Retrofit of Old Public Schools using Conservative and Innovative Procedures

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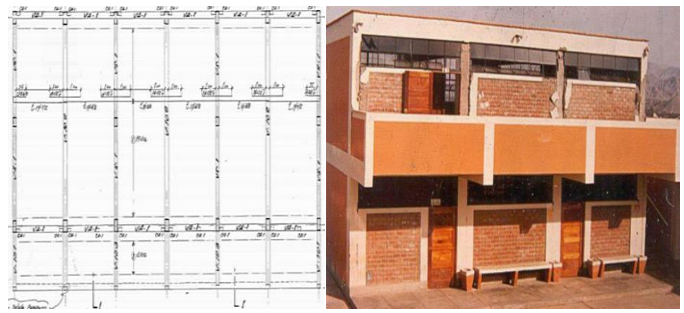
Abstract– Public school infrastructure in Peru has several old buildings which are vulnerable to earthquakes. The insufficient seismic capacity of these schools is due past design codes as well as poor construction practice such as short columns or poor quality of used materials. Therefore, it is necessary to retrofit these buildings. This study focuses on the seismic analysis and the reinforcement of a school module 780Pre which consist on reinforced concrete frames for longitudinal direction of the module and confined masonry walls for transversal direction The analysis is carried out based on a performance study of the structure, based on the non-linear static analysis and the seismic demand spectrum of the current design code in Peru. It is presented traditional and innovative procedures to retrofit this module. The traditional one consists to attach welded mesh covering both faces of the masonry wall. For the innovative procedure CFRP sheets are installed as diagonal ties, as well CFRP anchors are used at both extreme the ties in order to carry out the tension loads from this ties after debonding increasing the shear capacity and ductility the wall. It is found that the installed CFRP materials provides better seismic performance to the school module than using welded mesh.

Keywords-- School, Retrofit, Masonry Wall, CFRP Diagonal Tie, CFRP Anchor.

I. INTRODUCTION

Previous studies of the structural behavior of public schools in Peru indicate that these, for the most part, are vulnerable to large-scale seismic events. Many of these were built in the 90's, promoted by the Government of the time, which were designed with a design code that was permissive with maximum lateral displacements and that used coefficients with which displacements smaller than the real ones were obtained. [1]. The School Module 780pre is a representative model of the schools built during that time, therefore it does not comply with current design guidelines. In addition, it presents a potential short column failure and cracking in the walls as it is reported by Cardenas et.al [2]. Plan dimensions of 7.80m x 23.5m and 3.35m height per story as it can be seen at Fig. 1 (a) and (b); it was built before 1997 designed by old codes and built with no good practice, which caused important damages to public infrastructure [2,3].

On the other hand, there are investigations that focus on the reinforcement of masonry structures, since these do not give an optimal performance to the structure in the face of seismic forces. These reinforcement techniques use various materials, both traditional and innovative such as electrowelded mesh and carbon fiber reinforced polymer (CFRP) respectively. Additionally, according to Blandón and Bonett [4], reinforcement with electrowelded mesh in the masonry walls improves the seismic behavior of the structure, since there is a great increase in ductility and greater load resistance.



(a) (b)

Fig. 1 Original plan drawing (a) and "780 Pre" typical public-school building after the 1996 earthquake (b) [2].

Studies aimed at evaluating the behavior of reinforcement with CFRP strips or sheets diagonally and without anchors [5, 6] show important increases in ductility and resistance to shear; however, delamination failures of the reinforcement band occur. To avoid failure by delamination due to the detachment of the reinforcement sheets in the walls, Huaco and Jirsa [7, 8] propose the use of bands with CFRP anchors so that the reinforcement can reach its total traction capacity, improving the cutting capacity and granting a greater displacement to the wall.

This article proposes the structural reinforcement of a 780Pre school module, comparing traditional and innovative methods. In addition, the seismic behavior of the building is investigated through static nonlinear analysis and the performance point is determined for different types of soil.

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II. Procedure and Analysis

A. *Retrofit methods*

The building in the longitudinal axis consists of reinforced concrete porches with masonry walls as partitions that do not present joints and this represents a potential short column failure. In the reinforcement with the traditional method, the elimination of these partitions is proposed in order to eliminate the failure by short column and to increase the rigidity, reinforced concrete walls of 1 meter long and 0.2 meters thick are added, with which it is achieved adequate architecture in ventilation and lighting of the environments. The innovative method proposes the elimination of the partition walls in an interspersed way and to complete the panels that were left to later reinforce these with 100mm wide bands, determined according to the approach of Alcaíno and Santa María [5], with the multiplication of the cross-sectional area of the belt and the tensile stress of the CFRP belt. In addition, the CFRP anchors were calculated according to Huaco et al [9], with the proposal to use anchors with 80% of the amount of material from the bands in order to avoid failure by delamination, eliminating the possibility of a short column and achieving a suitable environment in the classrooms. The modification schemes in the longitudinal axis according to the reinforcement method are shown in Fig. 3.

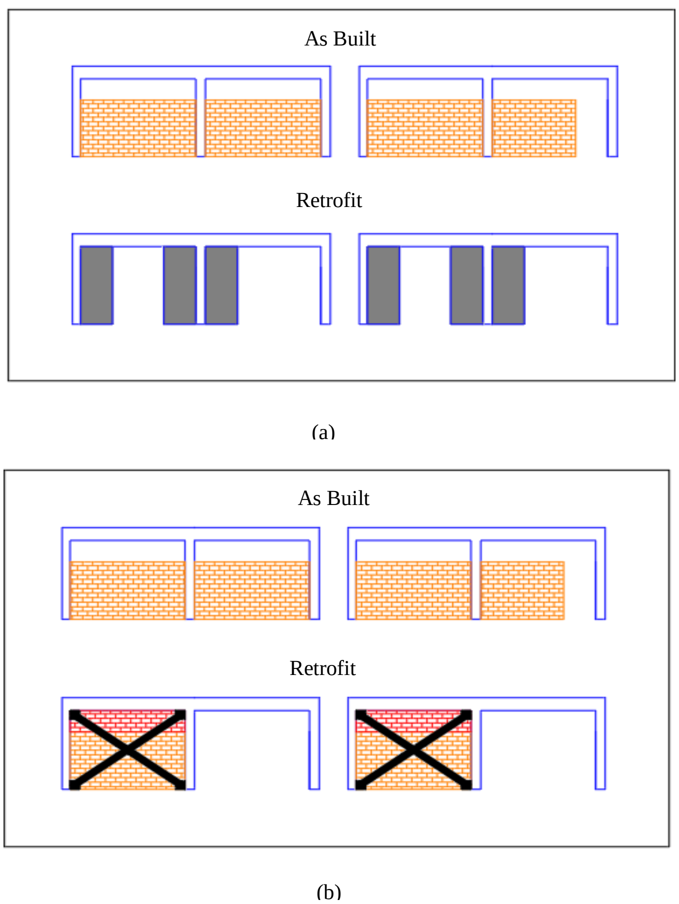


Fig. 3 Structural reinforcement in the longitudinal axis of the “780 pre” school building for the tradition-al procedures (a) and the innovative procedures (b).

In the transverse axis, the masonry walls are maintained and reinforced for the traditional method with electrowelded mesh, with a mesh of 4.5mm in diameter and a spacing of 150mm x 150mm, and for the innovative method with 100mm wide bands and anchors of CFRP. In Fig. 2 the reinforcement in the transverse axis is shown.

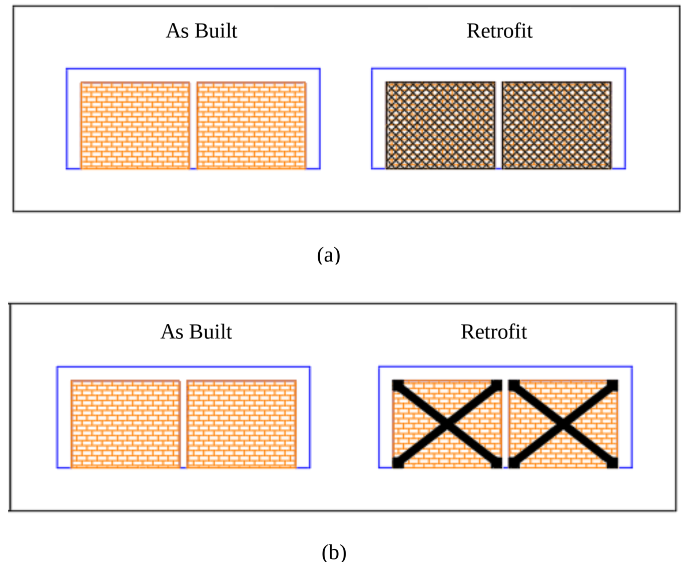
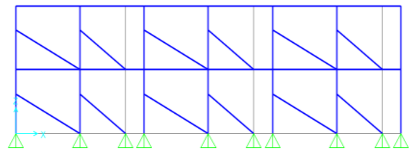


Fig. 2 Structural reinforcement in the transverse axis of the “780 pre” school building for the traditional procedures (a) and the innovative procedures (b)

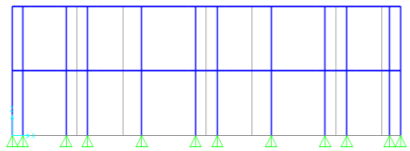
B. *Computational Modeling*

Building 780Pre consists of 2 levels 3.2 meters high per level and measures approximately 7.8m x 23.5m [2]. In the longitudinal axis, it has columns of confinement to the transverse walls of 25cm x 45cm with 6 Ø¾” reinforcement bars and central columns of 30cmx45cm with 8 Ø¾” reinforcement bars. In addition, it has masonry walls 15cm thick. In the transversal axis the building has 25cm thick masonry walls and central reinforcement columns of 25cm x 25cm with 4 Ø1/2” reinforcement bars. Among the mechanical properties, the compressive strength of concrete is 175 kg / cm2, compressive strength of masonry 40 kg/cm2 and tensile strength of steel is 4200 kg / cm2. The model is made using the SAP2000 software, version 20. For the modeling of the masonry walls, equivalent props were used, following the guidelines proposed by Bazan and Meli [10].

The model for the concrete walls in the longitudinal axis with the traditional reinforcement was used the equivalent frames method. The models in longitudinal and transverse axis for the as built models, with traditional reinforcement and with innovative reinforcement presented by Huaco and Jirsa [7, 8 and 9], as well as the detail of the use of CFRP anchors, are shown in Fig. 4 and Fig. 5.



(a)



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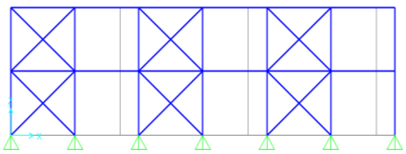
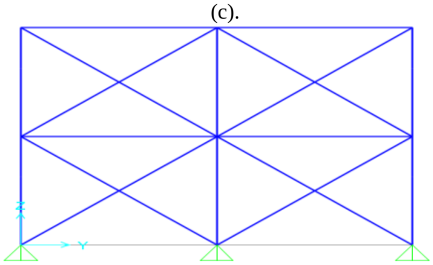
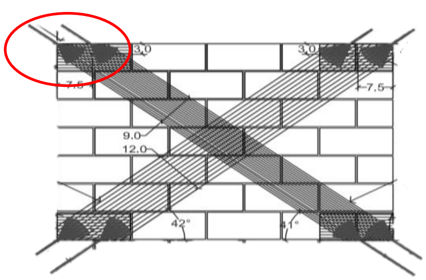


(c)

Fig. 4 Computational model of the longitudinal axis for As Built models with equivalent struts (a), reinforced with the traditional method with equivalent frames (b) and reinforced with an innova-tive method with equivalent struts (c).



(a)



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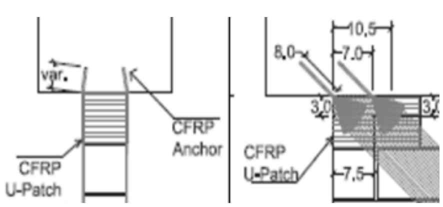
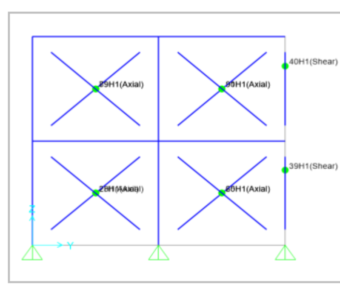


(c)

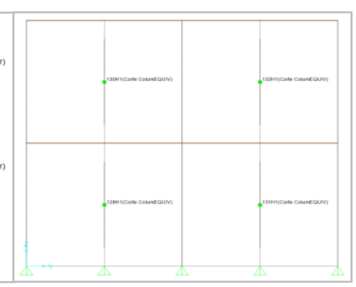
Fig. 5 Computational Model of the transversal axis for As Built, reinforced with traditional method and reinforced with innovative method, all with equivalent struts (a), and detail of the use of CFRP anchors in innovative reinforcement [7] (b), CFRP anchor dimensions in [7] (c).

The model for the transverse axis is the same in all 3 cases, varying the force and control displacement according to the proportions of previous studies. Chavez et al. [11] reported how CFRP anchors provide the wall to increase more than twice shear capacity as well ductility.

The axial plastic hinges were defined at 50% of the length of the equivalent strut with a compressive control force according to the V'm from Huaco [12] and at reduced tension with the poisson's modulus. In the case of the As Built model, they have a fragile behavior. In the reinforced cases, these were defined with a ductile behavior typical of the reinforcement. The plastic bending hinges were defined at the ends of the columns and beams to determine if the reinforcing steel and the strength of the concrete are adequate to the moments generated by seismic loads. To define the short column behavior in the columns glued to the partitions without seismic joints, plastic hinges were established by cutting at 50% of the free length of the columns between the partitions and the beams. In the case of traditional reinforcement, modeling was carried out with equivalent frames in order to obtain a behavior according to the type of reinforcement. In both axes of analysis a ductile behavior was established. For the transverse and longitudinal direction, the final resistance to shear of the elements was calculated, whether they are masonry walls or reinforced concrete walls, and the control force was established at 50% of the height of these elements. The innovative reinforcement was modeled with equivalent diagonal ties to follow the direction of the reinforcement CFRP laminate. In the same way, the reinforcement contribution was calculated and the axial hinges were established at 50% of the length of the struts. In Fig. 6 and Fig. 7 the modeling and assignment of plastic hinges for each case is shown.



(a)



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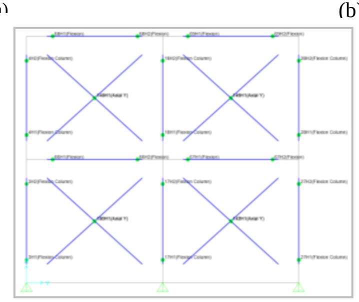


(c)

Fig. 6 Computational model of the plastic control hinges in the transverse axis for the As Built case (a), traditional reinforcement (b) and innovative reinforcement (c).

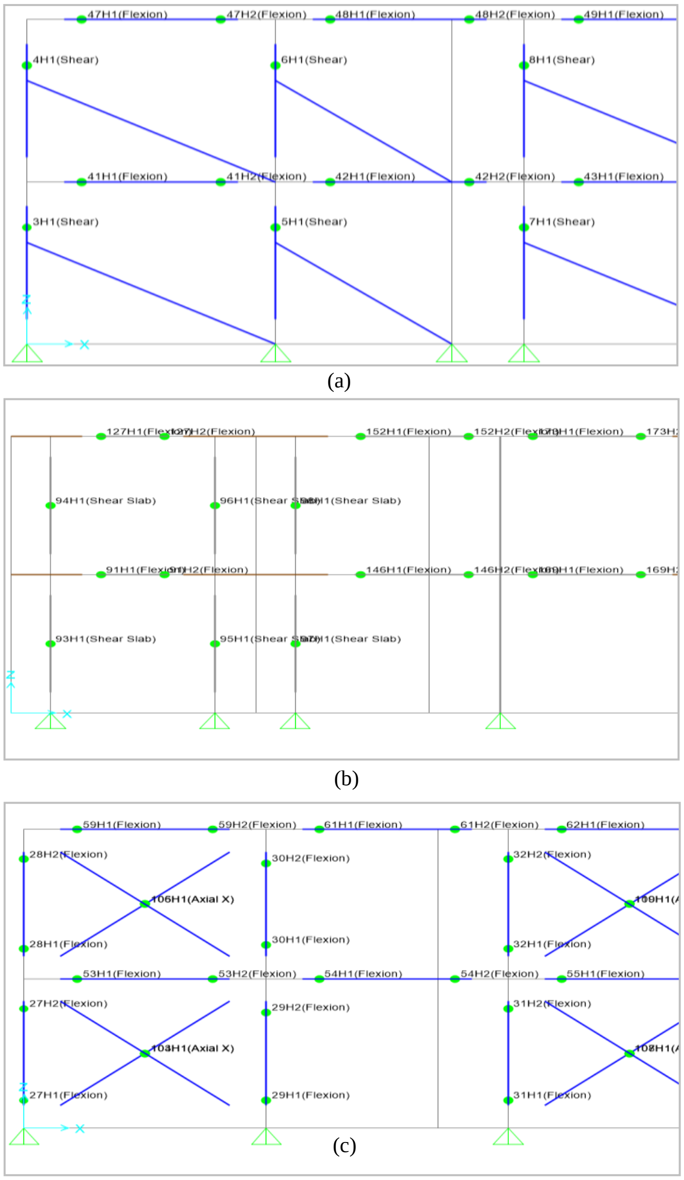


Fig. 7 Computational model of the plastic control hinges in the longitudinal axis for the As Built case (a), traditional reinforcement (b) and innovative reinforcement (c).

To define the behavior of the plastic hinges for the diagonal ties, laboratory results from previous studies were used. In the case of the Asbuilt model by Huaco [12], and Traditional Retrofit by adding electrowelded mesh on the infill, by Diaz [13]. The behavior of the diagonal ties in the innovative reinforcement was defined with the test carried out by Huaco and Jirsa [8]. The Fig. 8 shows the capacity curve obtained from the Huaco and Jirsa test and Fig. 9 shows the definition of the behavior of the patella in the innovative reinforcement. For concrete frame, flexural hinges were established in beams and columns at 15% and 85% of the length of the element, according to the calculated plastic length (Lp).

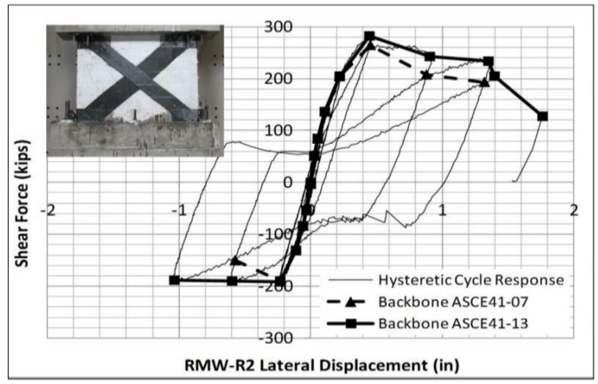
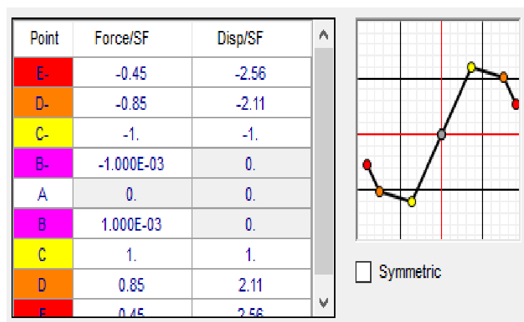


Fig. 8 Laboratory test capacity curves of wall reinforced with CFRP bands and anchors according to [8]



Point	Force/SF	Disp/SF
E-	-0.45	-2.56
D-	-0.85	-2.11
C-	-1.	-1.
B-	-1.000E-03	0.
A	0.	0.
B	1.000E-03	0.
C	1.	1.
D	0.85	2.11
E	0.45	2.56

Fig. 9 Behavior insertion of the plastic hinges of the equivalent props of reinforced walls according to the previous test of Huaco and Jirsa

C. *Capacity Curves from Non Lineal Static Analysis*

For Pushover analysis was by displacement control. The capacity curves are determined for each axis of analysis, longitudinal and transverse, and for each case, As Built, traditional reinforcement and reinforcement with CFRP, and are shown in Fig. 10 and Fig. 11.

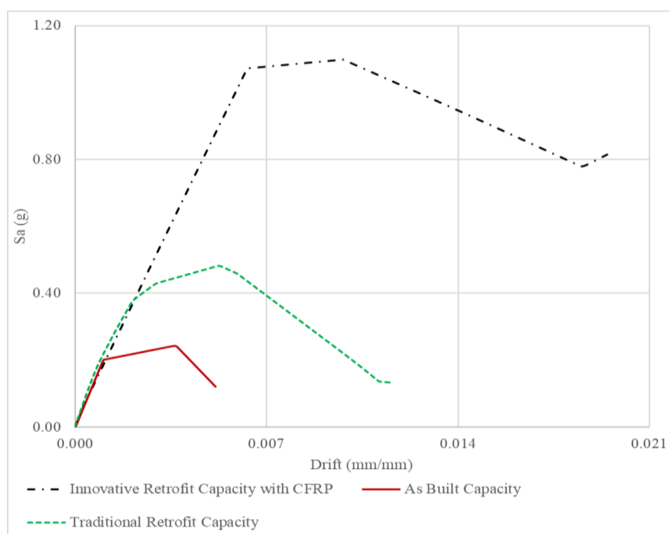


Fig. 10 Pushover Capacity Curves of the Longitudinal Axis for As Built and Reinforced Cases.

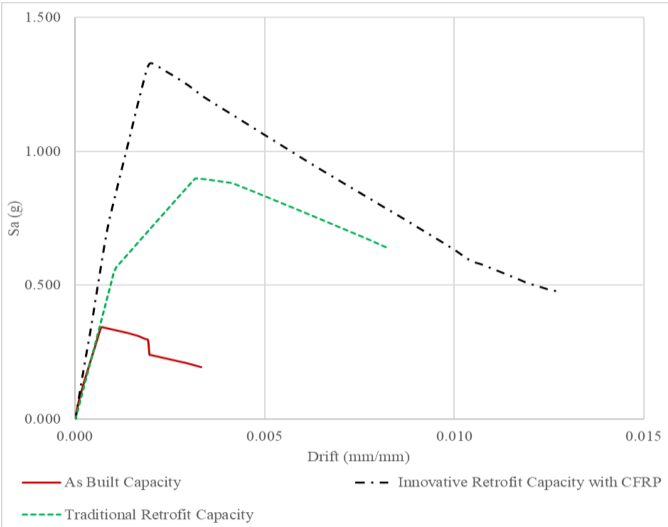


Fig. 11 Pushover Capacity Curves of the Transverse Axis for As Built and Reinforced Cases.

D. *Seismic Performance Level*

The performance level of the structure was determined according to the ATC-40 guidelines [14]. For this, the seismic demand curves for different types of soil were determined according to the E.030 standard [15], establishing soils S0, S1, S2 and S3, where S0 is equivalent to a rigid rocky soil and S3 is equivalent to a soil flexible. Then, the seismic and capacity demand curves are transformed into an ADSR format, using the conversion equations, thus obtaining the capacity and demand spectra. By crossing these curves, the performance level of the structure will be obtained for each direction of analysis. The Fig. 13, Fig. 12 and Fig. 14 show the capacity demand spectra for the longitudinal and transverse axis and for elastic and inelastic behavior.

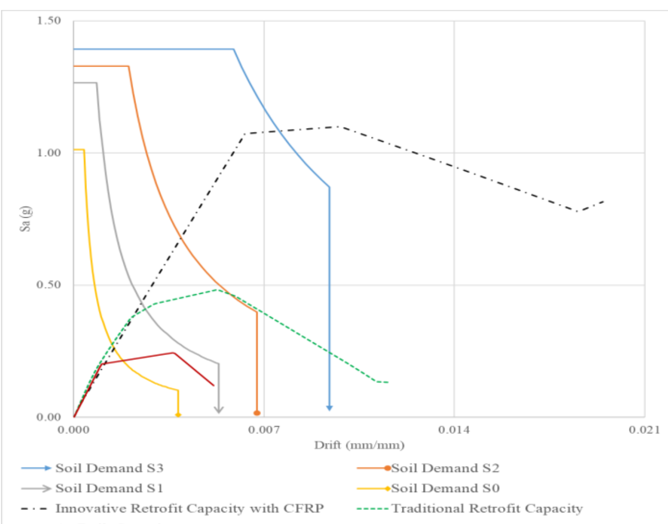


Fig. 13 Seismic performance evaluation for longitudinal axis for As Built and reinforced cases, according to elastic demand.

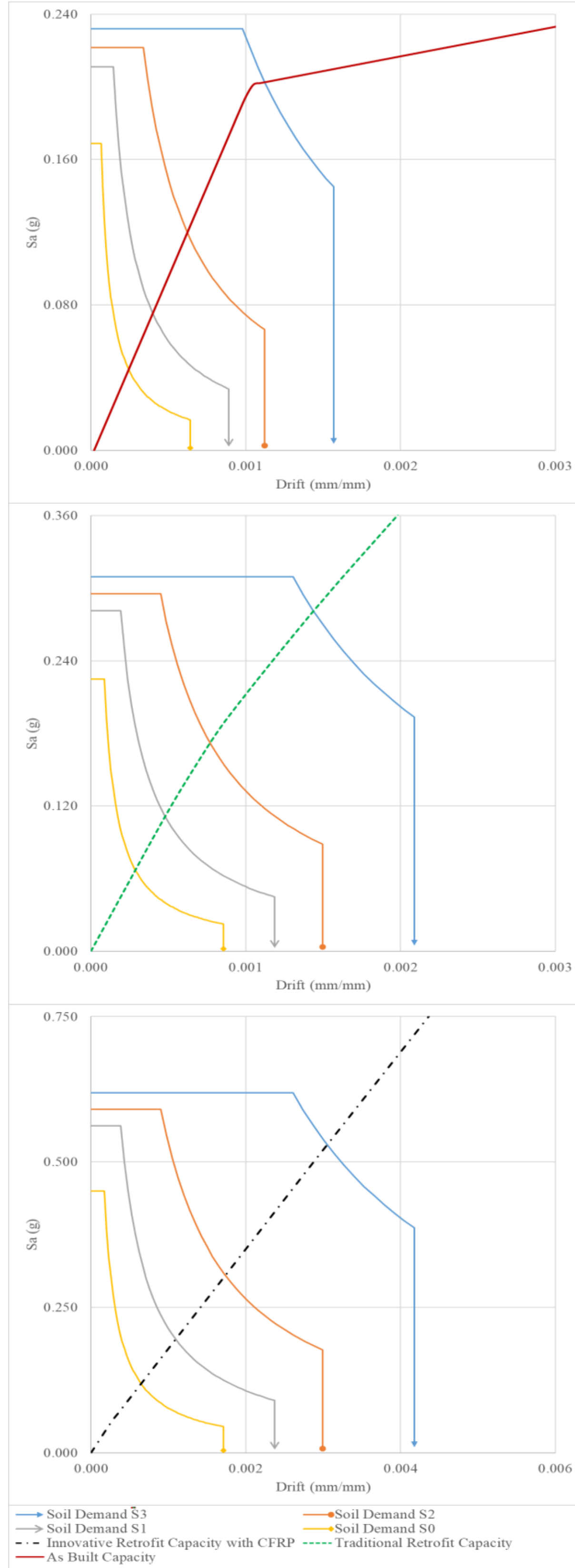


Fig. 12 Seismic performance evaluation for longitudinal axis for As Built and reinforced cases, according to inelastic demand.

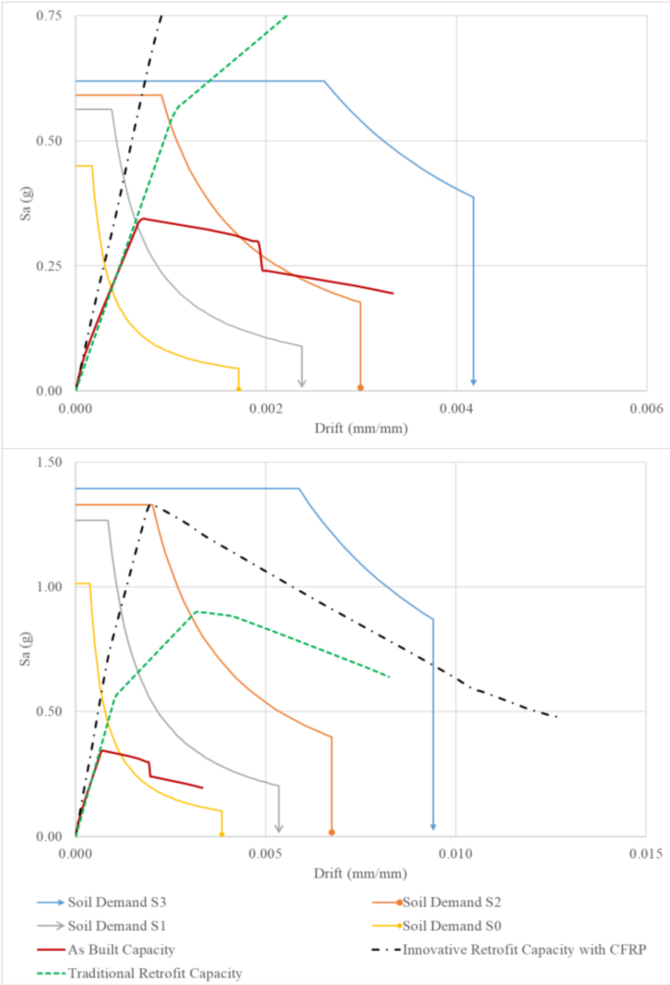


Fig. 14 Seismic performance evaluation for transverse axis for As Built and reinforced cases, according to elastic (bottom) and inelastic (top) demand.

According to estimates, the capacity curves of the reinforced cases are higher in strength and ductility than those of the as built case. In addition, the performance curves show better behavior and provide higher safety ranges to the occupants of the structure in the event of the seismic demands raised. Of the reinforced cases, the carbon fiber strip reinforcement (CFRP) stands out over the traditional reinforcement.

III. RESULTS

The non-linear static analysis in the longitudinal direction shows that the building in the As Built model fails because the columns are subjected to shear loads greater than those they can withstand in the free length between the masonry walls and the beams, leaving evidenced by the short column failure is the reason for the vulnerability of the building in this direction of analysis. The capacity of the structure in the longitudinal direction is 0.25g Sa with a drift of 1.2 ‰ and a pre-collapse drift of 5.1 ‰. In the model reinforced with the traditional method, the building shows an increase in stiffness due to the addition of reinforced concrete walls and the new failure pattern is given by the shear force that these walls are capable of supporting. The capacity in the reinforced model with the traditional method is 0.5g of Sa with a drift of 5.6 ‰. The building reinforced with CFRP bands and anchors provides greater rigidity to the structure than the As Built model, but less than the traditional reinforcement, due to the fact that the concrete walls are more rigid than the masonry walls. The capacity in the model reinforced with the innovative method is 1.1g with a drift of 9.6 ‰.

In the transversal axis, the failure of the school module occurs due to the cracking of the masonry walls that, later, fail under compression. The capacity curve in the transverse direction indicates that its capacity is 0.3g of Sa with a drift of 0.8 ‰ and a pre-collapse drift of 3.25 ‰. In the reinforced models, the failure of the school is due to the failure of the reinforcement and subsequent failure of the masonry wall. The capacity with the traditional booster is 0.6g Sa with a drift of 1.0 ‰. In the model with the innovative reinforcement the capacity is 1.3g with a drift of 2.0 ‰.

The evaluation of the seismic performance in the longitudinal direction shows that the structure in its As Built model, when faced with an elastic demand, only manages to intercept with a S0 soil that represents a rocky and rigid soil, that is, the structure would not withstand seismic forces in other soils that are more common. The performance point is 0.2g Sa with a drift of 2.0 ‰. For the reinforced models, the capacity curves do manage to intersect with all the demand curves, even with the S3 floor, which represents the worst floor of the 4, being a flexible floor. The performance point for the traditional method in the flexible soil is 0.25g Sa with a drift of 9.5 ‰, being in a range close to the collapse of the structure. In the model with innovative reinforcement, using CFRP bands and anchors, the performance point is 1.08g of Sa with a drift of 7.5 ‰, being within a structural stability range. On the other hand, for inelastic demand, the 3 capacity curves manage to intersect with the 4 seismic demand curves. The performance point for the As Built case with S3 soil is 0.2g Sa with 1.2 ‰ of drift. In the case of traditional reinforcement, the performance point with S3 soil is 0.28g of Sa and a drift of 1.5 ‰. The performance point of the building with innovative reinforcement and S3 soil is 0.55g Sa with a drift of 3.0 ‰.

On the transverse axis, in the face of elastic demand, the as built model only manages to intersect with the demand curve with soil S0, which indicates that it would not withstand seismic forces in other soils. The performance point in soil S0 is 0.32g with a drift of 1.5 ‰. In the reinforced models, the capacity curves manage to intercept with the demands of the other soils, with the exception of the flexible soil S3, which is only intercepted by the curve of the reinforcement with CFRP bands and anchors. The performance point of the model with traditional reinforcement and S2 soil is 0.85g of Sa and a drift of 3.2 ‰. In the model with innovative reinforcement, the performance point with S2 soil is 1.34g of Sa and a drift of 2.0

‰ and with an S3 soil it is 0.68g of Sa and a drift of 9.2 ‰. For an inelastic demand, the 3 models manage to intercept with all the seismic demand curves except for the As Built case, which only manages to intercept up to an S2 type soil, but in a range prior to the collapse of the structure, while the curves of reinforced models intercept the S3 soil demand in an immediate occupancy range for innovative reinforcement with CFRP and in a damage control range for traditional reinforcement.

For both directions of analysis, the reinforcements increase capacity and ductility to the structure, according to the proposals of previous investigations.

In the case of traditional reinforcement, response capacity is improved by up to 30%, in accordance with previous research [4] and in innovative reinforcement it rises to more than 2 times as built condition.

Also it is determined that the innovative reinforcement with CFRP bands and anchors give a better performance to the building and ensure the immediate occupation of the buildings in the event of large earthquakes so that they have a condition of refuge for society during these events catastrophic.

IV. CONCLUSIONS

The static non-linear analysis of the "780 pre" school building is carried out, a model that represents a typical public school module in Peru, in As Built models, with traditional reinforcement and with innovative reinforcement. The seismic performance is evaluated by comparing the capacity curves and the seismic demand spectra for the different types of soils of the Peruvian design code, both curves were converted to the ADRS format.

It is determined that the school building in its As Built condition does not guarantee its immediate occupancy as a shelter structure after a major earthquake.

The evaluation of the seismic performance of the reinforced models indicates that it is possible to increase the capacity of the structure in force and drift for each axis, ensuring life safety and structural stability in most cases. In addition, a greater response is obtained in the reinforcement with the innovative method, using CFRP bands and anchors than, with the traditional method, adding reinforced concrete walls and reinforcement with electrowelded mesh.

For a flexible S3 floor, only innovative reinforcement would prevent the structure from collapsing under elastic demand with which it is verified that this reinforcement gives the building structural security for its occupants and is the ideal one for reinforcement. This case would be applicable in the area with high seismicity in Peru, represented by the entire Peruvian coast, which consists of around 3000 units of 780pre type school modules.

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