EXTEND ABSTRACT

1. Abstract

This dissertation aims to identify structural reinforcement techniques used in schools intervened in the secondary school modernisation programme: *"PMEES"*. The programme was carried out by the company "Parque Escolar".

The dissertation is divided into three interconnected parts. At first, we describe *"PMEES"* and identify its goals and principles of intervention. In the following, we analyze two interventions of the *"PMEES"* at two schools. It accomplished a description the intervention performed and the techniques employed for structural reinforcement. Finally, these are detailed structural reinforcement techniques adopted.

Rainha Dona Leonor High School in Lisbon was built during the 1960s. It was constructed a new build to install the library and teachers room. The existent buildings were strengthened to the seismic behaviour with concrete shear walls founded on footings reinforced with micropiles. It was also used a steel bracing solution to increase stiffness in the longitudinal direction of the gym's building. Another example of seismic reinforcement was the introduction of new resistant end frames applied in shotcrete outside of Rainha Santa Isabel High School in Estremoz. In this school was constructed a new build to establish laboratories and refectory. It was further reinforced a slab that presented excessive deformation with composite materials – carbon fibre reinforced polymer (CFRP).

The rehabilitation techniques used in this two analysed schools are selected to obtain the best possible combination of stiffness, load bearing capacity and deformation capacity of the structural elements during the earthquake.

2. High school modernization programme: *"PMEES"*

Education in Portugal was born within the Catholic Church. In the mid twentieth century there was a democratization of education and an exponential growth of the school constructions. It's possible to divide school construction into three separate phases:

- until 1935 – lyceums (high schools) were built in the major cities. They presented a robust construction with freestanding walls, concrete frames and some metal elements;
- 1936 to 1968 – a network of technical schools was constructed (industrial and commercial schools). The buildings had a standard project adaptable to each location. They were executed in concrete frames with masonry walls and wood roofing;
- after 1968 – It took place a large-scale construction of prefabricated schools with a flat roof and of usually poor quality (P.E., 2009).

The technical schools emerged as a response of the education system to the needs of Portugal in economic growth and industrialization. The programme established was the responsibility of

JCETS *(“Junta das Construções para o Ensino Técnico e Secundário”)*, which means board of construction for technical and secondary education, under the jurisdiction of the Ministry of Public Works – MOP *("Ministério das Obras Públicas”)*.

To build up a large and dispersed network of technical schools economic and universal solutions were executed and adapted according to the location and topography of the ground. This standard solution was composed by three bodies – the main building (which housed the classrooms, the library and the administrative services), the physical education body (composed of a large and a small gym, changing rooms and canteen) and the workshops body.

Most of the *Parque Escolar*’s interventions were in buildings with over 30 years old, that presented physical deterioration and that were functionally obsolete.

One major hallmark of this programme were the great improvements that have taken place in terms of building habitability conditions, especially in terms of acoustics and thermal conditions. In most cases there was a problem with oversizing equipments of HVAC systems (heating, ventilation, and air conditioning).

The three programme purposes are:

- renovating and modernising the school buildings – correcting existing construction problems, improving the conditions of habitability and environmental comfort; adapting teaching and non-teaching spaces and modernising the respective equipment, ensuring the flexibility and adaptability of them to maximise their use and to minimise future investments; guaranteeing energy efficient buildings so as to reduce operating costs.
- opening the schools up to the community – increase the use by the local community for activities related to ongoing education/training (evening classes), cultural and social events, sports and recreation;
- creating an efficient and effective school building management system – after the rehabilitation and modernisation operations to ensure an effective and efficient response when isolated repair interventions are needed or in the planned conservation and upkeep interventions (P.E., 2012).

To achieve the previous objectives the company *“Parque Escolar”* had a large team composed by great portuguese experts in construction and education – architects, engineers, researchers and teachers. Another advantage was the permanent and close collaboration between their members and the schools management, from the planning phase of the projects until its implementation on works phase. During the operations external spaces or monobloc containers to install classes were rented. There was a concern to isolate the works from the rest of the school with rigid and opaque fences to improve the security of students.

In the programme of schools modernization it was introduced the concept of *Learning Street*. This theory advocates that the knowledge must be transmitted informally. Thus, spaces like study rooms were created so that students could learn by themselves.

The new organizational model of the building comprises nine functional areas as defined below:

1) Formal learning – composed by classrooms, space for experimental science teaching (laboratories and preparation rooms), technology core (workshops, IT classrooms) and arts core;
2) Library – beyond books it also has a multimedia centre and study rooms;
3) Sports – gyms, covered sports field, uncovered sports field, showers, changing rooms;
4) Nucleus of social and gathering spaces – pupils' social space, multipurpose room/auditorium, school shop, snack bar, canteen, kitchens;
5) Reception, administrative area and attendance to public – secretariat, archive, concierge, museum centre;
6) Management bodies – offices, meeting rooms articulated with offices, reception areas and service;
7) Teachers – offices, meeting rooms, attendance areas for parents and guardians, pause spaces (teachers room), sanitary;
8) Staff – break room, clothing; sanitary;
9) Adult education – offices, meeting rooms articulated with offices, reception areas and service (P.E., 2009).

3. Case studies: interventions in two industrial schools

Both buildings under study followed approximately the same normalized project, prepared by JCETS in the 1960s. The project was characterized by a system structurally designed for seismic loading. It included a concrete frames system in longitudinal facades and in the central corridor. It also had bracing systems like concrete frames, concrete diagonals or concrete stairs in transversal façades and in expansion joints.

Rainha Dona Leonor School in Lisbon had three large bodies laid out in 'U' shape, built in two stages. The first step ended in 1961 and included two bodies, the main building, which housed the classrooms and labs, and another building that accommodated the gyms, changing rooms and canteen. The second step construction occurred in 1967/68 and provided an extension to the classroom area (third body). In this phase the gym unit was also enlarged (ESRDLeonor, 2010).

The buildings under analysis presented problems of deterioration and poor maintenance. With the increasing number of students throughout the years it was necessary to introduce sports equipment and some temporary structures. There were also needed devices for people with limited mobility. Those constructions were made without discretion and limited the school's playground.

Dona Leonor School's plot was characterized by a small area for deployment of the solution recommended by "*Parque Escolar*". This question was solved in two ways: by digging to lower the implantation quota of the new entrance building, being applied a solution of ground consolidation; and by building up the uncovered sports field over the covered one.

The intervention was based on the following three principles:

- new construction (Blocks 1, 2) – to solve the problem of insufficient area to accommodate all the programme items;
- existing construction (Blocks 3, 4 and 5) – functional changes in buildings due to changes of uses;
- exterior areas – change of the location of the main entrance and construction of a new building for it (Block 7). Increase of the playground area with the construction of uncovered sports field under the covered field (Block 2). Creation of a waste house (Block 6).

Block 1 comprises a maximum of four floors. The façades were executed in unplastered prefabricated concrete panels. The roofing houses the HVAC equipments. The library and the areas allocated to teachers were installed in this building (Flor, *et al.*, 2009).

Block 2 contains a multi-purpose room with an area of about 172m^2 and a height of 6,60m, with a capacity of 168 telescopic bench seats. Contiguous was constructed the covered sports field and over this, the uncovered field (Flor, *et al.*, 2009).

In **Block 3** the gyms are located upstairs. At ground floor level are the showers, the changing rooms, the kitchens and the canteen with a capacity of 128 seats (Flor, *et al.*, 2009).

In **Block 4** remained the classrooms and laboratories on the upper floors. The ground floor was completely redesigned to accommodate the management bodies, school office, new area of IT education, school shop and snack bar (Flor, *et al.*, 2009).

In **Block 5** were implanted art classrooms with open wells zenith lighting, technology rooms and labs. It was introduced an emergency metal stair. On the ground floor was installed the archive, the warehouses and an area for the non-teaching staff (Flor, *et al.*, 2009).

Near the gym building there is a waste house (**Block 6**), accessible through the service entrance. **Block 7** is the main entrance of the school and it has a doorman. Finally, **Block 8** is an existing structure that houses the transformer substation (Flor, *et al.*, 2009).

We analysed two rehabilitation techniques used in this intervention, the introduction of new reinforced concrete walls and the construction of a steel bracing solution. Both procedures serve to increase the resistance of structures to seismic action (Proença, *et al.*, 2011).

- <u>addition of reinforced concrete shear walls</u>

The existing buildings (Blocks 4 and 5) were structurally divided into 7 modules. The modules were separated by expansion joints executed by duplicating structural elements.

To understand the seismic behaviour of the buildings it was created a computational model. Its analysis revealed excessive horizontal displacement in relation to the size of the expansion joints among blocks.

The final strengthening solution for buildings has combined the new concrete resistant walls with the following two connections between modules:

- permanent and rigid connections of three central blocks through the new reinforced elements. This operation increases longitudinal stiffness and eliminates the pounding between blocks;
- connecting blocks 1 to 2 and 4 to 5 at level of the roof slab, but not by doing it so rigidly. It's an ingenious solution that consists of introducing transverse rods at the joints, embedded in the slabs or beams on both sides. The rods are sheathed in a part of their length, not to adhere directly to the concrete. This solution allows displacements due to thermal fluctuations, preventing the pounding between modules.

The foundations for the concrete walls had a complicated compatibility with the existing footings. Thus, we chose to build independent foundations for new walls, reinforced with micropiles to solve the problem of high eccentricities.

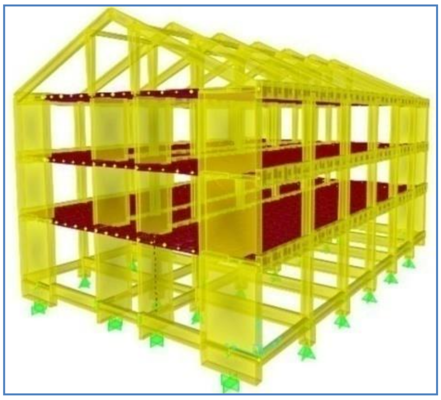

Figure 1 – Structural Model (Perestrelo, 2010)

Figure 2 – Reinforced footings with micropiles (photo taken in 2010-10-19 by author)

- steel high stiffness bracing lattice

The existing gym building had a reinforced concrete structure comprising transverse frames. According to the mobilized masses we chose to enhance longitudinal stiffness of buildings through a solution of steel high stiffness bracing lattice. This metal solution was installed in opposite façades, two plus two elements in the large gym and one plus one in the small one. Frames beams were used to continue the bracing into the roof to improve the diaphragm behaviour of the building (Flor, *et al.*, 2009).

To solve the torques resulting from the seismic moment and the structure/foundation interaction micropiles were used (Flor, *et al.*, 2009).

The buildings of **Rainha Santa Isabel School** in Estremoz were built in 1962. This school is another example of an industrial and commercial school, constructed under the responsibility of the JCETS-MOP. This institution was divided into three bodies – the main building (Body A), the core of physical education (Body C) and the workshops (Body B).

Some buildings areas presented deterioration, especially the floor covering, the walls and the windows. All construction had a bad behaviour in terms of thermal and acoustic environment. Once the soil had mechanical decompression it was necessary to deepen some foundations in order to obtain layers with good strength characteristics (Monteiro, *et al.*, 2009)

In this intervention the buildings' structures of the Body A and Body C (Existing gym) remained. Their behaviour was increased to seismic action with the introduction of the end frames in both longitudinal and transverse directions. Body C (Pavilion), Body D and Body F are completely new constructions. Body B is new but incorporates the workshop buildings partially demolished.

Body A – houses the classrooms, the library and the management bodies.

The building had a good general status, but their seismic behaviour and its environmental and functional conditions were improved. To upgrade the resistance of the structure to seismic action, beyond the end frames that unload directly in existing footings, there were also added metal sheets to reinforce the diagonal concrete elements.

The roof slab was carefully demolished and several flat slabs were built up to install the HVAC systems.

Body B – core where the laboratories, art classrooms, workshops, canteen, kitchens and bar are installed.

This building was built from scratch but incorporating some of the workshops structures. During the dig there were conflicts with old foundations and low ground resistance. To solve the problems the quota of footings had to be lowered and rearranged.

Body C (existing gym) – houses the large gym, small gym, changing rooms and showers.

In this building we applied the seismic reinforcement from outside using the same system of Body A. The gym floor was replaced because it presented deteriorated areas due to the wall moistures.

It was found the existence of a slab with excessive deformation in an annex construction. The problem was solved by using laminate composite material (CFRP – Carbon Fiber Reinforced Polymer).

Body C (pavilion) – It consists of the covered game field that features a self-supporting metal roof.

Body D can be used as the gardening and agriculture material warehouse. The main entrance of the school was called **Body E** and **Body F** is a dovecote.

- Addition of the reinforced concrete end frames by applying shotcrete

In order to regularize the structural stiffness and homogenize stress along the existing structures, end frames around main building (Body A) and gym (Body C) were constructed. This solution led to a global strengthening of the buildings to seismic action.

To facilitate the connections between the new and the old concrete elements the reinforced concrete structures were chipped until the steel bars were visible, being obtained a rough surface. To ensure the connection were executed holes in the pillars. Then were introduced steel bars (S500) into the holes and filled with epoxy resin mortar.

The new end frames built in this intervention discharged directly into existing foundations.

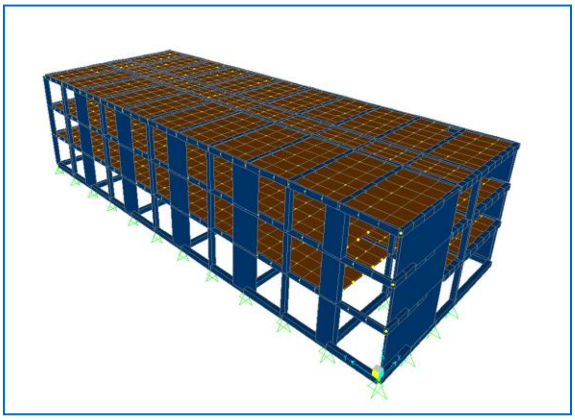

Figure 3 – Model of seismic strengthening of the main body (Monteiro, et al., 2009)

Figure 4 – Gym's seismic strengthening (photo taken in 2010-08-18) – (Laranjeira, 2008-2010)

- Reinforcement of a slab using carbon fibre laminates

The slab for reinforcing belongs to the gym's building. It had signs of deterioration such as infiltrations, biological colonization and excessive flexural deformation.

In order to correct the problem of excessive buckling slab it was applied an epoxy adhesive and a laminate of carbon fibre reinforced polymers (CFRP) on underside of its beams.

After the implementation of structural strengthening a thermal enhanced with polyurethane was placed.

4. Techniques of structural reinforcement

The new regulation of intervention in buildings is called *"RGE - Regulamento Geral de Edificações"*. It's applied to the construction of new buildings, to existing buildings works and to demolition jobs. This document classifies interventions in terms of structural safety in four levels. Letter Q represents the intervention cost divided by the cost of a new building.

- **Level I:** $Q \leq 5\%$ - Not worse (conditions apply structural safety cannot be lower than those existing before the intervention);
- **Level II:** $5\% < Q \leq 25\%$ and **Level III:** $25\% < Q \leq 50\%$ - Promote improvements (for actions and permanent overloads should ensure structural safety conditions of new buildings, but combining them with the remaining shares variables with a safety factor unit [seismic action without factor]);
- **Level IV:** $Q > 50\%$ - Equal to the new construction (the structural safety conditions applicable to new buildings [seismic action increased by a factor=1.5]) – (CSOPT, 2007).

The choice of the optimal retrofitting strategy relies on a good understanding of the dynamic behaviour of engineering structures and coordination with the future use of the structure. The goal of seismic retrofitting is the improvement of structures' seismic behaviour. This can be achieved through different strategies.

1. Improving regularity
2. Strengthening
3. Increasing ductility
4. Softening
5. Reducing seismic action through damping
6. Mass reduction
7. Changing the use (Wenk, 2008).

Strengthening actions can have an overall or a local goal. Note that even for local techniques the structural behaviour must always be analysed in general.

The following local reinforcement techniques can be identified:

- **jacketing of sections with concrete, metal or composite elements** – it´s one of the most commonly applied methods for rehabilitation of concrete components. This is a relatively inexpensive technique with fast application, which can present functionality and aesthetic problems;
- **adding external steel reinforcement** – additional steel plate bars are fixed to the outside of the existing section to improve bending and shear strength. Simple application technique;
- **strengthening with fibre-reinforced plastic (FRP) composites** – this practice improves shear and bending strength, or they can be used to improve the confinement of the concrete in critical zones;
- **external pre-stressing** – it's used in elements to increase its bending and shear resistant capacity, to correct service behaviour (excessive deformation or cracking), or to change structural system.

Figure 5 – Applying laminate of CFRP in Santa Isabel School (Jacinto, 2008-2010)

Figure 6 – Addition of shear walls in Leonor School (photo taken in 2010-10-25 by author)

The main global strengthening techniques are:

- **reinforced concrete jacketing** – identical to the technique mentioned above, applied broadly throughout the structure;
- **addition of shear walls** – it is one of the most common methods used for the strengthening of existing structures. This method is efficient in controlling of existing global lateral drift, thus reducing damage in frame members;
- **external buttresses** – usually used together with the above procedure, the buttresses are adopted when there is a failure overall action of horizontal forces.
- **steel bracing** – this system is an alternative to adding shear walls and it has the same purpose. It’s used to increase overall load bearing capacity of the structures to horizontal forces, reducing and regularising the distribution in the elevation of the horizontal displacements.

- **creation or elimination of internal connections** – relatively simple and economic technique, it solves problems with wrong internal stress distribution or with an excessive flexibility. However, it's characterized to be somewhat limited to more severe cases of structural deficiency.
- **imposing displacement** – this process normally applies to bridges or to buildings' footings. It's characterized by being relatively inexpensive, but not allowing large increases resistance. There is the risk of adding unwanted localized stress.

To finish this study we are going to highlight the most important reinforcement techniques used in schools.

- Addition of reinforced concrete shear walls or end frames

The addition of resistant walls in concrete is an effective method for the control of horizontal forces, allowing reduction efforts in existing elements (Proença*, et al.,* 2011).

It can be performed using it to insulated walls or to end frames in shotcrete. These frames may waive the use of form-work, it has a higher execution speed and ensures a better grip of the new concrete to the existing substrate, presenting a monolithic behaviour.

Normally, with the introduction of these walls, the existing foundations must be strengthened or new ones must be create. This foundation reinforcement can be achieved by micropiles that are characterized by presenting a high load capacity and a small size. This type of indirect foundations is decisive for the wall overturning resistance, because it's practically not subject to the stabilizing effect of the vertical load.

- Steel high stiffness bracing lattice

The addition of metallic reinforcement frames to resist to seismic action is a technique identical to the preceding one having, however, some advantages.

It shows the benefit of being faster in execution, of having the ability to accommodate openings in facade, of minimizing the added weight to the structure and in the case of external steel systems, of having a minimum disruption to the function of the building and its occupants (Thermou, et al., 2006).

This method presents serious difficulties for effective connection with the various floors.

- Reinforcement of a slab using carbon fibre laminates

Lastly, the reinforcement of beams in slabs is achieved with a carbon fibre composite. This technique is used to increase the load capacity of the structures.

The composite material is relatively recent and only resists tensile. It presents a very high resistance for a low density. In this process we have to ensure a good connection between its three elements: the composite material, the epoxy resin and the existent substrate (Cóias, 2007).

5. Concluding remarks

The main objectives of the high school modernisation programme: *"PMEES"* was reclassify school infrastructure, open the school to the community and ensure the maintenance and management buildings to maintain the degree of quality.

In reinforcement of Dona Leonor's buildings was used addition of reinforced concrete shear walls and steel high stiffness bracing lattice. In Rainha Santa Isabel School was used addition of the reinforced concrete end frames by applying shotcrete. To reduce the deformation of a slab was used carbon fibre laminates.

There is a range of structural rehabilitation techniques. The techniques should be selected to obtain the best possible combination of stiffness, load bearing capacity and deformation capacity of the structural elements during the seismic.

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