COMPARATIVE STUDY OF COMPUTATIONAL MODEL FOR PIPE WHIP ANALYSIS

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ABSTRACT

Many types of pipe whip restraints are installed to protect the structural components from the anticipated pipe whip phenomena of high energy lines in nuclear power plants. It is necessary to investigate these phenomena accurately in order to evaluate the acceptability of the pipe whip restraint design. Various research programs have been conducted in many countries to develop analytical methods and to verify the validity of the methods.

In this study, various calculational models in ANSYS code and in ADLPIPE code, the general purpose finite element computer programs, were used to simulate the postulated pipe whips to obtain impact loads and the calculated results were compared with the specific experimental results from the sample pipe whip test for the U-shaped pipe whip restraints. Some calculational models, having the spring element between the pipe whip restraint and the pipe line, give reasonably good transient responses of the restraint forces compared with the experimental results, and could be useful in evaluating the acceptability of the pipe whip restraint design.

1. INTRODUCTION

Presurized water reactor power plants have many types of pipe supports. Pipe whip restraints, a kind of them, are installed in order to protect the structural components from the dynamic effects of postulated pipe ruptures occurring at any location in high energy lines to which "Leak Before Break(LBB)" concept can not be applied.

Experimental and analytical studies of the pipe whip phenomena have been conducted in many countries to investigate the pipe whip phenomena accurately in order to avoid the excessive safety margin and to design the pipe whip restraint in more proper way because designers want to reduce the number of
pipe whip restraints as possible, and/or to evaluate the acceptability of the pipe
whip restraint design. Those research programs were conducted to develop
analytical methods of pipe whip phenomena and to verify the validity of the
developed methods. To investigate pipe whip phenomena, designers and
reviewers should perform three main evaluations as follows: (1) Evaluation of
fluid dynamic (blowdown) forces acting on the ruptured pipe which are induced
from a double ended guillotine break. (2) Evaluation of system response to
determine whether the pipe rupture will result in pipe whip or not. (3)
Evaluation of pipe whip behavior (pipe movement, impact loads, restraint strains,
etc.) when pipe whip is anticipated to occur.

Recently, several kinds of the general purpose finite element computer
programs have been developed to solve the elastic-plastic stress analysis
problems, and those programs are used in designing the components of a nuclear
power plant and in reviewing the design materials for those components. In this
study, calculational models using ANSYS code\textsuperscript{[1]} and ADLPIPE code\textsuperscript{[2]},
the general purpose finite element programs, were used to simulate the postulated
pipe whips to obtain impact loads. Calculated restraint strains, restraint forces,
impact times were compared with the corresponding experimental results
performed by Ueda et al.\textsuperscript{[3]}

This study is to develop the evaluation method of the mechanical integrity
of the pipe whip restraint, that is, corresponds to evaluation category (3) among
the above items.

2. ANALYTICAL MODEL

In this study, the dynamic analysis of pipe whip phenomena was carried
out using ANSYS code and ADLPIPE code to simulate the postulated pipe
whips and the calculated results were compared with the sample experimental
results. The sample experimental results were obtained from the cantilever type
pipe whip test performed by Ueda, et al.\textsuperscript{[3]} in 1983. That experiment was
performed on the dynamic behavior of pipe and restraints under loss of coolant
accident contained in a boiling water reactor. The test pipe was connected to
the pressure vessel which contained pressurized water and was fixed on a
location of 3,000 mm from the free end of the test pipe by the pipe support.
The pipe whip tests were performed under boiling water reactor operational
condition, that is, the test pressure is 6.77 MPa and the test temperature is 285
°C. The overhang length of 250, 400 and 1,000 mm and the clearance of 30,
50 and 100 mm were chosen as the experimental parameters, respectively.
The overhang length (OH) is the distance between the center of four restraints
and the pipe end. The clearance (CL) is the distance between the outer surface
of the pipe specimen and the inner surface of the restraints. The effective
clearance $C_e$ is the distance between the outer surface of the pipe specimen and the inner side of the restraint when the restraints work as load carrying devices. The bearing plates were attached on the inside surface of the restraint bars so that the pipe specimen should contact directly to the restraints after the jet thrust force was initiated. In this test, the clearance equals to the effective clearance because the bearing plates keep the inside diameter of the restraint uniform during pipe whip event.

All the pipe specimen portion from the free end to the fixed pipe support was modelled as a pipe element which was filled with pressurized water in the ANSYS calculation and in the ADLPIPE calculation. Fig.1 shows the finite element model of the 4-inch diameter pipe whip test in ANSYS code.

![Fig. 1 The ANSYS Finite Element Model of the Pipe Whip Test.](image)

Yano et al.\textsuperscript{[4]} had performed the fluid jet test whose pipe specimen had the same size as that in this pipe whip analysis in order to obtain the jet thrust force induced through the pipe break point. The results from the fluid jet test were simplified and inputed as a table form in the ANSYS calculation and in the ADLPIPE calculation. The pipe specimen and the restraints were fabricated from type 304 stainless steel. The pipe specimen used in this test were 4,500 mm in length and 114.3 mm in diameter and 8.6 mm in thickness. These four pipe restraints were modelled as a plastic beam element in the calculation. Stress-strain relations of the pipe specimen and the restraints were inputed as the table taken from the IPIRG program\textsuperscript{[5]} upon which the dynamic loading effect was considered. The clearance portion was modelled as a spring element. The spring constant of the element was selected so that the actual behavior of the clearance could be simulated in more proper way. In the clearance portion, the pipe specimen would move without any restriction for a few milliseconds and then would show very complicated motion after the pipe specimen contacts
to the restraints. The motion is that the pipe specimen would contact to the restraint and then be separated from the restraints, repeatedly.

To simulate the effect of damping factor of the pipe specimen on the velocity of the pipe specimen, one percent of critical damping was selected from the table in Reference[6].

3. ANALYTICAL RESULTS

The calculated pipe deflection at the restraint and the restraint deflection versus time and the pipe impact force at the restraint versus time are shown in Fig.2 and Fig.3 respectively for the case of 400 mm in overhang length and 30 mm in clearance. After the pipe collides with the restraint, the pipe moves together with the restraint. The analytical results are valid until the restraint deflection reaches the first peak value after the pipe collides with the restraint because the spring element cannot represent the real unloading hysteresis. But these analytical results using ANSYS code and ADLPIPE code are useful because the important quantities such as the maximum restraint deflection and the maximum restraint force appear until the first impact.

![Fig. 2 Calculated Pipe and Restraint Deflection at Restraint Position](image1)

![Fig. 3 Calculated Restraint Force vs. Time.](image2)

In Fig.4, the analytical results of the restraint strains, the restraint forces, the impact times are suggested for the various clearance at the overhang length of 400 mm. The calculated restraint strain was the maximum strain of the single beam element representing four restraints. The calculated strains are larger than the experimental values. The experimental value is the average of the first peak strains which were measured at the straight portion of four
U-shape restraints in the corresponding experiment. The experimental value of the maximum restraint force was measured only at the clearance of 50 mm, which was lower than the calculated value. The calculated results show that the maximum restraint strain increases slightly with increase of the clearance, while the maximum restraint force is nearly constant for the various clearance. This means that the kinetic energy of the pipe specimen is absorbed by the plastic deformation of the restraints and the pipe specimen.

The calculated impact time is shorter than the experimental results, and the difference increase with increase of the clearance. The calculated impact time corresponds to the time when the pipe deflection at the restraint reaches the initial clearance.

![Graph 1](image1.png)  ![Graph 2](image2.png)

**Fig. 4 Comparison Between Calculated Results and Experimental Results for Various Clearance.**

**Fig. 5 Comparison Between Calculated Results and Experimental Results for Various Overhang Length.**

In Fig. 5, the analytical results of the restraint strains, the restraint forces, the impact times are suggested for the various overhang length at the clearance of 100 mm. The calculated maximum restraint force are larger than the experimental result, and both of them decrease with increase of the overhang length. The calculated maximum restraint strain is larger than the experimental result, and the calculated value and the experimental value is the largest for the overhang length of 400 mm. This means that the kinetic energy of the pipe specimen is effectively absorbed by the restraints which are installed at the overhang length of 400 mm. The calculated impact times are shorter than the experimental result, and they increase with increase of the overhang length.
This means that the impact velocity of the pipe at the restraints decrease with increase of the overhang length.

The calculated results using ANSYS code and using ADLPIPE code give slightly conservative values, so that the calculational method could be useful in evaluating the mechanical integrity of pipe whip restraints during the pipe rupture event.

4. CONCLUSIONS

In this study, various calculational models in ANSYS code and in ADLPIPE code, the general purpose finite element computer programs, were selected to simulate the postulated pipe whips in proper way and the calculated results were compared with the specific experimental results from the corresponding pipe whip test. The following conclusions are obtained from this analysis.

(1) The calculated results give good transient response of the corresponding experimental results when the proper models are used in ANSYS code and in ADLPIPE code, the general purpose computer programs.

(2) The calculated results of maximum restraint force and maximum restraint strain are slightly larger than the experimental results. This means that the calculated results give slightly conservative prediction of pipe whip phenomena, so that the calculational method used in this study can be useful in evaluating the validity of the pipe whip restraint design.

(3) The calculated maximum restraint force and restraint strain are the first peak values of the restraint force and the restrain strain just after the impact. And the corresponding experimental results showed the first peak values of the restraint force and strain were the maximum values throughout the event.

5. REFERENCES

2. ADLPIPE, Inc., 1989, "ADLPIPE Static and Dynamic Pipe Design and Stress Analysis Manual".