Chapter I. INTRODUCTION AND OBJECTIVES

I.1. Introductory remarks

Reinforced concrete flat-plate structures have been and continue nowadays one of the cheapest and most popular ways to raise buildings. For relatively light loads, as experienced by apartment buildings, flat plates are used. It is a simple conception structure based on a group of vertical elements supporting a slab of uniform thickness. This structure type is the most economical for spans from 4.5 m to 6 m.(15 to 20 ft).

Fig 1. Flat plate built at Purdue University

The first American flat plate building was the C. A. Bovey Building in Minneapolis, Minnesota. It was built by C.A.P. Tuner in 1906. It was raised at the risk of its inventor, but performed well in the loading test. Between this structure and the paper on slabs by Westergaard and Slater in 1921, was plenty of room for argument. During that period some theories appeared from different authors trying to establish the amount of reinforcement to place in the flat plate. This amount was the point of discussion and had differences of 400% between different authors. During those years the use of the crossing beam analogy to design flat plates, induced somehow that statics were not applied in slab construction. In 1914 Nichols introduced statics to compute the moments in a flat plate. Nichols analysis was right but Turner design was not wrong, thus his work was generally refuted. Although ACI did not introduce the analysis until 1971, Nichols's analysis forms the basis for the actual ACI's slab design (direct design). Nowadays the behavior of flat plates under gravity loads is well known. The ACI code describes clearly how to design such structures. Flat plates subjected to gravity loads have a flexural behavior; here there are the three main points to describe the performance:

1. Before cracking the slab acts as an elastic plate.

2. Between cracking and beginning of yielding the slab is no longer of constant stiffness due to the loss of inertia. Also it can not be considered isotropic because the crack pattern may differ in both ways. However these considerations, the slab can be assumed behaving elastically because it predicts the moments adequately.

3. Yielding of reinforcement starts in one or more regions of high moment. After these regions reach yielding moment redistribution occurs and the yielding spread through the slab. With further load the slab gets divided into different elastic plates that can cause the collapse of the structure. The boundary load for that collapse can be computed with a yielding line analysis.

Also the vertical load can make the structure collapse under punching shear. This means that the slab is not able to resist the shear generated close to the supports or columns. Punching shear is also considered in the ACI code and can be avoided by simple geometrical restrictions and the correct design of the reinforcement.

Thus the performance of this kind of buildings under vertical loads is well known, but the scope of this study is for laterally loaded flat plates. The behavior under these conditions is totally different. Most of the structures are designed to resist lateral loads as wind, but this design in not enough when the structure is subjected to seismic forces. Along the history, flat plates have had a spotty response against earthquakes. In this case, the slab column connection becomes the critical element of the structure. The slab is a diaphragm with distributed strength and stiffness, and the column is a rigid bar perturbing the slab. The connections affect the response of the entire structure and can cause collapse of the building even if the connections have not reached failure. The entire structure is more vulnerable, and the response is not easy to predict; many aspects of the behavior become uncertain.

It is understood then that the behavior is difficult to predict, nevertheless there are some ways to model the structure into a system easier to understand. A structure responds to an earthquake excitation with a vibration that absorbs the energy transmitted by the earthquake. The amplitude of this response depends on the characteristics of the building, foundations and the non structural items inside. It has obvious complications to model the structure as a system with all that elements. Thus the usual methods for seismic analysis of structures try to simplify the structure into a simple degree of freedom. This is a concentrated mass, a spring and a damper. Then under the excitation the mass will oscillate and absorb the energy. In general the structures can not be represented by single degrees of freedom because they are more complicated. Then they can be modeled as a series of mass connected between them by different springs. This configuration still admits an easy dynamic analysis but introducing more details of the properties of the system. While modeling the structure into a system for its further dynamic analysis, it is important to well determine the stiffness of each floor as well as the connections.

Lately the main concern at seismic zones has been to differentiate between flat-plates safe enough and the ones that are not safe to resist seismic motions. A wide research has been developed around this topic trying to study the parameters that govern the lateral behavior of flat-plate structure. In this hunt some analytical research has been developed and also a wide variety of scale models have been essayed at different laboratories in order to get experimental data. Chapter II of this study gets into some of the preview research done around this topic and remarks the theories and ideas that will be used along this paper.

As it will be explained in next chapter, all the experimental data recorded till now has been on scale models. Purdue University has decided to perform a full-scale test on a laterally loaded reinforced concrete flat-plate structure. A real scale test will give the opportunity to transfer the behavior of the prototype to existing structures; also will increase the knowledge for the design of safer flat-plate buildings. This project started as an idea for reviewing the safety of buildings constructed in the middle 20th century. It will try to find their vulnerability to seismic loads and suggest if necessary the measures to reasonably protect them against earthquakes. The structure to be tested is described in detail in Chapter III after its design is done. The test needs a structure designed according to ACI building code to correspond with real structures. Also necessitates a building that will perform in a way that the experiment obtains the maximum amount of data. As well is needed previous to the experiment itself, a prediction of the behavior. This prediction must come from analysis either statics and dynamic, in this way, the approximated response of the structure is well known before start the test program. This dissertation includes the design and analysis of the three story flat plate structure going to be test at Purdue University. It helps to the development of the test structure and to the complete knowledge about it before the experiment starts.

I.2. Objectives

It will be seen in the next Chapter that the knowledge about the experiment developed in Purdue University will provide useful data of the lateral behavior of a flat plate. For the test to be successful is needed a consistent design, according to actual standards required by ACI building code. Is also needed a designed to optimize the test and laboratory characteristics; and finally and analysis of the system that provides enough knowledge of the structure to confront the test with guarantees. Looking for these purposes the objectives of this dissertation are:

- To review available research on flat-plate structures. Evaluate similar research done with scale models, or scale specimens that studied the flat-plate building behavior under lateral load. Find some conclusions that will help to establish the design and method for analysis.

- To design the structure accomplishing with ACI code requirements; and design a structure capable to develop its maximum capacity during the future test, looking for a pre-defined failure mode.

- To model the structure in the best way to represent its behavior and in a manner that fits the requirements for LARZ, the program that will be used. To perform a static analysis with LARZ. To complete a dynamic analysis with LARZ subjecting the structure to different earthquakes motions.

- To determine the limits of the structure resisting earthquakes. To decide whether the flat plate is safe or not.

- To suggest the behavior that will occur during the test and propose, if necessary, improvements in the structure or the test configuration.

I.1. Content of the Dissertation:

Chapter I Introduction and Objectives

This chapter contains an introduction to the problem of flat plates under lateral load. It briefly explains the history of flat plates in America, and describes the problem that initiate this experiment.

Chapter II Review of previous research

This chapter starts with an introduction of the basic points in earthquake engineering necessaries for this dissertation. Then summarizes in various points the most important research previously developed. Above all refers only to research relevant to the present study. It also describes the approximation for flat

plates form the ACI building code. Finally does an evaluation to resume the ideas and results that will be applied in this study.

Chapter III Design of the test structure

This chapter develops the design of the test structure. The main design is done using limit analysis, the method it is explained as well as their results. After the main design is done the characteristics are checked to accomplish with ACI requirements. Once the design is achieved there is a complete description of the test structure.

Chapter IV Analysis of the test structure

This chapter first describes the software used for the analysis, and how the structure was modeled for it. Then performs a static analysis with two different load configurations. Following comes the dynamic analysis, calculating first the structure period of vibration with two approximations. Finally ends performing the analysis with eighteen different ground motions.

Chapter V Discussion of results

This chapter discusses the results form the design of the structure, the static analysis and the dynamic one. Bases the discussion on the expected results for this kind of structure and on previous approximation in drift response. Its intention is to establish the bases for the further conclusions.

Chapter V Conclusions

This chapter summarizes the work developed in this study and adopts conclusions for the structure response and design. It also focus on the recommendations for the test in the laboratory