765
W02	6.95	0.52	3.614	rope	472.98	130.8744	157.7021	569.9354
W03	1.8	0.52	0.936	rope	53.9	57.58547	137.8653	129.0419
W04	1.8	0.52	0.936	rope	89.36	95.47009	148.4507	138.9498
W05	6.95	0.52	3.614	rope	150.93	41.76259	133.1954	481.3681
W06	6.95	0.52	3.614	rope	318.86	88.22911	146.4866	529.4026
W07	6.95	0.52	3.614	rope	332.83	92.09463	147.5384	533.2037
								2921.666

Floor 1 direction
X Правец

W1	0.7	0.52	0.364	горе	18.71	51.4011	136.0591	49.52552
W2	0.3	0.52	0.156	горе	14.27	91.47436	147.3701	22.98974
W3	3.65	0.52	1.898	горе	151.99	80.07903	144.244	273.7751
W4	1.32	0.52	0.6864	горе	60.95	88.79662	146.6415	100.6547
W5	0.65	0.52	0.338	горе	20.15	59.61538	138.453	46.79711
W6	1.77	0.52	0.9204	горе	103.69	112.6575	153.0118	140.832
W7	2.63	0.52	1.3676	горе	144.69	105.7985	151.2081	206.7921
W8	1	0.52	0.52	горе	24.27	46.67308	134.662	70.02422
W9	10.2	0.52	5.304	горе	451.38	85.10181	145.6302	772.4224
W10	9.4	0.52	4.888	горе	437.28	89.4599	146.8223	717.6675
W11	4.5	0.52	2.34	горе	80.47	34.38889	130.9623	306.4517
W12	7	0.52	3.64	горе	37.59	10.32692	123.3943	449.1553
W13	0.8	0.52	0.416	горе	19.89	47.8125	135	56.16
W14	8.1	0.52	4.212	горе	36.57	8.682336	122.86	517.4864
								3730.734

Floor 2 direction
X Праве

W101	21	0.52	10.92	горе	249.95	22.88919	127.4015	1391.224
W102	3	0.52	1.56	горе	39.21	25.13462	128.1045	199.8431
W103	1.85	0.52	0.962	горе	30.89	32.11019	130.2644	125.3144
W104	8.25	0.52	4.29	горе	47.11	10.98135	123.6063	530.2709
W105	1	0.52	0.52	горе	1.63	3.134615	121.0404	62.94099
								2309.593

Floor 2
X Правец direction

W101	21	0.52	10.92	горе	249.95	22.88919	127.4015	1391.224
W102	3	0.52	1.56	горе	39.21	25.13462	128.1045	199.8431
W103	1.85	0.52	0.962	горе	30.89	32.11019	130.2644	125.3144
W104	8.25	0.52	4.29	горе	47.11	10.98135	123.6063	530.2709
W105	1	0.52	0.52	горе	1.63	3.134615	121.0404	62.94099
								2309.593

Floor 3
X Правец

W201	0.8	0.52	0.416	горе	4.08	9.807692	123.2259	51.26196
W202	3.17	0.52	1.6484	горе	26.49	16.07013	125.2422	206.4493
W203	2.15	0.52	1.118	горе	17.37	15.53667	125.0717	139.8302
W204	1.75	0.52	0.91	горе	24.51	26.93407	128.6652	117.0853
W205	2.65	0.52	1.378	горе	30	21.77068	127.0498	175.0746
W206	1	0.52	0.52	горе	5.26	10.11538	123.3257	64.12937
W207	21	0.52	10.92	горе	154.57	14.15476	124.629	1360.948
								2114.779

X		
Rw	Sx	фактор
11076.77	3072.5	3.605134

Since the reliability factor is greater than 1.5, it can be concluded that the control according to the limit load method in the X direction is satisfied.

The following Table shows the results of the analysis performed according to the limit load method in the Y direction:

Wall ID	Length (m)	Depth (m)	Area of the wall	Control of the load capacity of the object				
				Section	Force (kN)	Stress (σ_0) Kn/m^2	Stress, kN/m^2	Shear Force (kN)

Tensile stress 180

W01	31.4	0.52	16.328	rope	289.27	17.71619	125.7668	2053.521
W02	1.7	0.52	0.884	rope	112.69	127.4774	156.8381	138.6449
W03	5.5	0.52	2.86	rope	444.79	155.521	163.8343	468.5661
W04	3.65	0.52	1.898	rope	320.77	169.0042	167.0938	317.144
W05	3.6	0.52	1.872	rope	322.92	172.5	167.9286	314.3623
W06	5.4	0.52	2.808	rope	412.76	146.9943	161.7391	454.1635
W07	2.05	0.52	1.066	rope	131.23	123.1051	155.719	165.9964
								3912.398

Floor 1
Y Пра direction

W1	1.7	0.52	0.884	rope	62.69	70.91629	141.6803	125.2454
W2	2.1	0.52	1.092	rope	68.39	62.62821	139.3207	152.1382
W3	1.75	0.52	0.91	rope	11.29	12.40659	124.0666	112.9006
W4	2.05	0.52	1.066	rope	14.84	13.9212	124.554	132.7746
W5	0.8	0.52	0.416	rope	13.61	32.71635	130.4504	54.26737
W6	1.5	0.52	0.78	rope	10.23	13.11538	124.2949	96.95005
W7	3.7	0.52	1.924	rope	21.81	11.33576	123.7209	238.039
W8	2.2	0.52	1.144	rope	11.15	9.746503	123.206	140.9477
W9	2.05	0.52	1.066	rope	11.46	10.75047	123.5315	131.6846
W10	2	0.52	1.04	rope	14.19	13.64423	124.465	129.4436
W11	4.35	0.52	2.262	rope	44.74	19.77896	126.4212	285.9647
W12	0.7	0.52	0.364	rope	1.89	5.192308	121.7185	44.30552
W13	4	0.52	2.08	rope	158.79	76.34135	143.2037	297.8638
W14	0.7	0.52	0.364	rope	16.54	45.43956	134.2951	48.8834
W15	3.48	0.52	1.8096	rope	154.24	85.23431	145.6666	263.5982
W16	4.35	0.52	2.262	rope	175.59	77.62599	143.5621	324.7375
W17	5.35	0.52	2.782	rope	237.12	85.23364	145.6664	405.2438
W18	9.5	0.52	4.94	rope	384.73	77.88057	143.633	709.5471
W19	1.59	0.52	0.8268	rope	25.2	30.47896	129.7625	107.2877
W20	3.11	0.52	1.6172	rope	42.86	26.5026	128.531	207.8603
W21	1.7	0.52	0.884	rope	70.21	79.42308	144.062	127.3508
W22	1.85	0.52	0.962	rope	71.38	74.19958	142.6042	137.1853
								4274.219

Floc direction
Y Правец

W101	20.9	0.52	10.868	rope	413.29	38.02816	132.0691	1435.327
W102	3.65	0.52	1.898	rope	50.29	26.49631	128.529	243.9481
W103	3.65	0.52	1.898	rope	75.33	39.68915	132.5712	251.6202
W104	3.6	0.52	1.872	rope	74.69	39.8985	132.6344	248.2916
W105	5.4	0.52	2.808	rope	81.27	28.94231	129.288	363.0407
W106	2.05	0.52	1.066	rope	20.19	18.93996	126.1554	134.4817
								2676.709

Flo direction
Y Правец

W201	1.7	0.52	0.884	горе	6.29	7.115385	122.3488	108.1563
W202	2.1	0.52	1.092	горе	5.92	5.421245	121.7937	132.9987
W203	4	0.52	2.08	горе	23.52	11.30769	123.7118	257.3206
W204	0.7	0.52	0.364	горе	1.68	4.615385	121.5287	44.23646
W205	0.7	0.52	0.364	горе	2.09	5.741758	121.8989	44.3712
W206	4	0.52	2.08	горе	21.59	10.37981	123.4114	256.6958
W207	1.7	0.52	0.884	горе	4.8	5.429864	121.7965	107.6681
W208	2.1	0.52	1.092	горе	6.76	6.190476	122.046	133.2743
								1084.721

Y		
Rw	Sy	фактор
11948.05	3072.5	3.888706

Since the reliability factor is greater than 1.5, it can be concluded that the control according to the limit load method in the Y direction is satisfied.

Strengthening the construction and comparing the results

As a measure to strengthen the construction of the sports hall “Partizani” in Debar, it was chosen to connect the walls with steel elements, namely: connection with steel braces with diameter 30 mm in the transverse direction, and a second measure, strengthening with steel beam elements in the transverse direction, with a section 200x200 mm and wall thickness 10 mm.

This measure of strengthening is defended as the simplest measure for global strengthening of the longitudinal walls of the building and ensuring the joint work of the walls as a whole. Also, strengthening of this type does not add additional mass or additional loads on the structure and is simple to perform. The steel elements are performed close to the upper end of the walls, but of course the walls should be secured at the point of connection with the steel braces by placing plates to prevent stress concentration in the walls.

For the construction of the hall, 3 three-dimensional numerical models were made, namely:

- Model 1 existing construction in which the longitudinal walls are not connected to elements in the transverse direction except for the end transverse walls,
- 2. Model 2, construction was strengthened by connecting the walls with steel braces with a diameter of 30 mm,
- 3. Model 3 – construction strengthened by connecting the walls with steel beam elements with a section of 200x200 mm x 10 mm.

For the three models and the loads determined by the load analysis, computer analysis was performed with the SAP2000 software package, which determined the significant periods and tone forms of the structure's oscillations. In the following table, the values of periods for characteristic tone forms and the participation of masses for all three models are shown.

N Model before retrofit						
Табела на тонови форми и учество на маси						
OutputCase	StepType	StepNum	Period	UX	UY	UZ
Text	Text	Unitless	Sec	Unitless	Unitless	Unitless
MODAL	**Mode**	**55**	**5.15E-02**	**4.30E-03**	**0.171142**	**1.58E-05**
MODAL	Mode	22	0.122848	5.20E-04	0.092675	4.24E-06
MODAL	Mode	36	7.24E-02	5.88E-03	7.81E-02	1.16E-05
MODAL	Mode	34	7.50E-02	4.53E-02	4.25E-02	4.05E-05
MODAL	Mode	82	3.63E-02	1.44E-03	3.15E-02	1.97E-04
MODAL	**Mode**	**32**	**7.72E-02**	**0.117017**	**3.10E-02**	**3.05E-04**
MODAL	Mode	50	5.60E-02	4.14E-03	2.47E-02	3.13E-07
MODAL	Mode	19	0.143932	1.13E-03	2.19E-02	3.15E-06
MODAL	Mode	52	0.054856	1.66E-02	2.10E-02	3.87E-04
MODAL	Mode	53	5.32E-02	9.15E-03	1.91E-02	6.36E-05
Санација со затега Ø30мм						
OutputCase	StepType	StepNum	Period	UX	UY	UZ
Text	Text	Unitless	Sec	Unitless	Unitless	Unitless
MODAL	**Mode**	**55**	**5.15E-02**	**6.15E-03**	**0.162002**	**4.26E-05**
MODAL	Mode	36	7.24E-02	6.08E-03	8.20E-02	1.17E-05
MODAL	Mode	21	0.122482	6.70E-03	6.99E-02	1.04E-05
MODAL	Mode	34	7.50E-02	4.50E-02	0.043413	4.27E-05
MODAL	Mode	18	0.137736	4.15E-04	3.98E-02	5.72E-06
MODAL	**Mode**	**32**	**7.72E-02**	**0.115766**	**0.030782**	**3.07E-04**
MODAL	Mode	82	3.63E-02	7.32E-04	2.89E-02	4.29E-05
MODAL	Mode	52	0.054812	1.59E-02	2.33E-02	4.58E-04
MODAL	Mode	50	5.57E-02	5.79E-03	2.05E-02	2.24E-05
MODAL	Mode	53	0.053127	7.49E-03	0.019608	7.82E-05
Санација со профил 200x200x10мм						
OutputCase	StepType	StepNum	Period	UX	UY	UZ
Text	Text	Unitless	Sec	Unitless	Unitless	Unitless
MODAL	**Mode**	**54**	**5.15E-02**	**1.20E-02**	**0.139634**	**1.64E-04**
MODAL	Mode	20	0.123488	3.73E-04	7.92E-02	3.16E-06
MODAL	Mode	36	7.02E-02	0.002524	5.26E-02	1.27E-05
MODAL	Mode	33	7.49E-02	0.038522	4.55E-02	6.13E-05
MODAL	Mode	18	0.135585	2.85E-04	4.20E-02	3.02E-06
MODAL	Mode	34	7.32E-02	3.94E-03	0.036558	1.15E-06
MODAL	Mode	30	7.72E-02	0.125213	3.06E-02	2.63E-04
MODAL	Mode	51	5.34E-02	1.96E-02	2.92E-02	4.18E-04
MODAL	**Mode**	**9**	**0.227045**	**0.127883**	**2.05E-05**	**1.87E-06**
MODAL	Mode	48	5.61E-02	2.04E-03	2.50E-02	1.66E-04

From the results, it can be observed that a significant reduction of the periods of oscillation of the construction is about the same ones for the unreinforced construction with unconnected walls.

The period T1=0.2468 sec for Model 2 is 27% less than the same for Model 1, T1 = 0.338 sec.

It indicates an increase in the stiffness of the construction. For Model 3, T1=0.227 sec, which is a 33% lower value compared to T1 for the existing construction. From here it can be concluded that the selected strengthening measures have an impact on the global behavior of the construction

For the existing construction as well as for the strengthened construction, the seismic forces in the walls as well as the horizontal displacements of the construction due to these forces were determined. The horizontal displacements in the transverse direction of the hall construction are shown in Figures 90-92, for the three models.

It can be seen from the pictures that the values of the maximum horizontal displacement in the x direction of the upper part of the wall at a characteristic point are: 0.00507; 0.00413; and 0.00344; for the three models respectively. This means that the displacement for the existing structure (Model 1) is 23% greater than the displacement in Model 2 and 47% greater than the displacement in Model 3. Or, in terms of stiffness, these values show a significant increase in stiffness with the addition of steel elements in the construction.

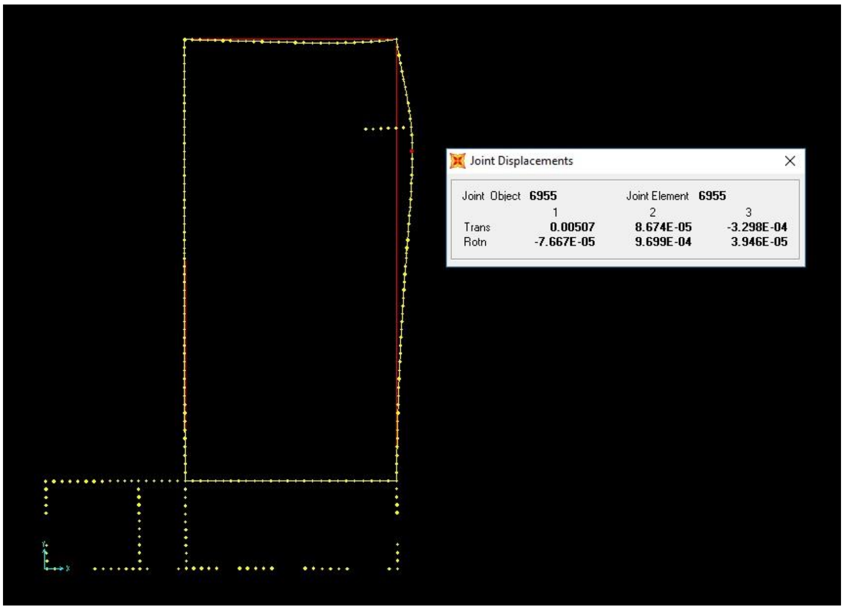

Figure 12: Horizontal displacement of the structure (Model 1)

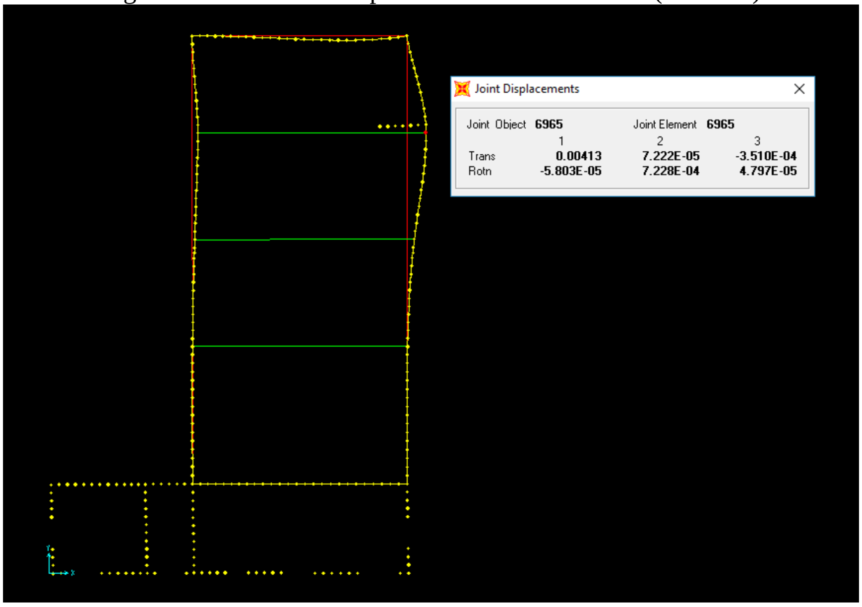

Figure 13: Horizontal displacement of the structure (Model 2)

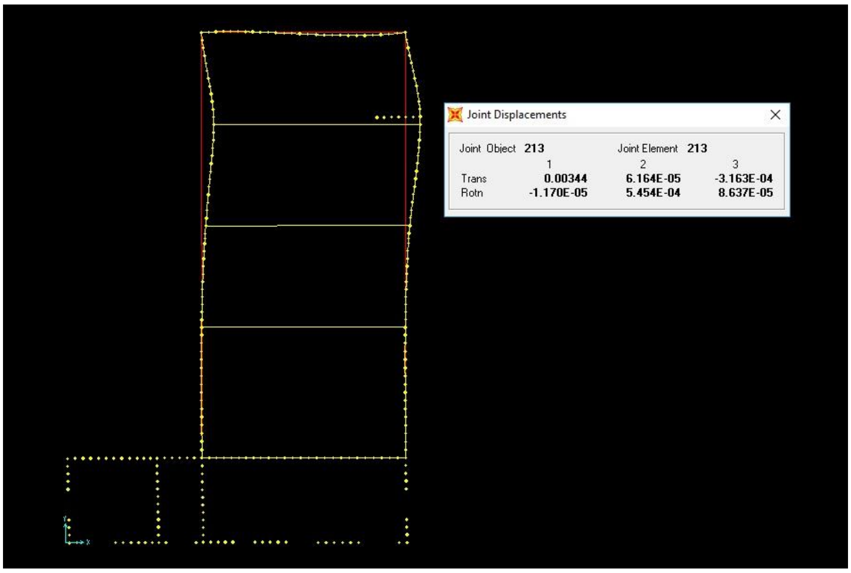

Figure 14: Horizontal displacement of the structure (Model3) due to seismic forces

It can also be noted that model 2 provides joint work of the braced walls but a more uneven distribution of the seismic load on both walls. Model 3 provides joint work of the walls, greater stiffness of the structure, and a more even distribution of seismic forces on both walls. The displacements of the two walls are approximately equal and the beam members somehow provide a connection between the walls much like a rigid diaphragm would.

In the following tables, the results of the calculated normal and tangential stresses in the walls of the hall construction are given.

Wall ID	Length (m)	Thicknes (m)	Area of wall	Stress Control - (Yes - Satisfies) (No - Does Not Satisfy)						
				Section	Normal		Tension		Main tensile stress	Control
					Force (kN)	Stress (σo) kN/m2	Force (kN)	Stress (τo) kN/m2		
State of stresses prior to rehabilitation										
	3.48	0.52	1.8096	up	161.13	89.04178	99.78	55.13926	49.40924	Yes
W15	3.48	0.52	1.8096	middle	206.86	114.3126	101.78	56.24447	44.74849	Yes
	3.48	0.52	1.8096	down	244.96	135.3669	83.69	46.24779	29.23651	Yes
	4.35	0.52	2.262	up	189.22	83.65164	157.77	69.74801	70.84701	Yes
W16	4.35	0.52	2.262	middle	260.82	115.305	184.94	81.7595	77.86206	Yes
	4.35	0.52	2.262	down	319.18	141.1052	164.03	72.51547	59.09801	Yes
	5.35	0.52	2.782	up	246.57	88.63048	192.61	69.23436	68.59616	Yes
W17	5.35	0.52	2.782	middle	349.39	125.5895	240.98	86.62114	81.51543	Yes
	5.35	0.52	2.782	down	434.73	156.2653	240.98	86.62114	73.48186	Yes
	9.5	0.52	4.94	up	411.62	83.32389	288.92	58.48583	55.4568	Yes
W18	9.5	0.52	4.94	middle	524.79	106.2328	320.86	64.95142	57.84935	Yes
	9.5	0.52	4.94	down	658.58	133.3158	301.06	60.94332	46.47907	Yes
Rehabilitation with steel braces ф30mm										
	3.48	0.52	1.8096	up	160.61	88.75442	99.78	55.13926	49.4849	Yes
W15	3.48	0.52	1.8096	middle	207.76	114.8099	102.37	56.57051	45.04421	Yes
	3.48	0.52	1.8096	down	247.64	136.8479	83.69	46.24779	29.01458	Yes
	4.35	0.52	2.262	up	184.13	81.40141	157.77	69.74801	71.55932	Yes
W16	4.35	0.52	2.262	middle	254.78	112.6348	184.94	81.7595	78.63457	Yes
	4.35	0.52	2.262	down	315.59	139.5181	164.04	72.51989	59.46702	Yes
	5.35	0.52	2.782	up	272	97.77139	192.61	69.23436	65.89651	Yes
W17	5.35	0.52	2.782	middle	389.06	139.849	240.98	86.62114	77.6278	Yes
	5.35	0.52	2.782	down	474.39	170.5212	240.98	86.62114	70.14731	Yes
	9.5	0.52	4.94	up	741.34	150.0688	288.93	58.48785	40.40834	Yes
W18	9.5	0.52	4.94	middle	935.54	189.3806	321.58	65.09717	41.32788	Yes
	9.5	0.52	4.94	down	1150.56	232.9069	301.06	60.94332	31.59419	Yes
Rehabilitation with steel beam 200x200x10mm										
	3.48	0.52	1.8096	up	161.13	89.04178	99.78	55.13926	49.40924	Yes
W15	3.48	0.52	1.8096	middle	206.8	114.2794	102.37	56.57051	45.16107	Yes
	3.48	0.52	1.8096	down	244.94	135.3559	83.69	46.24779	29.23818	Yes
	4.35	0.52	2.262	up	189.4	83.73121	157.77	69.74801	70.82199	Yes
W16	4.35	0.52	2.262	middle	261.14	115.4465	184.96	81.76835	77.83343	Yes
	4.35	0.52	2.262	down	319.5	141.2467	164.04	72.51989	59.07134	Yes
	5.35	0.52	2.782	up	249.61	89.72322	192.61	69.23436	68.26534	Yes
W17	5.35	0.52	2.782	middle	352.49	126.7038	240.97	86.61754	81.19674	Yes
	5.35	0.52	2.782	down	437.83	157.3796	240.97	86.61754	73.20797	Yes
	9.5	0.52	4.94	up	419.51	84.92105	288.92	58.48583	55.00346	Yes
W18	9.5	0.52	4.94	middle	532.45	107.7834	321.56	65.09312	57.63328	Yes
	9.5	0.52	4.94	down	666.15	134.8482	301.05	60.9413	46.16355	Yes

Wall ID	Length (m)	Thicknes (m)	Area of wall	Stress Control - (Yes - Satisfies) (No - Does Not Satisfy)						
					Normal		Tension			
				Section	Force (kN)	Stress (σo) kN/m2	Force (kN)	Stress (τo) kN/m2	Main tensile stress	Control
State of stresses prior to rehabilitation										
	20.9	0.52	10.868	up	474.49	43.65937	435.73	40.09293	42.14908	Yes
WIOI	20.9	0.52	10.868	middle	635.03	58.43117	447.62	41.18697	39.12456	Yes
	20.9	0.52	10.868	down	805.65	74.13047	455.65	41.92584	35.93358	Yes
	3.65	0.52	1.898	up	71.14	37.48156	71.42	37.62908	40.73274	Yes
W102	3.65	0.52	1.898	middle	188.11	99.10959	133.86	70.52687	67.26672	Yes
	3.65	0.52	1.898	down	259.16	136.5437	73.77	38.86723	21.50584	Yes
	3.65	0.52	1.898	up	82.56	43.49842	66.86	35.22655	35.39163	Yes
W103	3.65	0.52	1.898	middle	249.52	131.4647	148.99	78.49842	69.12033	Yes
	3.65	0.52	1.898	down	319.62	168.3983	47.77	25.1686	8.076405	Yes
	3.6	0.52	1.872	up	83.26	44.4765	66.42	35.48077	35.44217	Yes
W104	3.6	0.52	1.872	middle	249.52	133.2906	142.82	76.29274	65.78545	Yes
	3.6	0.52	1.872	down	322.91	172.4947	45.96	24.55128	7.533394	Yes
	5.4	0.52	2.808	up	106.13	37.79558	95.96	34.17379	35.73539	Yes
W105	5.4	0.52	2.808	middle	285.12	101.5385	172.7	61.50285	54.53208	Yes
	5.4	0.52	2.808	down	377.1	134.2949	85.07	30.29558	13.93202	Yes
	2.05	0.52	1.066	up	35.07	32.89869	34.79	32.63602	35.19442	Yes
W106	2.05	0.52	1.066	middle	102.1	95.77861	41.16	38.61163	27.26265	Yes
	2.05	0.52	1.066	down	123.89	116.2195	3.89	3.649156	0.257234	Yes
Rehabilitation with steel braces ϕ30mm										
	20.9	0.52	10.868	up	471.19	43.35572	435.71	40.09109	42.24667	Yes
WIOI	20.9	0.52	10.868	middle	634.02	58.33824	447.61	41.18605	39.14992	Yes
	20.9	0.52	10.868	down	804.93	74.06423	455.64	41.92492	35.9487	Yes
	3.65	0.52	1.898	up	64.64	34.0569	71.41	37.62381	41.92033	Yes
W102	3.65	0.52	1.898	middle	176.14	92.80295	133.85	70.5216	69.11049	Yes
	3.65	0.52	1.898	down	239.07	125.9589	80.62	42.47629	26.60816	Yes
	3.65	0.52	1.898	up	83.14	43.804	66.85	35.22129	35.28987	Yes
W103	3.65	0.52	1.898	middle	249.75	131.5859	148.98	78.49315	69.08239	Yes
	3.65	0.52	1.898	down	320.22	168.7144	47.76	25.16333	8.059365	Yes
	3.6	0.52	1.872	up	79.18	42.29701	66.42	35.48077	36.1206	Yes
W104	3.6	0.52	1.872	middle	182.56	97.52137	142.83	76.29808	75.64087	Yes
	3.6	0.52	1.872	down	257.13	137.3558	45.96	24.55128	9.250763	Yes
	5.4	0.52	2.808	up	21.34	7.599715	96.05	34.20584	47.64942	Yes
W105	5.4	0.52	2.808	middle	194.85	69.39103	172.75	61.52066	63.89231	Yes
	5.4	0.52	2.808	down	456.03	162.4038	85.12	30.31339	11.86408	Yes
	2.05	0.52	1.066	up	22.1	20.73171	34.77	32.61726	39.64608	Yes
W106	2.05	0.52	1.066	middle	24.91	23.36773	41.12	38.57411	47.34517	Yes
	2.05	0.52	1.066	down	47.44	44.50281	3.88	3.639775	0.66001	Yes
Rehabilitation with steel beam 200x200x10mm										
	20.9	0.52	10.868	up	485.26	44.65035	435.69	40.08925	41.81917	Yes
WIOI	20.9	0.52	10.868	middle	645.83	59.42492	447.59	41.18421	38.83784	Yes
	20.9	0.52	10.868	down	816.49	75.1279	455.61	41.92216	35.68461	Yes
	3.65	0.52	1.898	up	71.17	37.49737	71.4	37.61855	40.71233	Yes
W102	3.65	0.52	1.898	middle	188.63	99.38356	133.84	70.51633	67.1736	Yes
	3.65	0.52	1.898	down	259.57	136.7597	73.76	38.86196	21.47486	Yes
	3.65	0.52	1.898	up	86.13	45.37935	66.85	35.22129	34.80845	Yes
W103	3.65	0.52	1.898	middle	249.91	131.6702	148.97	78.48788	69.05391	Yes
	3.65	0.52	1.898	down	322.09	169.6997	47.76	25.16333	8.016623	Yes
	3.6	0.52	1.872	up	86.76	46.34615	66.42	35.48077	34.87417	Yes
W104	3.6	0.52	1.872	middle	252.43	134.8451	142.82	76.29274	65.40105	Yes
	3.6	0.52	1.872	down	325.45	173.8515	45.96	24.55128	7.479273	Yes
	5.4	0.52	2.808	up	108.93	38.79274	96.11	34.22721	35.48622	Yes
W105	5.4	0.52	2.808	middle	285.66	101.7308	172.79	61.5349	54.52442	Yes
	5.4	0.52	2.808	down	375.23	133.6289	85.16	30.32764	14.0165	Yes
	2.05	0.52	1.066	up	34.97	32.80488	34.76	32.60788	35.18638	Yes
W106	2.05	0.52	1.066	middle	101.66	95.36585	41.08	38.53659	27.25081	Yes
	2.05	0.52	1.066	down	123.67	116.0131	3.87	3.630394	0.255052	Yes

It can be observed that in terms of tangential stresses, the applied reinforcement measure has no noticeable influence. The normal stresses in the walls of the reinforced construction with the application of tensioners are significantly higher, which indicates the greater participation of the walls and the utilization of their bearing capacity in the construction.

The control of the principal tensile stresses in the walls in all three cases is satisfied.

Conclusion

The territory of our country is highly seismic, and the region around the city of Debar belongs to parts where very strong earthquakes occurred in the past. The existing old brick buildings are represented in a significant part of the built stock of buildings.

Special attention should be paid to the seismic resistance of non-reinforced masonry buildings. Older masonry public buildings, such as schools, are facilities of special importance that require a comprehensive strategy to assess their vulnerability and existing condition.

The old gymnasiums in schools or separately, with masonry construction, are particularly significant as objects with large dimensions and spans, as well as high walls.

A large part of these buildings are still in use, so it is of great importance to investigate and analyze the structural seismic load capacity as well as the need for strengthening.

There are several measures for the seismic retrofit of existing masonry buildings and they find wide application.

In this paper, the research was carried out on measures to strengthen non-reinforced masonry buildings with special reference to schools and sports halls. An analysis of the current state of the structure, analysis of the seismic response and stress control in the walls and analysis of the effects of various rehabilitation measures was carried out on a selected facility, Sports Hall "Partizani" in Debar.

A measure for global strengthening of the wall construction was applied using steel braces and steel beam elements in the transverse direction of the hall. This measure was chosen due to its simple application and in order not to increase the loads and mass of the structure.

The seismic response analysis is carried out on 3 three-dimensional computational models in the SAP2000 software package. The comparison of the results of the analysis shows that the behavior and integrity of the structure is greatly improved.

A significant reduction of horizontal displacements from seismic forces by more than 30% is observed, especially in the model with steel beam elements. The steel elements connect the longer walls of the hall, increase the rigidity of the construction and ensure joint work of the walls and better distribution of seismic forces.

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