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High Energy Pipe Break analysis for the pipelines of a nuclear power plant: No standard case

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ABSTRACT

The aim of this study is to show the application of the High Energy Pipe Break (HEPB) a level 3 methodology analysis, applied to the study of the pipelines of a standard pressurized water reactor. In particular, in this paper, a numerical approach for simulating the pipe impact against a reinforced concrete column is provided in order to evaluate a correct design of the column in terms of steel rebar and column dimension. Moreover, to finalize the problem, the coupled analysis (thermofluidynamic and mechanical) to calculate a real thrust force on the pipe is provided and the results of the new numerical analysis is shown.

1. Introduction

Nuclear power plants (NPP) are designed, constructed, operated and inspected to prevent pipe ruptures. Despite these preventive measures, plants are designed to mitigate the effects of hypothetical pipe ruptures, which therefore have to be postulated in any standard design process [1]. The hypothetical ruptures are in the form of leakage cracks and, for high energy lines (operating temperatures above 100 °C or operating pressures above 20 bar), full circumferential and longitudinal breaks. Nuclear power plants are designed to achieve a safe shutdown status if such a postulated High Energy Pipe Break (HEPB) was to occur. As reported in [2] for the steam line of Mochovce NPP, the methods and criteria for HEPB analysis are defined in Section 3.6 of the NRC Standard Review Plan (NUREG 0800).

In this paper we focus on dynamic effects in the form of pipe whip due to the discharge of hot pressurized fluid inside rooms and compartments. For this aspect, in general, three level of analysis are foreseen by the international standard. In this paper the analysis of level 2 and 3 are taken into consideration:

(a) Level 2: a FEM calculation is required to evaluate plastic hinge location and the whipping area. The thrust force is calculated in a simplified manner, as describe in [3], and, for this reason, the stress on the pipe and on concerned supports is overestimate.
(b) Level 3: refined analysis that combine together a FEM calculation of the pipe and a thermo-hydraulic calculation of the thrust force. This analysis allow to determine realistic results in terms of whipping area and support loads.

The HEPB analysis is, in general, focused on essential systems and components required to shut down the reactor and mitigate the consequences of a postulated piping failure without offsite power.

If an analysed break is considered “aggressive” (impact of the pipe on a safety equipment) a Pipe Whip Retrain (PWR) (see Fig. 1) is designed to prevent the break and to avoid the aggressiveness.

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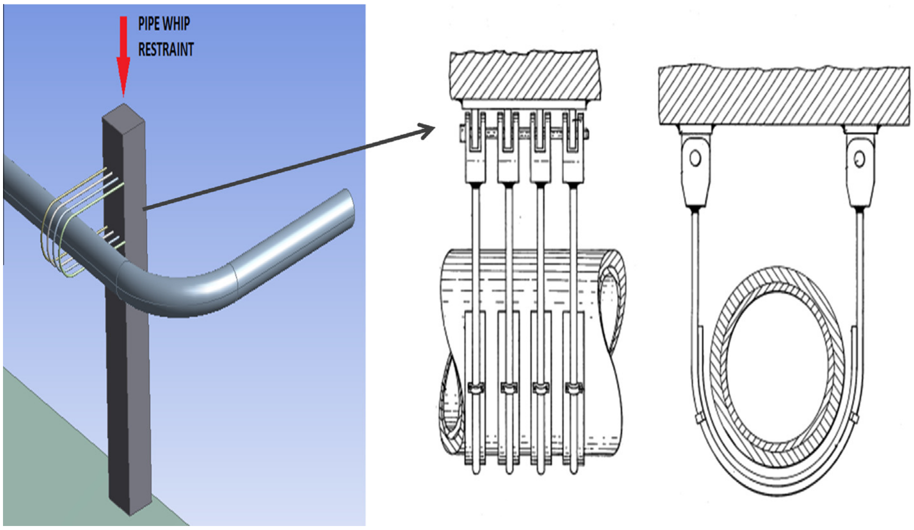

Fig. 1. Typical pipe whip restraint (PWR).

In the previous work [12] an elasto-plastic dynamic analysis has been performed to evaluate the aggressiveness of the piping break in terms of the pipe impact on the safety targets but no effect on the targets have been analysed. In general, only the dynamic analysis of the pipe is necessary to evaluate the aggressiveness of the pipe. In fact the dynamic analysis allows to define the maximum whipping area of the pipe (control area) and to determine if in this area a safety target is intercepted or not. If the aggressiveness analysis is positive (target intercepted), a PWR has to be installed.

Generally, the PWR requires an amount of space around the postulated break point to install the PWR structures. In this paper is analysed a particular case, observed in a real NPP construction, where there is no free space around the pipe break point as shown in Fig. 2. No safety equipment is placed around the potential trajectory of the pipe but the impact on a concrete column is expected.

The aim of this study is not to analyse the impact of the pipe on a safety target as made in general HEPB analysis [12] but to verify the pipe impact on the concrete column and to verify its structural integrity necessary for the room structural integrity. Three types of column are examined to verify the resistance of the column or to find its possible reinforcement design. In the first analysis (level 2) a standard thrust force [2] is apply to the pipe and a pipe column impact is analysed. Finally (level 3) a calculated thrust force with a thermo hydraulic code is applied to the pipe.

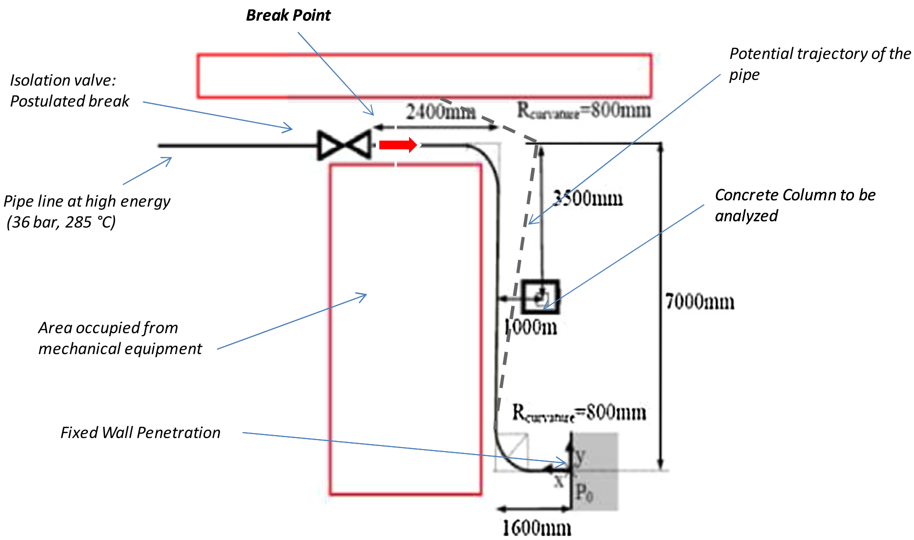

Fig. 2. Layout and geometry of the case under study.