Design of concrete structures with capacity to adapt to functional changes

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1 INTRODUCTION

Today, there is an increased need for structural interventions in many buildings due to their lack of capacity to adapt to unanticipated functional needs.

Amongst these types of structures are hospitals, schools, commercial areas and highway overpasses. Often, during the lifespan of these buildings it's necessary to change their original functionality but more times than not, it's understood that they are not prepared for these at times radical alterations consequently structural intervention is vital. Preventive steps must be taken into consideration during the project phase so that future alterations to the building will not be extensive and enable it the capacity to adapt.

The method used to examine this subject is to study previous and current policies, analyze case studies and try to typify the most common needs in certain kinds of structures. Ultimately, we are given some design methods trying to give the structures the capacity to adapt to those future needs.

To define all the functional changes a building will incur during its lifetime is an extremely difficult task. To better understand those kind of future requirements, relevant case studies were analyzed. The following structures were selected based on the diversity of each type as mentioned above: Hospital de Cascais as the hospital structure, Escola Secundária Passos Manuel, Escola Secundária Luís de Camões, Escola Secundária Pedro Nunes and Liceu Filipa de Lencastre as the scholarly buildings, IKEA as the commercial area and two highway overpasses. The two highway overpasses analyzed have a slight difference: one was intervened so that the main road had the possibility for enlargement and the other had been projected with the enlargement in mind.

2 HOSPITAL BUILDINGS

2.1 Technical specifications for the project of a hospital building

With rigid laws in place concerning hospital structures, a major cautiousness already exists within the project phase. There are guidelines [1] defined by Portuguese Associations(ACSS) with the purpose to give the structures the capacity to adapt to future needs. These guidelines define some requirements to the structure:

- Functional flexibility – the building must be able to suffer functional adaptations of certain spaces without a full intervention on the special installations and structure;
- Structural flexibility – the structure of the building must have capacity to be expanded with the minimum obstruction of the operation;
- Expansion flexibility – the expansion of the building's area needs to be predicted during the project phase, so that it will not interrupt the usual operation of the building.

These type of projects are created with a forecasted possibility of vertical expansion by two floors. This forecast effects the entirety of the design and because of that; all the vertical resistant elements are upper-designed so they can deal with that potential lift.

It is also established a pattern of columns and resistant walls with a minimum span of 7,30 m because, in the understanding of the responsible associations, this span is the ideal to deal with all the functional problems and give the structure enough flexibility to deal with all the usual requirements.

According to these guidelines, the fungiform slabs must be favored compared with the slab with beams. These slabs are better equipped to deal with special installations such as electrical cables, air conditioners, etc.

Hospital buildings are a vital part of our society and have a requirement of relentlessness against world disasters like earthquakes [2]. The way the regulation found to classify the buildings was introducing a hierarchy of importance based on classes and specific factors that amplify or reduce the effects of seismic actions. A hospital structure is categorized as class IV of importance; for "buildings whose integrity during earthquakes is of vital importance for civil protection" [6] and because of that, the effects of seismic actions are amplified.

2.2 Case study – Hospital de Cascais

The Hospital de Cascais is a building designed by Prof. José Câmara and Eng. Carlos Figueiredo [5] to replace the old building that was situated in the middle of the town of Cascais.

The building, represented in Figure 1, has a square footage of 154 m. For this range of length, it is typical that the building has various structural joints. However, with the precise placement of vertical resistance elements, the project engineer was able to reduce this number to a minimum. The strategic positioning of the structural joints was a stipulation of the investor whom considered future expansions of the construction. This decision was made so that the classification of the regularity of the building would not be affected if a possible expansion would take place. The judgement of the designer is an example of an adaptability measure, which improves the final and future quality of the overall construction.

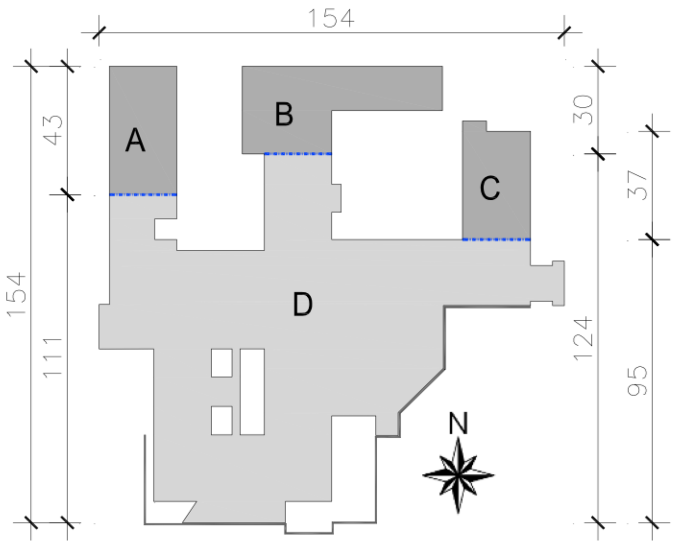

Figure 1 - Plant of the Hospital de Cascais [5]

2.3 Adaptability capacity for hospital structures

In an effort to avoid the possibility of short-term obsoleteness the adaptability design methods should consistently be present during the project phase. The consideration of a higher imposed load opposed to the standard is one of those measures, which enables the space the ability to change their functionality without high tension on the structure. There are some divisions in the hospital that require a higher imposed load such as the imaging department. The design of the entire hospital structure with that value (15 kN/m^2) is uneconomical so the designer and the promoter must define specific areas in the structure where it would be possible to implement one of these departments in the future if needed.

Another important measure to take into account during the project phase is the modularization of the structure. The directions from ACSS point to spans with 7,30 m as mentioned above and the same span length used in the case study here. ACSS technicians consider this value one that responds extremely well to all the needs of hospital structures. Although a few particular areas still exist like operating rooms, where this modulation is inefficient as bigger spans are required. Considering this unique feature the modulation from the general structure must be adapted for these areas, for example creating spans with 14,60 m.

Utilizing fungiform slabs are favored by ACSS as they are the ideal solution when dealing with technical installations. Generally, false ceilings are used and because of this slabs with beams are better solutions according to the adaptability design method. This recommendation must be pursued as it allows for more flexibility to the structure due to the easiness of opening *courettes* and a higher chance of passing the regulation for seismic actions.

3 SCHOLAR BUILDINGS

3.1 Actual project policies – Parque Escolar

The Parque Escolar program was defined with the purpose of "(…) planning, management, development and execution of a modern policy of modernization and maintenance of the public network of high schools."[10]. In order to implement these policies some guidelines were defined, by the Parque Escolar's technicians, which defined how the buildings should be designed [11]:

- Flexible spaces – adaptable spaces capable of response to the majority of the future needs in the educational, technological and functional level;
- Multifunctional spaces – the spaces must be designed with capacity to change their functionality;
- Lasting solutions – the lifetime of the scholar buildings is 50 years and to accomplish this objective the structures must be designed on an adaptable level in physical, environmental and functional terms.

3.2 Case Studies

3.2.1 Escola Secundária Passos Manuel

Escola Secundária Passos Manuel was designed in 1882 and was opened in the year of 1911. The building has three floors (one basement and two above ground) and its typology is based on brick and stone walls. These stone walls hold the floor composed of ceramic vaults and some metallic profile. To support those profiles there are trusses composed with I profiles and sometimes with angles that are 0,90 m high.

In general, the building is in a good preservation state and as it is an important building (it was the first high school building in Portugal), the new solution must take into account all the old materials used in the original construction.

In order to improve the air conditioning system of the building, it was necessary to install some heavy machinery in the mat slab. This slab was not prepared to hold the weight of these machines therefore it needed to be reinforced with metal beams HEB240 to deal with the 9,40 m span.

3.2.2 Escola Secundária Luís de Camões

Escola Secundária Luis de Camões is a high school building, composed of several buildings, each one with a different function, that was designed in 1907 and its main building opened in 1909. The latter has stone walls, wood floors and some metal profiles to support the floors. Some of the wood floors were replaced, during the second half of the XX century, by pre-stressed beams and ceramic vaulted.

The new architectonic program predicted the intervention in several areas of the structure, including the demolition of some walls due to the reorganization of the functional space in the building. Reinforcement to the floor structures permit them to work as a rigid diaphragm had also been designed. The way the designers found to implement this rigid diaphragm behavior was to include some “Cruzes de Santo André”, which are crosses built inside the floors so that the response to seismic actions are improved.

3.2.3 Escola Secundária Pedro Nunes

The buildings of Escola Secundária Pedro Nunes were built in different stages: the main building in 1911 and the lunch room and the gym in 1961. The former has stone walls around it and brick walls inside. The floors are fully supported by the outside walls without support on the interior brick walls.

The complete structure was intervened to improve the response to seismic action. Some reinforced concrete frames were built in order to decrease the stress on the masonry walls. The connection between perpendicular resistant elements is essential in masonry buildings because this connection improves their resistance to horizontal actions. Due to that, rods were built to connect parallels and perpendicular masonry walls.

3.2.4 Liceu D. Filipa de Lencastre

Arq Jorge Segurado projected Liceu D. Filipa de Lencastre building in 1933.and the construction was realized between 1933 e 1967. The plant is symmetric in the longitudinal axis, as represented in Figure 2.

Figure 2 - Areal image of Liceu D. Filipa de Lencastre [7]

One of the most important intervention was realized in the gym. There were one gym with a small high under its and were built two gyms on that area.

3.3 Adaptability capacity for scholar structures

In order to have structures that are more adaptable in the future, scholar buildings must be designed with a bigger imposed load of the floor. That option allows the structure to have a better response to some functional changes. Another important measure deals with the mat slab. This slab must be designed with the capacity to receive various installations, so the imposed load must be equal to the one which is used on the inside. The modularization must always be present so that the structures have more capacity to adapt to further changes referring to it’s functionality. In order to implement that the spans in the classroom must take into consideration the other spans. For the sake of accomplishing the multifunctional spaces defined by Parque-Escolar specific spaces that are capable of assuming new functionalities beyond those initially intended must be defined.

4 COMMERCIAL AREAS

Frequently, commercial area structures have large spans and are very expensive therefore they must be designed with the capacity to adapt to some changes to their functionality. These high spans and accelerated construction times usually lead these structures to pre-fabricated solutions.

4.1 Case Study

The case study used to interpret these kind of structures is the IKEA store. The project manual [8] was analyzed and conclusions were made based on that.

IKEA stores are designed for a lifetime of 20-30 years. This value is much lower than other structures analyzed, such as hospital or schools. This is because the IKEA directors believe their sale concept is constantly changing and they do not need a store that endures 50 or 100 years.

The project manual of IKEA states that the pre-fabricated structures must be favored as this is the solution that supplies the best cost/time ratio of construction.

The modulation is always present and the vertical resistant elements must be placed to create a certain kind of frame depending on which areas they are serving and the kind of material used. The reinforced concrete slabs must be supported in 8 x 16 m^2 columns and with the composite slabs the grid must be 16 x 24 m^2 [8]. In order to have a good control of deformation the IKEA project manual defines the limitation of deflection in L/400 [9].

Typically, technical installations are a huge problems in buildings and these issues increase when commercial structures are analyzed. In order to prevent these problems these structures are designed with a big high between floors.

The imposed loads are also defined in the project manual and the values are 5 kN/m^2 for the trade zones and 15 kN/m^2 for the warehouse. The overloads alternation must be taken into account and even the change between an empty and a full shelf must be considered. These values presented by the IKEA engineers are slightly bigger than the ones presented by Eurocodes, due to in-depth studies done directly by the company in an effort to understand the diverse type of loads their structures would likely incur.

Cracking is also a subject defined in the IKEA project manual. The IKEA engineers define the value of 0,2 mm of the opening of the crack. In Eurocodes this value is around 0,3 mm, which means the IKEA owners are rigorous in this aspect.

The expansion joints are not required in the IKEA project manual. This manual says that the temperature inside their stores is always accurate, between 15ºC and 25ºC, and due to that, there is no need of expansion joints. The preference of pre-fabricate structures has also some influence in this conception method whereas the connections between element are not 100% rigid and have some capacity to accommodate the displacements due to thermal actions.

One of the most interesting requirements referred to in the project manual is that the parking lot must be able to raise its height by two floors. This demanding force the vertical resistant elements to become over designed in order to accommodate that raise without any kind of reinforcement. There is also a search for the standardization whereas all the columns must have always, if possible, have the same dimensions. This attitude gives the structure some backup resistance, gaining more capacity to adapt to future changes, namely the parking lots vertical expansion.

4.2 Adaptability capacity for commercial structures

There is a large requirement of high values of spans in this structure along with accelerated construction times coincidentally pre-fabricated structures are several times used. The elevated cost of these kind of structures makes the capacity to adapt to new functions a big requirement.

The use of vertical resistant elements must follow a pattern in order to have big spans and some regularity of the structure. This kind of designing gives the structure some capacity to adapt to new functions.

The small lifetime defined in IKEA's project manual (20-30 years) suggest that the directors would ideally like to diversify their sale concept within short periods of time. This notion is also noted in the preference by the prefabricated structures as they allow a very fast construction times and a big standardization of all stores.

5 HIGHWAY OVERPASSES

The highway crossing is a very regular situation and can be solved with some kind of structures such as overpasses or underpasses. This cross must happen quite often because the distance between them cannot be too large.

The highway overpasses are structures that are many times requiring adapting. This happens because the traffic of the main road increases and becomes necessary to make an enlargement of it. So the overpasses must be prepared to accommodate this enlargement of the main road without suffering construction works. In order to give this capacity to this kind of structures, the overpasses must be designed to the future and be prepared for all the typical situations.

5.1 Case studies

5.1.1 Rehabbed highway overpass

The overpass analyzed [3] in this chapter was designed in 1978 without thinking about future changes to the main road and, in 2005 when the highway needed to be enlarged, the overpass needed some intervention in order to get bigger spans.

The overpass had a 3 spans modulation: 13,70 + 34,26 + 13,70 m. The cross section used was a single rib with 7,20 m large and 1,50 m high. The support structure were four columns with 0,90 m diameter. The main road was designed with 2x2 lines and the traffic raise led to the need of 2x3 lines. How the overpass was not ready for this enlargement of the main road, construction works were needed to raise the span of it.

The side columns were demolished, as may be seen in Figure 3 with the dashed lines marking the previous positions of the columns, and two longitudinal beams each side were raised with the purpose of hold the board. These changes lead to a possible future enlargement of the main road whereas now it is possible to build a 2x4 lines road.

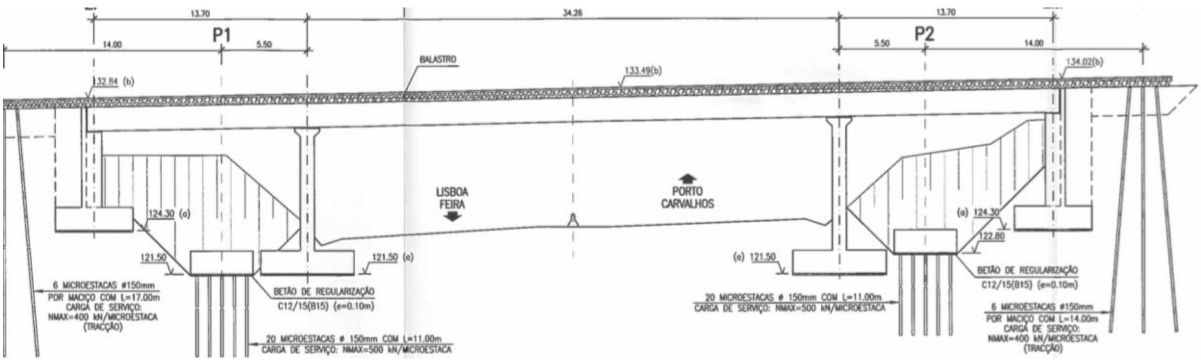

Figure 3- Changes to the longitudinal solution [3]

The solution used revealed too expensive, but some conditions, like the impossibility of shut down the railway of the overpass as well as the highway, make this the best possible solution.

5.1.2 Highway overpass designed with adaptability design method

This case study [4] was chosen because it represents an overpass designed with the possibility of the enlargement of the highway from the beginning.

This structure was designed with a 6,90 m large single rib and a maximum of 1,70 high. The longitudinal solution was projected with a column in the central reservation and two abutments in the side. It has a double 34 m span which deal with the 2x2 lane road able to enlarge to ten 2x4 lane road.

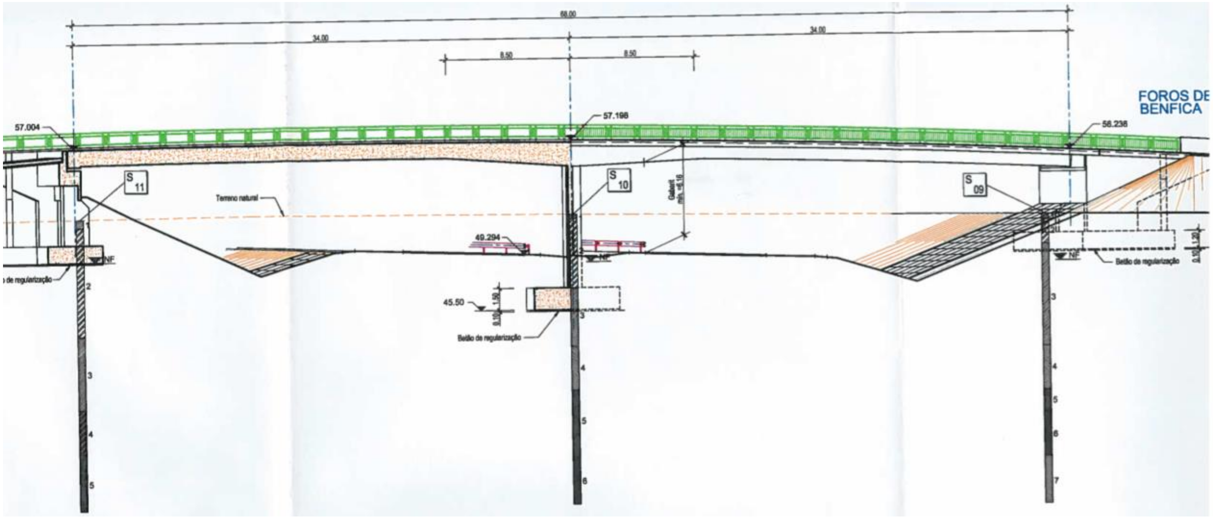

Figure 4 - Longitudinal solution of the overpass [4]

Some cross beams were built in the connection between the board and the abutments and has direct foundations. The columns deal with the horizontal loads because some support devices were put in the abutments so the board is able to move above them.

5.2 Adaptability capacity for highway overpasses structures

All the highway overpasses must be designed for possible enlargement of the main road in the future. This kind of worries in the present allows saving money and construction works in the future.

In order to give the highway overpasses to become more adaptive must have a preference for a longitudinal system with the column on the central reservation instead of a solution with side columns. This guideline makes the structure to have less span and so become longitudinal smaller when compared with the other solution. This preference has a lot more condition that only the span such as the plan of enlargement (for the inside or for the outside of the existent road), the possibility of put a column in the central reservation (due to the fact of lack of space) and the conditions of expropriations of the field around the overpass.

The enlargement of the board from the highway overpass must also be consider and the design of this structure must be done in agreement with that.

6 CONCLUSION

The ability of structural adjustment is a theme that must be always present in the project phase, both in buildings and highway overpasses. This notion may save both money and construction works in the future and so promote a long-term economy of the structures.

In order to apply this method the usual changes in the structures must be defined as well as some predictions about the future. With that information the project engineer is able to design a structure which can support several changes in the future. To achieve this point the coordination between all the teams involved is crucial. Both architecture and engineer teams must have in mind that the structure they are working on must be a durable in time.

In practical terms a certain kind of measures must be taken in account during tha project phase. In buildings the possibility of raise in high, for example, when that justifies, such as hospital or parking lots, must be taken into account and in overpasses the possibility of an enlargement of the main road must be present during the project phase.

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