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# THE SEISMIC BEHAVIOUR OF THE RC FRAMES WITH INFILL WALLS STRENGTHENED WITH PRECAST PANELS

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## Abstract

The aim of this study is the experimentally and analytically analysis of emerged behaviours, after the infill walls of the current reinforced concrete frame systems, which are weak resistant against the seismic effects, non-ductile, have been strengthened with the applied precast concrete panels. In this study has been researched so a strengthening method that this method can be applied without that the building residents need to leave the building. For this purpose, the three test specimens of the 1-bay (span), 2-storeyed and 1/2 scaled infill walls, which are weak resistant against the seismic effects, have been produced taking account of the commonly observed the defects in the current reinforced concrete buildings. The first of the test frames with the equivalent properties has been tested under the reversed-cyclic lateral loads as a reference specimen. The others haven been tested by the strengthening method, in which the produced panels of high reinforcement concretes that are interdigitated as I profile and as a rectangular such as a square are cemented to the infill walls of the current frame. The reinforced brick-infill walls using the concrete panels are modelled in different forms as equivalent pressure bar and shell elements. So the accuracy of the experimental studies are compared with the analytical results.

Experimental and analytical studies show that the applied strengthening method has significantly improved the properties such as energy consumption-capacity and the resistance of brick-filled concrete frames against the lateral loads.

## Key words

RC frame; seismic effect; infill wall; precast panel

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## 1 INTRODUCTION

The majority of the territories in Turkey is in the first-degree seismic zone and these regions are often shaken by large-scale earthquakes. The significant progresses on the construction of earthquake resistance building have been made as a result of the destructive and the rapid development of technology earthquake in the last 15 years. Further the researches on the earthquake resistance buildings have gained importance and new reinforcement methods have been developed. The method, cast-in-place concrete shear wall is one of the primarily and commonly used methods. This method is very practical and economical especially in case of the low lateral stiffness on the construction. But the residents must be leave building during the application because this method is a difficult and long application.

In this study, it is tried to complete the mentioned deficiency of the concrete shear wall. This method can be applied to strengthen the concrete frame constructions with the brick hollow walls and it does not require the evacuation of the building [1]. The mentioned strengthening method [2] has been examined, but the sufficient information on its design and application is not available. The first study related to this subject has been made in [3,4]. According to the study in [3], the non-ductile reinforced concrete frame systems have been strengthened using the precast infill panels. As a result of this study, it is observed that the precast-infill wall system has a good performance, non-ductile frame system against lateral loads transformed into the ductile shear wall system and so the values of its durability and stiffness are significantly higher. The experimental studies on this subject in Turkey were carried out in Earthquake Laboratory of Faculty of Civil Engineering in METU at the beginning of the 2000s [5-7].

In this performed study, the effectiveness of the strengthening method has been researched by the application of the different panel sizes and anchorage details for ½-scale reinforced concrete frames [1]. The principle of this applied technique is based on the cementing of high durability precast concrete panels on the brick hollow infill walls in the building [8]. The monolith displacement and application of the panels are not practical. Therefore the designed panels in different geometrical shapes must be in so sizes and weight limits that they can be quite easily carried by two people.

In this Study, panel shapes were differently chosen in the experimental frames with the same properties. According to the designed panel geometries in two different types, the contribution of this applied strengthening to the seismic behaviour of brick hollow infill concrete frames has been comparatively analysed.

Many studies have been made for the strengthening of reinforced concrete frames with various methods in the past years [9-12].

## 2 EXPERIMENTAL PROGRAM

In this study, 3 experimental specimens have been tested under the influence of reversed-cyclic lateral loads. The geometric and material properties are the same in the all experimental specimens. The specimens are 1-bay and 2-storeyed. Three reinforced concrete bare frames have been simultaneously manufactured in the horizontal position.

Then the brick hollow infill walls of the specimens in the vertical position have been built and the plastering has been applied on these walls. Some deficiencies-often observed- in the present constructions have been consciously reflected to the experimental specimens to the produce the frames with weak seismic effect. They are the deficiencies such as low durability of concrete, more durable beam-construction than columns, the using of a smooth surfaced reinforcement, the lack of the stirrup densification, the lack of the stirrup in the area of beam-column joints and stirrup hooks in 90°. The applied vertical load to the frame system is N≈ $0.1*A_c*f_c$. Fig. 1 shows the dimensions of the specimens and the reinforcement scheme.

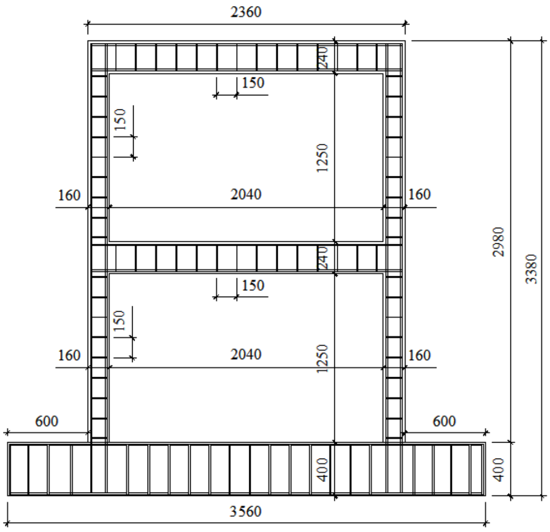
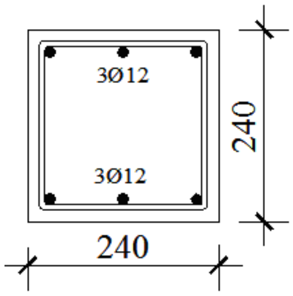
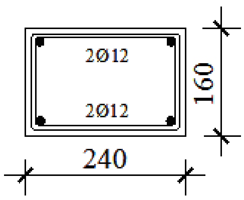
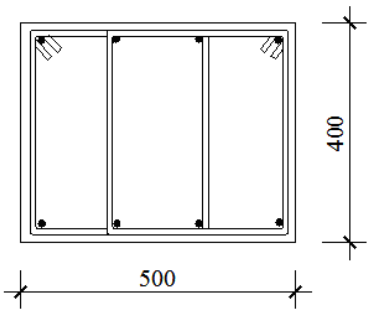



*Fig. 1: The dimension and reinforcement scheme of test frames (Dimensions are in mm.)*

There is not a pier-regulation on the beams of frame specimens. Hence the span and support reinforcement ratios have been fixed kept. The top and bottom reinforcement in beams have been extended to the the outer surface of the column and from this point have been bent $20\phi$ (240 mm) long upwards and downwards. The parts of beams, columns and basic elements are given in Table 1 and the mechanical properties of used reinforcement in the test frame are given in Table 2.

*Tab. 1: Cross-section and reinforcement details of test frame members*

| **Beam** | **Column** | **Foundation** |
|---|---|---|
|   Reinforcement: 6Ø12<br>Stirrupt: Ø8/150 mm |   Reinforcement: 4Ø12<br>Stirrupt: Ø8/150 mm |   Reinforcement: 8Ø14<br>Stirrupt: Ø10/200 mm(çift) |

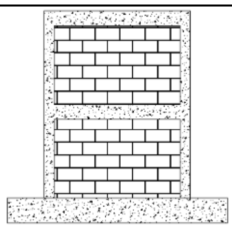
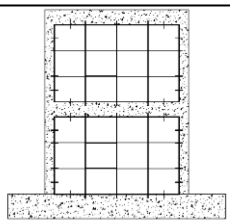
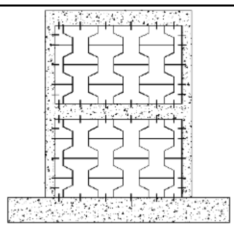
*Tab. 2: Properties of reinforcing bars*

| **Bar Diameter (mm)** | **$f_{sy}$(MPa)** | **$f_{su}$(MPa)** | **Type** |
|---|---|---|---|
| $\phi 8$ | 413 | 522 | S220 |
| $\phi 10$ | 440 | 492 | S220 |
| $\phi 12$ | 394 | 518 | S220 |

| | | | |
|---|---|---|---|
| $\phi$14 | 460 | 525 | S220 |

Before the application of the strengthening elements to the test frames, they were built by the usage of the commercially sold bricks in the dimensions of 190x135x85 mm and their both sides were plastered with cement rendering and lime plaster in thickness of 8-10 mm. Two different types of precast panels were manufactured under this study. The minimum conditions in [2] about the anchorage of the panel thickness and the panels to the frame elements were chosen according to test specimens at ½ scale [13]. The graut in the manufacture of the panels was used because the thickness of the panels is low, the graut is high strength, more homogeneous mix than concrete and does not cause the disintegrations while removing from the mold. The high strength and epoxy based adhesives were used for the anchorage of the panels to the wall and to the frame elements of anchoring irons. The figures of the specimens in the experimental program and concrete strength values are given in Table 3.

*Tab. 3: Properties of test specimens*

| **Specimen no:** | **Configuration** | **$f_c$ (MPa)** | |
|---|---|---|---|
| | | **Frame** | **Precast Panel** |
| 1 (RF) |  | 13.24 | - |
| 2 (A-TPF) |  | 14.73 | 55.53 |
| 3 (B-TPF) |  | 14.76 | 58.29 |

The tests were carried out on a rigid test platform of strong concrete walls and strong concrete floors in laboratory. The foundation beam was designed to fulfil the conditions of the fixed supports for the rigid and test element. The test elements were produced according to the knowledge on the foundation system and were fixed through the holes in the laboratory floor. The tests began as a load control and continued as the displacement control after the nominal flow load-value of the system. After the acceptance of triangular load alike seismic load, the horizontal load was applied to test frames as 2 units for top floor and 1 unit for ground floor and the vertical load was applied equally to both columns as a pressure force in the approximate value N = 0.1.Ac.fc.

## 3. THE COMPARISON OF THE EXPERIMENTAL AND ANALYTICAL RESULTS

The total lateral load of the analytical model for the test specimens- 2nd floor durability envelope and the total lateral load of the experimental studies-2nd floor displacement hysteretic curves are given in Fig. 2.

As shown in graphs, the higher increases on the strength and stiffness values of the frames were observed strengthening of the infill reinforced concrete frame specimens with precast panels.

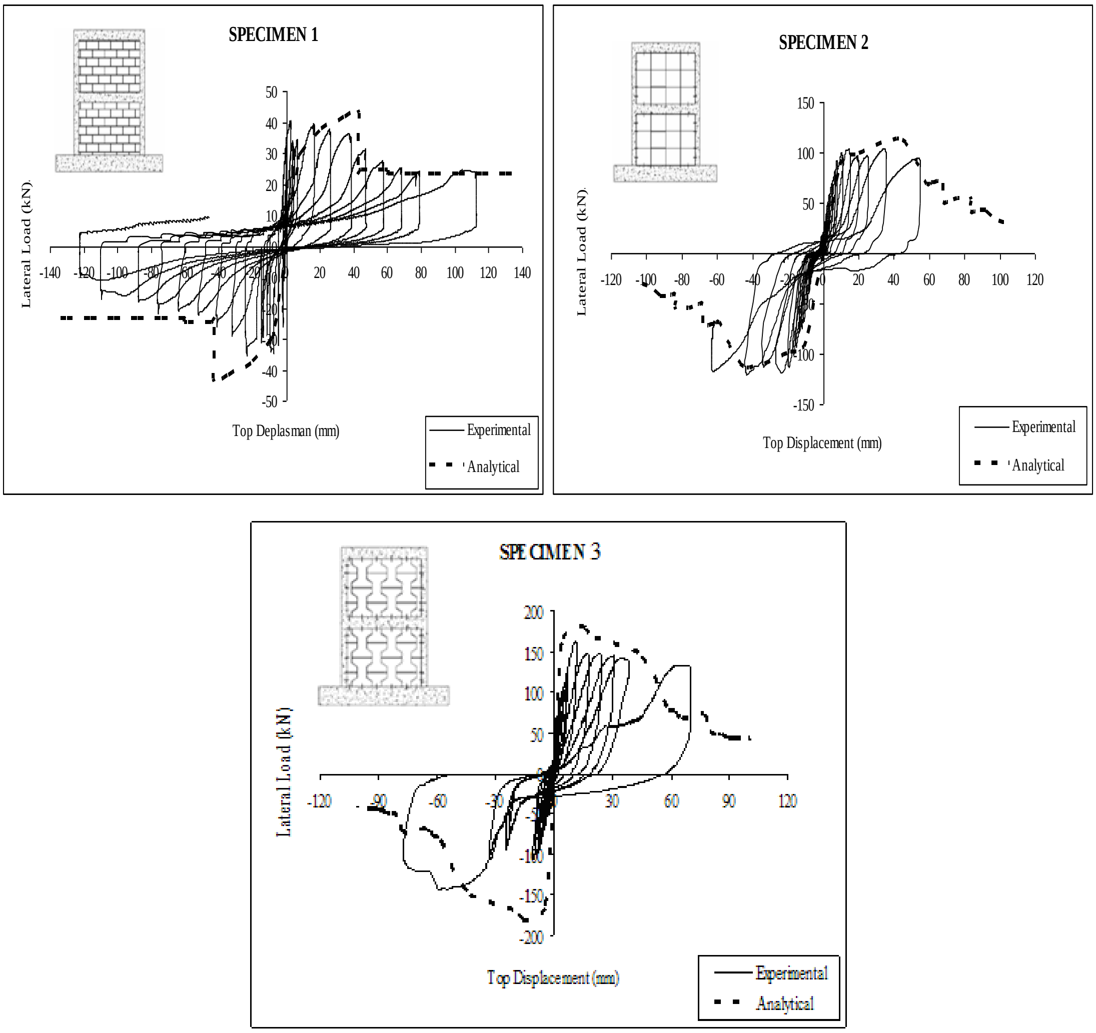
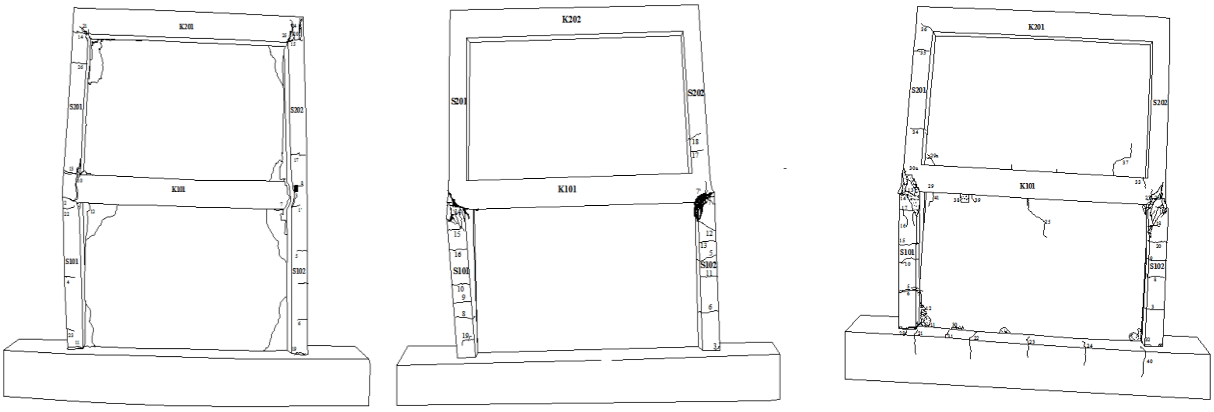



*Fig. 2: Load- displacement hysteresis curve of specimens*

The schematic damage forms of the test specimens at the end of the test are given in Fig. 3. The excessive damage in the beam-column joints such as in the reference specimen, test specimen with no: 1 caused to the ending of the 2. and 3. tests. While the damages for the specimens of the test 1 in low load level, the hinges of the strengthened test specimens are concentrated in the more advanced load levels.



*(a) Specimen 1* *(b) Specimen 2* *(c) Specimen 3*

*Fig. 3: Schematic shapes of test specimens after failure*

## 4 DISCUSSION OF TEST RESULTS

The displacement envelope curves of the test specimens are given in Fig. 4. In general, the changing strength values at different ratios for the reference specimen, „ test specimen with no: 1“ are shown in the strengthened test specimens. All the strengthened test specimens showed almost the same behaviour (2%) in terms of the reached maximum displacement ratio at the end of the test. The specimen of the test 1 has more displacement than the strengthened specimens with the displacement ratio 3.6%. This shows that the strengthening with the high durable and precast concrete panels has significantly increased the lateral stiffness of reinforced concrete frames.

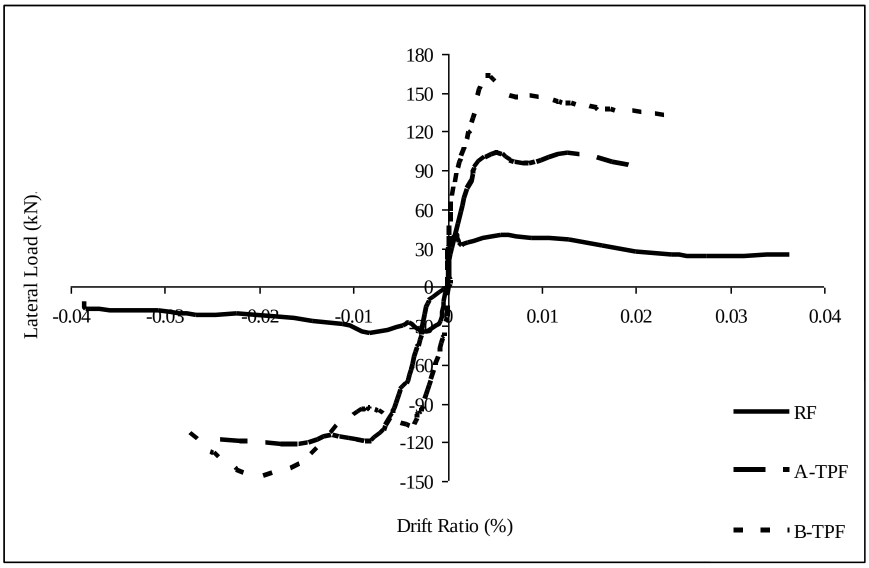



*Fig. 4: Load- displacement envelope curves of specimens*

The total energy dissipation graphics of test specimens is given in Fig. 5.

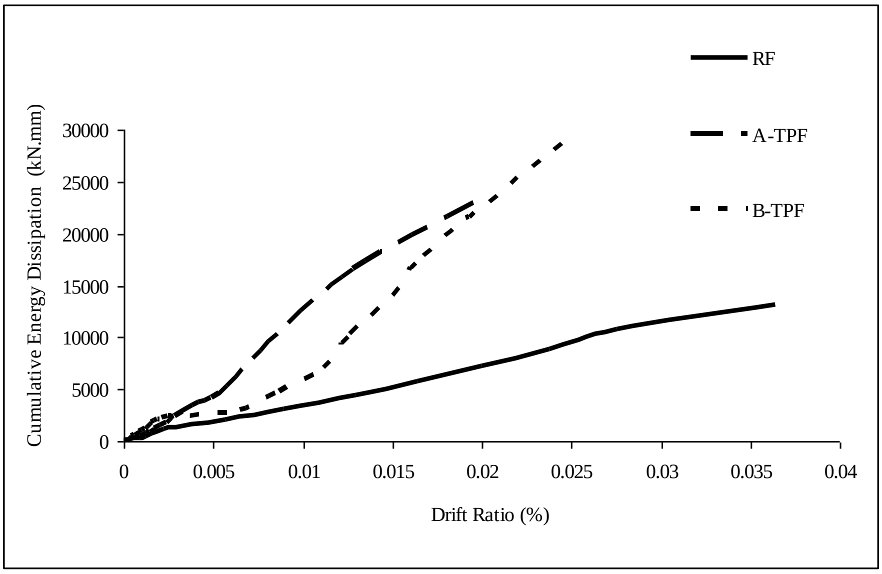



*Fig. 5: Energy Dissipation capacity graphs of specimens*

For the numerically comparison of the test results, the maximum horizontal bearing- loads of the test specimens and the displacement ratios for these loads have been given in Table 4 and the stiffness properties have been given in Table 5 and the energy dissipation values of the specimens have been given at maximum load and at the end of the test in Table 6.

*Tab. 4: A Comparison on the horizontal load bearing capacity of test specimens*

| **Specimen no** | **Ultimate load (kN)** | **Drift ratio at max. Load (%) (δ/Σh)** | ***** |
|---|---|---|---|
| RF | 40 | 0.00256 | 1.000 |
| A-TPF | 121 | 0.0065 | 3.025 |
| B-TPF | 162.77 | 0.0041 | 4.069 |

* Ratio of ultimate lateral load of infilled frame to that of bare frame

*Tab. 5: A Comparison on the stiffness test specimens*

| **Test Specimen** | **Stiffness values (kN/mm)** | | | **Displacement Ratios (δ/Σh)** | | **1. Cycle Stiffness ratio** | **Maximum Load Stiffness ratio** |
|---|---|---|---|---|---|---|---|
| | **1. Cycle** | **Maximum Load** | **Last cycle** | **Maximum Load** | **Last cycle** | | |
| RF | 26.32 | 5.53 | 0.237 | 0.00256 | 0.036 | 1.000 | 1.000 |
| A-TPF | 184.44 | 7.92 | 1.87 | 0.0065 | 0.024 | 7.00 | 1.43 |
| B-TPF | 382.45 | 14.63 | 1.933 | 0.0041 | 0.025 | 14.53 | 2.645 |

*Tab. 6: A Comparison on the energy dissipation capacity of test specimens*

| | **energy dissipation values (kN.mm)** | | **energy dissipation ratios** | |
|---|---|---|---|---|
| | **At Maximum Load** | **At the end of the test** | **At Maximum Load** | **At the end of the test** |
| RF | 509.81 | 13220.58 | 1.000 | 1.000 |
| A-TPF | 7961.47 | 23367.54 | 15.61 | 1.76 |
| B-TPF | 6250.336 | 29197.83 | 12.26 | 2.21 |

# 5 ANALYTICAL STUDIES

During the analytical calculation of frame specimens, the displacement-controlled pushover was applied using the computer program SAP2000 [14]. During the modelling of test specimens, the bearing system elements are modelled as bar elements. During the entering of the material properties, the cracked stiffness of the reinforced concrete elements are used because of the inelastic analysis. The applied vertical load level to the column in experiments is in the range of $0.10 \times b \times h \times f_c$. Therefore the column and beam bending stiffnesses were regarded as 0.5EI.

For the modelling of the infill walls, the effect of filling bricks has been neglected in the strengthened test specimens A-TPF, B-TPF and C-TPF and the precast panel elements have been modelled as shell elements, while brick infill walls attend to the model as an equivalent pressure bar in the not strengthened reference test specimens.

The results of the analytical study with program SAP2000 are shown in Fig. 6.

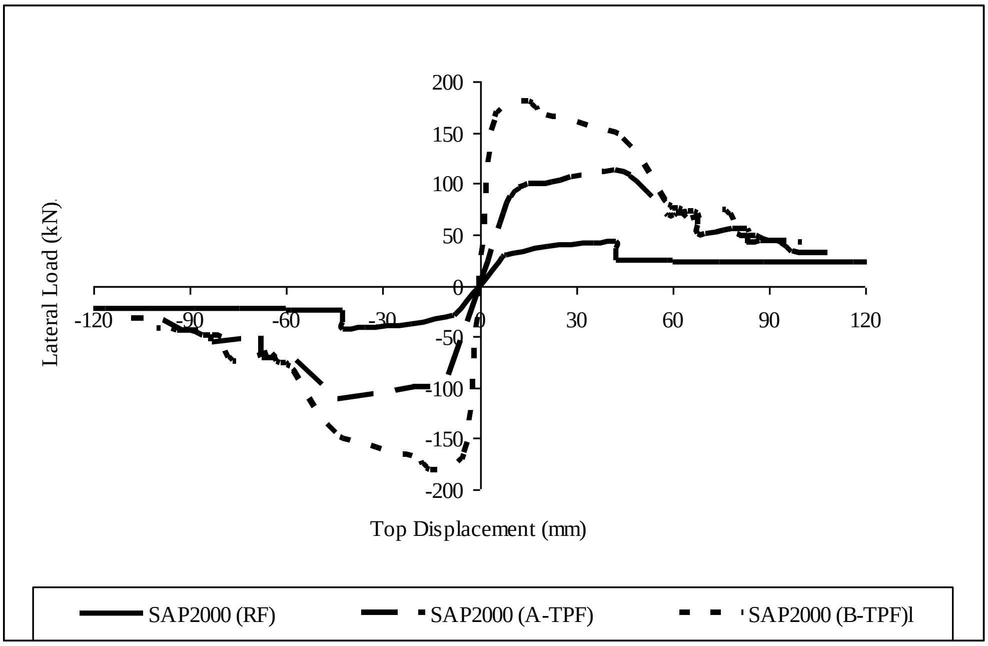



*Fig. 6: The strength envelope curves after analytical modelling of the test samples*

# 6 CONCLUSIONS

In this study, the behaviour of the strengthened RC frames, the hollow brick infill walls of which are high strength and strengthened with precast panels, under the reversible and repeated lateral loads has been researched. The performed tests gave a view about the contribution and applicability of the method, strengthening of frame walls with precast panels for the infill RC frame walls under the lateral loads.

In the tests, 3 hollow brick infill RC frames, design and construction defects of which are often encountered in practice, with 1-bay, 2-storeyed, ½ scale are manufactured. One of these was subjected to test as reference specimen and the other 2 of these were subjected to test by strengthening as a result of the adhesion of the panels, walls of which are manufactured by designing in different geometrical shapes.

As a result of experiments, it has been observed that maximum lateral load bearing capacity of the strengthened specimens has better results than initial stiffness and energy dissipation capacity. It is observed that there is not significant damage on the walls of strengthened specimens, while the damages emerged on the reference specimen brick infill walls during the tests. The damages are mainly more in the 1st storeyed columns and in beam-column joints. It is thought to arise this problem due to the inadequate dimensions of anchors between panels and frame members and because the concrete strength of the panels is relatively higher than concrete strength of the frames. In fact this is not a desirable situation and the standing of the system is provided, although the walls are quite rigid and the beam-column joints are disintegrated towards the end of the test. The specimen B-TPF of the strengthened test specimens has better results in terms of strength, stiffness, and energy dissipation capacity than the specimen A-TPF. So it appears that the flat or recessed structure of the panel geometry has influence on the strengthening by the precast concrete panels of the RC frames for the laterals loads.

Generally as a result of this study it is concluded that the strengthening method with the high strength precast panels is more a preferable method than the other strengthening methods because the application of this method is easy, it does not require the evacuation of the building, it can be applied to contiguous buildings and it increases adequately the strength of the construction against the lateral loads.

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