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# A study on the transient analysis of pipe and restraint due to impact loading

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**ABSTRACT** : In this study, the experiments were performed in order to simulate the pipe whip phenomena. The analytical method was developed by combining several kinds of elements in ABAQUS computer code/ Standard version 5.2(Hibbit 1984, 1992[a], 1992[b]). This study presents the transient analytical results and the experimental results of the pipe whip test using the 6 inch diameter pipe and U-shaped restraints.

It is shown that the adequate clearance decreases the restraint strains. As the overhang length increased, the maximum strains of restraints decreased. When the impact force increased, the maximum restraint strain increased slightly. The analytical models in this study simulate the experimental impact phenomena very precisely, with slight conservatism. It is verified that the analytical method developed in this study is very suitable to analyze pipe whip phenomena in nuclear power plants.

## 1. INTRODUCTION

Many types of pipe whip restraints are installed to protect the structural components from the anticipated pipe whip phenomena caused by high energy lines in nuclear power plants. Because the pipe whip could lead to another significant accident, pipe whip restraints should be installed around piping systems. It is neccessary and important to investigate these phenomena accurately to design the pipe whip restraints properly and to evaluate the acceptability of the pipe whip restraint design(Koh 1993[a],1993[b]).

The experiment was performed to investigate the dynamic behavior of pipe and restraints under drop imact load. Fig.1 shows the test facility of the cantilever type 6-inch pipe whip tests.

Thrust force is applied on the free end of test pipe, and the magnitude of the impact force depends on the weight and the drop height of the carriage. The conducted five test cases are shown in Table 1.

**Table.1 The specificaitons of the considered cases.**

| Case No | Nominal Pipe Diameter | Clearance mm | Overhang mm | Inner/Outer Diameter, mm | Thickness mm | Drop Height, mm |
|---|---|---|---|---|---|---|
| I | 152.4mm (6 Inch) | 15 | 800 | 151.0/165.2 | 7.1 | 100 |
| II | 152.4mm (6 Inch) | 30 | 600 | 151.0/165.2 | 7.1 | 300 |
| III | 152.4mm (6 Inch) | 26 | 600 | 151.0/165.2 | 7.1 | 50 |
| IV | 152.4mm (6 Inch) | 15 | 600 | 151.0/165.2 | 7.1 | 100 |
| V | 152.4mm (6 Inch) | 0 | 600 | 151.0/165.2 | 7.1 | 200 |

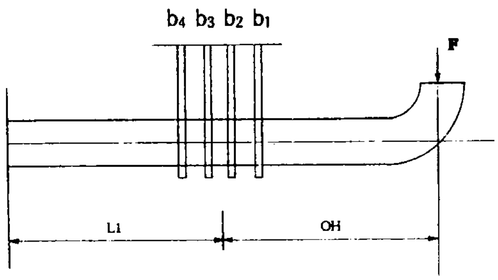



Fig.1 Schematic diagram of the pipe whip model in present study

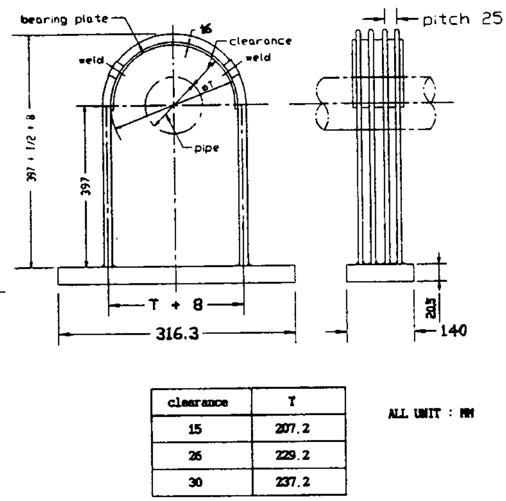



Fig.2 Geometry and dimensions of pipe whip restraint

Four-bar-type restraint was set on the restraint support as shown in Fig.2. The bearing plate was attached on the inside surface of the restraint-bars so that the pipe specimen should contact directly to the restraint after the impact load was applied. 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. The restraints were fablicated from type 304 stainless steel.

## 2. EXPERIMENTAL STUDY

### 2.1 Experimental setup

The experimental facility consists of the drop impact tower and the fixture jig on which the pipe specimen was set with restraints. The strain gages and accelerometers were attached on the pipe and restraints. Fig. 3 is the block diagram of this experimental setup.

The selection of the drop height was based on the calculation values from the corresponding analytical study in order to simulate the anticipated pipe whip phenomena in nuclear power plants. The maximum span of carriage drop height was 26 meters and the weight of the carriage was 1.8 tons. Fig. 4 shows the overview of the test facility for the present study.

The 6 inch pipe specimens were fablicated from 304 stainless steel (ASTM A135, SCH-40, KSD 3562), and the elbow was welded to each pipe specimen.

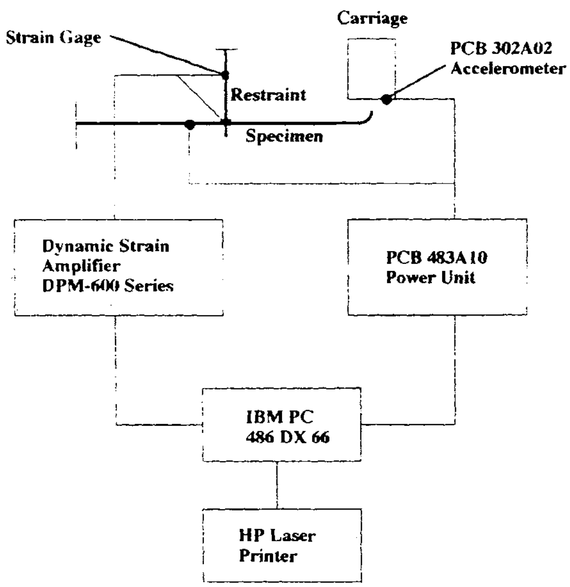



Fig.3 Block diagram for pipe whip restraint experimental setup

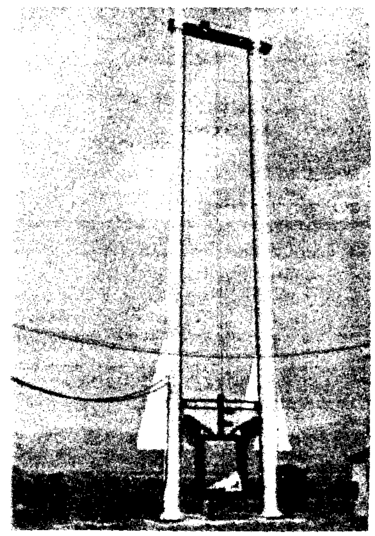


Fig.4 Overview of test facility for the present study

## 2.2 Experimental results

Fig. 5 shows pipe strain curve, marked as 'P' and restraint strains, marked as 'R1' and 'R2' for Case V which had the overhang length of 600mm, no clearance and the drop height of 200mm. R1 and R2 curves were obtained from the strain gages on the first and the second solid bars($b_1$, $b_2$) from impact point, respectively. In this case, the strain curve for the second bar($b_2$) shows an nearly elastic response because pipe and the first solid bar($b_1$) absorbed a large percentage of impact load. The welded part of the first bar($b_1$) was broken at 12 msec after impact. The maximum restraint strain was $2.036 \times 10^{-3}$.

Fig. 6 shows pipe strain for Case III which had the overhang of 600mm, the clearance of 26mm and the drop height of 50mm. When the maximum strain was $0.845 \times 10^{-3}$ at 50msec after impact, the strain was suddenly decreased to 60 percents of maximum value and increased again. The strain of the first solid bar shows same trend as pipe strain, and that of the second bar had an elastic response.

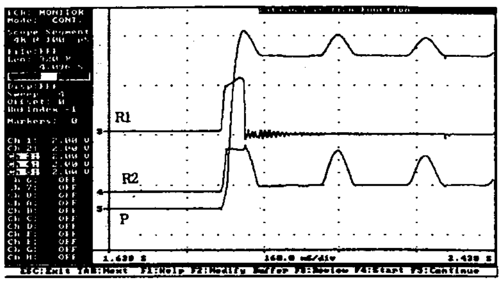



Fig.5 Experimental pipe and restraint strain time history of Case V

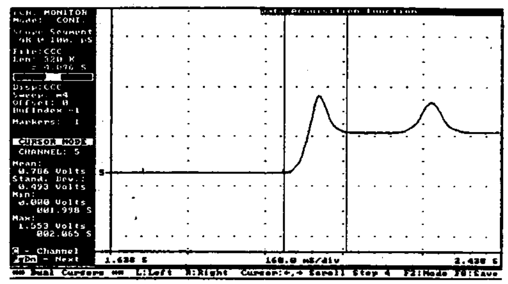


Fig.6 Experimental pipe strain time history of Case III

## 3. ANALYTICAL STUDY

Fig. 7 shows the finite element model on ABAQUS code of the 6-inch diameter pipe whip test. All the pipe specimen portion from the free end to the fixed pipe support was modelled as a pipe element. Restraint was modelled as a single truss element(C1D2) and gap element(GAPUNI) simulated the contact phenomena between a pipe and the bearing plate portion of a restraint. The lumped mass of 1.8 tons was modelled as the point mass element in order to simulate the jet thrust force through the broken pipe.

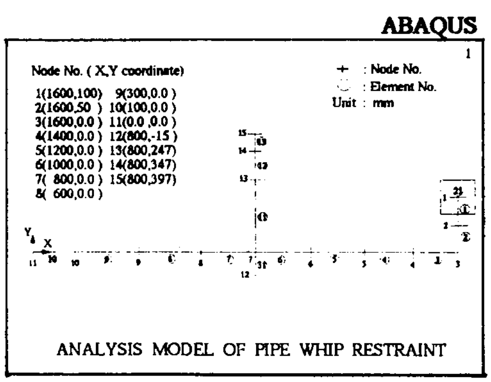



Fig.7 FEM model of pipe whip restraint system

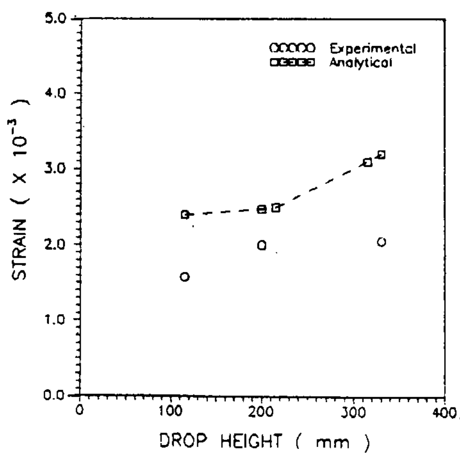


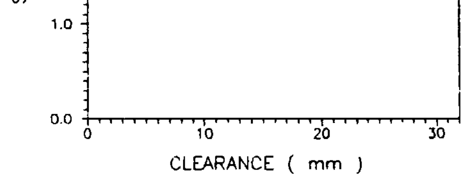

Fig.8 Maximum restraint strain with various drop height for OH=600mm

## 4. DISCUSSION ON MAXIMUM RESTRAINT STRAIN

In Fig. 8, the analytical results are compared with the experimental ones for the various drop height at the overhang length of 600mm. The calculated value is the maximum strain of the single truss element representing four solid bar restraint. The experimental value is the first peak strains which were measured at the straight portion of four U-shape bar restraint in the corresponding experiment. Both experimental results and analytical ones show that the maximum restraint strain slightly increases with increase of the drop height.

In Fig. 9, the analytical results are compared with the experimental ones for the various clearance at the overhang length of 600mm. The results show that Case IV has the minimum restraint strain. This means that the kinetic energy of the pipe specimen is absorbed by the plastic deformation of the restraints and the pipe specimen, and the restraint force is mitigated. Therefore, it is understood that the optimum plastic design method of the restraint is useful.

In Fig. 10, the analytical results are compared with the experimental ones of the restraint strains for the various overhang length at the clearance of 15 mm. The calculated maximum restraint strain is larger than the experimental result, and the both results are decreased with increase of the overhang length.



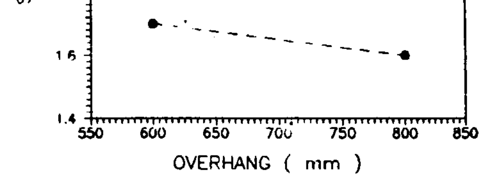




Fig.9 Maximum restraint strain with vaious clearance for OH=600mm

Fig.10 Maximum restraint strain with various overhang length for CL=15mm

The calculated results give slightly conservative values, so that the analytical method in this study could be useful in evaluating the mechanical integrity of pipe whip restraints during the pipe whip event.

## 5. CONCLUSIONS

(1) It is shown that the adequate clearance decreases the restraint strains, and that the optimum value of the clearance was verified as 15 mm for the pipe whip restraint system. This means that the restraint force is mitigated most properly when the system has the optimum value of the clearance, for most of the kinetic energy in the pipe specimen is absorbed by the plastic deformation of the restraint and the pipe specimen.

(2) As the overhang length increased, the maximum strains of restraints decreased. As the impact force increased, the maximum restraint strain increased slightly.

(3) Gap forces which act between the pipe and the restraint show the same trends of restraint strains. The dynamic load factor was found as 2.7-3.0 which is the ratio of maximum gap force and static load(carriage weight).

(4) The experimental results are in good agreement with other experiments performed by Kurihara(1987) in Japan. The discrepancy seems to be due to the difference of impact forcing functions.

(5) The analytical models of present study simulate the experimental impact phenomena very precisely, with slight conservatism. It is verified that the analytical procedure is very suitable to analyze pipe whip phenomena for the cases that have clearance in nuclear power plants.

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