Rehabilitation of Schools Damaged by Earthquake in Kraljevo on Sept.3th ,2010

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1 ABSTRACT

Over forty schools are analyzed and solutions of seismic rehabilitation are given by technology of System DC90. Masonry schools up to four floors and reinforced concrete skeletal structures are analyzed. The paper shows way of researching, technology design and the work carrying out technology. Shows the technologic and design solutions for strengthening the walls, for stiffening the ceilings, for joining ceilings with walls, for vertical prestressing of the walls and the interconnection of the walls. The technology is especially effective on a mass repair of masonry structures with aspect to the level of safety, cost and schedule.

2 INTRODUCTION

This research presents the application of technology of masonry and frame structures rehabilitation by means of DC90 System. After the examination of forty school facilities we elaborated the rehabilitation plan for twelve objects. The particular attention is devoted to the application of special equipment such as the dampers (seismic energy absorbers) and their effect on the control of hysteresis behavior of the object. In this paper we will explain the basic characteristics of the 12 schools damaged by the earthquake in Kraljevo, Serbia at 03.11.2010. Also the way of rehabilitation.

List of schools:

- Elementary School -Četvrti kraljevački bataljon
- Elementary School -Dimitrije Tucović
- Elementary School -Jovo Kursula
- High School –Gimnazija
- High School – Ekonomsko-trgovačka škola
- Machining High School -14. October
- Agriculture-Chemistry High School –Dr. Đorđe Rakić
- Elementary School -Vuk Karadzić
- Elementary School -Dragan Marinković, Adrani
- Elementary School -Dragan Marinković, separated class in Popovichi
- Elementary School -Čibukovački partizani
- Tehnic High School -Nikola Tesla

3 THE BASE CHARACTERISTIC OF OBJECTS AND DAMAGES WITH WAY OF SANATION

The base technical characteristics with pictures of characteristic damage are given. Also as disposition and shape of vertical stiffeners and short description of object conditions.

3.1 Elementary School -Četvrti kraljevački bataljon

Technical description of damaged object:

Dimensions of the base and floors : 10.4x63, BF+GF+2floors

- Construction system : reinforced concrete frame structure (cross-section columns 25x40cm cross-section beams 25x50cm.), cross grid 2.85m.
- Walls : bricks w= 25 cm.
- Foundation : strip footing foundations with columns on it width 160 cm.
- Roof construction and cover : wooden construction, roof tiles
- Floor slabs: reinforced concrete w=12 cm.
- Floor (Inter-storey) structure: reinforced concrete, w=12 cm.

Presentation of existing damage on the structure: photo and description, with particular reference on damage on the basic structural system. The extensive photo documentation shows that the secondary-wall systems suffered significant damage. The damage was due to the large deformability of the system, especially in the transverse direction. Poor quality of concrete walls and large distance to stiffening of concrete in the building length of 60 m caused significant damage to the walls between classrooms. Deformation in the transverse direction exceeds the permissible deformation of reinforced concrete skeletal systems.

At figure.1. is shown wall with damages

Figure 1. Characteristic Damages and Dampers

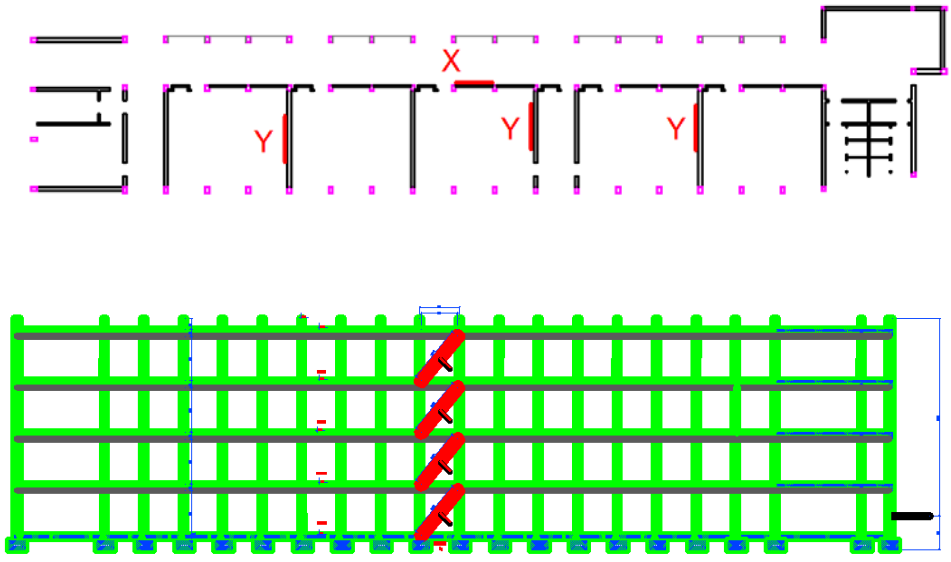

Figure 2 Disposition and Shape of vertical Stiffeners at X direction

Figure 3. Part of Delivered Equipment-Dampers

Figure 4. Connecting of verticals and diagonal with Damper by welding

Figure 5. Vertical stiffening in longitudinal Y-direction diagonal square cross-section 260x160x7 with damper. Force in damper +-1100 kN, displacement +-5mm.

Figure 6. Detail of anchoring the diagonal in Y-direction with dumper which is decorated with works of students during the hours of Art

3.2 Elementary School -Dimitrije Tucović

Technical description of damaged object:

- Dimensions of the base and floors : 12.50x42.00 m. GF+2, floor high 4.50 m.
- Construction system : masonry structure, without vertical columns
- Walls: bricks w= 50cm, mortared, without thermal insulation
- Foundations: strip foundations, reinforced concrete
- Roof construction and cover : wooden construction, roof tiles
- Floor slabs: wooden construction, with the ceiling of the cane
- Floor (Inter-storey) structure: reinforced concrete, small ribs

On next couple of figures damage and way of retrofit is shown:

Figure 7. Characteristic Damages, X crackes, and Dampers

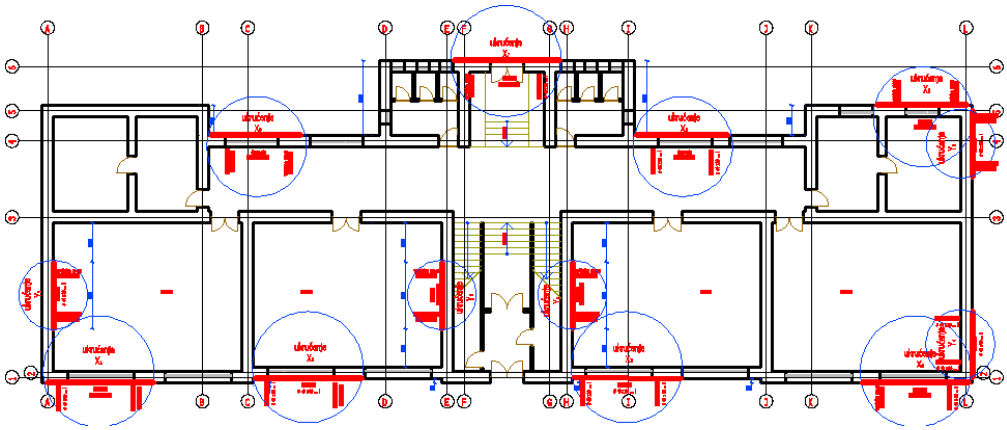

Figure 8. Disposition of stiffeners

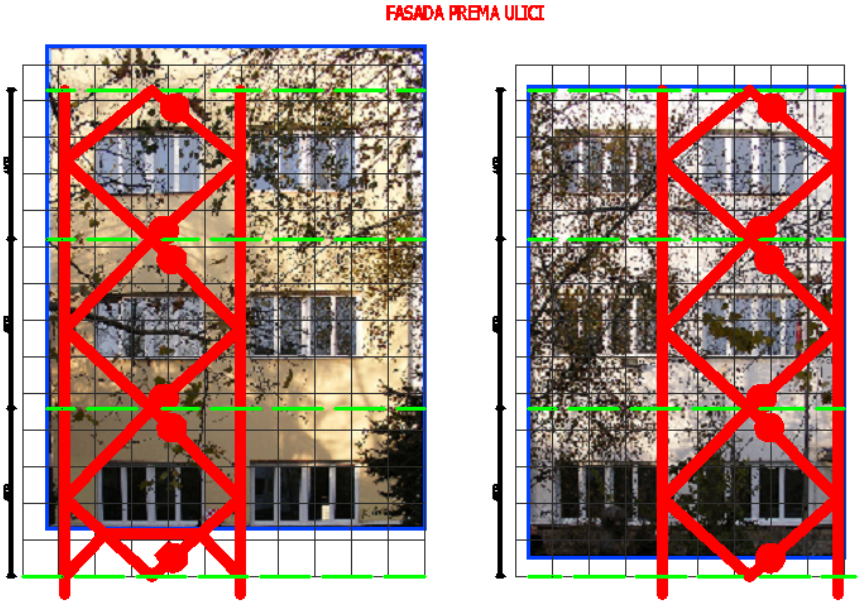

Figure 9. Shape of Stiffeners

At figure 9. shows the ortho-photo shot of the facade with marked vertical stiffeners. The building is damaged badly with crossed diagonal cracks between the windows.

3.3 Elementary School -Jovo Kursula

Technical description of damaged object:

- Dimensions of the base and floors : 10.80 x 60.19m. GF+1, floor high 4.30 m.
- Construction system : masonry structure, without vertical columns

- Walls : bricks w= 25cm, mortared, without thermal insulation
- Foundation : strip foundations
- Roof construction and cover : wooden construction, roof tiles
- Floor slabs: wooden construction, with the ceiling of the cane
- Floor (Inter-storey) structure : reinforced concrete, small ribs

Presentation of existing damage on the structure, photo and description, with particular reference on damage on the basic structural system:

The old part was made of masonry construction with reinforced concrete corners around windows, with a partition wall in the hallway made of brick at side. The wall is unstable and the ground and first floor are not allowed for use until rehabilitation. The pillars are made of brick. The inner columns were badly damaged and degraded.

Figure 10. Characteristic Damages

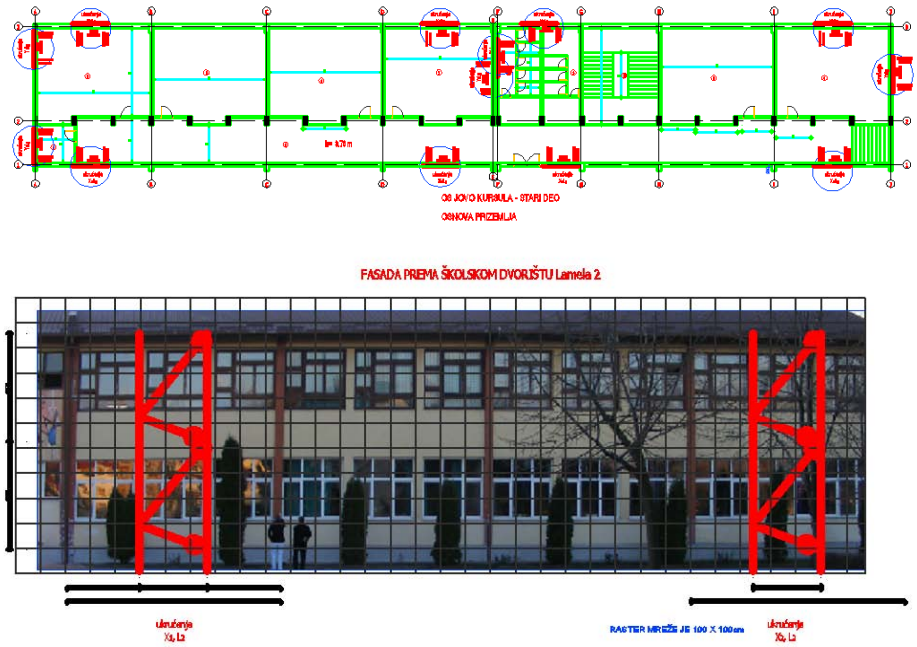

Figure 11. Disposition and Shape of Vertical Stiffeners

3.4 High School -Gimnazija i Ekonomsko-trgovinska

Technical description of damaged object:

- GF+3, floor high 3.70 m.
- The facility is basically made up of three parts. The end parts (Lamella 1) are dimensions 22,80x20,10m with basement.

- The central part dimension is 33,45x23,44m without basement, with increased height of ground floor because of the sports hall floor. All three parts are divided by dilatations.
- Construction system : masonry structure, without vertical columns
- Floor (Inter-storey) structure and Floor slabs are „Avramenko“ type .
- Foundations : Strip footing and spread footing foundations

Presentation of existing damage on the structure, photo and description, with particular reference on damages on the basic structural system:

The school consists of three constructional parts separated with dilatations. Objects previously strengthened with concrete in the transverse direction. The perceived need for longitudinal reinforcement capacity of facade walls. During the period of observation it was observed a progressive increase in cracks in walls, particularly in the facade of the wall space between windows.

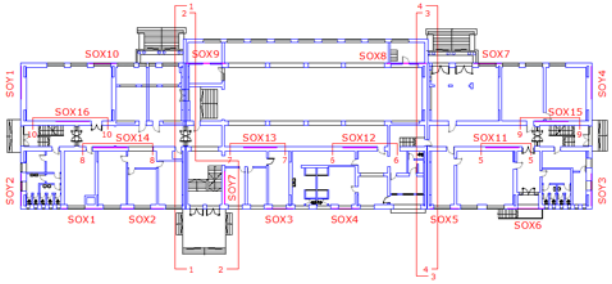

Figure 12. Disposition Stiffeners

Figure 13. Characteristic Damages

Figure 14. Beginning of retrofit

Figure 15. Disposition and Shape of Vertical Stiffeners

Figure 16. Disposition and Shape of Vertical Stiffeners

3.5 Machining High School -14. October

Technical description of damaged object:

- GF+1, floor high 3.70 m.
- Basically the facility is complex, consists of three parts. Central part (lamella 1) have a “T” shape, dimensions 57,3mx17,0m+29,0mx17,5 m and two end parts (lamella 2) dimensions 17,0x42,0m. without dilatations.
- Construction system: Lamella 1, masonry structure, without vertical columns, floor (Inter-storey) structure and Floor slabs are „Avramenko“ type .
- End parts, which are additionally reconstructed and upgraded(lamella 2) are a mixture of skeletal and masonry systems with massive floor (Inter-storey) structure and steel roof construction
- Foundations: Strip footing and spread footing foundation

On next couple of figures damage and way of retrofit is shown.

Figure 17. Characteristic Damages

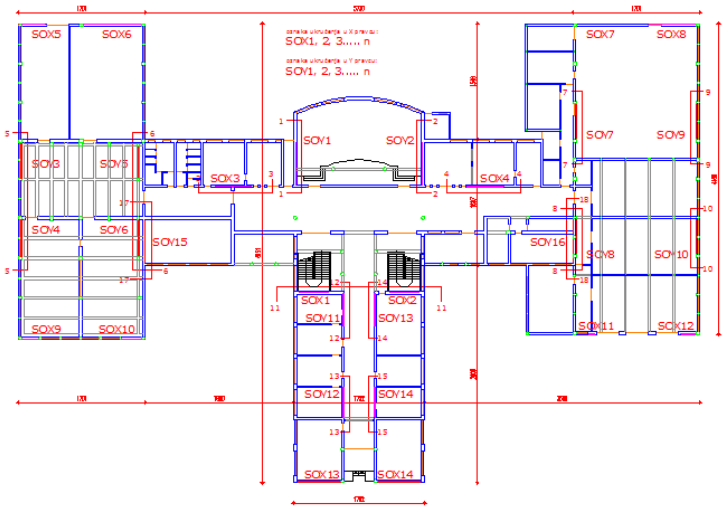

Figure 18. Disposition of stiffeners

Figure 19. Shape of stiffeners

3.6 Agricultural High School –Dr. Đorđe Rakić

Technical description of damaged object:

- BF + GF+1, floor high 4,50m
- Basically the facility is jagged, dimensions 61,65x25,40m sa manjim ispustima(do 1,5m) and with two half atriums.
- Construction system: Masonry structure, without vertical columns,with floor (Inter-storey) structure above the basement “Avramenko” type, massive floor (Inter-storey) structure additionally made across wooden construction at ground floor and wooden floor slabs and roof construction.
- Foundations: Strip footing foundations

Figure 20. Characteristic Damages and Dampers

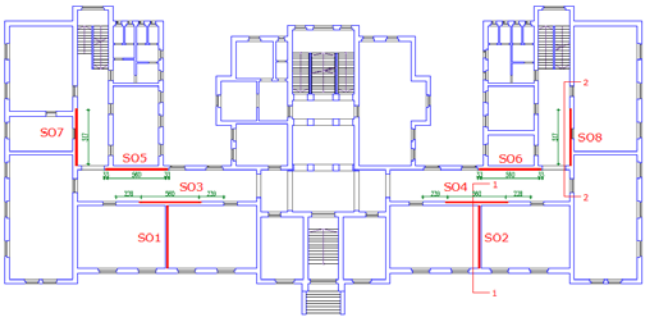

Figure 21. Disposition of stiffeners

Accepted stiffening type "D“ and “A” at X and Y directions made of diagonal solid square profiles 70x50mm, 60x30mm

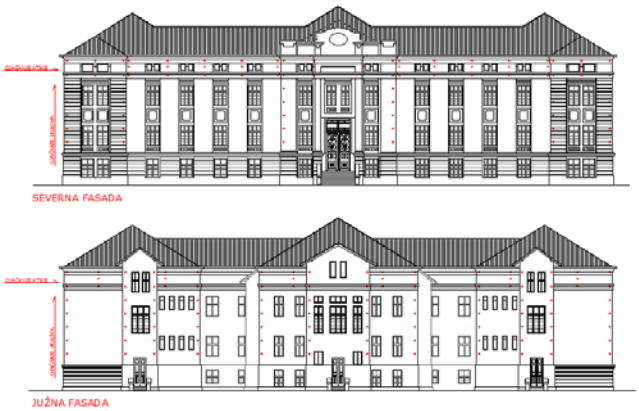

Figure 22. All stiffeners are on inside walls

The school is a historic building with the highest soft floor slabs

3.7 Elementary School -Vuk Karadzić

Technical description of damaged object:

- Dimensions of the base and floors :old part 23,12x39,26-(20,66x15,02+19,35x 1.10) m. central part 37,34x15,10 m, GF, floor high3.65 m.
- Construction system : masonry structure, without vertical columns
- Walls : bricks w= 40 cm, mortared, without thermal insulation
- Foundations: Strip footing foundation, reinforced concrete
- Roof construction and cover : wooden construction, roof tiles
- Floor slabs : wooden construction, with the ceiling of the cane

Figure 23Figure 20. Characteristic Damages

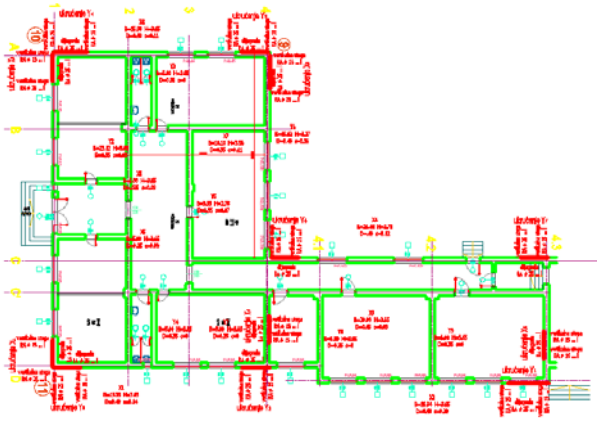

Figure 24. Disposition of stiffeners, old part of school

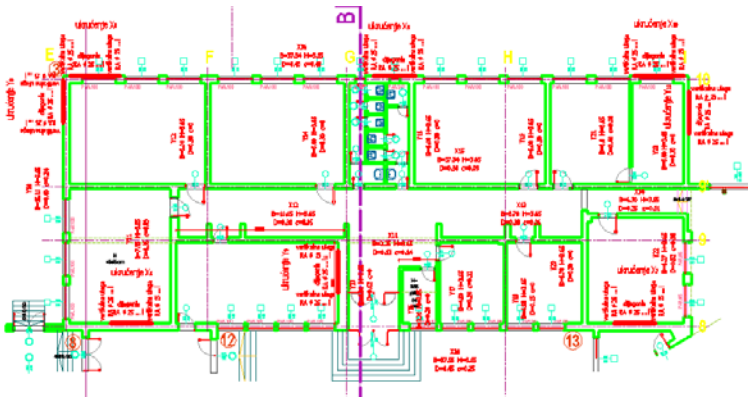

Figure 25. Disposition of stiffeners, central part of school

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Figure 26. Shape of vertical stiffeners

Figure 27. Wall prepared for installation of vertical stiffeners type, “D”, “R” and “K"

3.8 Elementary School -Dragan Marinković, Adrani

Technical description of damaged object:

- Dimensions of the base and floors : 46,15 x 9,85 m. , GF, floor high 3.88 m.
- Construction system : masonry structure, without vertical columns
- Walls : bricks w= 50 cm, mortared, without thermal insulation
- Foundations : Strip footing foundation, reinforced concrete
- Roof construction and cover : wooden construction, roof tiles
- Floor slabs: wooden construction, with the ceiling of the cane

On next couple of figures damage and way of retrofit is shown.

Figure 28. Characteristic Damages

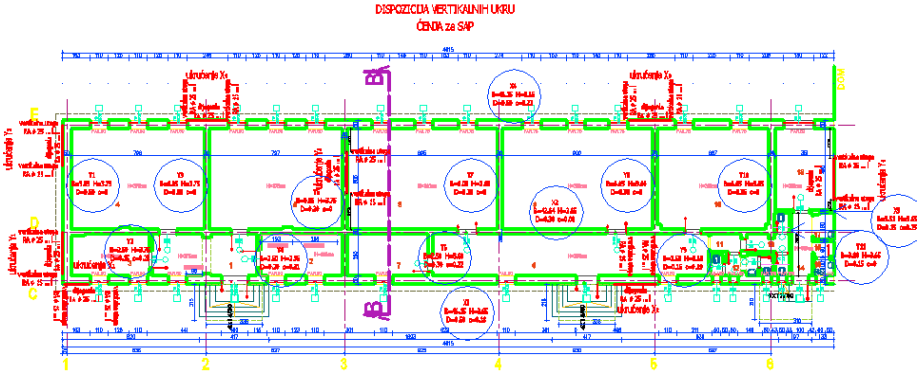

Figure 29. Disposition of stiffeners

Accepted stiffening type "D“ and “K” made of diagonal solid round profiles Ø25mm.

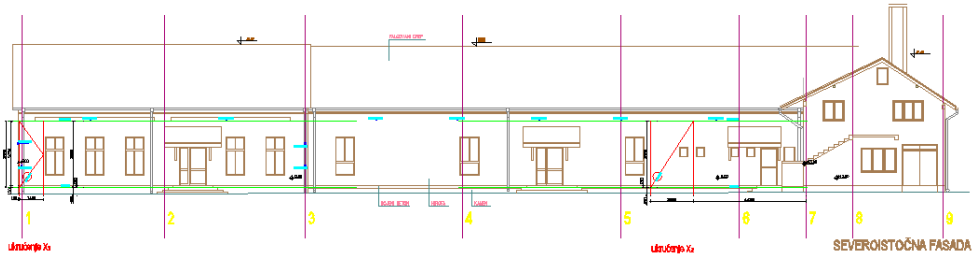

Figure 30. Shape of vertical stiffeners

3.9 Elementary School -Dragan Marinković, separated class in Popovichi

Technical description of damaged object:

- Dimensions of the base and floors : 8,95x19,75+10,10x11,05m., GF, floor high 3.95 m.
- Construction system : masonry structure, without vertical columns
- Walls : bricks w= 45cm, mortared, without thermal insulation
- Foundations: Strip footing foundations, reinforced concrete
- Roof construction and cover : wooden construction, roof tiles
- Floor slabs: wooden construction, with the ceiling of the cane
- On next couple of figures damage and way of retrofit is shown.

Figure 31. Characteristic Damages

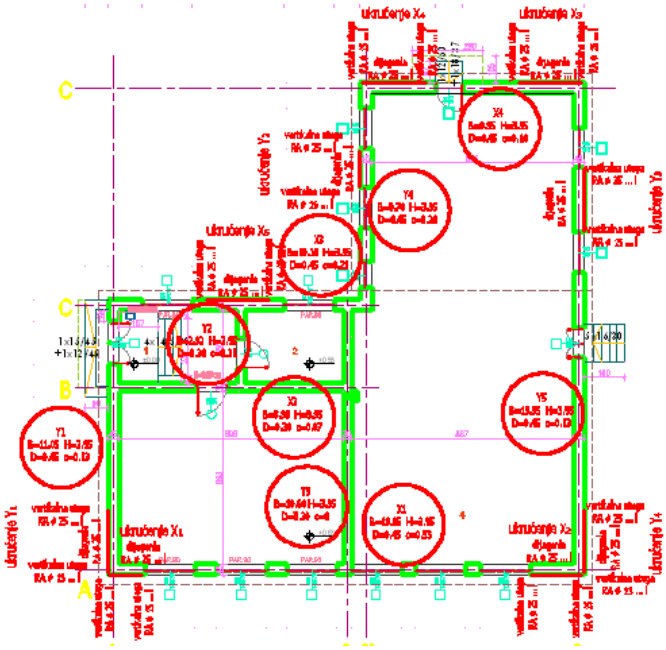

Figure 32. Disposition of stiffeners

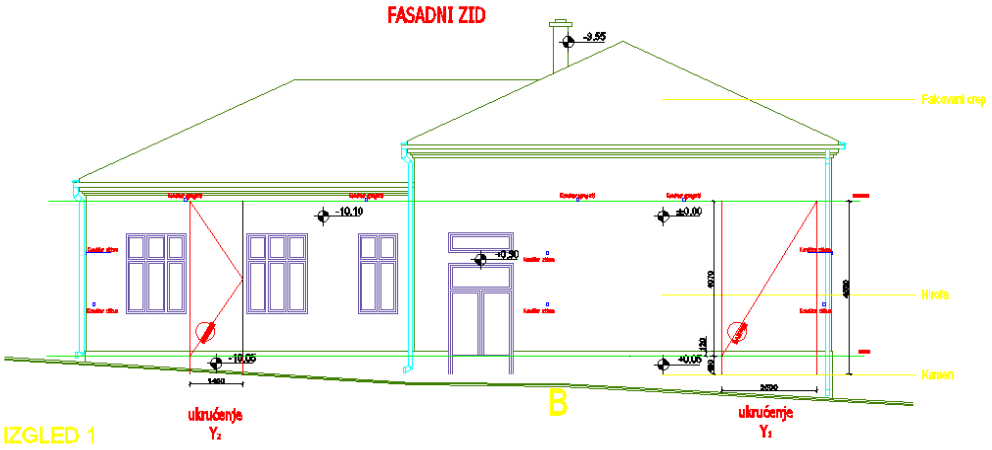

Figure 33. Shape of vertical stiffeners

3.10 Elementary School -Čibukovački partizani

Technical description of damaged object:

- Dimensions of the base and floors : part 1- 50,53 x 12,26 m.
- part 2- 47,10 x 29,50 m, GF, floor high 2,65, 3.75 and 3,85 m.

- Construction system : masonry structure, without vertical columns
- Walls : bricks w= 50cm, mortared, without thermal insulation
- Foundations : Strip footing foundations, reinforced concrete
- Roof construction and cover : wooden construction, roof tiles
- Floor slabs: wooden construction, with the ceiling of the cane

On next couple of figures damage and way of retrofit is shown.

Figure 34. Characteristic Damages

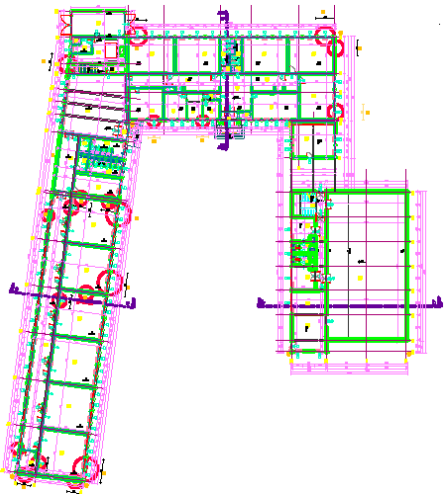

Figure 35. Disposition of stiffeners

Accepted stiffening type "D“ and “K” made of diagonal solid round profiles Ø25mm.

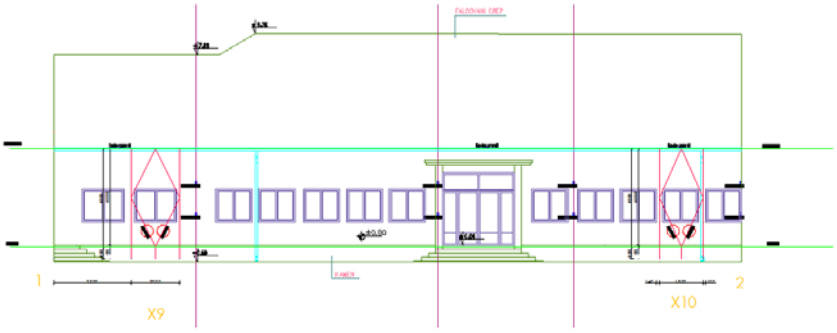

Figure 36. Shape of vertical stiffeners

3.11 2.11. Tehnical High School -Nikola Tesla

Technical description of damaged object:

- Dimensions of the base and floors : 33,30x30,63 m. GF+2, floor high 4.95 m (3,65m).
- Construction system: frame structure
- Walls: bricks w= 25cm, mortared, without thermal insulation
- Foundations: Spread footing foundation, reinforced concrete
- Roof construction and cover : wooden construction, sheet cover
- Floor (Inter-storey) structure: reinforced concrete

On next couple of figures damage and way of retrofit is shown.

Figure 37. Characteristic Damages

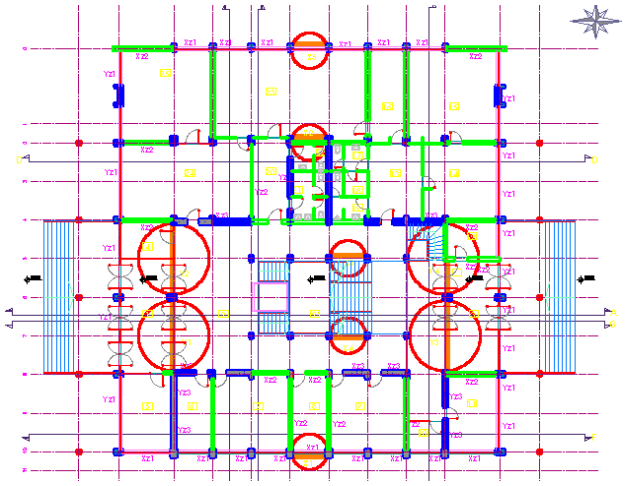

Figure 38. Disposition of stiffeners

Accepted stiffening type "D“ at X and Y direction made of diagonal solid square profiles and diagonal square tube profiles in fields of 2,80m and 3,80m: at the ground floor 200x200x6mm., at the first floor # 80/30...l and160x160x4mm. and at the second floor # 60/20...l and 160x160x4mm

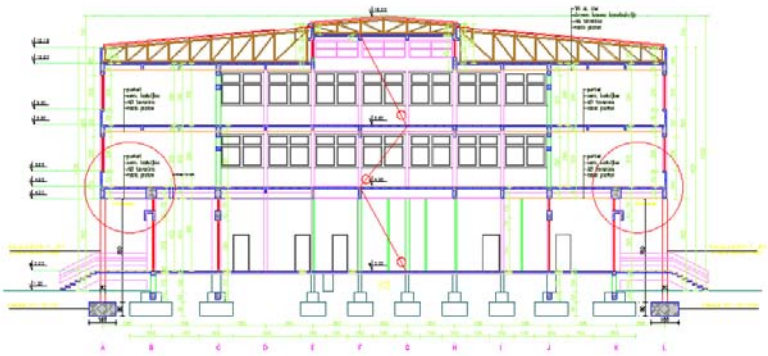

Figure 39. Shape of vertical stiffeners

Soft frame reinforced concrete structures has caused large damage on the walls. Vertical oscillations are heavily damaged consoles 3000 mm in length.

4 RECAPITULATION TECHNO-ECONOMIC CHARACTERISTICS

The following tables shows the size and shape of vertical stiffener elements and object areas, number of wall dampers, stiffeners length, stiffeners weight and total costs, so it make us able to calculate average stiffeners weight and average total cost for all 12 rehabilitated schools in Kraljevo.

No.	School name (sc)	Cross-section of stiffeners elements	Basement stiffeners size (mm)	Ground F. stiffeners size (mm)	1st.Floor stiffeners size (mm)	2nd.Floor stiffeners size (mm)	3th.Floor stiffeners size (mm)
1	IVKB	solid	60x30	100x50	80x40	60x30	
		square tubes	120x 160x4	260x 160x7	180x 160x6	160x 120x4	
2	DT	solid		80x40	70x30	50x20	
3	JK	solid		40x40	20x20		
4	G	solid		80x50	80x50	80x40	60x40
		square tubes			160x 160x6	140x 140x5	120x 120x5
5	E	solid		80x50	80x50	80x40	60x40
		square tubes			160x 160x6	140x 140x5	120x 120x5
6	M	solid		60x40	60x30		
		square tubes		140x 140x5	120x 120x5		
7	PH	solid		70x50	60x40		
8	VK	solid		Ø25			
9	DMA	solid		Ø25			
10	DMP	solid		Ø25			
11	CP	solid		Ø25			
12	ETSS	solid			60x40	60x20	
		square tubes		200x 200x6	160x 160x4	160x 160x4	

Figure 40. Table shows size and shape of vertical stiffeners elements

No.	Name of school (sc)	Object area (m^2)	Wall Dampers No.	Wall-ceiling Dampers No.	Stiffeners length (m)	Stiffeners weigth (kg)	Stiffeners weight per m^2 (kg)	Total cost (€)	Total Cost per m^2 (€)
1	IVKB	2,667	16	0	150	5,050	1.89	45,536.70	17.07
2	DT	1,575	70	20	858	16,474	10.46	95,332.50	60.53
3	JK	1,375	26	0	492	6,100	4.44	41689.70	30.32
4	G	5,935	133	0	1,486	25,262	4.26	166,204.10	28.00
5	E	2,350	66	0	704	12,631	5.37	80,781.60	34.38
6	M	6,217	65	0	720	8,382	1.35	126,036.40	20.27
7	P	5,132	18	32	122	1,650	0.32	121,996.70	23.77
8	VK	1,140	23	33	324	1,285	1.13	43,012.60	37.73
9	DMA	455	8	15	107	463	1.02	15,896.30	34.94
10	DMP	289	9	16	128	552	1.91	14,809.90	51.25
11	ČP	1,363	29	37	325	613	0.45	40,977.50	30.06
12	ETSS	2,729	28	0	170	7,933	2.91	61,815.20	22.65

Figure 41. Table shows Object areas, number of Dampers, Stiffeners length, Stiffeners weight and Total costs

We can see from upper table that all objects (Total Area 31,227m²) are rehabilitated with average 3.0 kg/m² of steel with average total cost 31.2 €/m². This price includes walls cutting, buying and implementation of vertical still stiffeners with Wall Dampers, filling remaining space with small-grained concrete, interconnection of the walls, stiffening the ceilings and joining ceilings and walls with Damper Connectors .

5 CONCLUSION

This paper presents the application of technology of masonry and skeletal structures repair by technology of System DC90. Over forty inspected facilities, plans were drawn for the rehabilitation of the twelve schools. In particular, it shows the use of special equipment, Dumpers-seismic energy absorbers and their effect on the control of hysteresis behavior of structure. Also shows the details of the execution of repair works on the first school that provided seismic technology of System DC90. The technology is especially effective on a mass repair of masonry structures with special aspect on the level of safety, cost and schedule.

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