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Seismic retrofitting of typical RC frame residential building by using textile reinforced mortar (TRM)

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Abstract
Using of infill walls is a common practice as partitions in RC frame buildings in all around the world. Usually, in design period of buildings the infill walls is not considered and assumed them as bare frame. Infill walls change the predicted behavior of buildings during earthquake actions. Mostly the seismic loads have not been considered in the design of existing RC frame buildings. Damage of infill walls identified as the main cause of loos of life, serviceability, property and harming injuries. To enhance the seismic capacity and energy dissipation of vulnerable buildings an appropriate reinforcing system is necessity. Different infill walls strengthening systems in respect of materials, configuration, difficulties in their application and effectiveness have been proposed and studied in last decades.
A four and half story typical residential building in Kabul city, Afghanistan was selected as case study in this study. Using of textile reinforced mortar (TRM) was adopted as rehabilitation method for improvement of masonry walls. Seismic performance of the building was evaluated using nonlinear three dimensional pushover static analysis on nonlinear model of the building in Perform 3D as a tool.
Collapsing of first floor infill walls and plastic deformation of first floor columns leads to soft story mechanism and poor seismic performance of un-retrofitted building. Adopted strengthening systems provided additional lateral strength and sufficient stiffness and control soft story mechanism. Obtained result from TRM retrofitted model analysis showed significant reduce of inelastic deformation in the columns and shifted damage condition of infill walls from collapse state to extensive cracking. By used method the building can withstand with severe cracking of infill walls and minor damage of frame elements against strong ground motions.

Keywords: Bare frame, infilled RC frame, textile reinforced mortar, soft story, seismic performance, nonlinear pushover static analysis

Introductions

Kabul city, Afghanistan with high seismicity contains of most vulnerable buildings. Structural and architectural deficiencies, weak of construction materials, non-standards and high density of population are common problem in construction industry in Afghanistan (Sultani, D.A., 2016) [35].

Brittle behavior of infill wall protect the RC frame building in low/medium seismic action, but against medium/strong seismic action may be lead to abrupt failure of structure and soft story mechanism. Stress and loads concentration on structural elements due to local damage of infill walls and columns make them to fails with low strength and load bearing capacity. Short time of natural period due to high lateral stiffness of buildings result of high design acceleration. Horizontal and vertical irregularity of infill walls cause the unwanted result of dynamic tendencies like soft story mechanism and torsions.

The differences between design assumption as bare frame and existing of solid and with openings panels remarkably modify the cyclic response of the structure. The failure modes of infill panels influenced by numbers and location of openings. (Niyompanitpattana, S., & Warnitchai, P., 2017) [30].

TRM is one of the major types of composite materials which commonly used for fabrication of precast and retrofitting of structural and non-structural elements (Koutas, L. N., Bousias, S. N., & Triantafillou, T. C., 2016) [25].

Modeling of elements and materials

Infill walls

The infill walls model as compression strut and tension tie. The model was suggested by Poliakov and used by Holmes and Stafford in the 1960s. The proposed model is one the most common and rational way to represent the effect of the infill walls in the global response of the buildings.

The main parameter to determine in strut model is width of the equivalent compression strut.

Beam-Column elements model

For the modeling of the frame elements, to represent the real nonlinear behavior of columns and beams the fiber model method is used. Nonlinearity usually occurs at the end parts of the columns and beams. The plastic behavior and hinge formation distributed at the ends, hence the only the ends part of the elements were modeled as finite length hinge zone. (Kaba and Mahin, 1984), (Mark, 1976).

Foundation model

The shallow foundation modeled as springs stiffness with six degrees of freedom according of FEMA 356 guideline.

1. Mander's confined and unconfined model was used for Core and Cover Concrete.
2. Pinto and Menegotto (1973)'s stress-strain model was used for steel Rebar.

Modeling of strengthened infill RC frame with TRMs

The strengthened infill walls with TRM was modeled as diagonal tension ties and compression struts Fardis and Panagiotakos (1997) [8].

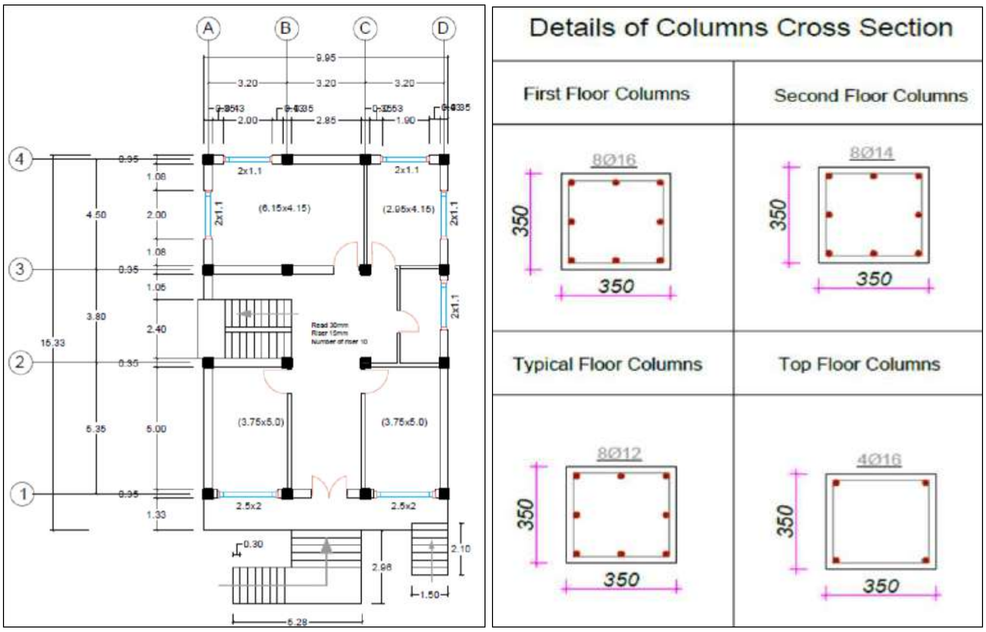
In this model the compression ties represent the behavior of infill walls in compression and tension ties represent the behavior of retrofitted materials in tension forces (Koutas, L. *et al*., 2014) [26].

Case study

A four and half story residential building was selected as case study of this research. The height of each story is 3m in all story. The bays are the same number in x and y directions with different dimensions.

Table 1: Materials properties which used in the building

Concrete strength	**26 Mpa**	**Tensile strength per running meter (kN/m)**	**115**
Modulus of elasticity Concrete (E_c)	25495 Mpa	Young modulus of elasticity (MPa)	73000
Longitudinal rebar yield Strength	420 Mpa	Thickness of TRM sheets (mm)	0.005
Transverse rebar yield Strength	280 Mpa	Fiber density (gr/cm3)	2.6
Modulus of elasticity of Steel (E_s)	200000 Mpa	Mesh size (mm)	25x25
Masonry Prism Strength	6 Mpa	Rupture Strain (%)	2.5



Red lines show the location of FRP sheets on the walls

Fig 1: Plan and section properties of case study building

Analysis methods

Due to plan and elevation irregularity the nonlinear analysis has been adopted for seismic evaluation and retrofitting of the building. Nonlinear procedure represent the real behavior of the structures and the accuracy of the result is very high.

Nonlinear static procedure

The cyclic loading test was displacement controlled. The loading was smoothly exceeded until the loss of strength and stiffness of the building. The loading procedure and manner is selected as based on the FEMA 461 (2007) [9, 10] recommendation.

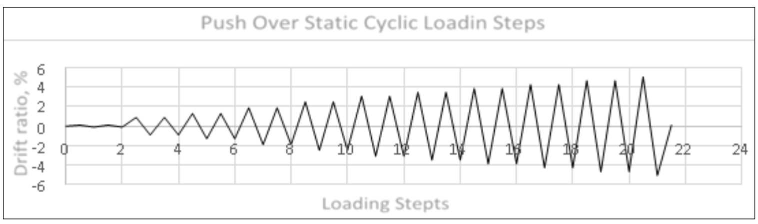


Fig 2: Pattern of lateral cyclic displacements

Nonlinear static pushover analysis

Due to lack of stiffness and long beams in Y-direction the first mode of the building is along of the weak direction (Y-axis). Pan and elevation non-uniform stiffness and irregularity make the second of the building as coupled.

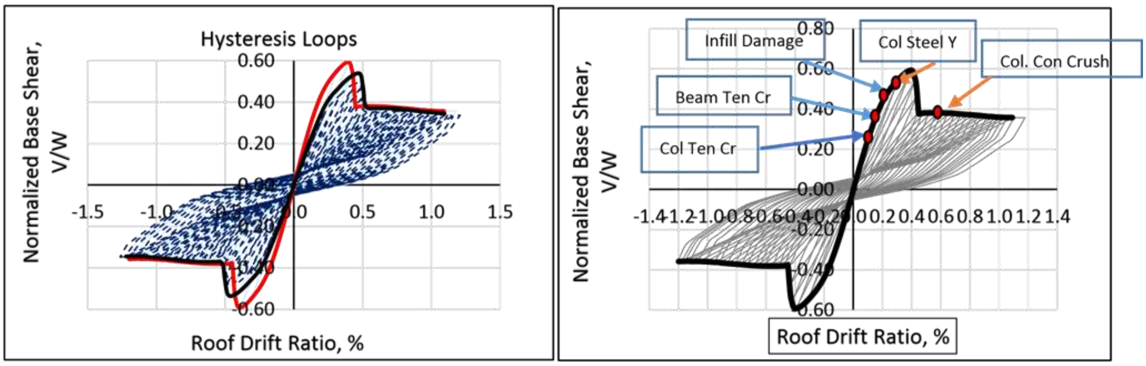


Fig 3: Hysteresis loops of infilled frames in both directions and damage notation only in X-direction

Table 2: Natural period of case study building with and without of infill walls

Mode	Natural period without of infill (Sec)	Type	Natural period with infill (Sec)	Type
1	0.6813	Translation (Y-dir)	0.41	Translation (Y-dir)
2	0.6056	Coupled (X-dir)	0.369	Coupled (X-dir)
3	0.5258	Torsional	0.308	Torsional

The following formula recommended for the calculation of plastic rotation of the hinges and frame elements.

$$\theta_p = (\varphi_u - \varphi_y) \quad (1)$$

Where, φ_u- Ultimate curvature φ_y- Yield curvature L_p- Plastic hinge length.

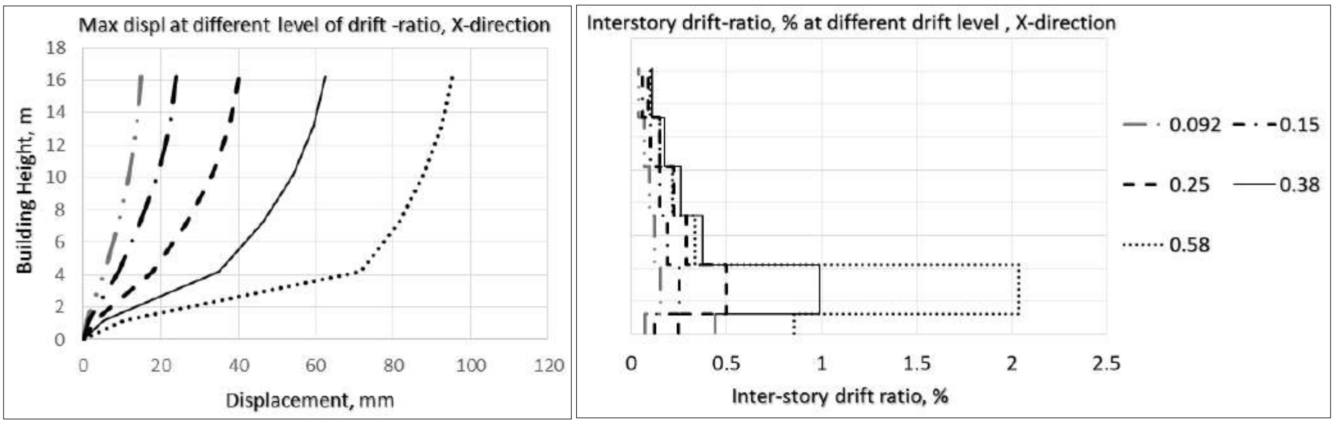


Fig 4: Maximum displacement and drift-ratio in, x-direction for different drift-ratio level

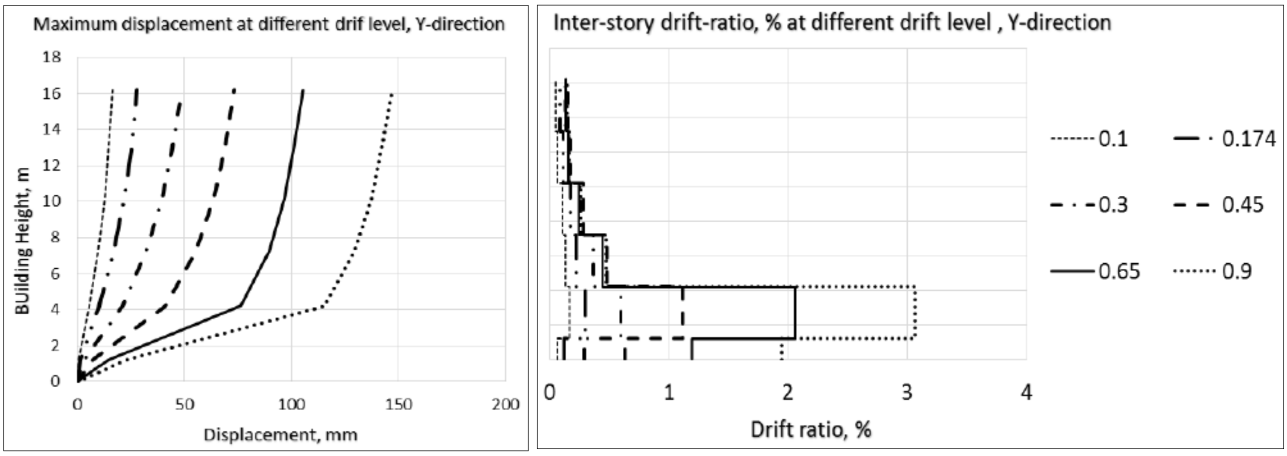


Fig 5: Maximum displacement and drift ratio in y direction for different drift ratio level

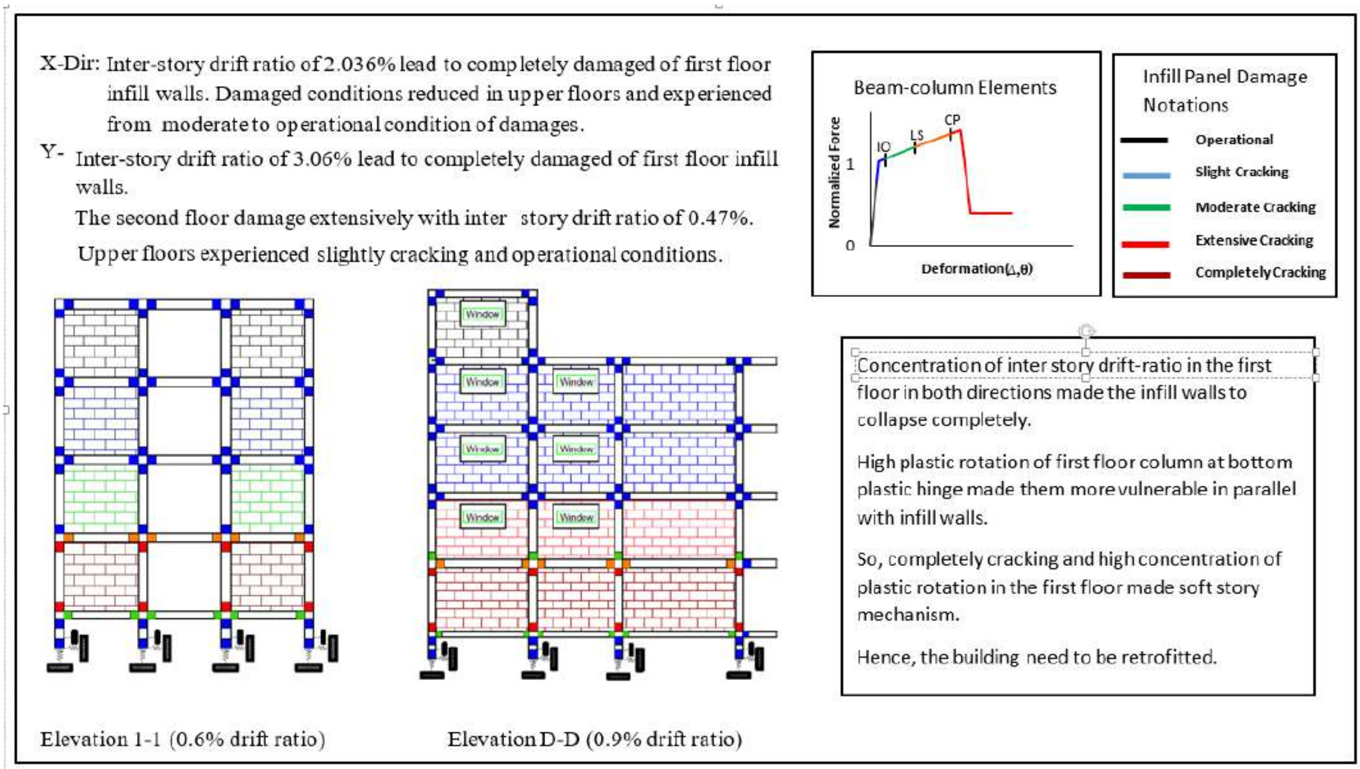


Fig 6: Damage notation of case study building for static pushover analysis in both directions

Retrofitting scheme of the case study building by TRM

One layer of Textile Reinforced Mortar (TRM), was adopted as strengthened method of the only solid infill panels. Retrofitting of infill panels changed the first mode excitation from Y-direction to X-direction. Originally the weak axis was Y-direction, but retrofitting of infill panels make it stiffer in Y-direction and weaker in X-direction. The modulus of rupture for the used mortar is 0.65MPa.

Table 3: Natural period of original and modified of case study building

Mode number	Original (Un-retrofitted)	Modified (Retrofitted)
1.0	0.41	0.313
2.0	0.37	0.306
3.0	0.308	0.245

Result of NSP analysis

The maximum level of roof drift ratio which the building was pushed is 0.52% in X and Y directions. For the above roof drift ratio the diagram of inter-story drift ratio, floor displacement, infill panels damage notation were plotted and extracted in the figures of 10, 11 and 12. Hysteresis loops of originally and retrofitted of cases study and their comparison in both direction have been shown in figure 9. The sequence of failure in monopush action of frame elements and infill walls have been shown in figure 8.

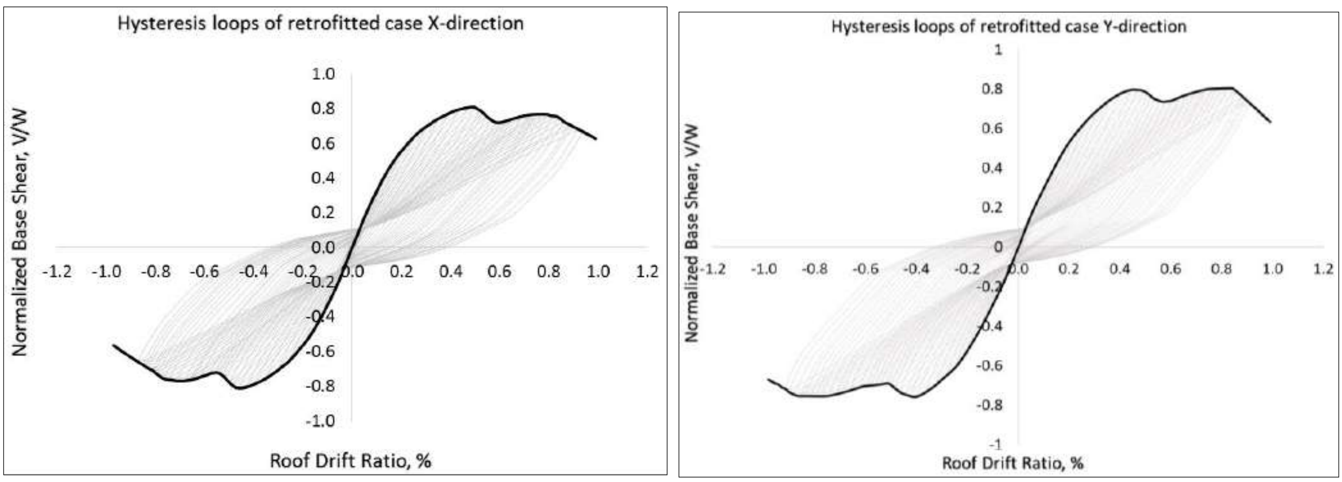


Fig 7: Retrofitted case hysteresis loops in X and Y directions

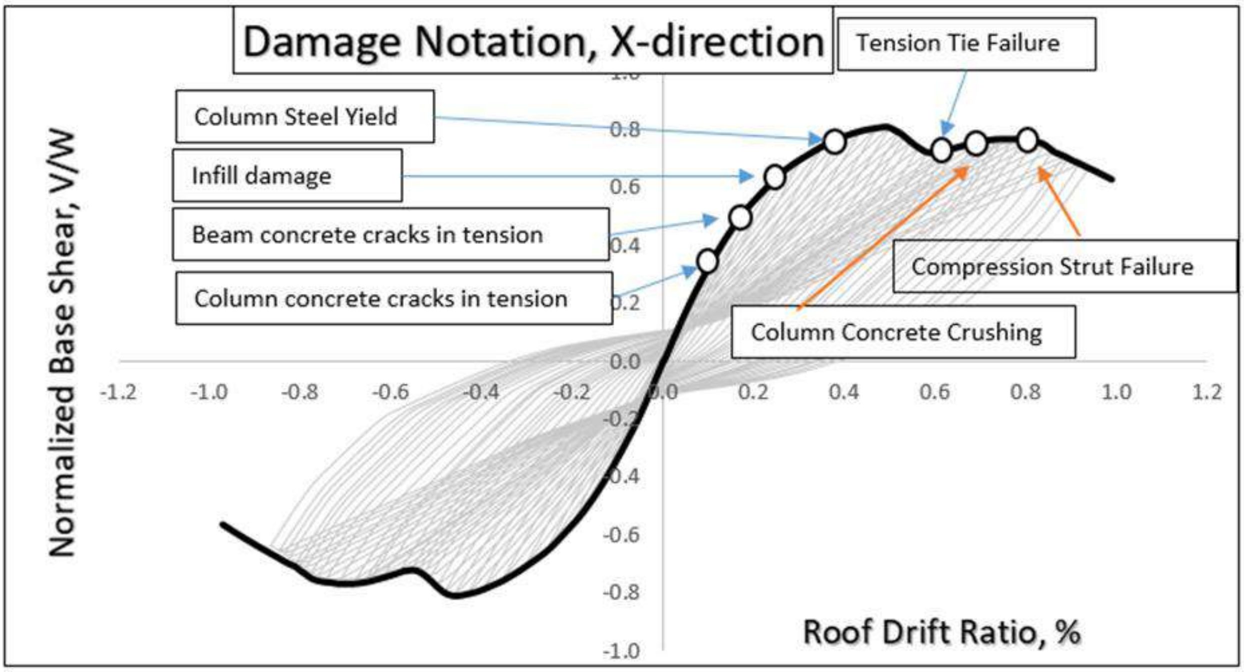


Fig 8: Failure sequences in frame elements and infill panels in retrofitted condition

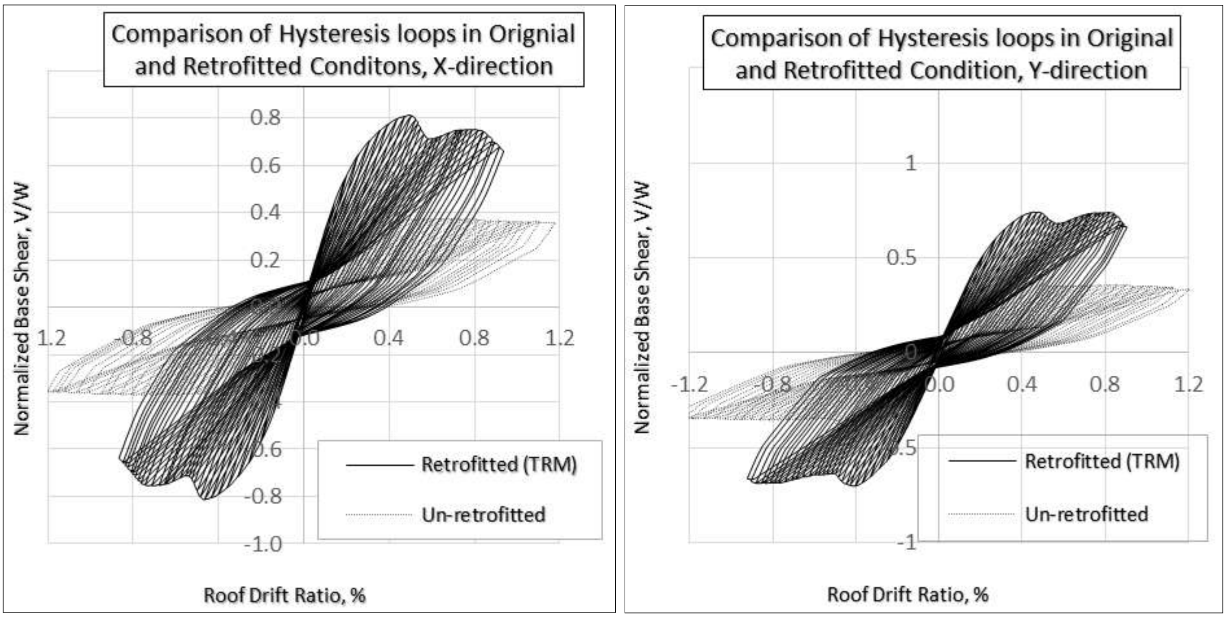


Fig 9: Improvement of stiffness and strength and effect of retrofitting on hysteresis loops of case study building

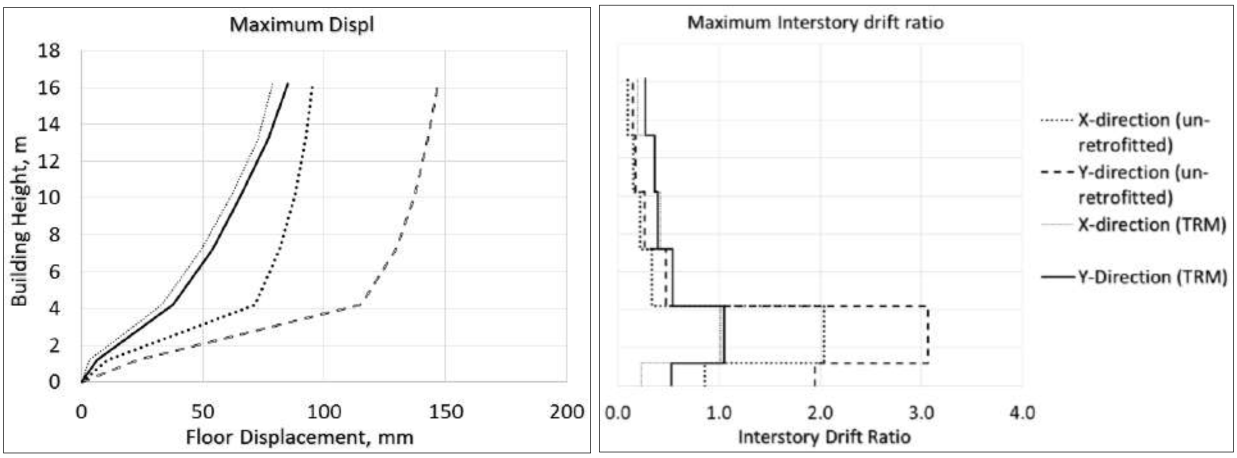


Fig 10: Max displ and corresponding inter-story drift ratio on original and modified condition of case study building

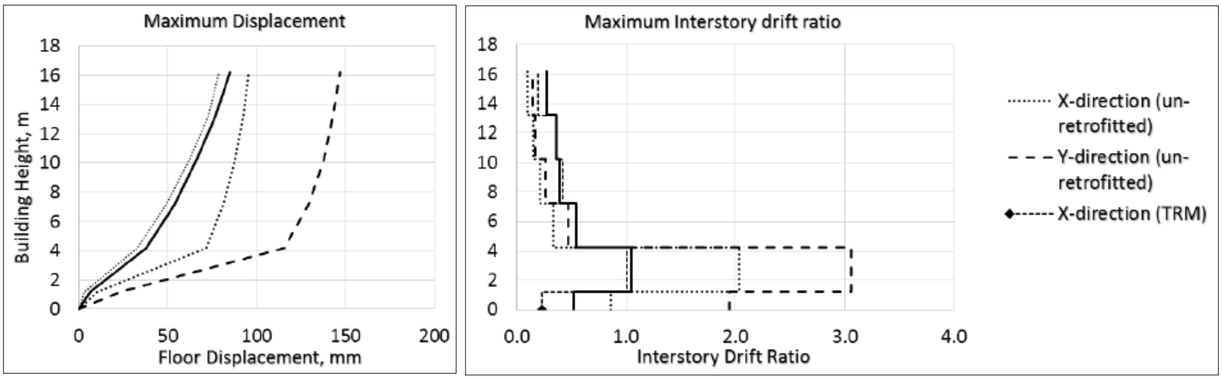


Fig 11: Maximum displacement and inter-story drift of un-retrofitted and TRM retrofitted CSB

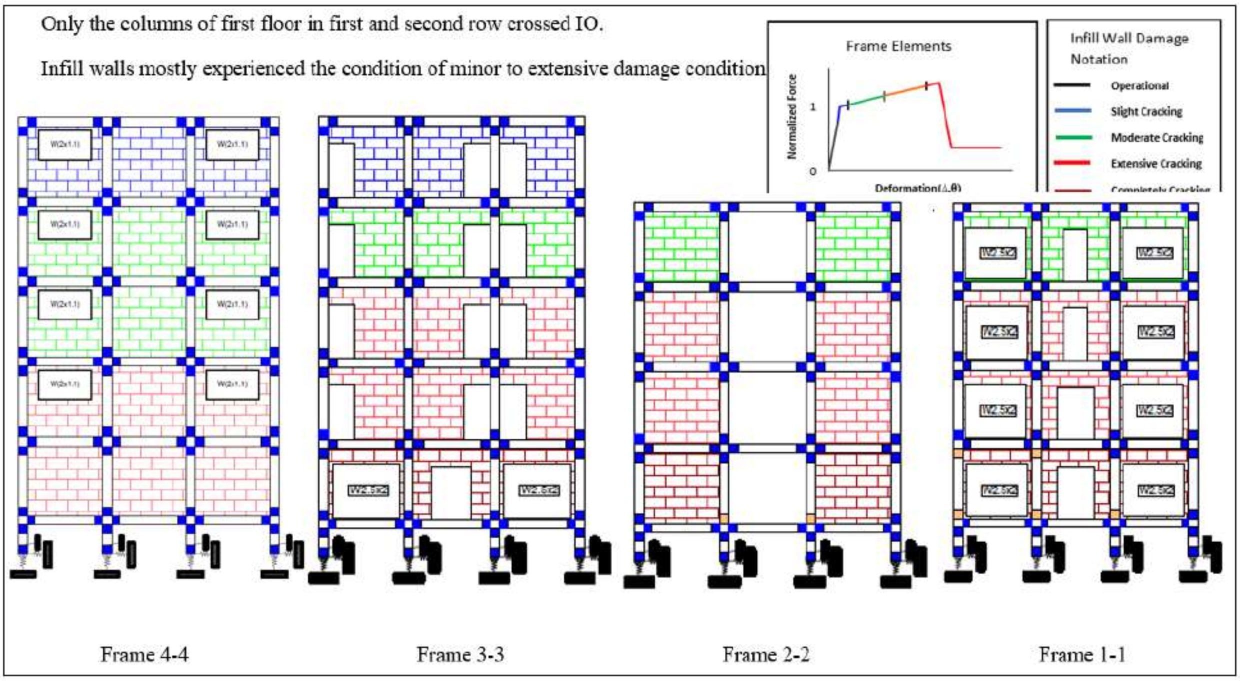


Fig 12: Damage condition of retrofitted case study building with TRM in, X-direction

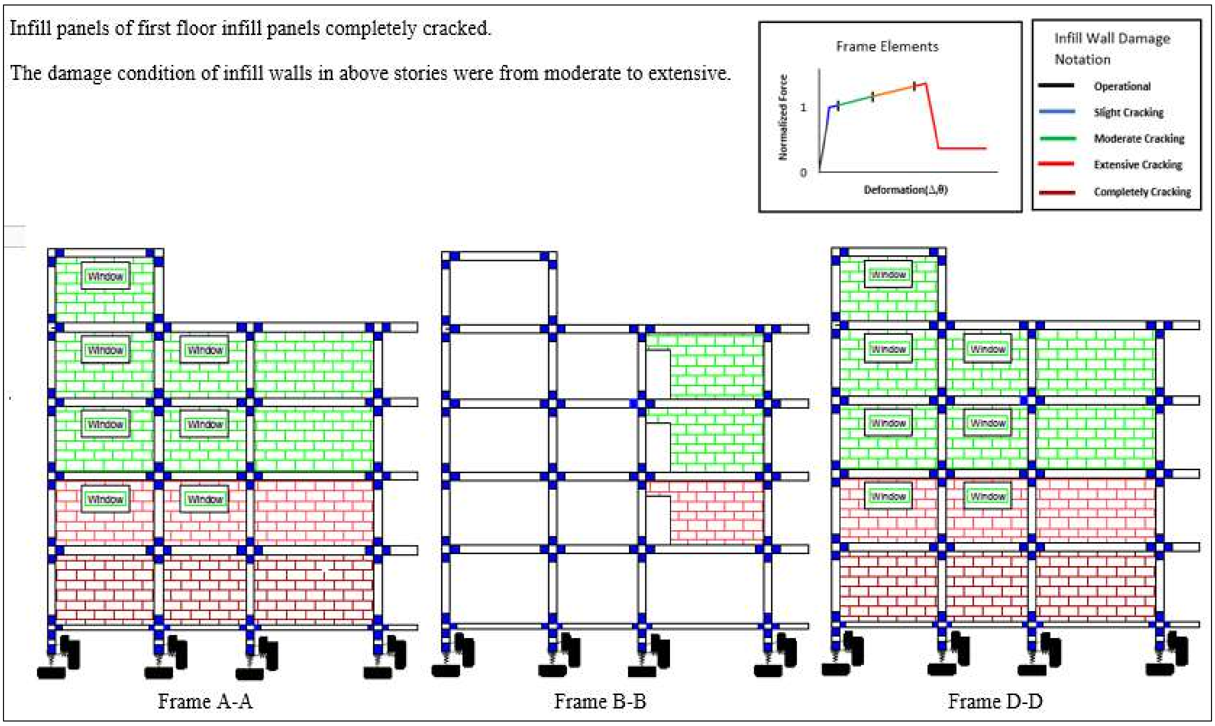


Fig 13: Damage condition of retrofitted case study building with TRM in, Y-direction

Conclusion

By using of TRM as retrofitted scheme resulted in increasing of base share about 37.5% and 61.4%, and decreasing of ductility about 20.34% and 25.62% in X and Y directions respectively, in comparison of original case.

According of figures 10 and 11 the used method decreased the inter-story drift ratio of first floor from 2.036% and 3.06% to 1.0% and 1.05% in X and Y direction respectively. By retrofitting of 1st floor infill walls the inerstory drift ratio slightly increased in the upper floors.

The infill walls damage conditions shifted from collapse condition to extensive cracks in Y directions completely and X direction only in two frame of front side building with low in-plan stiffness. Infill panels of upper floors experienced the damage conditions of minor to extensive cracks figures 12 and 13.

Used method is completely effective for reducing of interstory drift ratio and lateral displacement, the infill walls and frame elements damages are reduced remarkably. Due to its availability of raw materials and easy applications it is the best method for retrofitting of vulnerable buildings.

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