ELASTIC-PLASTIC DYNAMIC BEHAVIOR OF GUARD PIPES DUE TO SUDDEN OPENING OF LONGITUDINAL CRACKS IN THE INNER PIPE AND CRASH TO THE GUARD PIPE WALL

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Integrity of guard pipes is an important parameter in the design of nuclear steam supply systems. A guard pipe shall withstand all kinds of postulated inner pipe breaks without failure. Sudden opening of a crack in the inner pipe and crash of crack borders to the guard pipe wall represent a shock problem where complex phenomena of dynamic plastification as well as dynamic behavior of the entire system have to be taken in consideration.

The problem was analyzed by means of Finite Element computation using the general purpose program MARC. Equation of motion was resolved by direct integration using the Newmark ß-operator.

Analysis shows that after 1,2 m sec crack borders touch the guard pipe wall for the first time. At this moment a considerable amount of local plastification appears in the inner pipe wall, while the guard pipe is nearly unstressed. After initial touching, the crack borders beginn to slip along the guard pipe wall. Subsequently, a short withdrawal of the crack borders and a new crash occur, while the inner pipe rolls along the guard pipe wall.

The analysis procedure described is suitable for designing numerous guard pipe geometries as well as U-Bolt restraint systems which have to withstand high-energy pipe rupture impact.

1. Introduction

Integrity of guard pipes is an important parameter in the design of nuclear steam supply systems. A guard pipe shall withstand all kinds of postulated inner pipe breaks without failure. Sudden opening of a crack in the inner pipe and crash of crack borders to the guard pipe wall represent a shock problem where complex phenomena of dynamic plastification as well as dynamic behavior of the entire system have to be taken in consideration.

A previous report by the author [1] (4th SMIRT Conference, Aug. 77 San Francisco) dealt with computation of a suddenly appearing longitudinal crack in a pressurized pipe utilizing elastic-plastic dynamic Finite Element analysis. In the present paper, main emphasis is placed on the behavior of guard pipes when inner pipe crack borders crash to the guard pipe wall, in order to demonstrate the integrity of guard pipe during and after crash event. All computations are performed using the general purpose Finite Element program MARC [2].

2. Theoretical considerations

The discretized equation of motion for a nonlinear structural dynamic problem can generally be written for time t^{n+1}:

$$Ma^{n+1} + Cv^{n+1} + I^{n+1} = F^{n+1} \qquad (1)$$

$$I = \sum \int \beta^T \sigma \, dv$$

As shown by [3] low frequency components dominate the response under quasi-static and slow varying loads, while high-frequency components control stress-wave phenomena under shock loads.
Time integration procedures of equation of motion are divided into two categories: explicit and implicit methods. In explicit methods, the equations of motion are used to find the accelerations which are then integrated to find velocities and desplacements. In implicit methods, the temporal difference equations are combined with the equation of motion and the displacements are found directly by solving these equations. A comparison of integration procedures is given in [3] and [4].
The solving procedure used here was the direct time integration Newmark ß-operator with $\gamma = 1/2$, $\beta = 1/4$.

The generalized form of the Newmark-ß-operator is

$$u^{n+1} = u^n + \Delta t v^n + (\frac{1}{2} - ß) \Delta t^2 + ß \Delta t a^{n+1} \quad (2)$$

$$v^{n+1} = v^n + (1-\gamma) \Delta t a^n + \gamma \Delta t a^{n+1} \quad (3)$$

Eq. (1) becomes:

$$(\frac{u}{\Delta t^2} M + \frac{2}{\Delta t} C + K) \Delta u = F^{n+1} - I^n + M (a^n + \frac{u}{\Delta t} v^n) + Cv^n \quad (4)$$

Eq. (4) allows implicit solution of the system $u^{n+1} = u^n + \Delta u$ and then (2) and (3) gives a^{n+1} and v^{n+1}.

3. Model details

The analysed inner pipe has an inside diameter of 682,8 mm and a thickness of 14,2 mm. The guard pipe has an inside diameter of 780,8 mm and a thickness of 16 mm. The material of both is 15 NiCuMoNb 5.

The inner pipe is hypothesized to initially be uncracked and at normal operating pressure of 87 bar. The axial load corresponding to this pressure is applied around the whole model. Initial conditions for the analysis are computed by static analysis of the uncracked pipe under operating pressure. In order to cover all possible longitudinal cracks, an infinitely long throughwall crack was assumed to suddenly appear in the pressurized inner pipe. The crack is simulated by releasing at time 0.0 msec all retained boundary conditions along the crack border. The crack borders tear up and approach the guard pipe wall with increasing velocity. The flow area through the crack increases equally. The system is therefore subjected to an increasing jet force acting on both, guard pipe and inner pipe. The dynamic behavior of the system caused by these jet forces is simulated with spring constants of 222 $N.mm^{-1}$ and 377 $N.mm^{-1}$ respectively. Node points along the outer surfaces of the medium pipe are connected to the points along the inner surface of the guard pipe by gap elements. The FE-Model is shown in Fig. 1.

Equation of motion was resolved by direct integration using the Newmark-ß-operator. First part of analysis was performed with time steps of 0.1 msec. Increasing plasticity during crack opening and crash to guard pipe wall requires a reduction of time steps to 0.025 and 0.005 msec.

4. Results

Analysis shows that after 1,2 msec, crack borders touch the guard wall for the first time. At this moment, a considerable amount of local plastification appears in the inner pipe wall while the guard pipe is nearly unstressed. After initial touching, the crack borders begin to slip along the guard pipe wall. Subsequently, a short withdrawal of the crack borders and a new crash occur, while the inner pipe rolls along the guard pipe wall.

The opening geometry at time points of T = 0.1 msec., T = 0.3 msec., T = 0.5 msec., T = 0.7 msec., T = 0.9 msec., T = 1.1 msec. and T=1.2msec. is shown in Fig. 2 ÷ 8.

Analysis shows that the main impact direction is tangential. The maximum crack opening before the impact event is 88 mm. At this time the velocity of crack border in tangential direction is 84500 $mm.sec^{-1}$. The variation of tangential velocity of crack border is:

Time msec.	Gap opening mm	Velocity in tang. direction $m \cdot sec^{-1}$
0.1	35	0
0.3	33.8	12.3
0.5	30.3	27.3
0.7	24.2	43.3
0.9	16	59.6
1.1	6	76.2
1.3	-	55.0
1.5	-	52.0
1.7	-	48.4
1.9	-	47.0
2.1	-	37.1

The maximum strain in the guard pipe wall is 4.0 %. This value is limited to the instantaneous impact location and decreases as the contact point procedes along the circumference.
The relative high local plastification of the inner pipe allows a "rolling" along the guard pipe wall. This unexpected phenomenon represents a considerable load reduction of the guard pipe.

Conclusions

The analysis procedure described is suitable for designing numerous guard pipe geometries as well as U-Bolt restraint systems which have to withstand high-energy pipe rupture impact.

References

[1] THEUER, E.,"Analysis of Leakage Areas in Pipes", Paper F6/e - 4rd. International Conference on Structural Mechanics in Reactor Technology, San Francisco 1977.

[2] MARC, General purposed Finite Element Program developed by MARC Analysis Research Corporation. Information available through Control Data Corporation, Minneapolis, Minnesota.

[3] PARK, K.C. "Evaulating Time Integration Methods for Nonlinear Dynamics Analysis" in Finite Element Analysis of Transient Nonlinear Structural Behavior" - AMD Vol. 14 1975

[4] NICKELL, R.E., "Direct Integration Methods in Structural Dynamics", Journal of the Engineering Mechanics Division, ASCE, V. 99, No. EM2 (April 1973).

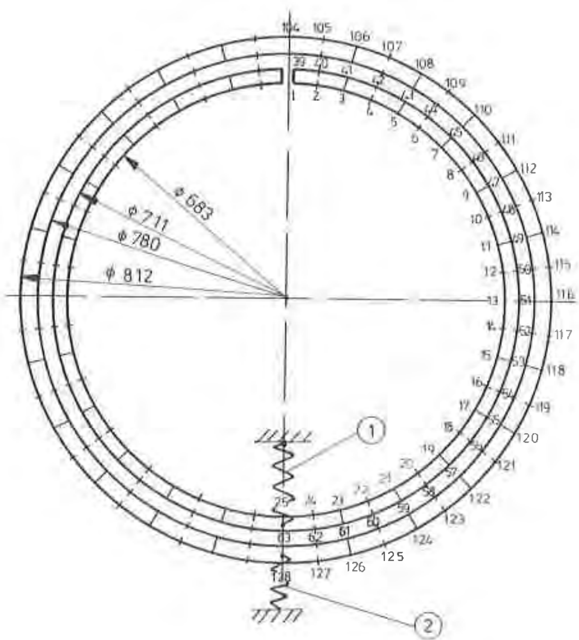

Fig 1
Finite Element Model

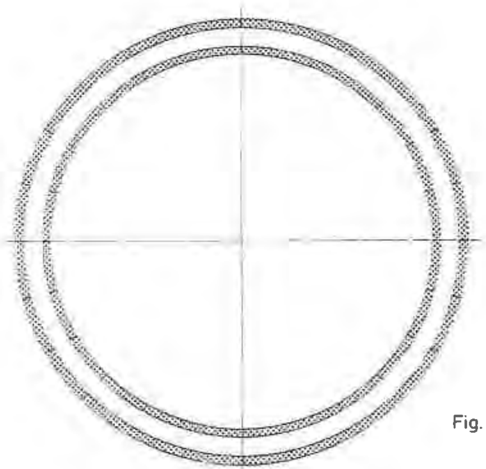

Fig. 2. Geometry at T=0,1 msec

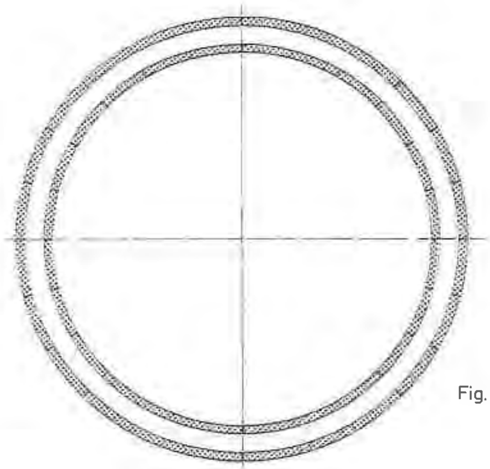

Fig. 5. Geometry at T=0,7 msec

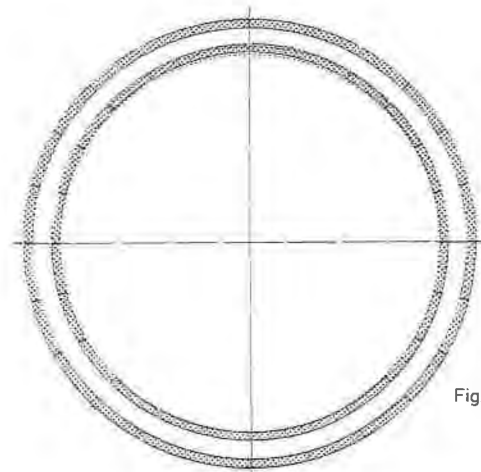

Fig. 6 Geometry at T=0,9 msec

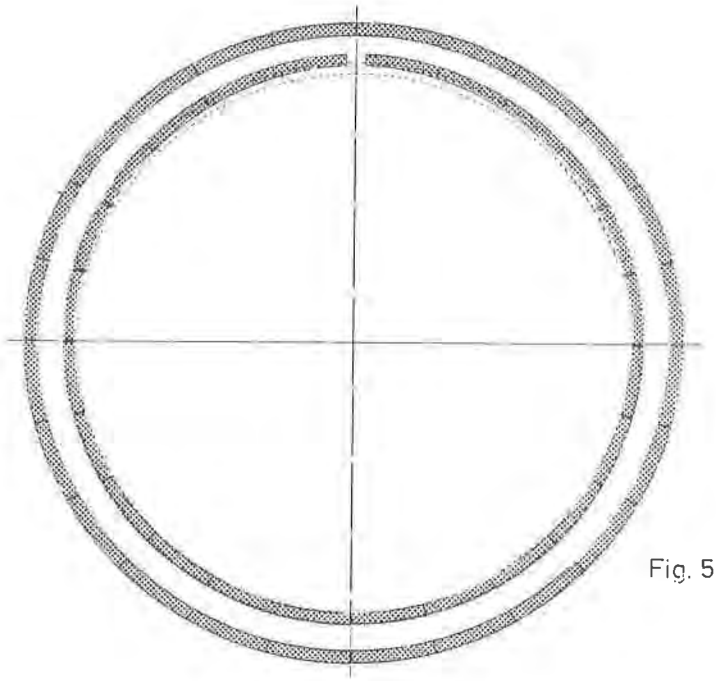

Fig. 5 Geom

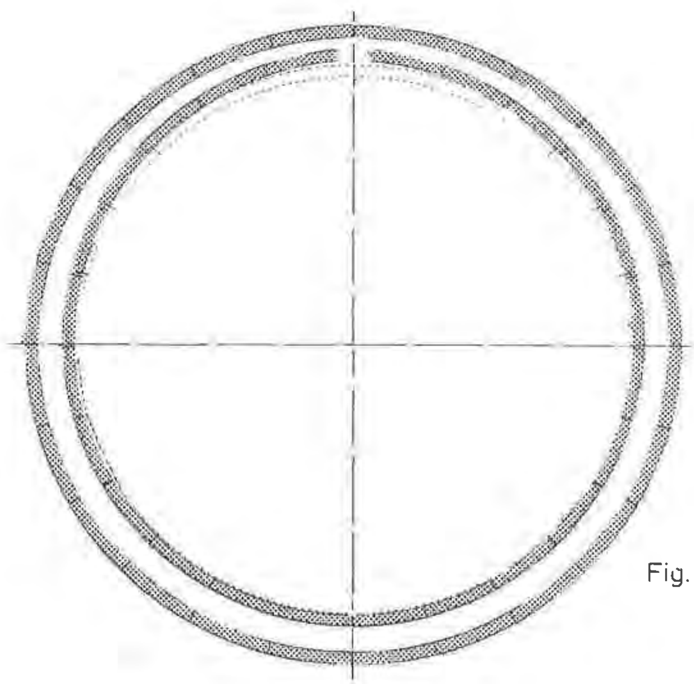

Fig. 6. Geometry at T=0,9 msec

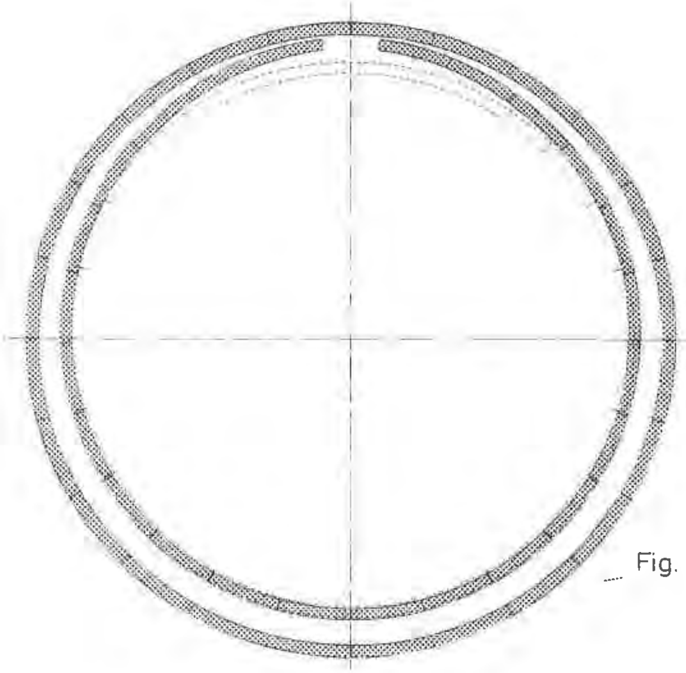

Fig. 7 Geometry at T=1,1 msec

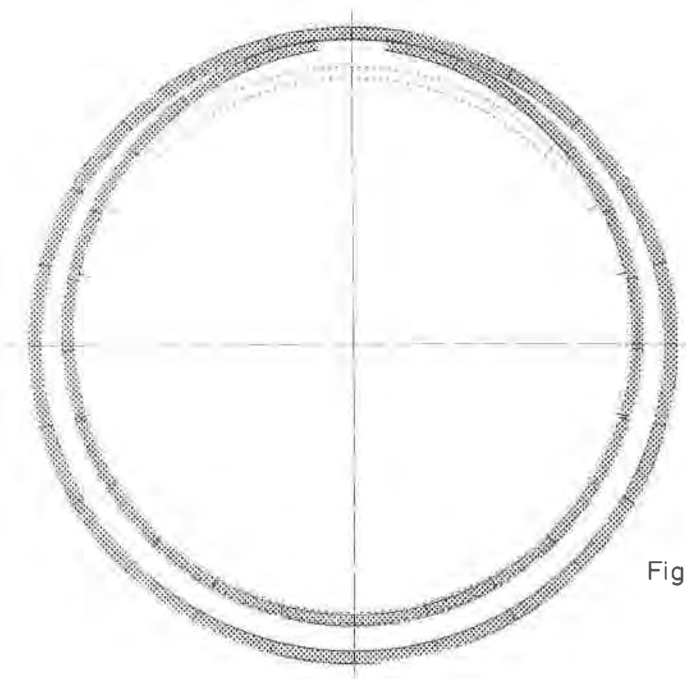

Fig. 8. Geometry at T=1,2 msec