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Simulation of a shock absorber with vertical buckling tubes welded in the longitudinal direction

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ABSTRACT

The Ignalina Nuclear Power Plant (NPP) has two RBMK-1500 graphite moderate boiling water multi-channel reactors. The Ignalina NPP Unit 1 was shut down at the end of 2004 while the Unit 2 was shut down at the end of 2009. Spent fuel assemblies are located in the pools of Ignalina NPP Units. These spent fuel assemblies will be loaded to the special casks for storage of the spent fuel assemblies. The drop of the cask during the lifting and lowering operation has to be taken into account as an unlikely event.

Shock absorbers are mounted on the bottom of the stepped pool. A special shock absorber design using vertical buckling tubes has been developed. In case of a drop of the cask, the buckling tubes dissipate the kinetic and potential energy and reduce the impact force to the floor. These tubes are made of a stainless steel sheet and welded in the longitudinal direction. Therefore, the influence of the weld on vertical buckling of the tubes should be evaluated. Finite element analysis software ABAQUS was used to estimate the influence of the weld on the plastic deformation behaviour of the tubes.

1. Introduction

The safety assessment of equipment, intended for on-site transportation of RBMK fuel, is an issue of highest importance. Therefore, the structural integrity analysis of equipment designed to mitigate consequences during an accident is very important in order to demonstrate that the proposed set of this equipment performs all functions and assures the required level of safety.

Special casks for storage of the spent fuel assemblies are loaded with fuel in the spent fuel storage pools of the Ignalina NPP Units with RBMK-1500 reactors. The equipment for loading/unloading and transportation of the casks was designed. During loading/unloading of the cask with SFA theoretically the accident with drop of a cask from height of ~5 m to the floor of the pool is possible. A special shock absorber design with vertical buckling tubes was developed in order to dissipate the kinetic and potential energy and reduce the impact force to the floor in case of an accident. These tubes are produced of a sheet welded in the longitudinal direction, because it is difficult to produce a solid tube due to its very large size. Therefore the influence of the weld on vertical buckling of the tubes should be evaluated. Design of pipelines usually comprises

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calculation for plastic strain account both for resistance to tension and to compression along the axial direction of the pipe. Design of welded pipelines with longitudinal welds in tension is related to the failure modelling of plastic collapse or fracture, while compression resistance failure modes are related to buckling of the pipe in the vertical or horizontal direction, or combination with these modes, when a pipeline may buckle in the local area of the pipe wall.

However, in nuclear energy industry operations, such as transportation of irradiated materials, where safety assessment should be ensured, it is important to design equipment, which would withstand heavy static and dynamic loading and, in emergency situations, would withstand the same bulk, dropped from the predicted height, with the ability to dissipate the energy from impact loading. Since this task is related with high safety requirements, the design of the structure should be performed as accurately as possible. The major objective in designing such equipment is to maximize its energy absorption of a possible impact.

Experimental, analytical, and numerical studies were carried out in order to gain better understating of the crush mechanism of thin-walled structures and evaluation of their characteristics in terms of the buckling, mean crush force, folding deformation, and energy dissipation associated with progressive plastic collapse under static and dynamic axial compression. These studies focus on the tubes made of steel and aluminium alloys with some having foam-filled cavities [1–5]. Practical implications of such studies usually are energy absorbing structures for automotive industry [6,7]. Equally, the thin-walled structures ability to absorb kinetic energy is utilized in a wide range of various industries. A special shock absorber was designed to avoid failure of fuel assemblies in case of a hypothetical spent fuel assemblies drop accident during uploading/unloading of spent fuel assemblies to/from a container [8,9]. The main requirement for the construction of this shock absorber was that the absorber during loading of fuel assemblies would ensure damping due to elastic-plastic deformation. The proposed design of this shock absorber must prevent buckling of shock absorber and reduction of the inner diameter. The use of thin-walled tubular structures in protective cladding was investigated in papers [10,11]. The authors propose a solution to the problem of blast protection using a sacrificial layer. The response of sandwich-type panels using thin-walled tubes between steel plates is examined while several design parameters are varied in order to determine the suitability of using thin-walled tube structures as a core material under blast loading. Analytical and numerical models are utilized to gain further understanding of the response of such structures.

However, studies on shock absorbers with vertical buckling tubes containing longitudinal welds for nuclear engineering were not conducted. The aims of this work were to analyse if the selected welding electrode is suitable to achieve similar mechanical properties of the main tube material and the weld along with the heat affected zone (HAZ) avoiding the occurrence of a stiffness zone, as well as to evaluate the longitudinal weld influence on vertical buckling of the shock absorber tube during dynamic loading by computer simulation. The finite element method (FEM) has been used extensively to simulate many applications in structural dynamics [12–16]. Finite element codes are able to accurately model the plastic deformation via bending, compression or full collapse of the structures. Finite element codes, such as LS-DYNA, ANSYS, PAM-CRASH and ABAQUS/Explicit, are powerful tools in numerical simulations of the large deformation dynamic response of structures. A simulation of tube crushing was performed using finite element analysis software ABAQUS/Explicit in this study.

2. Design of the shock absorber

Containers with the nuclear fuel waste are transported to the storage place. During the transportation, there is a possibility of an accident. The container might fall down. If this happens in a cooling pool or a lifting shaft, the covering and building structures might be damaged. In Ignalina NPP the possibility of accidents could be prevented with the help of a shock absorber erected at the bottom of the pool or lifting shaft. The main principle of operation of the shock absorber is the transformation of container's kinetic energy through plastic deformation of vertical pipes [17].

The shock absorber (general view presented in Fig. 1) consists of stainless steel tubes attached to an upper platform and a lower platform. Three types of shock absorbers with different geometrical data are used at the Ignalina NPP. The geometrical parameters (tubes diameter and height, wall thickness) depend on the possible height of cask drop. The tubes are welded in the longitudinal direction.

The stiff top construction distributes the cask weight and, in case of the drop of the cask, the impact forces to all buckling tubes. The buckling tubes will carry the weight of the cask under normal conditions. In case of a drop of the cask, the buckling tubes dissipate the kinetic and potential energy and reduce the impact force to the floor.

The as-received mechanical properties of the sheet material presented by the manufacturer in the quality certificate vary in a wide range, therefore, the accurate mechanical properties of the sheet metal and the welded zone are required for buckling simulation of the shock absorber. It should be also noticed that in the manufacturing process of the shock absorber tube, it is necessary to use such welding electrodes which produce welds with similar mechanical properties to the tube material in order to avoid the occurrence of a stiffness zone. A stiffness zone in the tube would influence an adverse effect on the crashworthiness of the tube.

For these reasons, the standard tensile test was carried out for tube-contoured specimens with the cross-section size of 20×5 mm and the wall thickness of 5 mm (3 ones, marked as series T-C) and tube-contoured specimens with the same dimensions containing longitudinal welds (2 ones, marked as series T-C-W) (Fig. 2). The specimens were produced of a stainless ASME 321 steel sheet [18] and welded by a longitudinal axial weld using an automatic arc-welding machine with electrodes CT36 [19] without any thermal treatment. The dimensions of the specimens are presented in Table 1.