COMPDYN 2013
4th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, V. Papadopoulos, V. Plevris (eds.)
Kos Island, Greece, 12–14 June 2013

STUDY OF THE IN-PLANE BEHAVIOUR OF GROUND FLOOR REINFORCED CONCRETE (R/C) FRAMES RETROFITTED WITH JACKETING AND AN ENCASED R/C PANEL IN ORDER TO WITHSTAND SEISMIC FORCES

George C. Manos[1], V. Soulis[1], K. Katakalos[1]*, G. Koidis[1]

[1] Laboratory of Strength of Materials and Structures, Dept. Civil Engineering, Aristotle University, Thessaloniki, GREECE
gcmanos@civil.auth.gr

Keywords: Retrofitting, Reinforced Concrete Frames, Encasement R/C Panels, Jacketing, Soft Ground Floor

Abstract. *The in-plane behaviour of one-bay single-storey reinforced concrete (R/C) frames was numerically examined when they were subjected to cyclic seismic-type horizontal loading and their retrofitting scheme included jacketing of their columns together with a cast-in-place infill R/C panel as an encasement. This numerical study examined the influence of the presence of such an encased R/C panel, being connected with the surrounding frame with or without steel ties, on the overall behaviour of such a system. From the preliminary numerical analysis results it can be concluded that such an encasement results in a considerable increase of the stiffness and the bearing capacity of the studied system, especially when steel ties are present at the interface. Moreover, the placement of steel ties also moderates the amplitude of the forces that are transferred at the narrow column-to-beam joint regions in a direction normal to the interface through the contact/gap mechanism, and consequently, mitigate the possibility of crushing the encased panel and/or parts of the columns or beams at these regions. Consequently, it can be concluded that the presence an encased R/C panel being connected by the appropriate steel ties with the surrounding R/C frame, has an overall beneficial effect on the behaviour of this type of structural system subjected to seismic type loading An experimental sequence was also performed in order to quantify the behaviour of such steel tie connections at the interface under a stress field that is expected to develop at this part of the encasement during seismic type loading. Such measured behaviour is in agreement with the assumptions made concerning the behavioural characteristics of these steel ties in the preliminary numerical analysis*

1 INTRODUCTION

Many multi-storey reinforced concrete (R/C) structures, built in seismic regions, have their ground floor designed to function as a parking space. Therefore, the bays of the R/C frames at this level are left without masonry infills whereas all the stories above have their corresponding bays of the R/C frames infilled with external masonry walls (with or without door and window openings) or with internal masonry partitions. It was demonstrated by extensive past research that the dynamic and earthquake behaviour of such structures, having a relatively flexible (soft) ground floor and stiff upper stories, results in increased demands on the structural elements of the ground floor, due to the interaction of the masonry infills with the surrounding R/C frames. This, in turn, leads to structural damage, unless the structural R/C elements at the ground floor are properly designed ([1], [3], [5], [6], [7]). As this behaviour was not well understood in the past, there are many structures with such a soft storey that were designed and constructed with their R/C structural elements now in need of upgrading their capacity in order to meet such increased demands imposed on them from potential future seismic actions.

The objective of this paper is to investigate the performance of a retrofitting scheme that can be easily applied to such a soft ground floor of multi-storey reinforced concrete (R/C) structures ([2], [4], [8], [9], [10]). A common retrofitting scheme usually consists of:

- R/C jacketing of the existing R/C columns at the ground floor level.
- R/C jacketing of the existing R/C beams at the ground floor level.

The jacketing at this level is considered as feasible due to fewer construction constraints than a similar jacketing scheme at the upper stories, which will be prevented from various obstacles such as: the existing partitions, the floors and many other non-structural features.

With the jacketing of the main ground floor structural elements, a certain increase in their strength and ductility is expected to be achieved. The current Greek guidelines for retrofitting reinforced concrete buildings [4], also provides for the addition of an R/C panel that can be added as an encasement, filling the space between the jacketed columns and beams. This can be done for a number of bays at such a soft ground floor in need of being strengthened. The placement of such infilling R/C encasement panels will provide additional stiffness and possible strength at this level, thus balancing the initial abrupt change of stiffness between this floor and the rest of the upper stories, that initiates its unfavourable performance.

In the relevant provisions of these guidelines [4] the designer is provided with a number of distinct choices. In the present investigation the following choices will be studied:

a. The encasement of the R/C panel is done without any connection with the surrounding R/C structural elements within a bay (columns or beam). The provisions describe a limited connection of the R/C panel to the upper and lower horizontal boundaries (beams) of the bay.

b. The encasement of the R/C panel is constructed together with a connection with the surrounding R/C structural elements strengthened by jacketing within a bay (columns or beam), utilizing steel ties. In this case, the thickness of the encasing R/C panel is smaller than the width of the beams that form the encased bay.

c. The previous case is differentiated by a third type of encasement, where the added R/C panel has a thickness larger than the width of the beams of the bay. This is envisaged as a construction of an additional shear wall rather than an encasement and should be treated differently. This last case is not investigated here. Therefore, the present study is limited to cases a and b described above.

2 PRELIMINARY NUMERICAL SIMULATION

The numerical study was limited to examining a single storey one bay R/C frame formed by two columns (left and right) and two beams (top and bottom), as shown in figure 1. The overall dimensions of this frame were chosen, arbitrarily, as follows: The length between the mid axes of the two columns equal to 6m. The height between the mid-axes of the top and bottom beams equal to 3m. The cross section of the columns 340mm x 340mm; that of the top beam 300mm x 600mm and that of the bottom beam with large flexural stiffness representing a rather stiff foundation beam, to be specially constructed for this purpose. The numerical model included three non-linear springs located at all the interconnections between the columns and the beams either at the top and bottom of each column or at the left and right side of each beam, whereas the region representing the actual beam-column joint was considered as non-deformable. These non-linear springs were provided with tri-linear moment-rotation properties thus representing the possibility of plastic hinges forming at these locations. The properties of these moment-rotation springs were derived considering typical reinforcing details for the columns and beams for such structural elements at the ground floor as well as an axial force level for the columns equal to 510 KN, representing the axial force level for a building with three more stories above the ground floor where the examined single-storey one bay R/C sub-assembly is assumed to be located. In this way, only the scenario of non-linear behaviour from flexure, by the formation of the plastic hinges is considered, excluding any shear non-linear behaviour of the R/C structural members.

In this preliminary numerical simulation, the behaviour of the encased R/C panel itself was considered to be elastic. A subsequent numerical simulation considered the possibility of non-linear behaviour of the encased R/C panel itself.

The properties of these moment-rotation springs were derived considering typical reinforcing details for the columns and beams for such structural elements at the ground floor as well as an axial force level for the columns equal to 510 KN, representing the axial force level for a building with three more stories above the ground floor where the examined single-storey one bay R/C sub-assembly is assumed to be located. The thickness of the encased R/C panel was assumed to be equal to 150mm constructed with a material having Young's modulus equal to E=7GPa to account for a level of cracking.

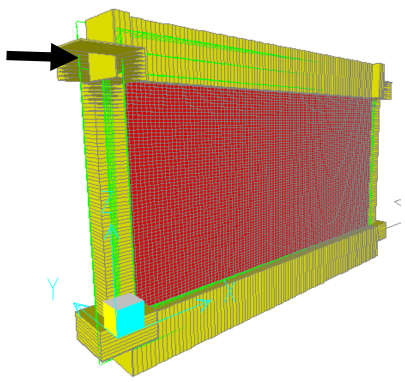

Figure 1. The studied single-storey one bay R/C frame with the encased R/C panel

The following distinct models were considered:

1. *bare frame*" model. This first model was that without any encasement.

All the other models, which were studied and are described briefly below, included an encased R/C panel (with a 150mm thickness) which was connected to the surrounding frame in a variety of ways, as will be explained below. The connection of the encased R/C panel with the surrounding frame was numerically simulated with two distinct types of non-linear link elements each one representing a distinct force transfer mechanism ([1], [7]). The first type of link represents the contact/gap mechanism between the R/C panel and the surrounding frame. As such, this link can transfer only compressive forces with a direction normal to the interface without any limitation, transferring at the same time forces with a direction tangent to the interface, considering an acceptable friction transfer mechanism. However, when the stress field at the interface between the encased R/C panel and the structural member of the surrounding frame becomes tensile then this transfer of forces either in the normal or in the tangent to the interface direction through the first type of link becomes neutralized. The second type of connection between the R/C encasement panel and the surrounding frame represents an additional force transfer mechanism that simulates the presence of a steel metal tie. These metal ties are embedded at both the R/C panel and the structural elements (columns or beams) of the surrounding frame at certain intervals on the interface. They are placed in a direction normal to the interface and can thus transfer tensile forces normal to the interface (the compressive forces being transferred mainly by the contact/gap mechanism) or tangential forces in addition to the contact transfer mechanism. This second type of link was assumed to have an elasto-plastic behaviour in its longitudinal direction, representative of a steel reinforcing bar with a diameter of 12mm and a yield stress of 500MPa. A similar elasto-plastic behaviour was also assumed in the tangential direction representing such tangential behaviour of a 12mm diameter tie. Towards the quantification of such tangential behaviour of a steel tie, a sequence of tests was conducted that will be briefly described in section 4. These metal ties were assumed to be spaced at 180mm intervals along the interface of the numerical models

The behaviour of the following three distinct models were studied that included an encasement of an R/C panel within the one-storey one bay R/C frame.

2. *Encased model a***.** This model was provided with only the first type of links all around the interface of the R/C encased panel with the surrounding frame, thus representing a connection between the R/C encased panel and the surrounding frame that could transfer forces at their interface only through the contact/gap mechanism.
*3. Encased model b***.** In this model, the previous contact/gap transfer mechanism was retained through the first type of links. In addition to that the second type of links were added only at the interface of the encased R/C panel with the top and bottom beams of the surrounding R/C frame, as provided by the relevant guidelines, representing 12mm steel ties spaced at 150mm intervals.
*4. Encased model c***.** In this model, the contact/gap transfer mechanism was again retained through the first type of links. The second type of links were added both at the interface of the encased R/C panel with the top and bottom beams of the surrounding R/C frame as well as at the interface of the encased R/C panel with the left and right columns of the surrounding R/C frame, representing 12mm steel ties spaced at 150mm intervals.

3 NUMERICAL RESULTS

All the previous numerical models were subjected to a horizontal incremental force in a direction coinciding with the mid-axis of the top beam, This was done in a "push - over" type of loading with sufficient increment so that equilibrium could be established through an iteration process, taking into account all the non-linear mechanisms that were included in these models. These were the following:

- The possibility of developing plastic hinges at the top and bottom of the columns as well as at the left and right edge of the top beam.

- The possibility to triggering the contact/gap mechanism at the interface between the encased panel and the surrounding R/C frame
- The possibility of the steel ties connecting the encased panel with the top and bottom beam and the left and right column behaving in an elasto-plastic way both in a direction normal as well as tangential to the interface.
- The non-linear mechanisms were not extended to include the R/C panel itself at this preliminary numerical analysis. This non-linear behaviour of the encased R/C panel was included in a subsequent simulation that is not presented here.

In the subsequent figures the obtained numerical results include: a) The variation of the applied horizontal force at the axis of the top beam against the corresponding displacement. b) The deformed shape of the single-storey one bay frame with or without the encasement at the maximum deformation level at the end of the “push – over” loading sequence. c) The variation of the forces that developed at the interface between the encased panel and the surrounding R/C frame.

3.1 Behaviour of the “bare frame’ model

The non-linear trend in the curve representing the variation of the applied horizontal force at the axis of the top beam against the corresponding displacement, as depicted in figure 2a, is quite evident when the horizontal displacement level exceeds the value of 15mm. When the top beam horizontal displacement level reaches the maximum amplitude of 24.5mm, plastic hinges develop at the critical locations of the beams and columns, as depicted in figure 2b. The maximum amplitude of the horizontal force at that level is 174KN which represents the bearing capacity of the bare frame whereas its initial stiffness is approximately 10KN/mm

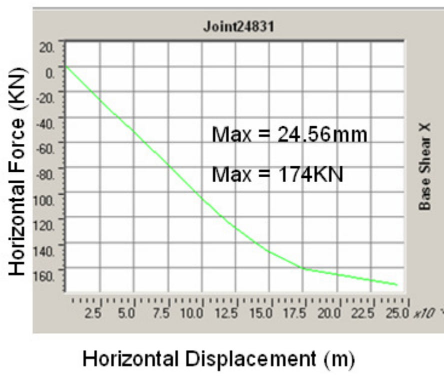

Figure 2a. The Horizontal force - Horizontal displacement “bare frame response

Figure 2b. The studied “bare frame” single-storey one bay R/C frame without the encased R/C panel

3.2 Behaviour of the “encased model a”

The non-linear trend in the curve representing the variation of the a applied horizontal force at the axis of the top beam against the corresponding displacement, as depicted in figure 3a, is quite evident when the horizontal displacement level exceeds the value of 10mm. These non-linear trends are less pronounced than what can be observed in the corresponding curve for the bare frame model. When the top beam horizontal displacement level reaches the maximum amplitude of 19.92mm, the corresponding maximum amplitude of the horizontal force at that level is 1950KN (figure 3b). If this force level is compared to the bearing capacity of the bare frame it, represents an increase of 800%. A similar increase can also be observed in the stiffness that reaches the level of 150KN/mm.

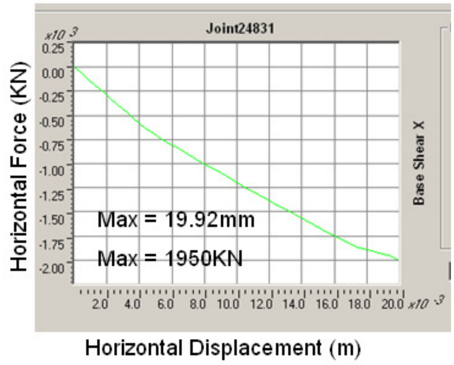

Figure 3a. The Horizontal force - Horizontal displacement "encased model a" response

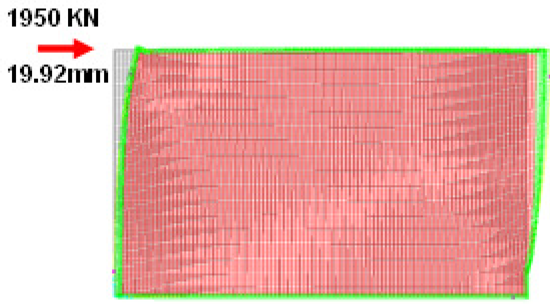

Figure 3b. The studied "encased model a" single-storey one bay R/C frame with the encased R/C panel

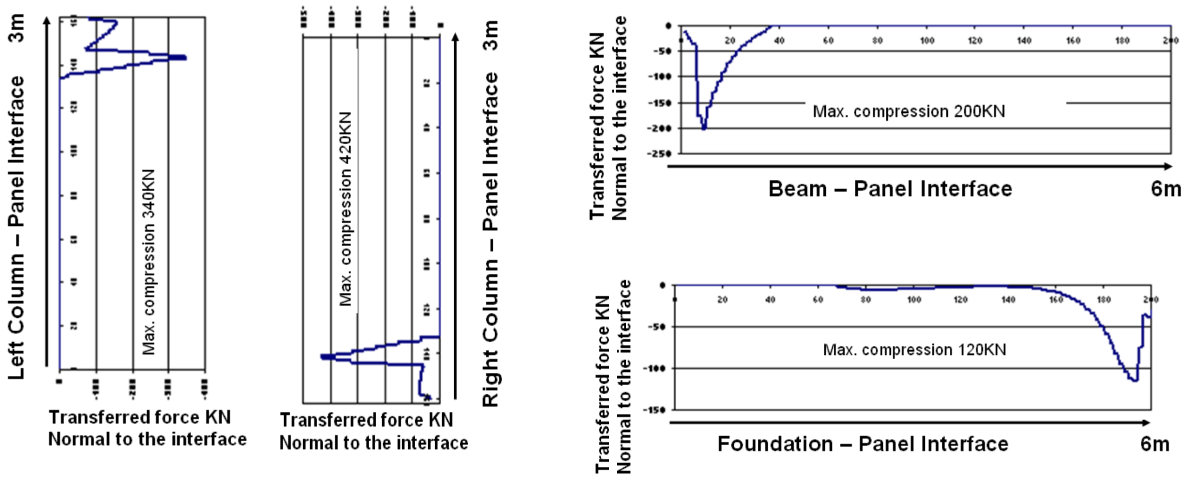

Figure 4. Transfer of forces at the interface between the encased panel and the top and bottom beams as well as between the left and right columns for the simulation of the encased model a

Figures 4 represent the transfer of forces at the interface between the encased panel and the surrounding frame through the contact/gap mechanism alone ([1], [7]). As can be seen, this transfer takes place at the corners of the encased panel where it contacts the columns and the beam near the region of column-to-beam joints whereas a large part of the interface is free of forces due to the gap that forms at the interface at these locations. It can also be seen that these contact forces in a direction normal to the interface reach a relatively large amplitude in these narrow column-to-beam joints regions. Such high amplitude forces are expected to introduce additional non-linear mechanisms such as crushing of the encased panel and/or parts of the columns or beams at these regions. These additional mechanisms are not included in this preliminary numerical simulation.

3.3 Behaviour of the "encased model b"

The non-linear trend in the curve representing the variation of the applied horizontal force at the axis of the top beam against the corresponding displacement, as depicted in figure 5a, is quite evident when the horizontal displacement level exceeds the value of 8mm.

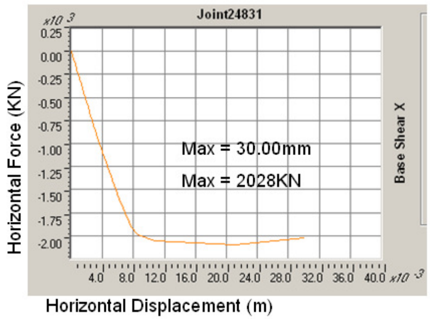

Figure 5a. The Horizontal force - Horizontal displacement "encased model b" response

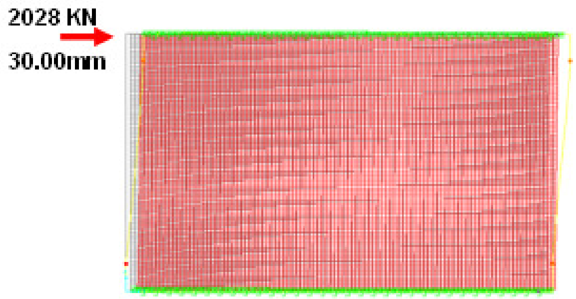

Figure 5b. The studied "encased model b" single-storey one bay R/C frame with the encased R/C panel

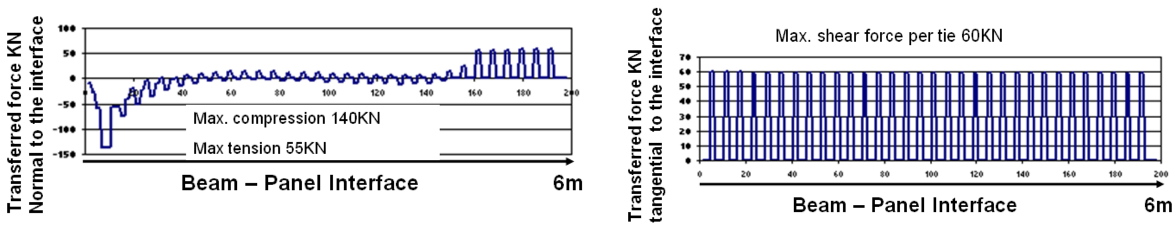

Figure 6. Transfer of forces at the interface between the encased panel and the top beam from the simulation of the encased model b

When the top beam horizontal displacement level reaches the maximum amplitude of 30.00mm, the corresponding maximum amplitude of the horizontal force at that level is 2028KN (figures 5a and 5b). The presence of steel ties between the encased panel and the surrounding frame retained the increase in the bearing capacity and the stiffness that was observed in the *encased model a* before. The stiffness reaches the value of 250KN/mm. Figure 6 represent the transfer of forces at the interface between the encased panel and the surrounding frame through the steel ties. As can be seen, the transfer takes place partly through the steel ties that are located at the interface between the encased panel and the top beam in the tangential direction. This transfer mechanism also results in moderating the amplitude of the forces that are transferred at the narrow column-to-beam joints regions in a direction normal to the interface through the contact/gap mechanism. Such transfer of forces at the interface will mitigate the possibility of crushing of the encased panel and/or parts of the columns or beams at these regions.

3.4 Behaviour of the "encased model c"

The non-linear trend in the curve representing the variation of the a applied horizontal force at the axis of the top beam against the corresponding displacement, as depicted in figure 7a, is quite evident when the horizontal displacement level exceeds the value of 7.5mm. When the top beam horizontal displacement level reaches the maximum amplitude of 24.95mm the corresponding maximum amplitude of the horizontal force at that level is 4880KN. The presence of steel ties between the encased panel and the surrounding frame both at the top and bottom beam as well as the left and right columns further augments the increase in the bearing capacity and the stiffness that was observed in the *encased model b* before (figures 7a and 7b). The stiffness reaches the value of 300KN/mm.

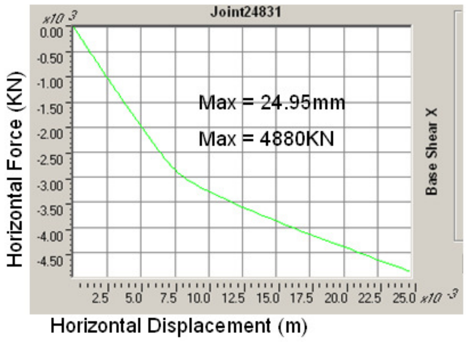

Figure 7a. The Horizontal force - Horizontal displacement "encased model c" response

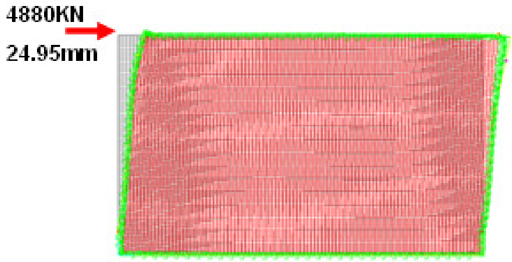

Figure 7b. The studied "encased model c" single-storey one bay R/C frame with the encased R/C panel

Figures 8 represent the transfer of forces at the interface between the encased panel and the surrounding frame through the top beam steel ties whereas figures 9 depict the transfer of forces through the ties that are located at the left and right columns.

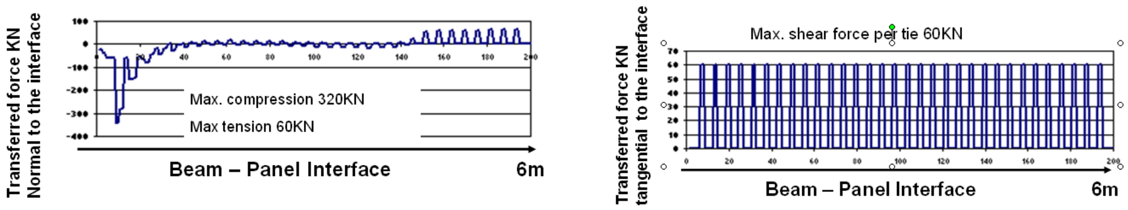

Figure 8. Transfer of forces at the interface between the encased panel and the top beam from the simulation of the encased model c

As can be seen, the transfer takes place partly through the steel ties that are located at the interface between the encased panel and the surrounding frame in the tangential direction.

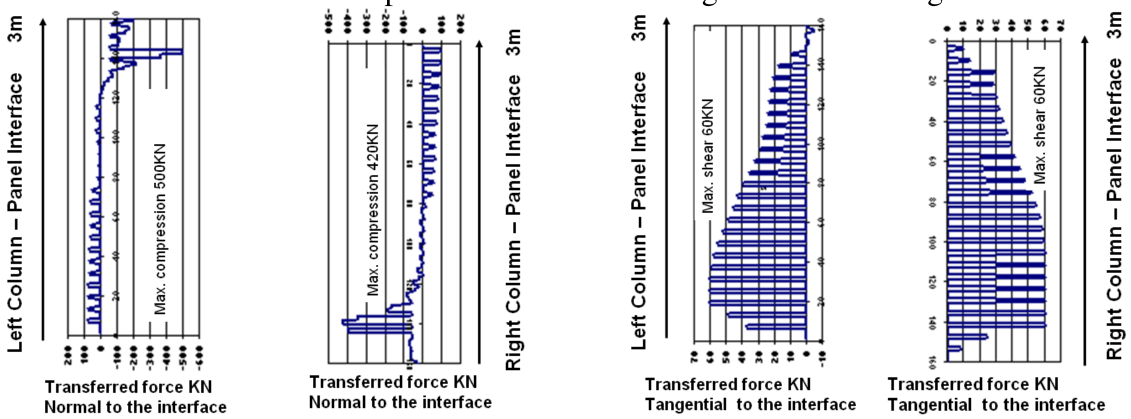

Figure 9. Transfer of forces at the interface between the encased panel and the left and right columns from the simulation of the encased model c

This transfer mechanism also results in moderating the amplitude of the forces that are transferred at the narrow column-to-beam joints regions in a direction normal to the interface through the contact/gap mechanism. Such transfer of forces at the interface will mitigate the possibility of crushing of the encased panel and/or parts of the columns or beams at these regions.

3.5 Conclusive observations of the influence of the encased R/C panel and its connection with steel ties to the surrounding R/C framer

As could be observed from the preceded preliminary numerical analysis, the encasement of the R/C panel within the single-storey one bay R/C frame resulted in a significant increase of the stiffness and the bearing capacity of the studied system. Moreover, the placement of steel ties apart from increasing the stiffness and the bearing capacity also resulted in moderating the amplitude of the forces that are transferred at the narrow column-to-beam joints regions in a direction normal to the interface through the contact/gap mechanism. Such moderation in the amplitude of the transferred forces at the interface will mitigate the possibility of crushing of the encased panel and/or parts of the columns or beams at these regions. As a final observation, it can be concluded that the presence of steel ties in the interface between the encased R/C panel and the surrounding R/C frame has an overall beneficial effect on the behaviour of this type of structural system to seismic type loading. Figure 10 depicts typical horizontal and vertical cross-sections that include part of either the beam or the column together with the corresponding part of the encased panel. As shown in the preliminary numerical study when there are steel ties in such an interface these ties will transfer forces in a direction normal and tangential to the interface simultaneously. The level of these forces may vary in amplitude as well as in direction during the loading of the structure in a cyclic seismic type of loading. An experimental investigation was carried out with its main objective to study the mechanism of the transfer of such forces at the interface in such a way that this mechanism can be described both in terms of bearing capacity at a limit-state level linked with failure modes that are expected to appear. A summary of this study is presented in the next section.

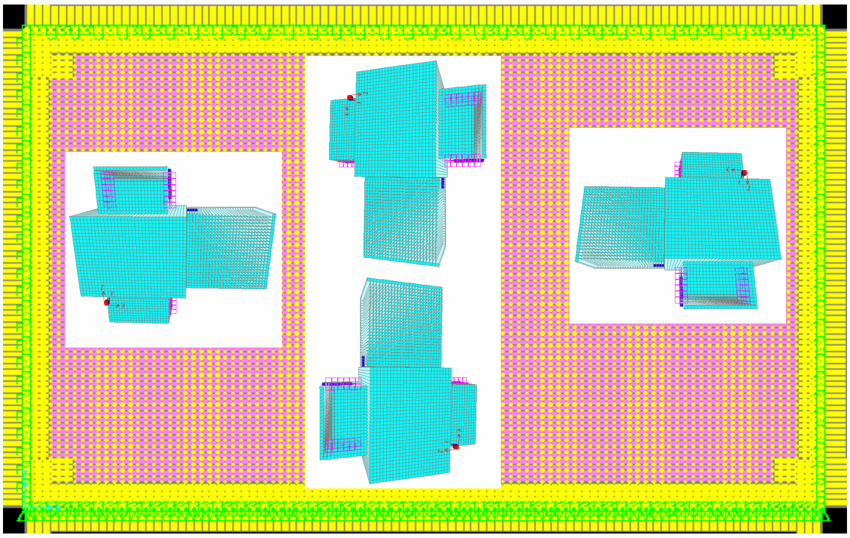

Figure 10. Cross sections that include part of the R/C encased panel and part of either column or beam of the surrounding frame together with the embedded steel ties.

4 SUMMARY OF THE EXPERIMENTAL SEQUENCE

4.1 Description of the studied specimens

Figure 11 depicts the dimensions of the studied specimens. As already explained, such a specimen represented a portion of an R/C encased panel connected with a portion of a column of the surrounding frame with the use of steel ties, which are embedded at the mid-plane of the panel and are anchored to the mass of the old concrete of the column, which is also retrofitted with a jacket. Both the jacket and the R/C encased panel are indicated in a different color in figure 11 in order to signify the new concrete as compared to the existing column (old concrete). If this detail is rotated 90^o clockwise it represents a similar connection between part of the R/C panel and the top beam (see figure 10).

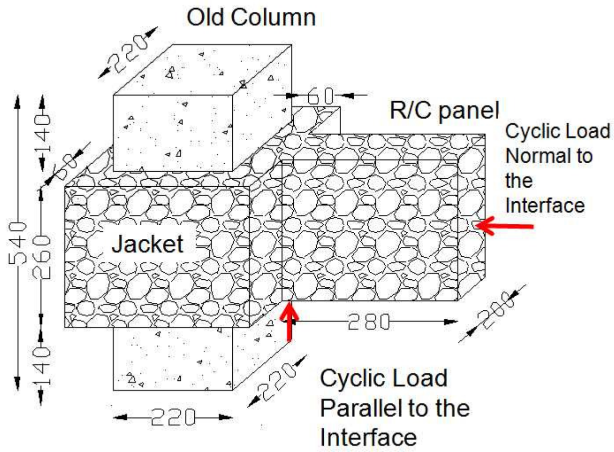

Figure 11. Specimen representing portion of encased R/C panel and the jacketed column

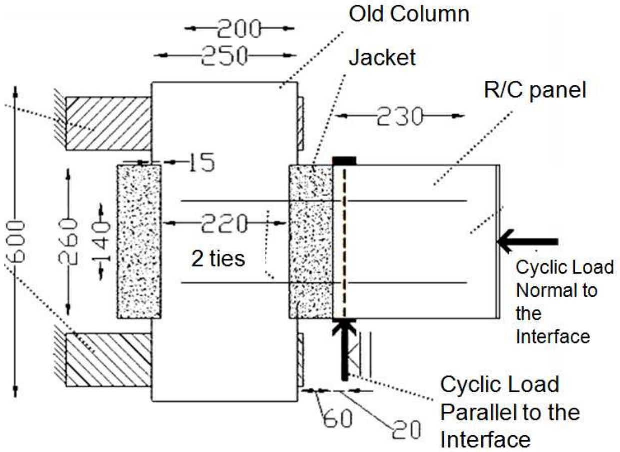

Figure 12a. Loading arrangement of the specimen representing portion of encased R/C panel and the jacketed column

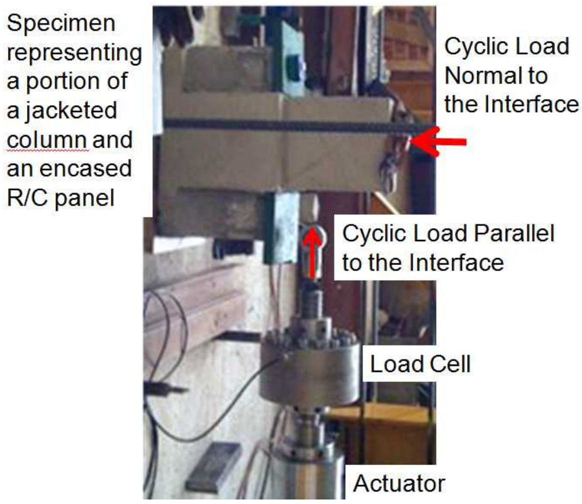

Figure 12b. Loading arrangement of the specimen representing portion of encased R/C panel and the jacketed column

This specimen was loaded as indicated in figure 12a and 12b. A load was applied normal to the interface (horizontal in figures 12a and 12b) whereas at the same time an additional load was applied in a direction parallel to the interface (vertical in figures 12a and 12b). The load that was applied parallel to the interface was varied in time in a manner consisting of three sinusoidal cycles of constant amplitude with a frequency 0.1Hz. The load that was applied normal to the interface was either kept constant at a predetermined level (tension or compression) or it was also varied in the same way as the load applied parallel to the interface. This type of load was expected to represent the transfer of forces at such an interface with the presence of steel ties, as was found by the preliminary numerical analysis described in a summary form in section 3 and shown schematically in figure 10. The total loading sequence per specimen consisted of a series of such cycles with continuously increasing amplitude till the failure of the specimen. This type of combined cyclic loading is believed to be adequately representative of the stress field that is expected to develop at this part of the encasement from the transfer of forces between the R/C panel and the surrounding frame arising from the seismic type of loading of the single-storey one bay frame, as was indicated by the preliminary numerical analysis results. The increase in the amplitude in such a gradual cyclic way is consistent with a similar variation of the horizontal force at the level of mid-axis of the top beam (figure 1), representing in this way the variation of a seismic type load.

Instrumentation was provided to measure the variation of the applied loads as well as the deformation of the specimen during the loading sequence. Figure 13 depicts such measured response for one of the specimens, namely specimen bare21 with 4 steel ties of 12mm diameter. The applied load in a direction parallel to the interface is measured in the ordinates whereas the measured sliding displacement at the interface between the portion of the panel and the jacketed column is measured at the abscissa. It was expected that due to the stress field that would arise in the vicinity of the interface when the combined loading was applied, the expected modes of failure would include a shearing pattern for the concrete accompanied by a local deformation of the steel ties. As can be seen in this figure, the measured response reveals three stages in the performance of such a steel-tie connection. Up to a relatively small cyclic displacement level, in this case of the order of 1.0mm, the measured response is almost linear elastic. Then, when the maximum capacity of the connection is reached there are small amplitude plastic deformations. Finally, the plastic deformations increase substantially accompanied by a significant drop in the bearing capacity. At this final stage, excessive cracking of the interface occurs that reveals the deformed shape of the steel ties, as they are shown in figure 14.

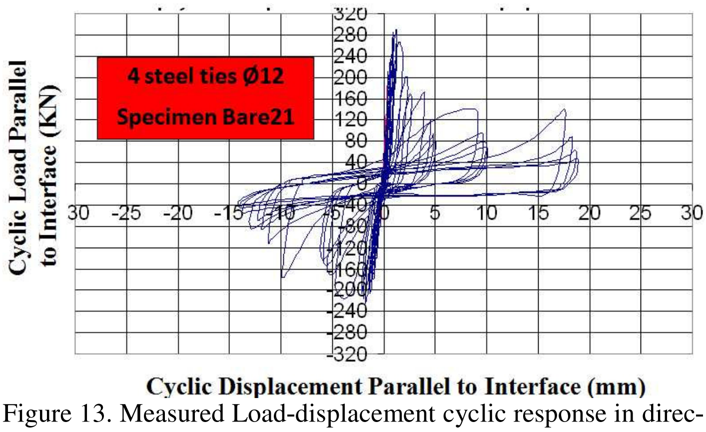

Figure 13. Measured Load-displacement cyclic response in direction parallel to the interface

Figure 14. Deformed shape of the steel ties at the final stage of the loading sequence. They are still anchored to the old column

The measured response of this steel tie connection at the interface, in a direction parallel to the interface, under a combined loading representative of the stress field that is expected to develop at this part of the encasement, is in agreement with the assumptions made concerning the behavioural characteristics of the these steel ties in the preliminary numerical analysis described in section 3. Therefore, the main observations made on the performance of the encasement, as derived from this preliminary numerical analysis, are expected to be in general valid, especially concerning the performance of the interface.

5 CONCLUSIONS

- The in-plane behaviour of one-bay single-storey reinforced concrete (R/C) frames was numerically examined when they were subjected to cyclic seismic-type horizontal loading and their retrofitting scheme included jacketing of their columns together with a cast-in-place infill R/C panel as an encasement. This numerical study examined the influence of the presence of such an encased R/C panel, being connected with the surrounding frame with or without steel ties, on the overall behaviour of such a system.
- From the preliminary numerical analysis results it can be concluded that such an encasement results in a considerable increase of the stiffness and the bearing capacity of the studied system, especially when steel ties are present at the interface. Moreover, the placement of steel ties also moderates the amplitude of the forces that are transferred at the narrow column-to-beam joints regions in a direction normal to the interface through the contact/gap mechanism, and consequently, mitigate the possibility of crushing of the encased panel and/or parts of the columns or beams at these regions.
- Consequently, it can be concluded that the presence of encased R/C panel being connected with the appropriate steel ties with the surrounding R/C frame, has an overall beneficial effect on the behaviour of this type of structural system to seismic type loading
- An experimental sequence was also performed in order to quantify the behaviour of such steel tie connections at the interface under a stress field that is expected to develop at this part of the encasement during seismic type loading. Such measured behaviour, is in agreement with the assumptions made concerning the behavioural characteristics of the these steel ties in the preliminary numerical analysis

ACKNOWLEDGEMENTS

- Partial financial support for this investigation was provided by the Hellenic Earthquake Planning and Protection Organization (EPPO)

REFERENCES

[1] G.C. Manos, V. J. Soulis, J. Thauampteh "*The behaviour of masonry assemblages and masonry-infilled R/C frames subjected to combined vertical and cyclic horizontal seismic-type loading*", J. Advances in Engineering Software, 45 (2012) 213-231.

[2] G.C. Manos (2012) "*Cyclic In-plane Behaviour of R/C Frames Retrofitted with Jacketing and an Encased R/C Panel*" Report to Hellenic Earthquake Planning and Protection Organization (EPPO) in Greek

[3] [Organization of Earthquake Planning and Protection of Greece (OASP), Guidelines for Level—An earthquake performance checking of buildings of public occupancy, published by OASP, Athens, 2001.

[4] Organization of Earthquake Planning and Protection of Greece (OASP), Guidelines for Retrofitting in Reinforced Concrete Buildings, Government Gazette, Δ17α /04/5/ΦΝ 429-1, No 42, Athens, 20 Jan. 2012.

[5] Provisions of Greek Seismic Code 2000, Organization of Earthquake Planning and Protection of Greece OASP, Dec. 1999 published by OASP. Revisions of seismic zonation introduced in 2003, Government Gazette, Δ17α /115/9/ΦΝ275, No. 1154, Athens, 12 Aug. 2003.

[6] G.C. Manos, Consequences on the urban environment in Greece related to the recent intense earthquake activity, Int. Journal of Civil Eng. and Architecture 5 (12) (2011) 1065-1090.

[7] G.C. Manos, V. J. Soulis and J. Thauampteh. “A Nonlinear Numerical Model and its Utilization in Simulating the In-Plane Behaviour of Multi-Storey R/C frames with Masonry Infills”, *The Open Construction and Building Technology Journal,6,* (Suppl. 1-M16) 254-277,2012.

[8] Klingner R. E. and Bertero V.V." Infilled Frames in Earthquake-Resistance Construction", EERC Report No.76-32, Dec. 1976.

[9] Klingner R. E. and Bertero V.V. " Earthquake Resistance of Infilled Frames", ASCE Journal of Structural Engineering. Vol 116, pp. 973-989, 1978.

[10] T. Sugiyama, Y. Matsuzaki, K. Nakano, “Design for Structural Performances of R/C Frame with Cast in Place Non-Structural R/C Walls”, 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, 2004, Paper No. 1277