„ОТПОРНИ КОНСТРУКЦИИ“ “RESILIENT STRUCTURES”

ЗБОРНИК НА ТРУДОВИ PROCEEDINGS

ДГКМ

ДРУШТВО НА ГРАДЕЖНИ КОНСТРУКТОРИ НА МАКЕДОНИЈА

MASE

MACEDONIAN ASSOCIATION OF STRUCTURAL ENGINEERS

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RESILIENT STRUCTURES
ОТПОРНИ КОНСТРУКЦИИ

Resilience refers to the ability of a system or structure to withstand and recover from adversity. In the face of natural disasters, climate change and other unforeseen challenges, resilient structures play a vital role in ensuring the safety and well-being of communities. It is crucial that we prioritize resilience in our design and construction practices to create a more sustainable and secure future.

One of the primary reasons why resilient structures are essential is their ability to withstand natural disasters. Earthquakes, hurricanes, floods, and wildfires pose significant threats to our built environment. Resilient structures are designed to resist the forces generated by these disasters, reducing the risk of collapse and minimizing damage. By integrating advanced engineering techniques, we can design and construct structures that can better withstand the forces of nature.

The collapse of buildings and infrastructure is a leading cause of casualties during earthquakes and extreme weather conditions. By investing in resilient structures, we can significantly reduce the loss of life and injuries. Through proper urban planning, evacuation routes, and the incorporation of safety features like reinforced concrete shelters, we can ensure that our buildings are not only strong but also provide a safe haven during times of crisis.

Resilient structures are not limited to saving human lives. They also protect the economy and the environment. When a disaster strikes, the impact extends beyond the immediate loss of life and property damage. Critical infrastructure failures can disrupt supply chains, interrupt essential services, and hamper economic recovery. Failure of one bridge caused by earthquake, fire or flood can leave hundreds of thousands people trapped and with no connection to the rest of the country. By investing in resilient structures, we can minimize the economic losses associated with disasters and speed up the recovery process.

If we go back in time, 60 years ago, on 26th of July 1963, Skopje was struck by a devastating earthquake with a magnitude of 6.1. More than 1070 were killed, more than 3000 injured and countless displaced. Most of the city was ruined. Obviously, the structures were not so resilient. However, the people of Skopje were much more resilient. The whole world and the international community responded with compassion and solidarity, offering assistance and support in the monumental task of reconstruction coordinated by the United Nations. The reconstruction of Skopje was a colossal undertaking, but it was also an opportunity for transformation. The city was redesigned and rebuilt, embracing modern architectural styles. Skopje's rise from the ashes today serves as a symbol of hope and resilience.

Skopje 1963 earthquake is a chronological landmark, evolutional turning point of the Macedonian, as well as European structural and earthquake engineering. In 1964 at a conference in Skopje, the European association for earthquake engineering was founded. The first structure in the world with modern base isolation with rubber bearings was the Pestalozzi primary public school in Skopje, designed and constructed in the period 1965-1969. At which stage of implementing base isolation are we now? How many hospitals, fire stations, schools, bridges and other crucial structures are designed and constructed with base isolation, with appropriate fire resistance and appropriate measures for flood protection?

Investing in resilient structures requires national strategy and collaboration among various stakeholders. Architects, engineers, policymakers and community members must work together to ensure that resilience is prioritized in our building codes, regulations and infrastructure planning. Resilient structures are the backbone of a resilient society. By fostering a culture of resilience, we can create a more prepared and adaptive society. We can create more resilient world, which we can proudly leave to the next generations.

Assoc. Prof. Darko Nakov,

President of MASE

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EXPERIMENTAL AND ANALITICAL RESEARCH OF THE BEHAVIOR OF MECHANICAL ANCHORS AS SHEAR CONNECTORS

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ABSTRACT

In order to work out in more detail the behavior of the composite structures, especially the means for connecting (shear connectors) as part of a structure, at the Department of Metal Structures, starting from 2012 started the collection of materials, preparation of experimental test probes and constructions as well as examinations on them for the needs of the experimental part of several doctoral theses and master`s theses.

As a continuation of a series of tests in the field of composite structures, a test was carried out on specific cases of composite structures usings mechanical anchors in the role of shear connectors, using mechanical anchors in a solid concrete slob. At the same time during the experimentation there will be used orientational and recommended parameters in Eurocode 4 for making of the models. The models that will be made will represent a modified test from the standard test presented in Eurocode 4.

Keywords: mechanical anchors, composite structures, shear connectors

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1. MODIFIED TEST OF SHEAR CONNECTORS

The modified test sample is T-beam cross section with HEA 260 as main steel beam, with anchor bolts Φ16 used instead of the classical shear connectors. The concrete slab thickness is 120mm, reinforced with ribbed bars B500B Φ8/12.5 cm, as showed in figure 2. The concrete strength class is C25/30 according to EN 1992-1-1, Table 3.1. At the top of the steel beam, detail for receiving the force is constructed from steel plate 300x300x15mm and UNP120 profiles as stiffeners. The bottom face of the concrete slab is bedded in mortar (Exmal) with thickness of approhimately 50mm.

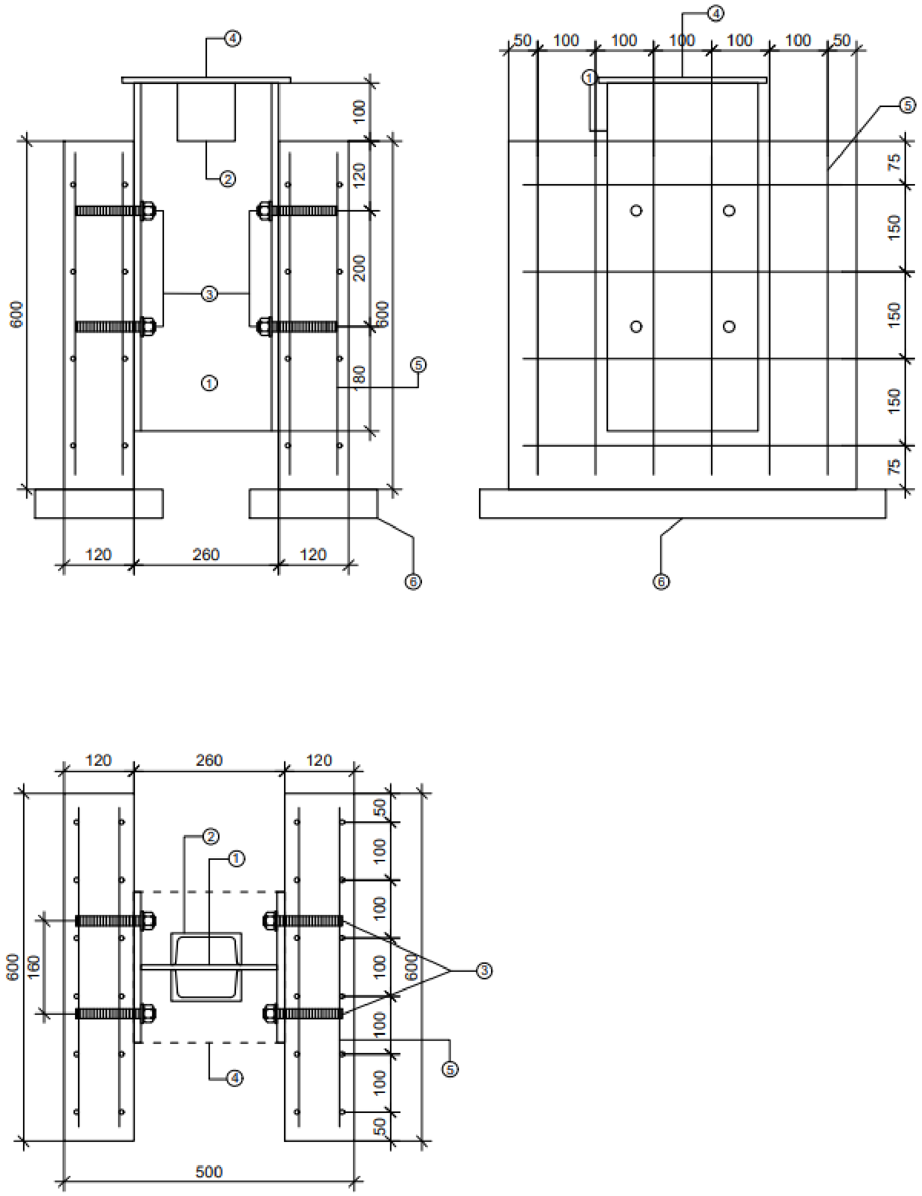

Fig. 1. Test specimen for modified (specific) testing

Where:

1. Steel beam HEA 260 … 600 S 235JR
2. 2 Steel beams UPN 120 …150
3. Bolt anchor Φ16mm (8.8) fu=80MPA
4. Steel plate 300x300x15
5. Reinforced ribbed bars B500B Φ8/12.5cm
6. Fast setting concrete

The casting of the concrete slabs was made in horizontal position on a construction site, at the same time samples were taken for examination. After the concrete gained its strength the specimen were transported to the laboratory at the Faculty of Civil Engineering in Skopje.

Fig. 2. Casting of the concrete for the modified testing specimen

After the concrete specimens were transported to the laboratory, so began the embedding of the concrete specimens with the steel beams and the anchor bolts.

Fig. 3. Embedding of the concrete specimens with the steel beams and the anchor bolts

1.1. Testing the strength of the concrete

After every casting of the concrete a sample was taken for testing the strength of cubes with dimensions 150x150x150 mm. The testing of the cubes for the strength of the concrete was carried out on the 28th day form the casting of every concrete slab and on the 65th day from the casting of every concrete slab in order to mark the progress of the strength of the concrete with time. For concrete strength class C25/30, according to EN 1992, the strength of cylinder is f_{ck}=25 N/mm^2, and the strength of cube is $f_{ck,cube}$=30 N/mm^2.

Fig. 4. Testing the strength of the concrete

Table 1. Concrete characteristics for concrete of 28 days of age

No.	Dimension	Date of concrete production	Date of concrete examination	Age of the concrete [days]	Temperature of the concrete [°C]	Weight of the concrete [g]	Density $[kg/m^3]$	Force [kN]	$f_{ck,cube}$ $[N/mm^2]$
1	15/15/15	20.10.2022	17.11.2022	28	18	8075	2393	790.08	35.11
2	15/15/15	20.10.2022	17.11.2022	28	18	8020	2376	715.21	31.79
3	15/15/15	20.10.2022	17.11.2022	28	18	8225	2437	793.37	35.26

Table 2. Concrete characteristics for concrete of 65 days of age

No.	Dimension	Date of concrete production	Date of concrete examination	Age of the concrete [days]	Temperature of the concrete [°C]	Weight of the concrete [g]	Density $[kg/m^3]$	Force [kN]	$f_{ck,cube}$ $[N/mm^2]$
1	15/15/15	20.10.2022	24.11.2022	65	18.1	7934	2351	820.45	36.46
2	15/15/15	20.10.2022	24.11.2022	65	18.1	7993	2368	819.48	36.42
3	15/15/15	20.10.2022	24.11.2022	65	18.1	7900	2341	753.35	33.48

The results from the testing of the strength of the concrete show that the concrete strength class is C25/30 with satisfactory fracture character.

1.2. Testing process

The three samples for the modified (specific) testing of the behavior of the shear connectors are tested in the same environment, with the same testing equipment and testing conditions.

The testing is carried out according to EN 1994, with cycled loading with first step of loading from 0% to 40%, then 25 cycles of loading from 5% to 40%. After the cycled load, the samples were loaded until failure in time not less than 15 minutes.

For the need of the testing, measuring and loading equipment is used. The load is applied through 100 ton press where the force is regulated with electronic dynamometer. The longitudinal slip between the steel and the concrete is measured with 3 electronic comparators. The transverse separation between the concrete slab and the steel section is measured with 4 dial comparators. The accuracy of the testing equipment is in the range of ±3%.

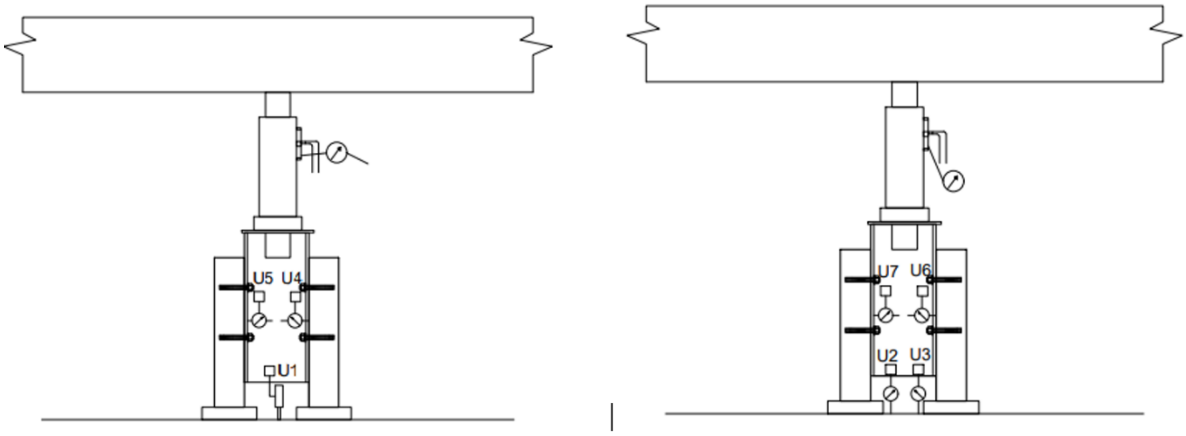

Fig. 5. Disposition of the loading and the measuring equipment (front and back view)

Fig. 6. Disposition of the loading and the measuring equipment in the University laboratory

Where:

- 100 ton press for load application;
- (U4-U17) dial comparators for transverse separation;
- (U1-U3) electronic comparators for longitudinal slip.

The electronic equipment is connected to the HBM Quantum data acquisition system amplifier with direct connection to the computer. The measuring of the electronic equipment is carried out through the whole testing in real time.

1.3. Analysis of the design resistance and expected results

According to the standard analysis in Eurocode 4 we received that the maximum expected Force is 448kN.

2. RESULTS FROM THE TESTING

2.1. Results of the testing of the first 25 cycles 5-40%

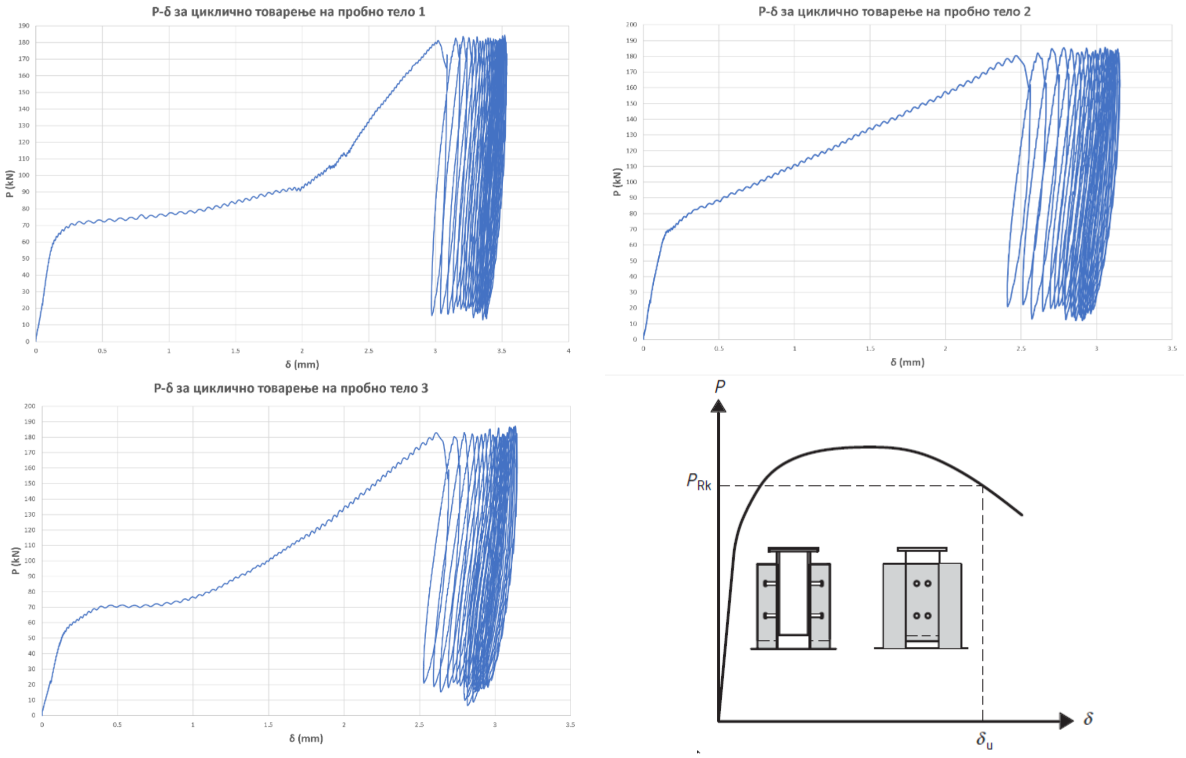

Fig. 7. Results from the force application 5-40% for 25 cycles for all 3 test subjects seperately and the P-δ" diagram, slip capacity

2.2. Results of the P-δ diagrams until force failure

Fig. 8. P-δ Diagram until force failure appears and the visible failure in the test subject 1

The force failure happens when the force reaches the value of 554.93 kN and slip of 8.35mm. Failure in the anchor bolts appears because of the sheer force of the tangential force.

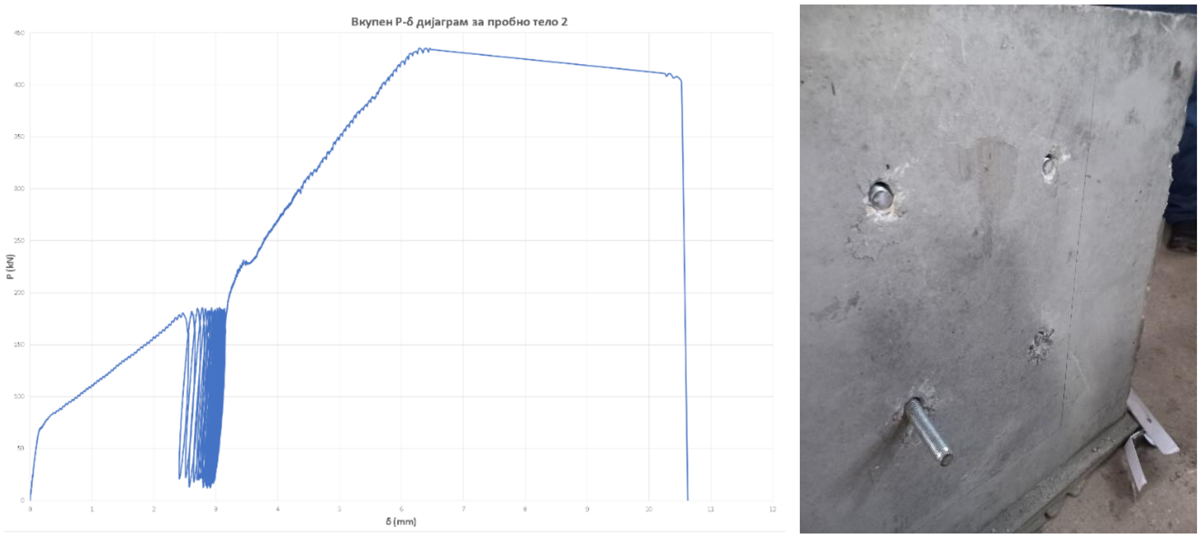

Fig. 9. P-δ Diagram until force failure appears and the visible failure in the test subject 2

The force failure happens when the force reaches the value of 435.08 kN and slip of 6.29 mm. Failure in the anchor bolts appears because of the sheer force of the tangential force as well as a failure of the connection between the anchor bolt and the concrete.

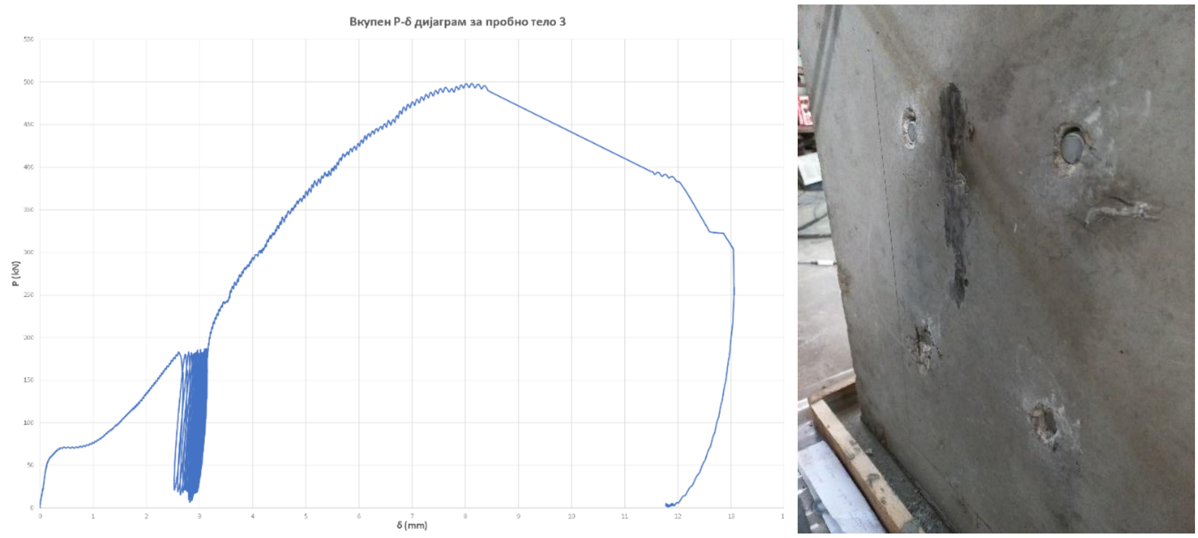

Fig. 10. P-δ Diagram until force failure appears and the visible failure in the test subject 3

The force failure happens when the force reaches the value of 498.10 kN and slip of 8.12 mm. Failure in the anchor bolts as well as in test subject 1.

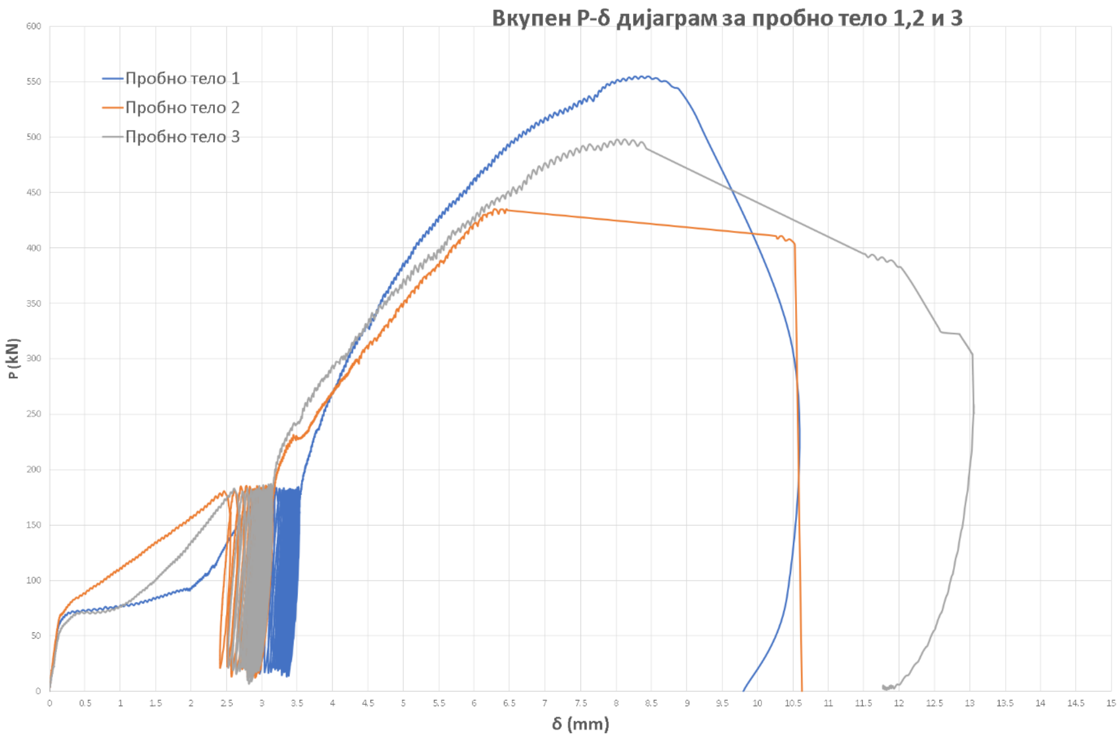

Fig. 11. P-δ Diagram until force failure appears for all 3 test subjects

In figure 12 we can make clear distinction between all 3 test subjects and how all of them reacts when a certain force is applied on them.

2.3. Results of the ductility of the sheer connectors

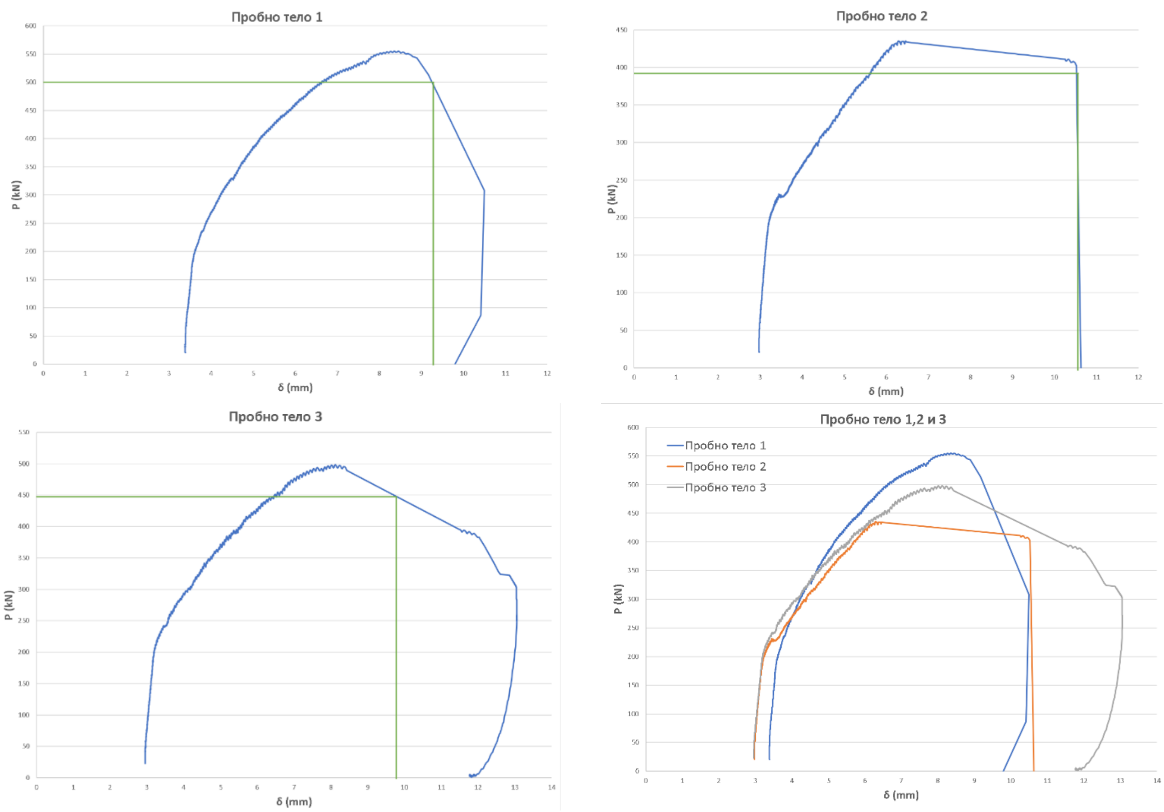

Fig. 12. Results from the force of failure testing on all 3 test subjects separate and together

Table 3. Results from the force of failure testing

Test subject	Force [kN]	Test results of the Force [kN]	For 1 anchor bolt	90% Prd
1	448.000	554.93	69.37	499.44
2		435.08	54.39	391.57
3		498.10	62.26	448.29

Table 4. Results from the slip testing

Test subject	Slip received by testing [mm]	Calculated slip [mm]	90% δ_{min} [mm]	From diagram δ [mm]	δ_u [mm]
1	8.35	6.94	8.28	9.20	10.50
2	6.29	5.44		10.50	
3	8.12	6.23		9.80	

In table 4 and table 5 we can see the maximum calculated force and the force needed to calculate the capacity of slip which is by 10% smaller than the maximal reached force, as well as the calculated force for 1 anchor bolt.

The calculated slip when the failure appears and the maximal slip calculated with the maximal force reduced by 10% as well as the characteristic capacity of slip are used to calculate the ductility of the anchor bolts.

According to the results from the examination of the test subjects we can conclude that the sheer connectors used in this examination (the mechanical anchor bolts) meet the requirements for ductile sheer connectors.

2.4. Time until the failure appears

As seen in table 5 the time needed for the failure to appear in all 3 test subjects is higher than 15 minutes which means the test has been conducted with the regulation of Eurocode 4.

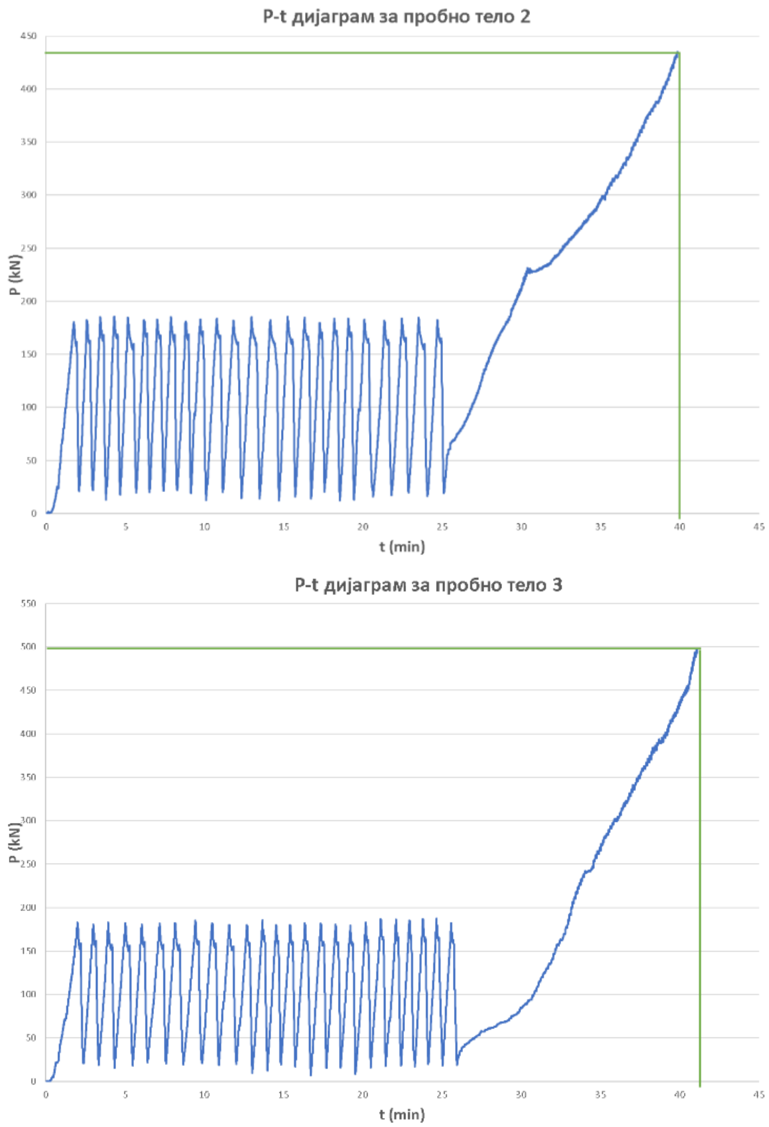

Fig. 13. Results from the time the failure appeared

Table 3. Results from the force of failure testing

Test subject	Force by testing [kN]	Time when the failure appears [min]
1	554.93	16
2	435.08	15
3	498.10	15

3. CONCLUSION

After the examination has been successfully completed, we can make the following conclusions:

- The character of the failure depends on a lot of factors but mostly on the:
  - Characteristics of the concrete
  - The way the anchor bolts are inserted
  - The ratio hef/d
- In the composite structures the mechanical anchors behave as intended – as anchor bolts on sheering, and not as welded sheer headed stud connectors, giving better behavior and greater load capacity.
- The expressions given in Eurocode 4 for determining the bearing capacity of the sheer stud connectors are not fully corelated with the results obtained from the experimental research.
- The failure in the anchor bolts by tearing of the steel cross-section of the anchor bolt, which is accompanied by the crushing of the concrete on the surface where the shear force acts, as a result of the large plastic deformations that occur in that zone, appears as the dominant type of failure.
- Placing reinforced ribbed bars in the concrete near the anchorage prevents cracks from occurring in the concrete slab, and the shear capacity of the anchor is a function of the anchorage method at the end of the anchor.

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