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Research Article

Experımental Research On Flexıble And Frıctıon Joınts Between Brıcks For Dampıng The Movements

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ABSTRACT

This study was prepared for determining the effectiveness of polymer flexible joint for damping the movement which occurs between bricks in a masonry wall. In recent years also dry stack masonry was offered as infill wall in a reinforced concrete frame. To compare the effectiveness of polymer joint with friction based damping and to compare the behaviour with traditional stiff joints , dynamic and shear tests were performed. In the dynamic experiments the behaviours of three different masonry specimens are compared and the highest damping ratio is obtained in situation with polymer PM. When the bricks were fixed to the concrete beams with epoxy, damping values were decreased. Also it was seen that polymer joint increases the ductility of the assembly

KEYWORDS: *- Masonry, Flexible Joint, Stiff Joint, Damping.*

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1. INTRODUCTION

In the past, many studies and applications in engineering practice were done for seismic retrofitting of RC structures against earthquakes. Adding RC walls into RC frames to increase the lateral stiffness of the structures is a popular method, but it is well known that many owners of buildings can not afford this kind of strengthening. Other popular methods in engineering practice are: increasing the ductility of structure by using CFRP, GFRP or jacketing columns, as well as beams with ductile materials. And in the engineering practice there are several applications of structural dampers, including metallic yielding dampers, frictional dampers, viscoelastic dampers, viscous wall dampers etc.. Dry stack masonry as an infill for RC frames was proposed to act as a frictional damper during earthquakes[1,2,3].

In a previous study it was seen that dry stack infill wall acts as an equivalent compressive strut when the gap between wall and frame closes and friction increases at this stage to help damping the lateral movement of frame during earthquakes. Also polymer flexible joint was proposed Kwiecien [4] , using to reduce stress concentrations and increase energy dissipation in structures. Using of highly deformable polymers for repair and strengthening of cracked masonry structures was proposed . In historical buildings the only method for repair and strengthening of cracked masonry is injection, mostly due to architectural reasons. Typically, cracks are filled using mineral or epoxy grouts, which do not increase masonry capacity due to brittle behaviour and low deformability and generation of stress concentrations. Highly deformable polymer flexible joints, made of polyurethane mass, were also proposed for bonding of FRP strips to masonry. A destructive test was also done by using a caterpillar as a lateral load to a masonry structure. The test showed that polymer PM reduces stress concentrations and introduces the huge amount of capacity of the cracked masonry structures to absorb the input energy. Research showed that repair of cracked masonry wall by injecting using the highly deformable polymer PM restores up to 95% of the original masonry strength, but increases ultimate shear strain over 10 times and energy dissipation capacity 14 times [4].

In another study, behaviour of epoxy resin vs flexible polymer was compared using single–lap shear tests Four kinds of fabric were tested: glass, carbon, steel and basalt. Research showed that epoxy resin generates stress concentrations in masonry. Masonry strengthened with FRP and epoxy has brittle failure behaviour. Typical failure mode is the FRP detachment with the removal of a thin layer of the masonry material. It was seen in the experiments that the GFRP and BFRP specimens repaired by polymer PS bonds manifest 21% higher capacity than the same specimens bonded with epoxy resin [5].

In another study, it was seen that displacement capacity of the walls strengthened or repaired by flexible coating was increased by 20% to 66%, depending on the type of strengthening. The bond between masonry and coating was not lost and hysteretic damping energy with the strengthening of flexible coating is 2 times higher than the stiff one [6].

In another study, possibility of the repair of the detached composites after the failure of the masonry strengthening was studied. They found that stress distributions in the composite systems (bonded on stiff and brittle adhesives) is of exponential character with a peak of stress concentration responsible for failure. The approximation of flexible polymer adhesives in strengthening of masonries using of FRP composites allows reducing stress concentrations. The reduced stress in the bond layer protects the brittle substrate against locally acting peak of stress concentration. Models made in ABAQUS program showed that more even stress distribution increases the ultimate load of the strengthening system [7].

In this study, an experimental research was performed to obtain the effectiveness of polymer joint for damping the movements in masonry units. Also static experiments were performed to obtain how much the flexible joint with polymer pm increases the ductility and behaviour. The behaviour was compared with traditional stiff joints and frictional behaviour to enlight the way for future studies with dry stack masonry or polymer joint to improve the earthquake behaviour of structures.

2. EXPERIMENTS

Static and dynamic experiments were designed and done, to understand how much of the motion can be damped in the situation of using dry stack masonry or polymer joint in a dynamic load situation.

2.1 MATERIALS USED IN EXPERIMENTS

Rosso Vivo San Marco brick is an Italian brick which dimensions are 250*120*55mm. The mechanical properties of Rosso vivo bricks were driven from the catalog of the producer firm, and are presented in figures 1 and 5. [8]

TABELLA DELLE PRESTAZIONI / PERFORMANCE TABLE

MATTONI 12x25x5.5 h 2.4-2.8 kg	DIMENSIONI [cm] E TOLLERANZE	RESISTENZA E COMPRESSIONE MEDIA [perp.faccia maggiore, N/ mm2]	FORZA DI ADESIONE [N/mm2]	ASSORBIMENTO D'ACQUA [%]	MASSA VOLUMICA LORDA [kg/m2] E TOLLERANZA	CONDUCIBILITA' TERMICA EQUIVALENTE [W/mK]
Giallo Vivo	12x25x5,5 T2-R2	22	0.19	28	1450 D2	0.384
Rosa Vivo	12x25x5,5 T2-R2	21	0.152	23	1500 D2	0.344
Rosso Vivo	12x25x5,5 T2-R2	18	0.128	22	1560 D2	0.369
Rosso Massimo	12x25x5,5 T2-R2	36	0.22	14	1765 D2	0.458
Grigio Chiaro	12x25x5,5 T2-R2	20	0.19	28	1450 D2	0.384
Grigio	12x25x5,5 T2-R2	20	0.19	28	1450 D2	0.384
Grigio Forte	12x25x5,5 T2-R2	20	0.19	28	1450 D2	0.384

Figure 1. The mechanical properties of Rosso vivo Bricks [8]

ROSSO VİVO PROPERTİES	
weight of one brick:	2,40-2,80kg
wright of 1m2:	144-168kg
compressive strength	18Mpa
adhesion strength	0,12Mpa
water absorption	%22
thermal conductivity(W/mk)	0,37
Number of bricks in 1m2:	60

Figure 2. The mechanical properties of Rosso Vivo bricks

Commercial epoxy resin Sikadur-30 was provided as a stiff joint between concrete beam and bricks in the experiments. Its mechanical properties were driven from the catalog of the producer [9]: Young modulus: 12800 MPa ,tensile strength: 28 MPa adhesion: bigger than 4 MPa , ultimate strain: 0,22%

2.2 DYNAMIC EXPERIMENTS

2.2.1 FRICTIONAL DYNAMIC EXPERIMENT

Three rosso vivo bricks were prepared as follows (Figure 2): the brick at the top and the brick at the bottom are joined with the concrete beams by using stiff epoxy joint. A dynamic load was applied to the brick in the middle by using the modal hammer, which was connected to both bricks only with friction. For each level of axial force generated by a testing machine, the horizontal dynamic force was applied several times. Dynamic horizontal forces were applied on the middle brick, when the axial forces were generated on a real dry stack masonry: 10N, 179N, 260N, 453N, 615N. The accelerometeres on the middle and bottom bricks recorded the acceleration-time values and were aquised by the computer system. The horizontal motion of the brick is damped thanks to friction between bricks. To obtain the damping ratio the half power bandwith method was used. with using of Fast Fourier Transfrom (FFT), changing the acceleration-time graphs to acceleration/frequency graphs. FFT changes a discrete signal shown in time domain into a discrete signal in frequency domain.

Figure 3. Friction test specimen (left) and modal hammer (right).

To calculate damping ratio by using Half power bandwidth method, the accelerations derived from the accelerometer on the middle brick was corrected. The values deriven from the bottom accelerometer were deducted from the values of the middle brick's accelerometer – equation (1).

$$|\ddot{x}(\omega)| = |\ddot{x}(\omega)|_{(top)} - |\ddot{x}(\omega)|_{(bottom)} \quad (1)$$

By using this acceleration value (1), the modulus of inertance (2) and the modulus of compliance (3) functions and the damping ratio (4) were calculated. Modulus of compliance function is calculated by FFT analysis, to find dominant response frequencies of each lateral load levels. Angular frequency is defined as follows: ω = 2*3,14*f, where f is frequency in Hz.

$$|I(\boldsymbol{\omega})| = \frac{|\ddot{x}(\omega)|}{|F(\omega)|} \tag{2}$$

$$|A(\omega)| = \frac{|I(\omega)|}{\omega^2} \tag{3}$$

$$\xi = \frac{\Delta\,(\omega)}{2\,\omega_r} \tag{4}$$

In figure 7, an example of A(ω)-f graph is seen from the experiment.

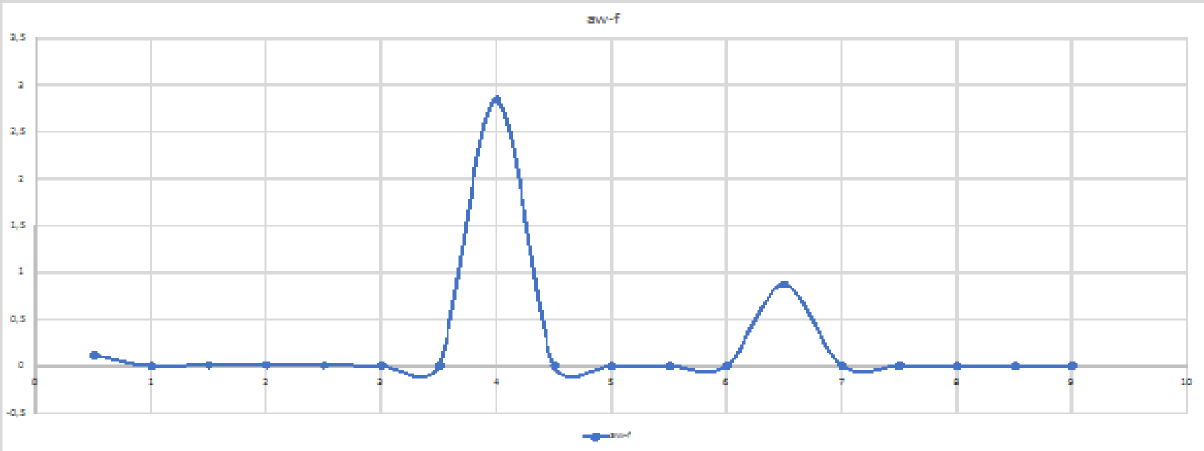

Figure 4. $A(\omega)$-f graph from frictional experiment.

Later the damping ratios were calculated by using first dominant response frequencies of each specimen. In each axial load level, several times the lateral dynamic loads were applied, so for using a statistical approach at least 6 different graphs of different load levels and times were derived and analysed by using FFT. The graphs wchich were not from representative signals were not taken into account.

Results of damping ratio calculation are seen in Figure 4. From acceleration time graph of experiment, different time values were derived and FFT analysis was applied. Graphs which were not from representative signals were not taken into consideration. In Figure 4 values only from representative graphs were taken into consideration. Later average values are corrected by deleting values which are 2 times standard deviation (S.D) far from average value.

Experiment type	**damping ratios**
	average
friction 10 N	0,067
friction 179N	0,033
friction 260N	0,074
Friction 453N	0,051
Friction 615N	0,082

Figure 5. Damping values after deleting non responsive values and new average ones received by statistical approach

2.2.2 DYNAMIC EXPERIMENT WITH EPOXY and POLYMER PM

As seen in Figure 5, three rosso vivo bricks were prepared like the frictional experiment (with polymer between bricks and epoxy between bricks and concrete) and a dynamic forces were applied to the brick in the middle in the horizontal direction by using the modal hammer, when the axial forces were generated on a real masonry: 33N, 255N, 425N, 608N, 733N. The acceleration-time values were recorded by the computer. Damping ratios were calculated by using the half power bandwidth method that was explained in the first experiment.

Figure 6. Tested specimen of dynamic test with polymer between bricks and and epoxy between bricks and concrete.

Results of damping ratio calculation are seen in Figure 6. From acceleration time graph of experiment, different time values were derived and FFT analysis was applied. Graphs which were not from representative signals were not taken into consideration. In Figure 6 values only from representative graphs were taken into consideration.

Experiment type	**damping ratios**
	average
polymer 33 N	0,102
polymer 255N	0,116
polymer 425N	0,098
polymer 608N	0,092
polymer 773N	0,004

Figure 7. Damping values after deleting non responsive values

2.2.3 DYNAMIC EXPERIMENTS WITH POLYMER PM

As seen in Figure 7, three rosso vivo bricks were prepared like the frictional experiment (with polymer between bricks and between bricks and concrete) and a dynamic forces were applied to the brick in the middle in the horizontal direction by using the modal hammer, when the axial forces were generated on a real dry stack masonry: 96N, 368N, 498N, 641N, 747N. The acceleration-time values were recorded by the computer. Damping ratios were calculated by using the half power bandwidth method that was explained in the first experiment.

 

Figure 8. Test specimen of dynamic test with polymer PM

Results of damping ratio calculation are seen in figure 8. From acceleration time graph of experiment, different time values were derived and FFT (Fast Fourier Transform) analysis was applied. Graphs wchich were not from representative signals were not taken into consideration. In figure 8 values only from representative graphs were taken into consideration.

Experiment type	**damping ratios**
	average
polymer 96 N	0,095
polymer 368N	0,088
polymer 498N	0,105
polymer 641N	0,108
polymer 747N	0,120

Figure 9. Damping values after deleting non responsive values

2.3 STATIC EXPERIMENTS

2.3.1 FLEXURAL TESTS

For the flexural tests 3 specimens were prepared. Each of the specimens includes 2 bricks combined with polymer PM. The 4 point bending test was applied. The length between constraints was 31cm, the length between loads was 7 cm. In the first experiment the displacement ratio was 10mm/sec. In the second, the displacement ratio was 1mm/sec, and in the third was 0,1mm/sec. The aim of changing speed is to observe polymer PM properties. When loading is slow, polymer PM behaviour is better. In Figure 9 test specimen is seen:

Figure 10. Flexural test specimen

In Figure 10, the load-deflection curve for the first bending test with displacement ratio of 10mm/s is seen. Calculating the area under the curve, we can detect the ductility of the flexible joint.

Sum of total Area: 6751,77 Nmm

Area under the curve until failure: 2912,15Nmm

Area under the curve after failure :3839,62Nmm

Ductility rate: 6751,77/2912,15= 2,31

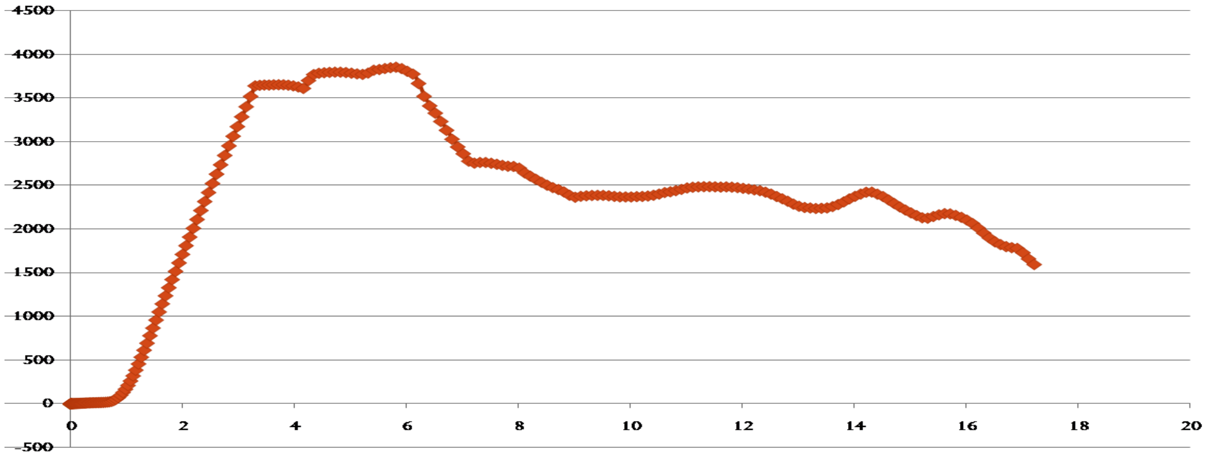

Figure 11: Load [N] - deflection [mm] curve of the first flexural test with displacement ratio of 10mm/s

In Figure 12, the load-deflection curve for the second bending test with displacement ratio of 1mm/s is seen. Calculating the area under the curve, we can detect the ductility of the flexible joint.

Sum of total Area: 32597 Nmm

Area under the curve untill failure: 9003,75Nmm

Area under the curve after failure :23593,95Nmm

Ductility rate: 3,62

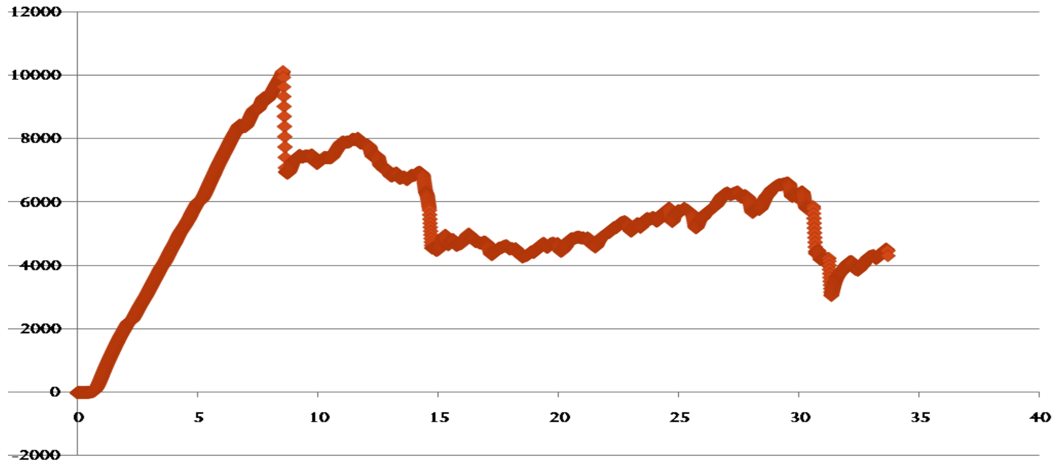

Figure 12. Load [N] - deflection [mm] curve of the second flexural test with displacement ratio of 1mm/s

In Figure 12, the load-deflection curve for the third bending test with displacement ratio of 0.1mm/s is seen. Calculating the area under the curve, we can detect the ductility of the flexible joint.

Sum of total Area: 78750Nmm

Area under the curve untill failure: 16250Nmm

Area under the curve after failure :62500Nmm

Ductility rate:4,8

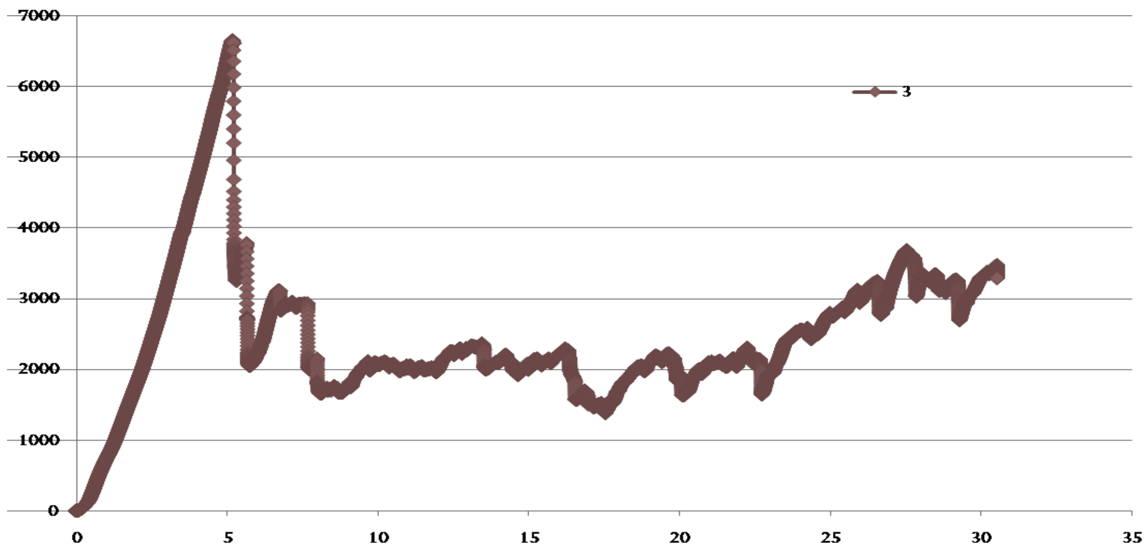

Figure 13. Load [N] - deflection [mm] curve of the third flexural test with displacement ratio of 0.1mm/s

2.3.2 SHEAR TESTS

2 static and 1 dynamic loading were done. For these 3 shear test specimens were prepared. Each specimen was consisted of 3 San Marco bricks, which were combined by using polymer PM. In the static test 10mm/sec

displacement ratio was applied and in the second one 1mm/sec. The aim of this was to understand how polymer PM changes the behaviour of the test. In Figure 14, the shear test specimen is seen.

Figure 14. Shear test specimen

In the dynamic test 10mm/sec displacement ratio was applied. The loads were changed cyclicaly and several trials were done with the same specimen. In the first trial, the load were changing between 1-5KN and it was repeated for 30 times. In the second trial, the load were changing between 1-10 KN and it was repeated for 30 times. In the third trial the load was changing between 1-15 KN and it was repeated for 30 times. In the 4th one the load was changing between 1-20KN and it was repeated for 30 times. After the experiments the specimen was crushed mechanically, and the failure load was 20KN. In Figures 18 and 19, the static shear test and dynamic (cyclic) shear test results are presented, respectively.

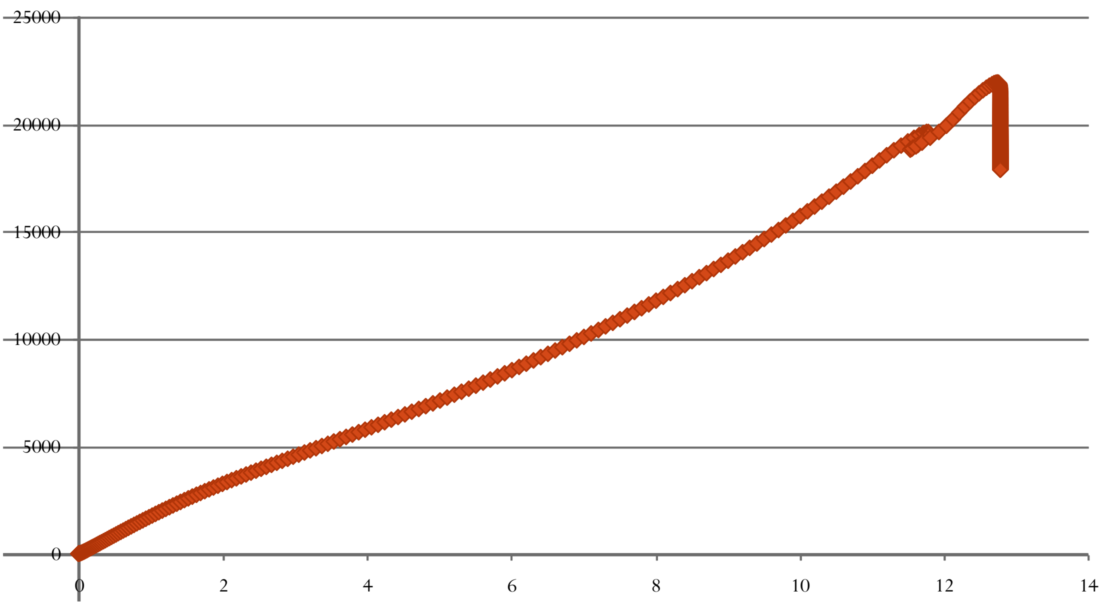

Figure 15. Load [N] - deflection [mm] curve of the shear test (10mm/s)

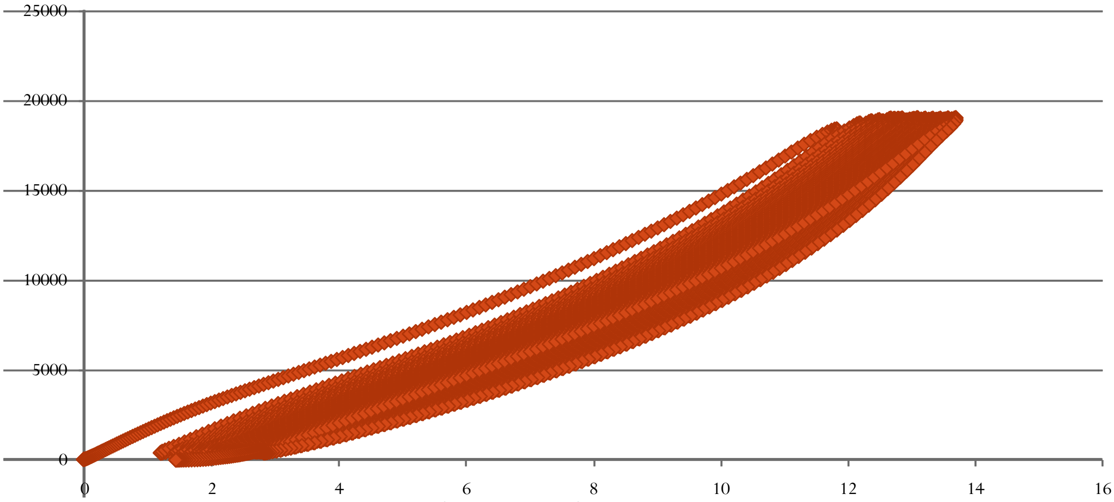

Figure 16. Load deflection curve of dynamic (cyclic) load shear test (10mm/s)

3. CONCLUSION

In the dynamic experiments the behaviours of three different masonry specimens are compared and the highest damping ratio is obtained in situation with polymer PM. When the bricks were fixed to the concrete beams with epoxy, damping values were decreased.

In the previous studies it's claimed that the failure criteria of dry stack masonry can be described by Mohr-Coulomb failure criteria. In all kinds of experiments generally when axial force is greater , damping values are increased ecxept a few experiments. This observation supports the idea that, dry stack masonry behaviour can be explained by Mohr –Coulomb criteria.

In the flexural and shear tests , it was observed that polymer PM is very effective in increasing ductility of masonry elements. And also after damage in post failure zone, it still prevents failure of masonry. In lower loading displacement ratios it behaviour is better.

Instead of traditional masonry, using of polymer PM and dry stack masonry is promissing for future, and this must be taken into account for further research to improve energy dissipation in structures during earthquakes.

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