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Reliability study and simulation of the progressive collapse of Roissy Charles de Gaulle Airport

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ABSTRACT

Paris Charles de Gaulle Airport also known as Roissy Airport is the world's eighth-busiest airport in passengers served. In May 2004, the news of collapse of a portion of Terminal 2E leaving four casualties shook the world. Luckily, no boarding had been taking place in the collapsed area which consisted of a boarding area and three footbridges. This part of the terminal had an innovative design consisting of a vaulted concrete tube. We chose to model a representative part of the terminal to observe the structure's behavior. The purpose of our research is to explain the structure's collapse and to see if there were deficiencies from the design phase. Also, our new fine-grained model using Ansys Software makes it possible to explain the progressive collapse of the structure, which was the main challenge of our study. Moreover, a sensitivity analysis was performed in order to study the importance of each of the variables taken into account in the model.

1. Introduction

Terminal 2E, with a daring design and wide open spaces, was Charles de Gaulle Airport's newest addition. Terminal 2E had been inaugurated in 2003 after some delays in construction. On the 23rd of May 2004, not long after its inauguration, a part of Terminal 2E's ceiling collapsed early in the day, leaving four casualties. Some questioned the construction methods as being the primary cause, which were rushed as the project was a month behind schedule due to technical problems, and some have also considered the possibility of improper design as the cause of the accident. In the following, a deterministic analysis and a mechanical reliability assessment will be elaborated. We will show the importance of reliability assessment and long term strains of materials, especially for public constructions where the human and economic repercussions are heavy to bear. The purpose of our research is to study the problem using the available data in order to examine the real reasons of the incident, to see if it were possible to predict the structure's failure from the beginning and to simulate the progressive collapse of the structure.

2. General overview of Roissy's Terminal 2E [1]

We will first describe the terminal, its different construction phases, the incidents that occurred before the accident and the collapse itself. Then we will present in a general way the principle of finite element modeling, recommendations for good

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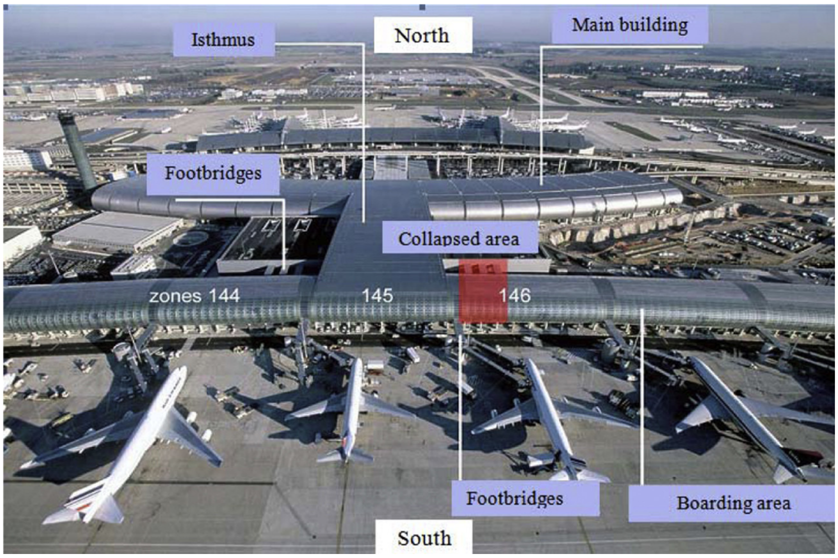

Fig. 1. General view of the terminal.

modeling and problems encountered during the process. We will also talk briefly about the behavior of concrete (creep, shrinkage).

2.1. Description of the terminal

Terminal 2E consists of three parts: the main building, the boarding area and the isthmus that connects the two buildings. The boarding area is formed by a succession of ten shells giving access to aircrafts through nine gateways (Fig. 1).

The 650 m long terminal is made up of a series of 4 m wide panels adjacently connected, forming a deformed tube which rests on parallel longitudinal beams. Structurally it acts as a form of an extreme portal frame. There is a 30 cm thick precast concrete shell and a steel external tension truss, with simple vertical struts connecting the elements. The tube is surrounded by a glazed roof which feeds light into the structure through square voids cast into the shell (Fig. 2). Three walkways are cut into the structure (it was at one of these points that the structure failed). These footbridges link the boarding area to the central area of the terminal.

2.2. Construction of the terminal

A full-scale prototype consisting of two common arcs (total height of 18 m, maximum opening of 31 m) based on four columns was achieved. But it is interesting to note here that the prototype did not allow testing the behavior of the extremity zones of the shells or the behavior of beams. It should be also noted that it is after the striking that the shell takes in its own weight. The striking was accompanied by an instantaneous deformation of 10 cm vertically while the design had predicted 2.8 cm. These deformations continued later on with time. This observation lets us imagine the consequences in the case of striking of asymmetrical arcs where the footbridges are located.

2.3. Incidents before the collapse

Between the beginning of the construction phase and the date of the collapse, many incidents took place: right after installing the first rings, cracks were seen in the columns. After the striking, we had instantaneous deformations and a spreading of the shell. This deformation continued over time because of the creep and shrinkage of the concrete. Cracks near the fixation plates of the footbridges were observed in zones where the collapse occurred. These cracks have been attributed to the deformation of the shell, but without showing any undue concern. Transverse cracks appeared very quickly in the midline (under the support line of struts) of all solid elements located at the extremity of the shells.

2.4. Collapse of the terminal

On Sunday May 23rd at 6:57, six arcs located in the boarding pier collapsed abruptly with a loud cracking noise (Fig. 3). A police lieutenant who witnessed the collapse found around 6:45, a significant tear in the lateral wall of a concrete element of a solid shell adjacent to the footbridge in the middle of the zone which later on collapsed. This tearing was reported about 5:30 by a cleaning crew and it also seemed that there was concrete dust that fell before the accident. The following