NUREG/IA-0093

International Agreement Report

RELAP5/MOD3 Assessment for Calculation of Safety and Relief Valve Discharge Piping Hydrodynamic Loads

Prepared by
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Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
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Prepared as part of
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NOTICE

RELAP 5/MOD 3 ASSESSMENT FOR CALCULATION OF SAFETY AND RELIEF VALVE DISCHARGE PIPING HYDRODYNAMIC LOADS

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Abstract

This report presents an assessment study for the use of the code RELAP 5/MOD3/5M5 in the calculation of transient hydrodynamic loads on safety and relief discharge pipes. Its predecessor, RELAP 5/MOD1, was found adequate for this kind of calculations by EPRI. The hydrodynamic loads are very important for the discharge piping design because of the fast opening of the valves and the presence of liquid in the upstream loop seals.

The code results are compared to experimental load measurements performed at the Combustion Engineering Laboratory in Windsor (U.S.A.). Those measurements were part of the PWR Valve Test Program undertaken by EPRI after the TMI-2 accident.

This particular kind of transients challenges the applicability of the following code models

- Two-phase choked discharge
- Interphase drag in conditions with large density gradients
- Heat transfer to metalic stuctures in fast changing conditions
- Two-phase flow at abrupt expansions.

The code applicability to this kind of transients is investigated. Some sensitivity analyses to different code and model options are performed. Finally, the suitability of the code and some modeling guidelines are discussed.

EXECUTIVE SUMMARY

In 1979, following TMI, the US Nuclear Regulatory Commission (USNRC) recommended utilities operating nuclear power plants to develop a program in order to test the performance of the valves which were used in the reactor primary coolant system. The program was undertaken by EPRI as requested by those utilities.

The objectives of the EPRI Safety and Relief Valve Test Program were the following

- To test the full scale operability of a set of valves representative of those to be utilized in PWRs over the full range of fluid conditions under which they were expected to operate.
- To establish a basis to evaluate discharge piping configurations and supports.

From all the loads considered in discharge piping design, the transient hydrodynamic loads are particularly important for safety and relief valve discharge piping since the opening time of the safety valves is very fast and can induce large hydrodynamic forces on the downstream piping, especially when water solid loop seals are present. An accurate solution of the dynamic evolution of the fluid inside the piping is required in order to evaluate the hydrodynamic loads.

The safety valves were tested at the Combustion Engineering experimental facility at Windsor, U.S.A. The discharge piping at that facility consisted on 4 pipe segments. Loads were measured at the supports of those segments that were made as stiff as possible so as to reflect directly the transient fluid loads.

RELAP 5/MOD1 was selected by EPRI to verify its application to calculation of the transient hydrodynamic loads. The RELAP 5/MOD1 results were satisfactorily compared to the measured data. The structural effects were considered by processing of the RELAP 5/MOD1 predicted loads with a dynamic analysis structural model.

The goal of this report is to repeat the validation performed on RELAP 5/MOD1 over its updated and improved version RELAP 5/MOD3. The changes introduced in this latter version (mainly the addition of a 6th field equation and improvements in the empirical closure relations as compared to MOD1) could eventually modify the results of the former validation. The objectives of this validation process can be summarized as follows

- Assess RELAP 5/MOD3 for predicting safety and relief valve discharge piping hydrodynamic loads
- Propose modelization guidelines
- Highlight the impact that the different physical models in the RELAP 5 versions have on the piping load results.

From all the tests performed at the Combustion Engineering laboratory the ones involving loop seal discharges have been chosen to benchmark RELAP 5/MOD3. The reasons for that choice are the following

- liquid loop seal discharge induces the largest loads on the piping supports
- the discharge of a liquid slug through a valve and its attached pipes is a very fast two-phase process that challenges the applicability limits of the code.

Neither code changes nor result postprocessing have been performed in order to evaluate the induced loads (the code does not calculate them). The loads have been calculated with the appropriate control blocks available in RELAP 5 put together with the aid of TROPIC, the TRACTEBEL's preprocessor code for RELAP.

The conclusions that have been obtained in the assessment process for RELAP 5/MOD3 are

1. - The effect of heat transfer to the pipe heat structures need not be modeled for a correct evaluation of liquid discharge loads. This was also true for RELAP 5/MOD1 but not for RELAP 5/MOD2.

2. - RELAP 5/MOD3 underestimates the coupling between the liquid and vapour phases giving a lower liquid slug velocity than in the experiments. Although the maximum loads are quite comparable to measurements, they are delayed in time.

3. - The inclusion of a transition zone between subcooled and two phase choked flow in RELAP 5/MOD3 produces a characteristic two-bump flow that is reflected on the loads of the downstream piping.

4. - Some recommendations are to be added to the RELAP 5/MOD1 modelization guidelines. A proper orientation of pipe segments (horizontal or vertical) and a 2 velocity solution at the valve junction should be considered.

5. - RELAP 5/MOD3 can be considered acceptable to evaluate the hydraulic forces following a discharge from safety or relief valves, when above options are used and a suitable safety margin is added for design of the piping support.

1. Introduction

In 1979, following TMI, the US Nuclear Regulatory Commission (USNRC) recommended utilities operating nuclear power plants to develope a program to test the performance of the valves which were used in the reactor primary coolant system (ref. 1). The program was undertaken by EPRI as requested by those utilities.

The objectives of the EPRI PWR Safety and Relief Valve Test Program were twofold. On one hand the full scale operability of those valves was to be tested over the full range of fluid conditions under which they were expected to operate. On the other hand, a basis to evaluate discharge piping configuration and supports was to be established (ref. 2).

Several loads are considered in discharge piping design : deadweight, seismic, thermal expansion, pressure and transient hydrodynamic loading. The last one is particularly important for S/RV discharge piping since the opening time of safety valves is very fast and can induce large hydrodynamic forces on the downstream piping, especially when loop seals are present. For the calculation of these transient hydrodynamic loads EPRI selected two codes SOLA-NET (EPRI version of SOLA-LOOP code developed at LASL) and RELAP5/MOD1. The application of those codes to the calculation of hydrodynamic discharge loads was compared to experimental data (refs 3 and 4). These references showed the capacity of those codes to calculate the discharge induced loads and to provide appropriate input data to the structural analysis codes.

The purpose of this report is to assess the potential of RELAP 5/MOD3/5M5 (ref. 5) for evaluating discharge piping hydrodynamic loads. First, the main objectives of this study are presented followed by a brief description of the EPRI/Combustion-Engineering (CE) experimental facility at Windsor. The RELAP 5 model for the experiment is described next, as well as the method to compute induced loads. The results of the study are shown as well as a sensitivity analysis on the most relevant parameters. Finally the conclusions and guidelines for the code options are summarized.

2. Objectives

As RELAP 5/MOD3 can be considered as an updated version of MOD1, it is of interest to demonstrate its applicability to the transients that the first version was validated for. It is of particular interest to illustrate the impact of the addition of a 6th field equation and improvements in the empirical closure equations on the calculated hydrodynamic loads and to gauge the sentivity of the valve opening time and the loop seal temperature on the induced forces on the downstream piping. The objectives of this report can be summarized as follows

1- Assess the potential of RELAP-5/MOD-3 to predict safety and relief valve discharge piping hydrodynamic loads

2- Propose modelization guidelines for this kind of transients and analysis

3- Highlight the impact that the different physical models in the RELAP 5 versions have on the piping load results.

The results of this assessment process for RELAP5/MOD3 will be presented in next paragraphs. It must be pointed out that no structural analysis results are given in this report. The EPRI/CE test rig was originally designed as stiff as possible to allow for a direct comparison between load measurements and the loads computed with RELAP 5. The hydraulic snubber supports originally installed were replaced by solid links to achieve that purpose. However, load oscillations were measured on the supports resulting from an incomplete rigidity of the structures. This dynamic load response can be obtained by a structural analysis code with fluid conditions supplied by RELAP 5. The maximum load values that are given by the structural codes are also different from the thermal hydraulic code results. From this point of view the results that are presented in this report should be considered as partially valid, provided no structural analysis is done.

3. Basic data : EPRI / CE test facility description

The selected safety valves (Crosby, Dresser and Target Rock), representative of the valves used in most of the plants, were tested at the Combustion-Engineering's Kreising Development Laboratory in Windsor, Connecticut (U.S.A.). The major components of the system are shown in Fig. 3.1. Tank 2 was fed by steam from the boiler of the Laboratory and served as the driver vessel by expansion or evaporation of the fluid inside it. The smaller accumulator (tank 1) served as a surge vessel and played the role of the PWR pressurizer. Fig. 3.1. shows two inlets configurations to the valve : short vertical inlet and long loop seal configuration. Simulations in this report are done on the latter (i.e., loop seal). Outlet piping was divided in four segments (Table 3.1.) : horizontal, vertical downwards with an area increase at its middle part, long horizontal and short vertical upwards discharging into the atmosphere (Fig. 3.2). Load data are measured for each of these segments provided the pipe supports were made as stiff as possible so as to reflect directly the transient fluid loads. To achieve this goal ("limit the peak dynamic response amplification to 1.1. of the hydraulic forcing fonction peak value", ref. 2, Vol. 2) extremely rigid supports were designed. The snubbers that originally supported the discharge piping were replaced by solid links. The pipe oscillation in its perpendicular direction was restricted by springs. The pipe deadweight was supported by spring hangers. All those springs were conveniently adjusted in the hot experiment conditions. Fluid temperature and pressure were measured at the inlet and downstream the valve. Flow rate was measured by a venturi nozzle at the outlet of tank 1. Different test valve parameters were measured, including the valve stem position. A summary of the main characteristics of the instruments is presented in Table 3.2. A detailed and complete description of the EPRI/CE test facility can be found in volume 2 of ref. 2.

Discharge of fluid through the test valves was made at different upstream conditions from pure steam to subcooled liquid, as well as hot and cold water loop seal followed by steam discharge. Transients in this report refer to all the water loop seal discharge cases available : two cases for the Crosby valve (tests 917 and 908) and one case for the Dresser valve (test 1017). These tests have been chosen because they are representative of the normal plant conditions and because they give place to the largest loads. A brief description of these tests follows.

Test number 917 consisted on a hot water loop seal discharge through a Crosby valve. The slug temperature ranged from 150°C up to 350°C, the saturation temperature at Tank 1 pressure. The mass of the liquid contained in the loop seal was approximately of 9 kg. Test number 908 was repeated on the same configuration of test 917, but an orifice plate was installed at the end of the discharge pipe. The conditions of the slug were different to test a cold water loop seal discharge temperature from 40°C up to 350°C). Test number 1017, over the Dresser valve, had a configuration similar to test 917 (slight changes due to minor differences in valve dimensions) and slug temperature identical to the one of test 908 (cold water loop seal discharge).

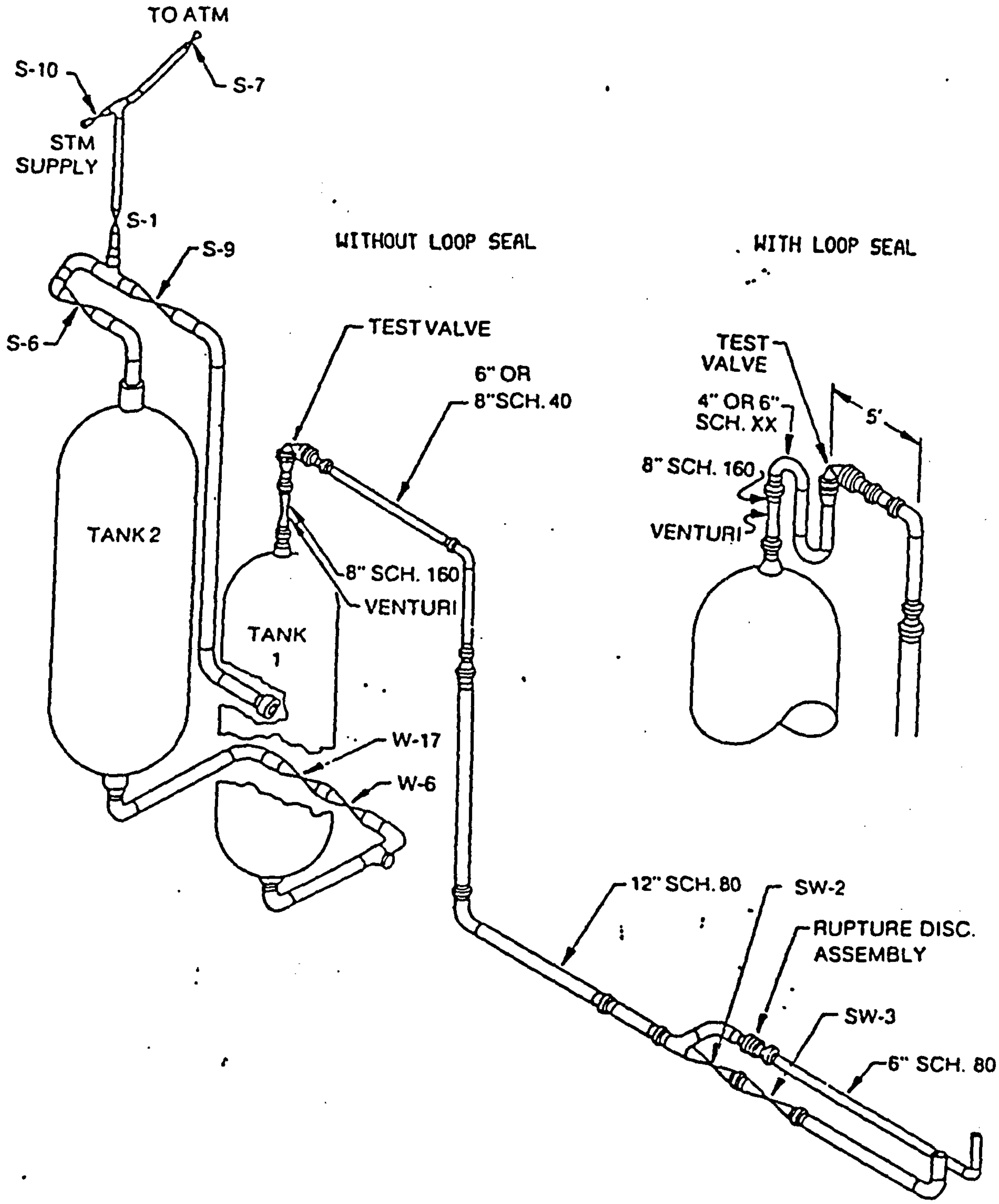


Figure 3.1. EPRI/CE Test Loop Schematic

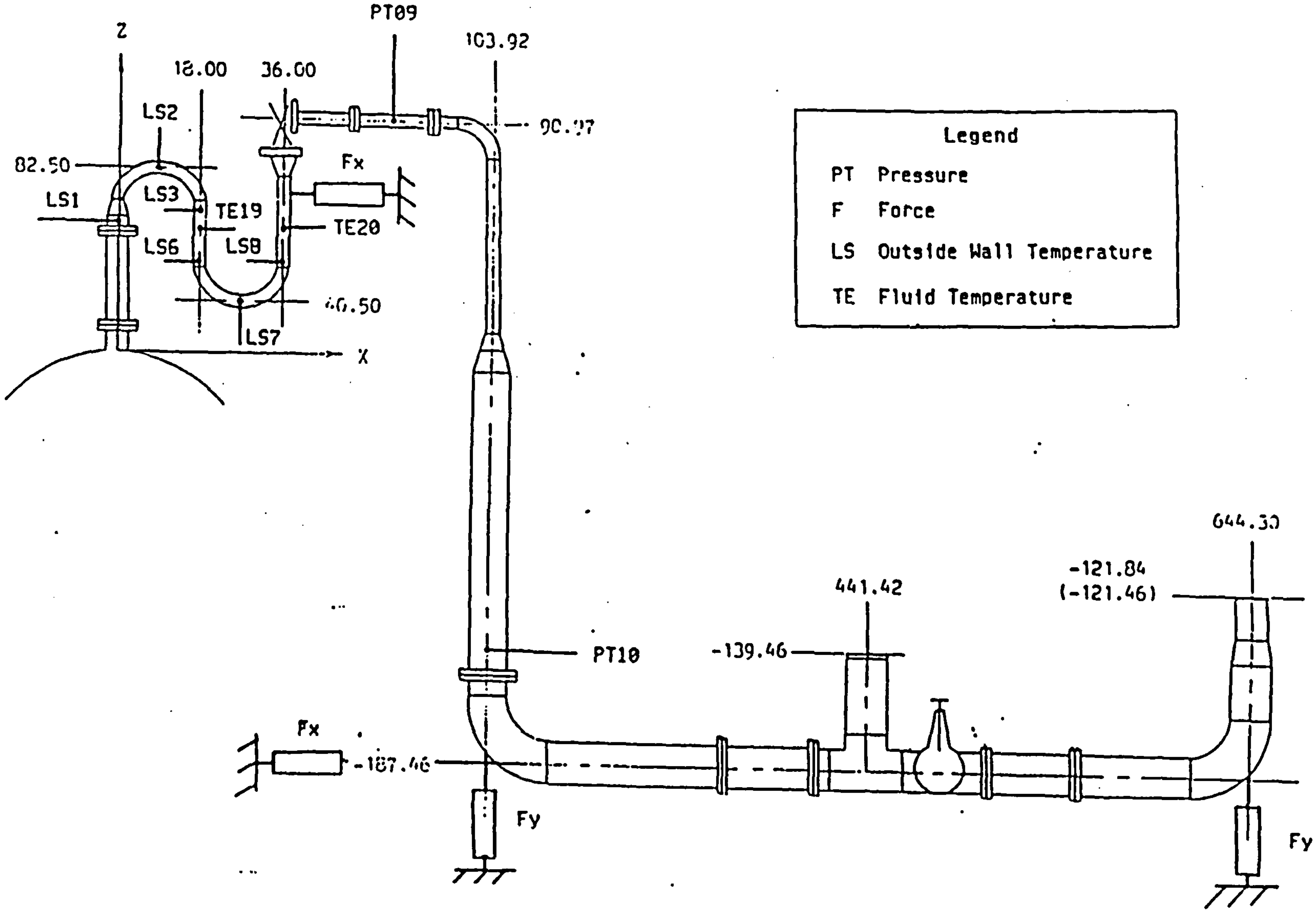


Figure 3.2. Dimensions and measurement locations for the Crosby valve tests

TABLE 3.1. : DISCHARGE PIPING GEOMETRIC PARAMETERS

SEGMENT	SCHEDULE	AREA (m2)	LENGHT (m)	INCLINATION
1	6"SCH 40	0.0186364	1.6764	HORIZONTAL
2	6" SCH 40	0.0186364	1.8288	VERTICAL DOWN
2	12" SCH 80	0.0655710	4.572	VERTICAL DOWN
3	12" SCH 80	0.0655710	13.228	HORIZONTAL
4	12"SCH 80	0.0655710	0.4572	VERTICAL UP

TABLE 3.2. : SUMMARY OF INSTRUMENT CHARACTERISTICS

PARAMETER	TYPE TRANSDUCER	SYSTEM ACCURACY (% full scale)	FREQUENCY RESPONSE	SCALE RANGE
FORCE	Strain Gage Load Cells	± 0.5	400	± 445 kN
PRESSURE	Strain Gage Diaphragm	± 0.27	>1000	0-3500 psia
TEMPERATURE	k Thermocouples or Platinum RTD	± 2.2°C	10 or lower	0-430°C
POSITION	Linear Variable Differential Transformers (LVDT)	± 0.25	250	-

4. Relap 5 simulation of the EPRI/CE experiments

Modeling guidelines developed for RELAP 5/MOD1 application to calculation of hydrodynamic loads were assumed as a starting point. Those guidelines can be taken as more or less generic for any finite difference code applied to this kind of computation and can be summarized as follows

- control volumes should have a length between 0.5 and 1.0 feet (0.15 to 0.30 m) to prevent numerical diffusion .
- time step must be limited externally since RELAP 5 overrides material Courant limit in some volumes
- no-choking option should be selected downstream the valve
- heat transfer to the pipe walls must be considered for properly determination of loads
- cold water (< 100°C) loop seal cases, should be initialized with the loop seal water distributed isenthalpycally in the first control volumes downstream of the valve (due to valve leakage prior to fast opening).

Figure 4.1. shows the nodalization diagram of the experimental facility for RELAP 5/MOD3. The model has been built with TROPIC, the TRACTEBEL'S RELAP Object-Oriented Preprocessing Interactive Code (ref. 6). Tank 1 was represented by a "time dependent volume" for simulating upstream fluid conditions as a function of time. The safety valve was modeled by a "servo valve" component with a linear area opening characteristic. Piping network downstream the valve was modeled using "pipe" components for straight lenghts of pipe and "single volumes" components for elbows. Dimensions and code options correspond to the RELAP 5/MOD1 model (ref. 4). Tables 4.1. and 4.2. present the geometric data and component options for the upstream and downstream piping parts respectively. Table 4.3. shows the heat structure data.

Two minor changes had to be done to the original RELAP 5/MOD1 model to avoid program errors. Valve discharge junction originally taken as homogeneous (one velocity) had to be turned into nonhomogeneous solution. Time dependent volume representing the atmosphere was changed into a single volume modelization to avoid an error related to heat transfer coefficient evaluation.

Code changes described in ref. 4 have not been included in RELAP 5/MOD3. Loads are calculated making use of the control systems available within RELAP. The method for load determination and its implementation are described in the next paragraph.

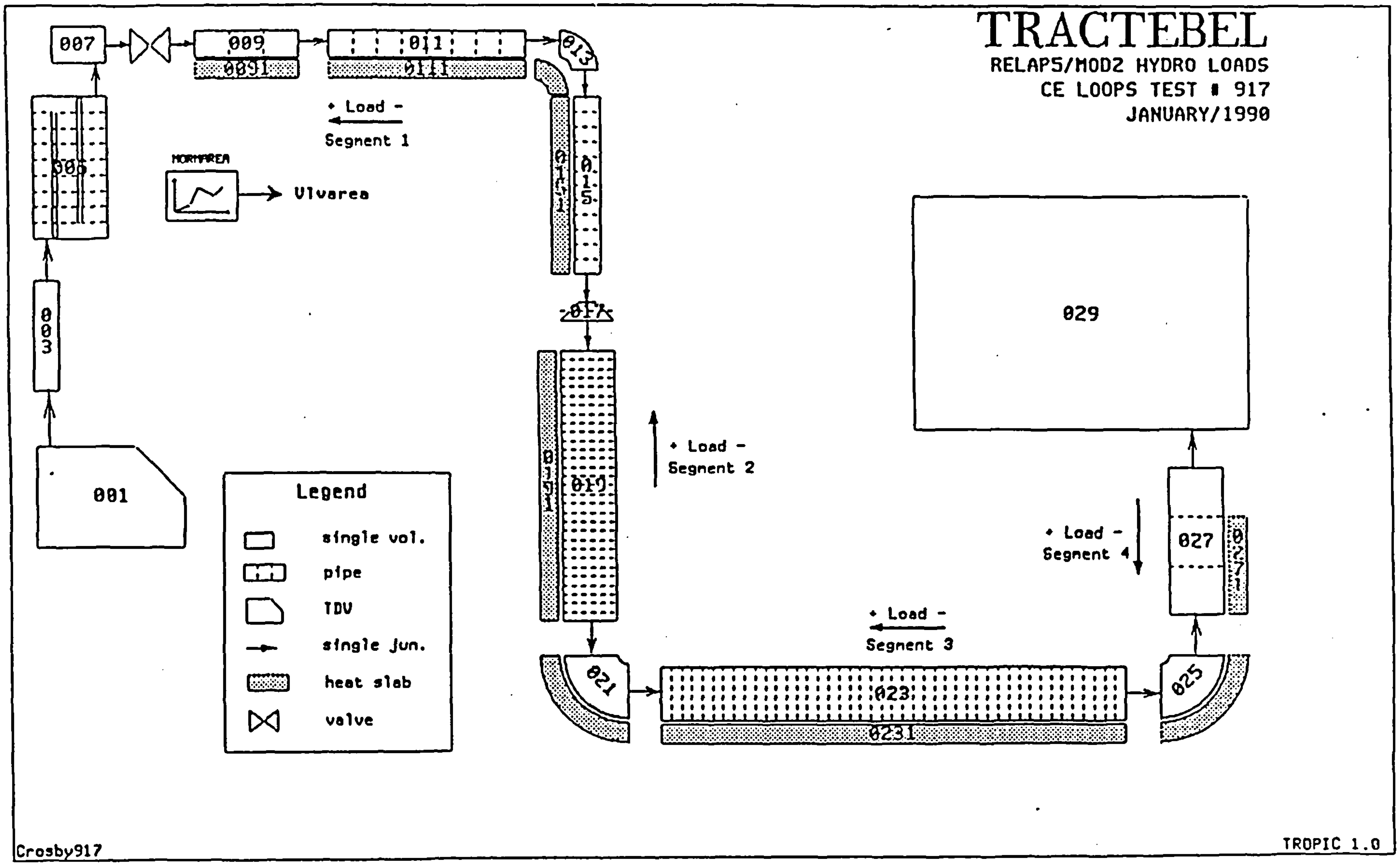


Figure 4.1. TROPIC representation of RELAP nodalization

Table 4.1.

UPSTREAM PIPING GEOMETRIC DATA (CROSBY TESTS)

Component Number	Volume or Junction Number	Component Type	Lenght (ft/m)	Area (ft^2/m^2)	Forward Loss Coefficient	Reverse Loss Coefficient	Junction Flags or Volume Flags	Comments
001	V 1	TMDPVOL	20.0/6.096	25.0/2.3226	--	--	11	Accumulator
002	J 1	SNGLJUN	--	0.2532/0.0235231	0.04	1.0	00000	Nozzle
003	V 1	SNGLVOL	5.0/1.524	0.2532/0.0235231	--	--	01	Venturi
004	J 1	SNGLJUN	--	0.1308/0.0121517	0.0	0.0	00100	Reducer 8-in. x 6-in.,
005	V 1-9	PIPE	1.0/0.3048	0.1308/0.0121517	--	--	00	Loop seal piping
	J 1		--	0.1308/0.0121517	0.0	0.0	00000	
	2		--	0.1308/0.0121517	0.195	0.195	00000	
	3		--	0.1308/0.0121517	0.0	0.0	00000	
	4		--	0.1308/0.0121517	0.195	0.195	00000	
	5		--	0.1308/0.0121517	0.0	0.0	00000	
	6		--	0.1308/0.0121517	0.195	0.195	00000	
	7		--	0.1308/0.0121517	0.0	0.0	00000	
	8		--	0.1308/0.0121517	0.0195	0.195	00000	
006	J 1	SNGLJUN	--	0.0204/0.0018952	0.0	0.0	00100	Valve in
007	V 1	SNGLVOL	1.0/0.3048	0.0204/0.0018952	--	--	10	Valve

Table 4.2.

DOWNSTREAM PIPING GEOMETRIC DATA (CROSBY TESTS)

Component Number	Volume or Junction Number	Component Type	Lenght (ft/m)	Area (ft^2/m^2)	Forward Loss Coefficient	Reverse Loss Coefficient	Junction Flags or Volume Flags	Comments
008	J1	VALVE	-	0.0204/0.00189522	0.0	0.0	00100	Servo-valve
009	V-1-3	PIPE	0.50/0.1524	0.2006/0.0186364	-	-	10	Valve Discharge
	J 1-2			0.2006/0.0186364	0.0	0.0		
010	J1	SNGLJUN	-	0.2006/0.0186364	0.0	0.0	01000	
011	V 1-8	PIPE	0.50/0.1524	0.2006/0.0186364	-	-	01000	
	J 1-7		-	0.2006/0.0186364	0.0	0.0	00	
							01000	
012	J1	SNGLJUN	-	0.2006/0.0186364	0.210	0.210	01000	Elbow 1 in
013	V 1	SNGLVOL	0.50/00.1524	0.2006/0.0186364	-	-	00	Elbow 1 volume
014	J1	SNGLJUN	-	0.2006/0.0186364	0.0	0.0	01000	Elbow 1 out
015	V 1-12	PIPE	0.50/0.1524	0.2006/0.0186364	-	-	00	
	J 1-11		-	0.2006/0.0186364	0.0	0.0	01000	
016	J1	SNGLJUN	-	0.2006/0.0186364	0.0	0.0	01000	Expansion in
017	V 1	PIPE	0.50/0.1524	0.2006/0.0186364	-	-	00	
	V 2		0.50/0.1524	0.7058/0.0655710	-	-		
	J1		-	0.2006/0.0186364	0.51235	0.51235	01000	
018	J1	SNGLJUN	-	0.7058/0.0655710	0.0	0,0	01000	Expansion out

Table 4.2. (Cont'd)

DOWNSTREAM PIPING GEOMETRIC DATA (CROSBY TESTS)

Component Number	Volume or Junction Number	Component Type	Lenght (ft/m)	Area (ft^2/m^2)	Forward Loss Coefficient	Reverse Loss Coefficient	Junction Flags or Volume Flags	Comments
019	V 1-30	PIPE	0.50/0.1524	0.7058/0.065571	-	-	00	
	J 1-29		-	0.7058/0.065571	0.0	0.0	01000	
020	J1	SNGLJUN	-	0.7058/0.065571	0.182	0.182	01000	Elbow 2 in
021	V 1	SNGLVOL	0.70/0.21336	0.7058/0.065571	0.0	0.0	00	Elbow 2 volume
022	J1	SNGLJUN	-	0.7058/0.065571	-	-	01000	Elbow 2 out
023	V 1	PIPE	0.70/0.21336	0.7058/0.065571	-	-	00	
	V 2		1.00/0.3048	0.7058/0.065571	-	-	00	
	V 3-42		1.00/0.3048	0.7058/0.065571	-	-	00	
	V-43		1.00/0.3048	0.7058/0.065571	-	-	00	
	V 44		0.70/0.21336	0.7058/0.065571	-	-	00	
	J 1-25		-	0.7058/0.065571	0.0	0.0	01000	
	J 26-28		-	0.7058/0.065571	0.3192	0.3192	01000	Valve SW-2
	J 29-43		-	0.7058/0.065571	0.0	0.0	01000	
024	J1	SNGLJUN	-	0.7058/0.065571	0.182	0.182	01000	Elbow 3 in
025	V 1	SNGLVOL	0.70/0.21336	0.7058/0.065571	-	-	00	Elbow 3 volume
026	J1	SNGLJUN	-	0.7058/0.065571	0.0	0.0	01000	Elbow 3 out

Table 4.2. (Cont'd)

DOWNSTREAM PIPING GEOMETRIC DATA (CROSBY TESTS)

Component Number	Volume or Junction Number	Component Type	Lenght (ft/m)	Area (ft^2/m^2)	Forward Loss Coefficient	Reverse Loss Coefficient	Junction Flags or Volume Flags	Comments
027	V 1-2	PIPE	0.50/0.1524	0.7058/0.065571	-	-	00	
	V 3		0.50/0.1524	0.5592/0.0519514	-	-	00	
	J 1-2		-	0.7058/0.065571	0.0	0.0	01000	
028	J 1	SNGLJUN	-	0.5592/0.0519514	0.0	0.0	01100	
029	V 1	SNGLVOL	10000.0	10000.0	-	-	11	Atmosphere

Table 4.3.

DOWNSTREAM PIPING HEAT STRUCTURE (CROSBY TESTS)

Description	Geometry	Mesh	Material	Left Boundary (ft/m)	Right Boundary (ft/m)	Heat Structure Number	Left Boundary Volume	Right Boundary Volume	Volume Lenght (ft/m)
009 Valve outlet flange	CYL	1-10	Carbon steel	0.2527/0.077023	0.2760/0.084125	0091	0901-03	2901	0.50/0.1524
011 Pipe 1 Horizontal	CYL	1-10	Carbon steel	0.2527/0.077023	0.2760/0.084125	0111	1101-08	2901	0.50/0.1524
013 Elbow 1	CYL	1-10	Carbon steel	0.2527/0.077023	0.2760/0.084125	0131	1301	2901	0.50/0.1524
015 Pipe 2 Vertical	CYL	1-10	Carbon steel	0.2527/0.077023	0.2760/0.084125	0151	1501-12	2901	0.50/0.1524
017 Expansion	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
019 Pipe 3	CYL	1-10	Carbon steel	0.4740/0.144475	0.53129/0.161937	0191	1901-30	2901	0.50/0.1524
021 Elbow 2	CYL	1-10	Carbon steel	0.4740/0.144475	0.53129/0.161937	0211	2101	2901	0.70/0.21336

Table 4.3. (Cont'd)

DOWNSTREAM PIPING HEAT STRUCTURE (CROSBY TESTS)

Description	Geometry	Mesh	Material	Left Boundary (ft/m)	Right Boundary (ft/m)	Heat Structure Number	Left Boundary Volume	Right Boundary Volume	Volume Lenght (ft/m)
023									
Pipe 3 Horizontal	CYL	1-10	Carbon steel	0.4740/0.144475	0.53129/0.161937	0231	2301	2901	0.70/0.21336
							2302	2901	1.00/0.3048
							2303-42	2901	1.00/0.3048
							2343	2901	1.00/0.3048
							2344	2901	0.70/0.21336
025									
Elbow 3	CYL	1-10	Carbon steel	04740/0.144475	0.53129/0.161937	0251	2501-01	2901	0.70/0.21336
027									
Pipe 4 Vertical	CYL	1-10	Carbon steel	04740/0.144475	0.53129/0.161937	0271	2701-02	2901	0.50/0.1524

5. Mechanical loads determination

Two methods are commonly used for evaluating the mechanical loads on a piping system : force balance and momentum balance (ref. 7). The force balance method equates the resultant force transmitted from the fluid to the structure as the sum of the pressure and frictional forces acting on the wetted surface of the pipe. The momentum balance method equates the force on the element to the time rate of change of fluid momentum within the pipe. The former has the difficulty of calculating fluid friction forces on the wetted surface. The latter has the potential risk of numeric instabilities coming from the time derivative nature of the method. This latter method has been used in this analysis and no instabilities have been found.

Two kind of terms appear in the momentum balance method (ref. 8) : the wave or acceleration force.

$$F_w = -\int_{c_v} \frac{\partial}{\partial t}(\rho v)\,dV \qquad (5.1)$$

(where ρ and v stand for the density and velocity of the fluid in the pipe respectively and the volumetric integral extends to the fluid control volume c_v in the pipe).

And the blowdown force that appears only for open ended pipe segments.

$$F_B = \pm A\,(P + \rho v^2) \qquad (5.2)$$

(where A is the area, P, ρ and v are the relative pressure, density and velocity of the fluid at the open end respectively ; the positive sign is applied to inlets and the negative one to outlets). The numerical discretisation of the wave force (eq. 5.1) yields for segment K,

$$F_{wk} = -\Sigma_i \frac{\partial}{\partial t}\left[V_i(\alpha_{gi}\rho_{gi}v_{gi} + \alpha_{fi}\rho_{fi}v_{fi})\right] \qquad (5.3)$$

where the sumation extends to all the nodes i of a bounded segment K of the pipe. The phasic void fraction, density and velocity are represented by α, ρ and v respectively. The subindexes g and f refer to the gaseous and liquid phases. V stands for the node volume. Figure 5.1. shows the implementation of that expression for a part of segment 2 with the aid of the TROPIC preprocessor. The Vi factor in expression 5.3 is included as a multiplier in the adder control block. For the last segment in the test facility, which is an open-ended segment, the total force is the sum of the wave force (eq. 5.1) and the blowdown force (eq. 5.2) which can be computed as follows

$$F_B = -A_o\left(P_o + \alpha_{go}\rho_{go}v_{go}^2 + \alpha_{fo}\rho_{fo}v_{fo}^2\right) \qquad (5.4)$$

where the subindex o refers to the conditions at the discharge junction.

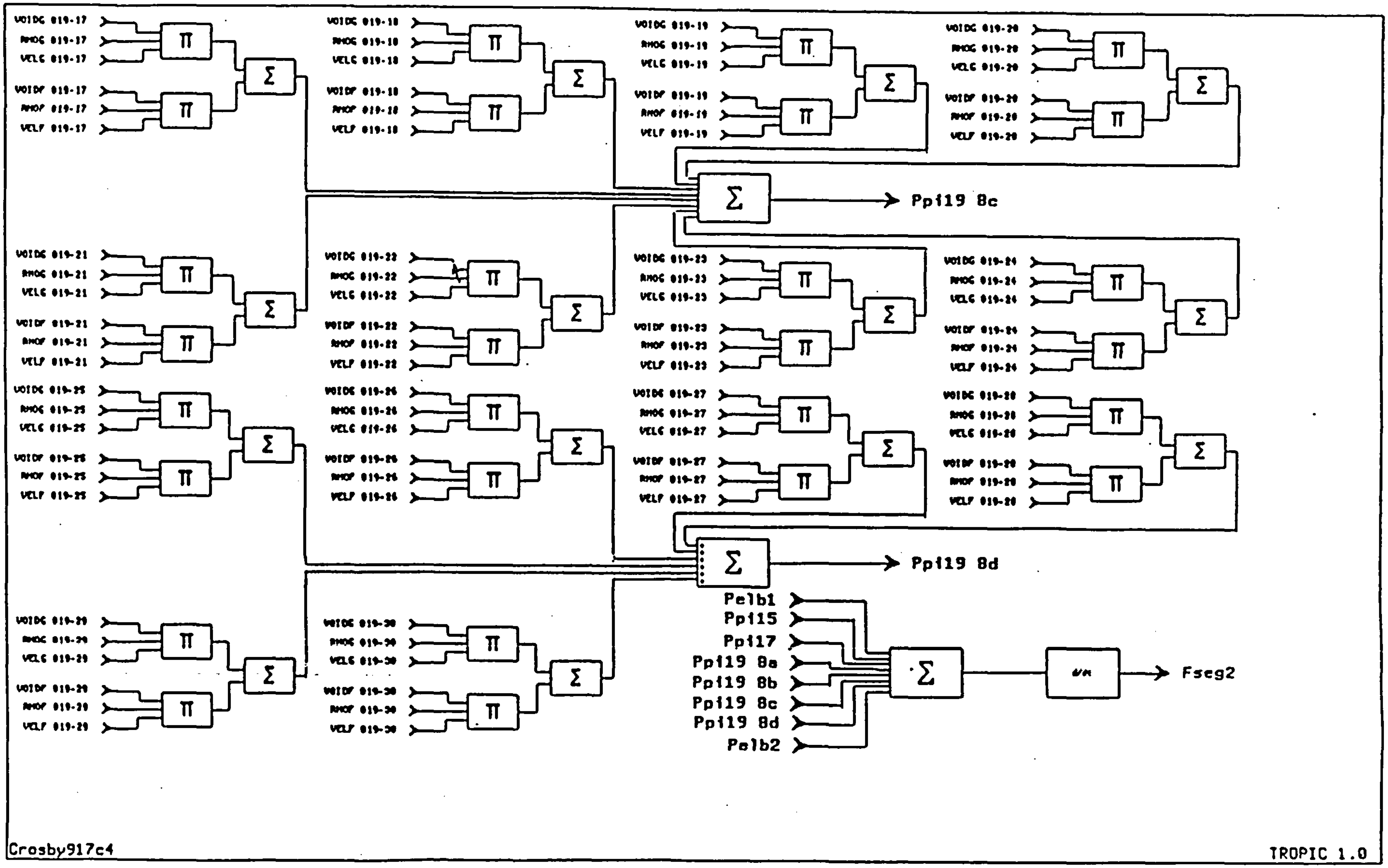


Figure 5.1. TROPIC modelization of segment loads

6. Analysis and results

The RELAP 5/MOD3 code version has been received at TRACTEBEL recently. As it is going to be the future tool for thermal hydraulic analysis, an assessment has been conducted to prove the convenience of its application to the evaluation of discharge piping hydrodynamic loads. Different code options had been tested on this version to check the range of the modifications and new models introduced in the MOD3 version. EPRI/CE test number 917 is used for this assessment process.

6.1. Test 917 (Crosby hot water loop seal discharge)

Table 6.1. summarizes the different options that have been tested on RELAP 5/MOD3. Table 6.2. compares the characteristic values of the loads on the segments and pressures to test measurements and MOD1. Figures 6.1. to 6.6. present the time evolution of those variables for some significative cases compared to experimental data. The results are commented in next paragraph.

6.1.1. Results with the original MOD1 model (CASE 0)

Load peak values are close to the test measurements and RELAP 5/MOD1 results (Table 6.2.). However, it can be observed from Figs 6.3. to 6.6. that RELAP 5/MOD3 loads are clearly delayed with respect to the experiment, just the opposite of MOD1 results, reflecting a lower slug velocity in MOD3 transient discharge evolution.

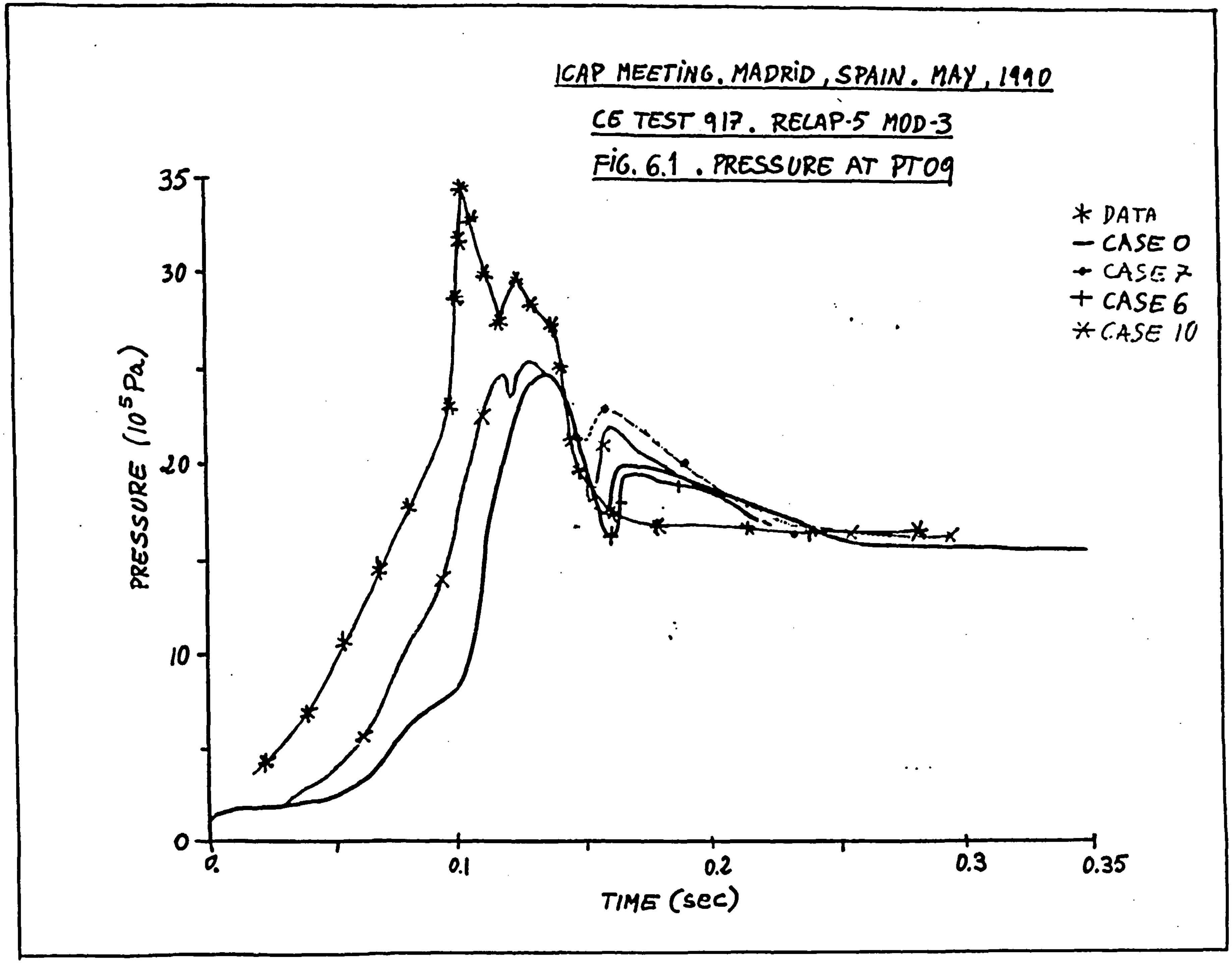
This is the consequence of a low coupling between phases (low interphase drag coefficients , Fig. 6.7.) given by the last version of RELAP 5. On the contrary MOD1 exhibited a high coupling between liquid and steam that is translated into a higher slug velocity and hence an anticipation in the loads as compared to the experiment.

6.1.2. Results with bundle interphase friction (CASES 1 and 8)

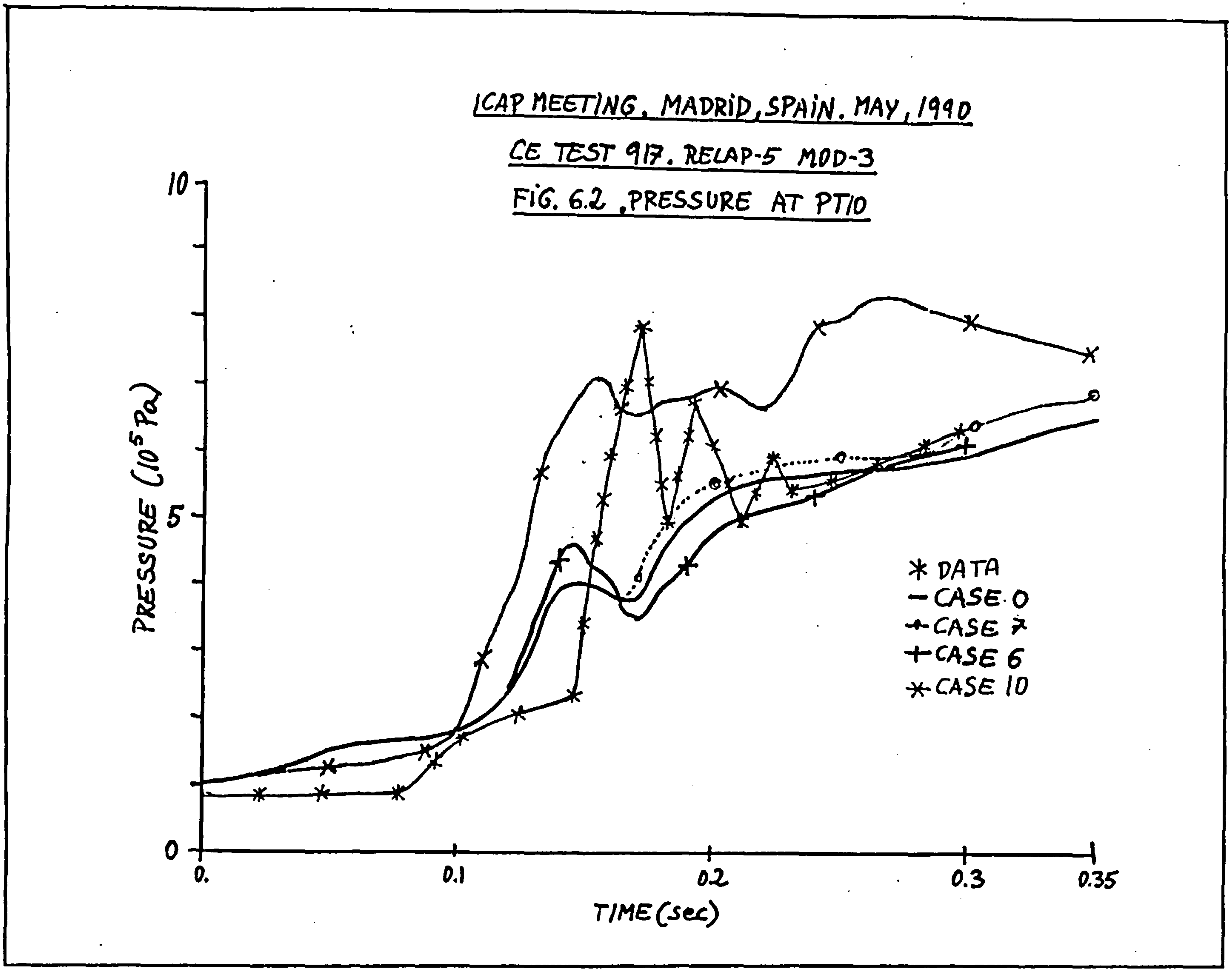
The liquid loop seal discharge is extremely dependent on the interfacial friction between phases. RELAP 5/ MOD3 allows for the possibility of choosing an alternative interphase friction correlation that is applicable to bundle geometries. In order to test the effect of this new correlation on the loads, two trials have been done : case 1 and case 8 (Tables 6.1. and 6.2.). Case 1 was equivalent to base case 0 (piping is arranged horizontally) and case 8 was similar to case 4 (segment 2 is considered vertical) but both cases used the bundle interphase drag option. Comparison of case 1 to case 0 results and case 8 versus case 4 shows no effect neither on the loads nor on the pressure. The Bestion's interfacial friction correlation for rod bundles is only applied in bubbly /slug flow regime. Such regimes are not developed in the discharge of a liquid loop seal and the results must be unsensitive to this option.

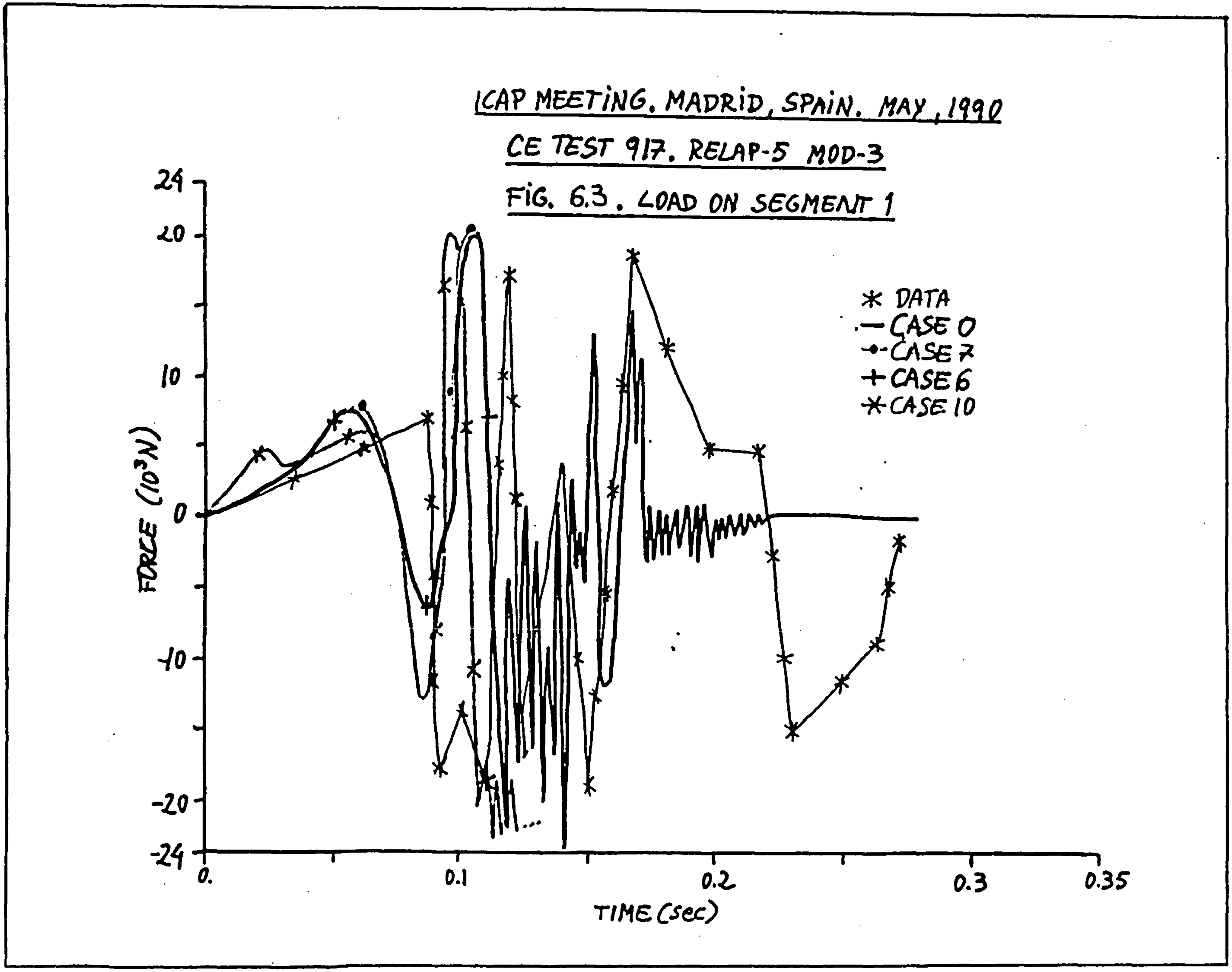
6.1.3. Sensitivity to the horizontal stratification option at junctions (CASE 2)

Most of the flow regime during the loop seal discharge is annular-mist. Horizontal stratification is initially present since an air-steam-liquid mixture is assumed filling the pipe. Junction options were changed in this case (case 2 in Tables 6.1 and 6.2) to account for a possible horizontal stratification downstream the valve. The results show a negligible or null effect on the loads or pressure values. The very small amount of liquid that is initially stratified and the fast development into annular-mist regime are the reasons for that minor effect.



ICAP MEETING, MADRID, SPAIN. MAY, 1990
CE TEST 917. RELAP-5 MOD-3
FIG. 6.1 . PRESSURE AT PT09
PRESSURE (10^5 Pa)
TIME (sec)
35
30
20
10
0
0.
0.1
0.2
0.3
0.35
* DATA
— CASE 0
• CASE 7
+ CASE 6
* CASE 10

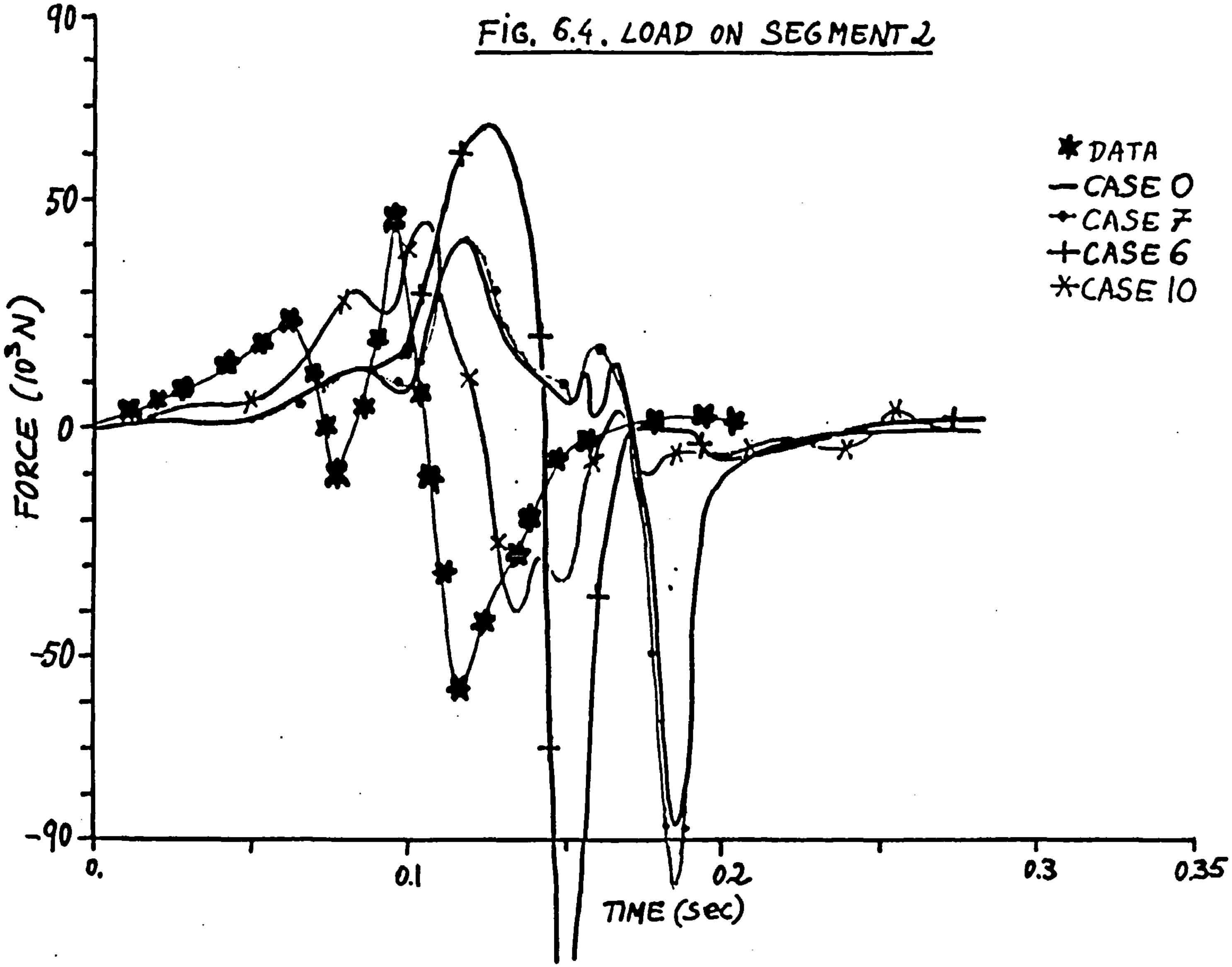

ICAP MEETING, MADRID, SPAIN, MAY, 1990
CE TEST 917, RELAP-5 MOD-3
FIG. 6.2, PRESSURE AT PT10
PRESSURE (10^5 Pa)
10
5
0
0.
0.1
0.2
0.3
0.35
TIME (sec)
* DATA
— CASE 0
+ CASE 7
+ CASE 6
* CASE 10

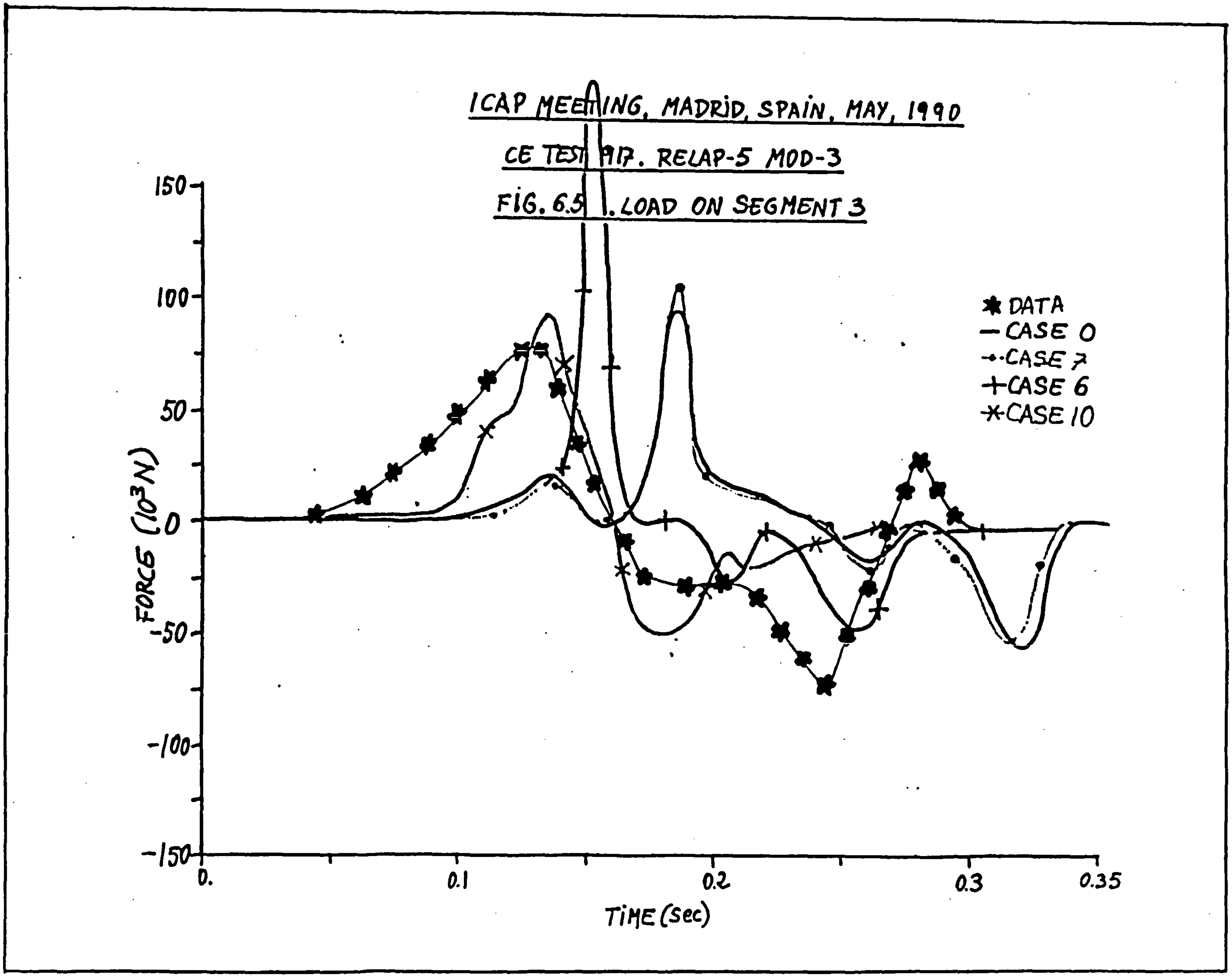

ICAP MEETING, MADRID, SPAIN, MAY, 1990
CE TEST 917, RELAP-5 MOD-3
FIG. 6.3. LOAD ON SEGMENT 1
FORCE (10³N)
24
20
10
0
-10
-20
-24
0.
0.1
0.2
0.3
0.35
TIME (sec)
* DATA
— CASE 0
-•- CASE 7
+ CASE 6
* CASE 10

ICAP MEETING. MADRID, SPAIN. MAY, 1990

CE TEST 917. RELAP-5 MOD-3

FIG. 6.4. LOAD ON SEGMENT 2

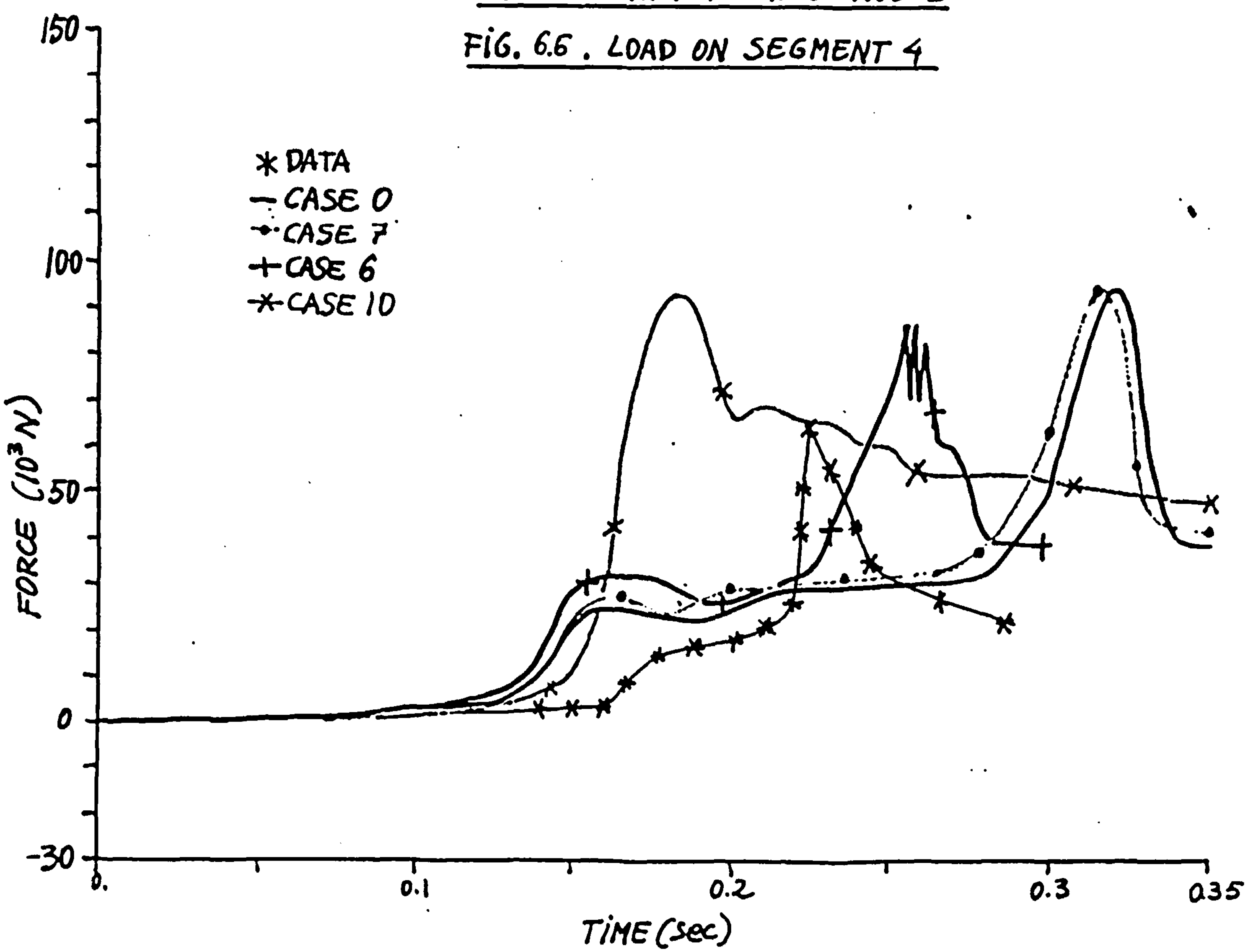



ICAP MEETING, MADRID, SPAIN, MAY, 1990
CE TEST 917. RELAP-5 MOD-3
FIG. 6.5 . LOAD ON SEGMENT 3
150
100
50
0
-50
-100
-150
FORCE (10³N)
0.
0.1
0.2
0.3
0.35
TIME (sec)
DATA
CASE 0
CASE 7
CASE 6
CASE 10

ICAP MEETING. MADRID, SPAIN. MAY, 1990

CE TEST 917. RELAP-5 MOD-3

FIG. 6.6. LOAD ON SEGMENT 4



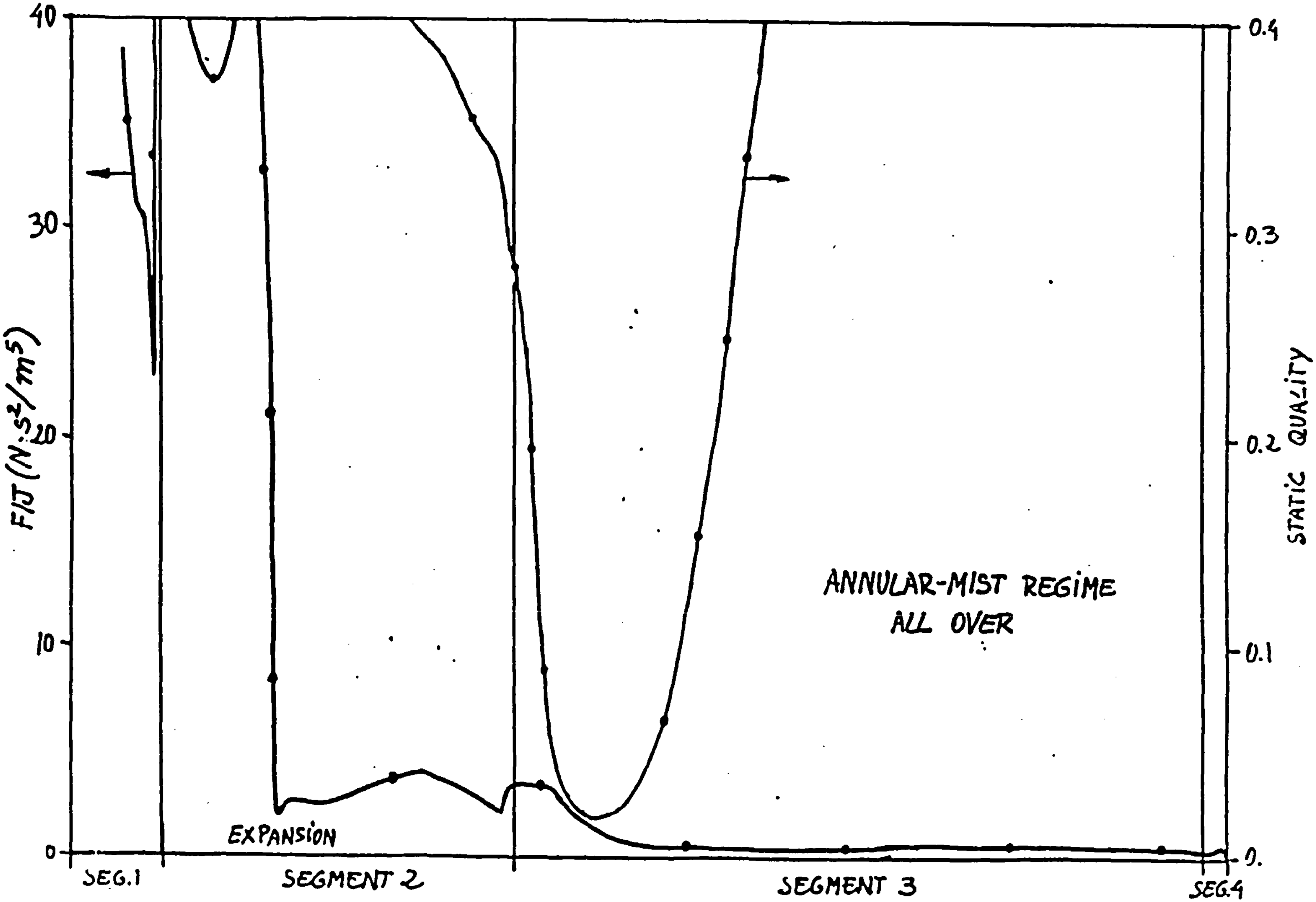


FIG.6.7. QUALITY AND INTERPHASE DRAG DISTRIBUTIONS IN MOD3 (BASE CASE, 0.2 sec)

Table 6.1 Summary of run sequence for RELAP-5/MOD-3, Test CE 917

PARAMETER SELECTION	BASE CASE 0	CASE 1	CASE 2	CASE 6	CASE 7	CASE 4	CASE 8	CASE 9	CASE 10	RECOMMENDED OPTION
Interphase friction model	pipe (b=0)	bundle (b=1)	pipe	pipe	pipe	pipe	bundle	pipe	pipe	Pipe interphase friction
Horizontal Stratif. in Jun.	off (v=0)	off	on (v=3)	off	off	off	off	off	off	No horizontal stratification
Expansion -Contraction	K_f	K_f	K_f	Abrupt area	K_f	K_f	K_f	K_f	K_f	Local pressure losses
Heat slab modeling	yes	yes	yes	yes	no	no	no	no	yes	No heat slab modeling
Vertical orientation of seg. 2	no	no	no	no	no	yes	yes	yes	no	Apply appropiate orientation
Choking model downstream	no	no	no	no	no	no	no	yes	no	No choking option downstream
Phase velocity option	2 (h=0)	2	2	2	2	2	2	2	1 (h=2)	Two velocity solution

Table 6.2 Comparison of RELAP 5/MOD 3 results from parametric studies and experiment for test CE 917

		TEST	RELAP5/ MOD1	CASE 0	CASE 1	CASE 2	CASE 6	CASE 7	CASE 4	CASE 8	CASE 10
LOAD (kN)	max*	-	-	8.3	8.3	8.3	8.3	8.4	8.1	8.1	7.2
ON SEGMENT 1	MAX	18.4	10.5	21.2	21.2	21.2	20.4	21.2	20.7	20.7	19.7
	MIN	-19.8	-11.3	-23.0	-23.0	-23.0	-16.0	-33.1	-32.4	-32.4	-23.6
LOAD (kN)	MAX	50.8	56.8	40.3	40.3	40.3	65.0	40.4	45.8	45.8	45.6
ON SEGMENT 2	MIN	-59.8	-65.3	-87.3	-87.3	-89.3	-205.3	-101.4	-66.0	-66.0	-41.2
LOAD (kN)	MAX	78.3	123.3	96.3	96.3	98.7	191.4	110.9	77.1	77.1	90.3
ON SEGMENT 3	min	-31.6	-42.1	-20.1	-20.1	-20.3	-25.8	-21.4	-	-	
	MIN	-74.3	-47.5	-55.2	-55.2	-55.0	-46.7	-52.2	-43.9	-43.9	-48.7
LOAD (kN) ON SEGMENT 4	MAX	64.8	70.9	96.2	96.2	95.9	86.7	95.2	78.9	78.9	95.2
PRESSURE (bar)	MAX	34.3	28.8	24.9	24.9	24.9	24.9	24.9	25.0	25.0	25.6
AT PT 09	STEADY	16.3	17.0	15.9	15.9	15.8	15.9	15.9	16.8	16.8	16.4
PRESSURE (bar) AT PT 10	MAX	7.7	6.9	6.6	6.6	6.6	6.2	6.8	6.5	6.5	8.0

* Values in the table are given for characteristic points in the figures : maximum (MAX), minimum (MIN), local minimum and maximum (min and max), and steady state (t = 0.3 sec).

6.1.4. Sensitivity to the abrupt area change model at expansion (CASE 6)

It was proven for MOD2 that using the abrupt area change model at the expansion in segment 2 instead of a local pressure loss coefficient contributed to reduce induced loads. The results are just the opposite for MOD3 (see Table 6.2, case 6). The negative load in segment 2 and the positive load in segment 3 are doubled when using the abrupt area change. The explanation for the contradiction is that in MOD2 the important variable driving the load was the mass profile and in MOD3 (with a smoother slug mass distribution) the relevant parameter is the slug velocity. The abrupt area change model results in a lower pressure loss for the liquid phase than in the base case where a local form loss coefficient is applied. As the liquid is not slowed down when the slug goes through the expansion, the effect of front densification in MOD2 is not enhanced and loads are lower. MOD3 does not produce sharp fronts and a lower pressure loss at expansion makes slug velocity larger and induced loads have higher values.

6.1.5. Effect of heat slab modeling (CASE 7)

It has been shown that heat transfer to pipe walls had an striking effect on RELAP 5/ MOD2 computed loads. The sensitivity analysis has been repeated on RELAP 5/ MOD3. The results are presented in Table 6.2 under the header case 7 (to be compared to base case 0). Except for the loads on segment 1 that exhibit a very oscillatory pattern, all load and pressure values are quite similar to the case with heat transfer to the cold pipe walls (case 0). The same low influence was observed for MOD1 results (Tractebel results for MOD1 differ from ITI ones in heat slab modeling). Comparing condensation rates for MOD2 and MOD3 it has been found that MOD2 produced 10 times more condensation than MOD3. Because of this the influence of heat slab modeling in MOD2 was so important , while being negligible for MOD3.

6.1.6. Effect of vertical orientation of segment 2 (CASE 4)

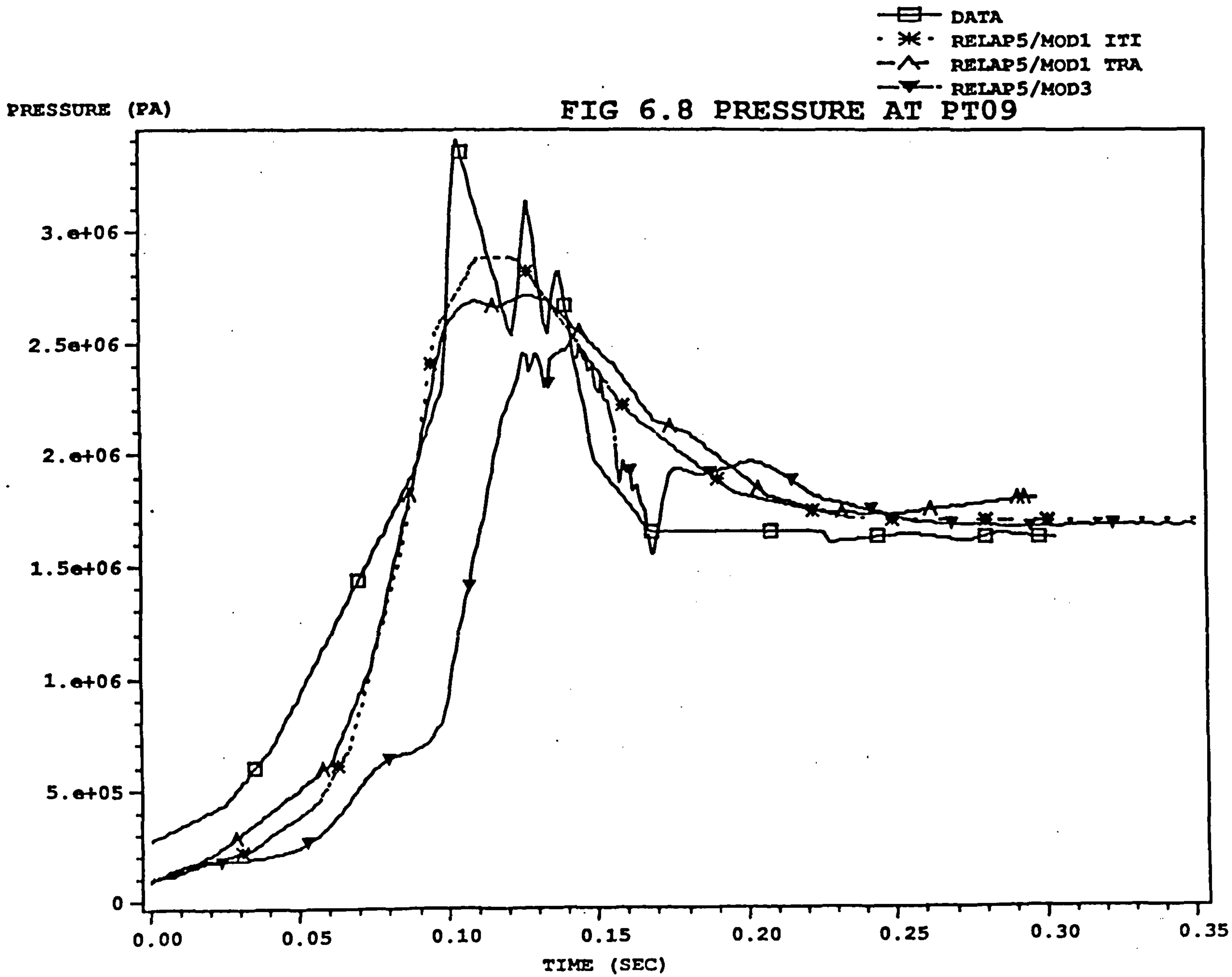
The original MOD1 input model assumed there was no change in the elevation for the discharge pipes, i.e., an horizontal arrangement was considered for the input model. It has been already pointed out that the dominant flow regime is annular-mist. There are no different correlations for the interphase drag coefficient on vertical and horizontal pipes. Any possible difference when verticality is imposed should be attributed to body force effect on the slug and/or changes in the onset of annular-mist conditions.

Table 6.2 shows the results under the case 4 header. Positive load on segment 2 increases and negative one is reduced, getting closer to the experimental measurements. The other loads are also closer to the experiment (except load on segment 1 because of its oscillatory behaviour).

Case 4 includes all the recommended options for the application of RELAP 5/MOD3 to the calculation of hydrodynamic loads. Figures 6.8 to 6.14 compare the pressure and load results to the experimental measurements and the MOD1 computations (ITI results are the EPRI validation for MOD1 and TRA results are the TRACTEBEL check for MOD1). Some oscillations can be observed in the load for segment 1 as a result of the new choking model for MOD3 (Fig. 6.14).

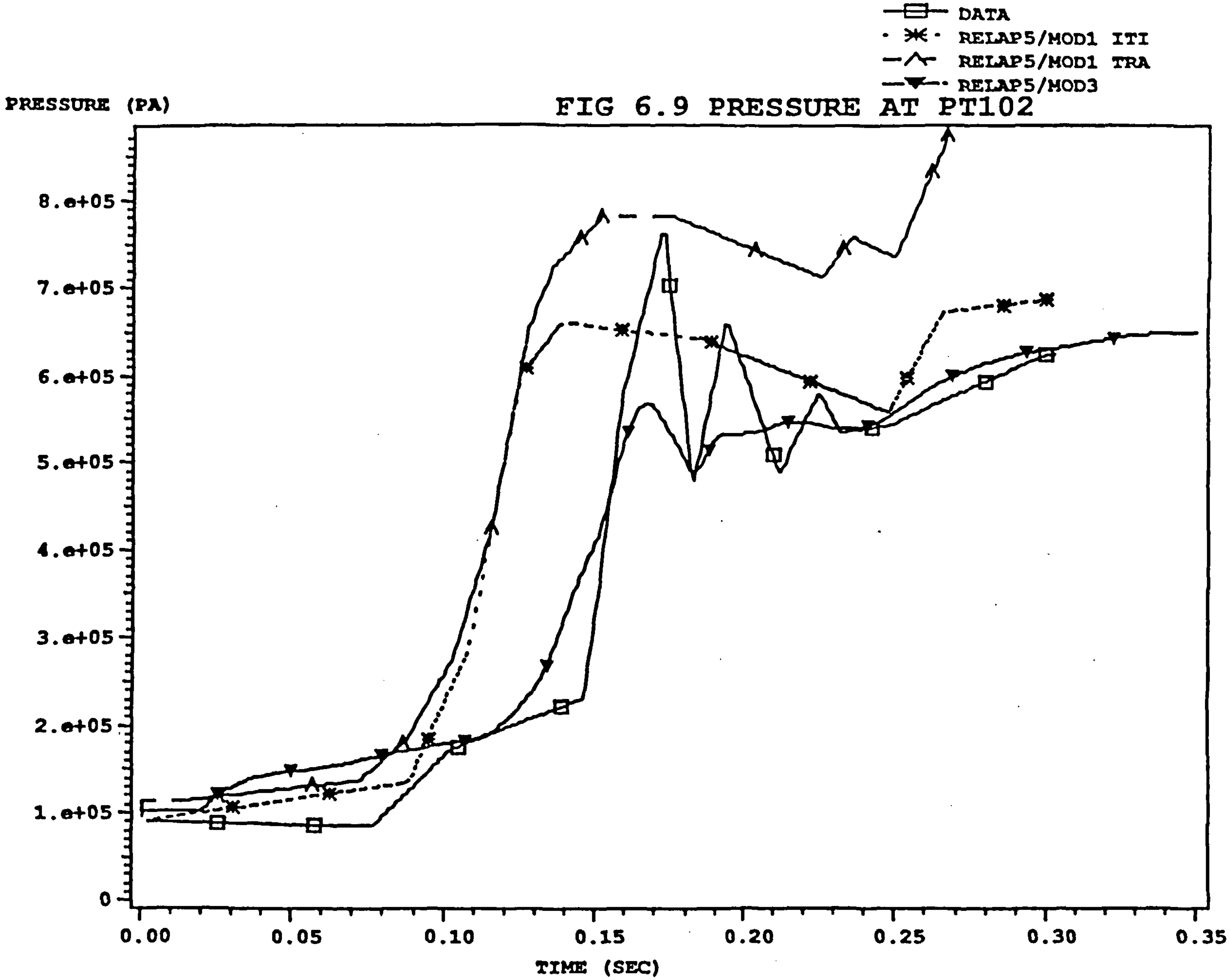
RELAP5/MOD3/V5M5 23/07/90
CE TEST NO.917. CASE 4

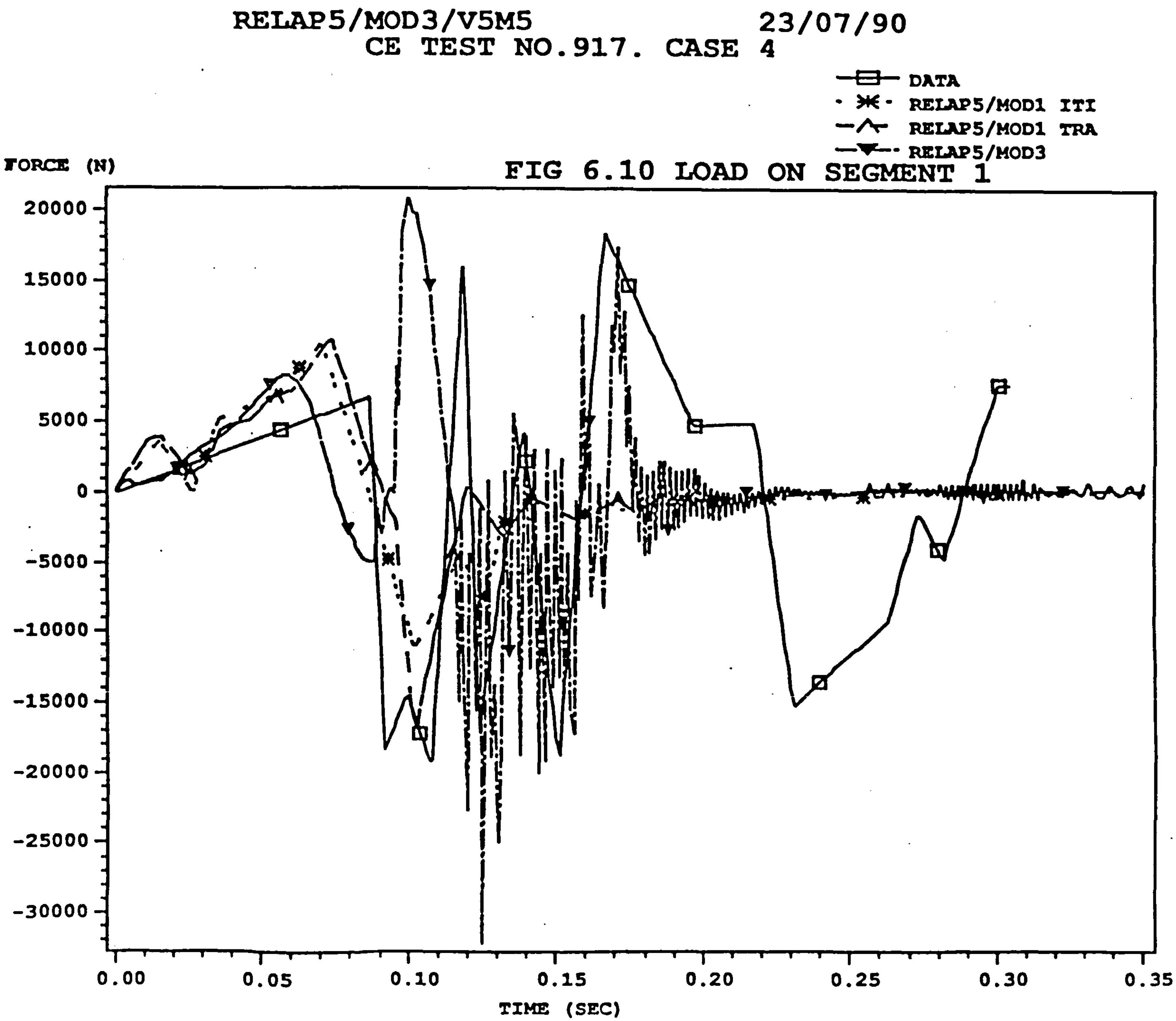
FIG 6.8 PRESSURE AT PT09



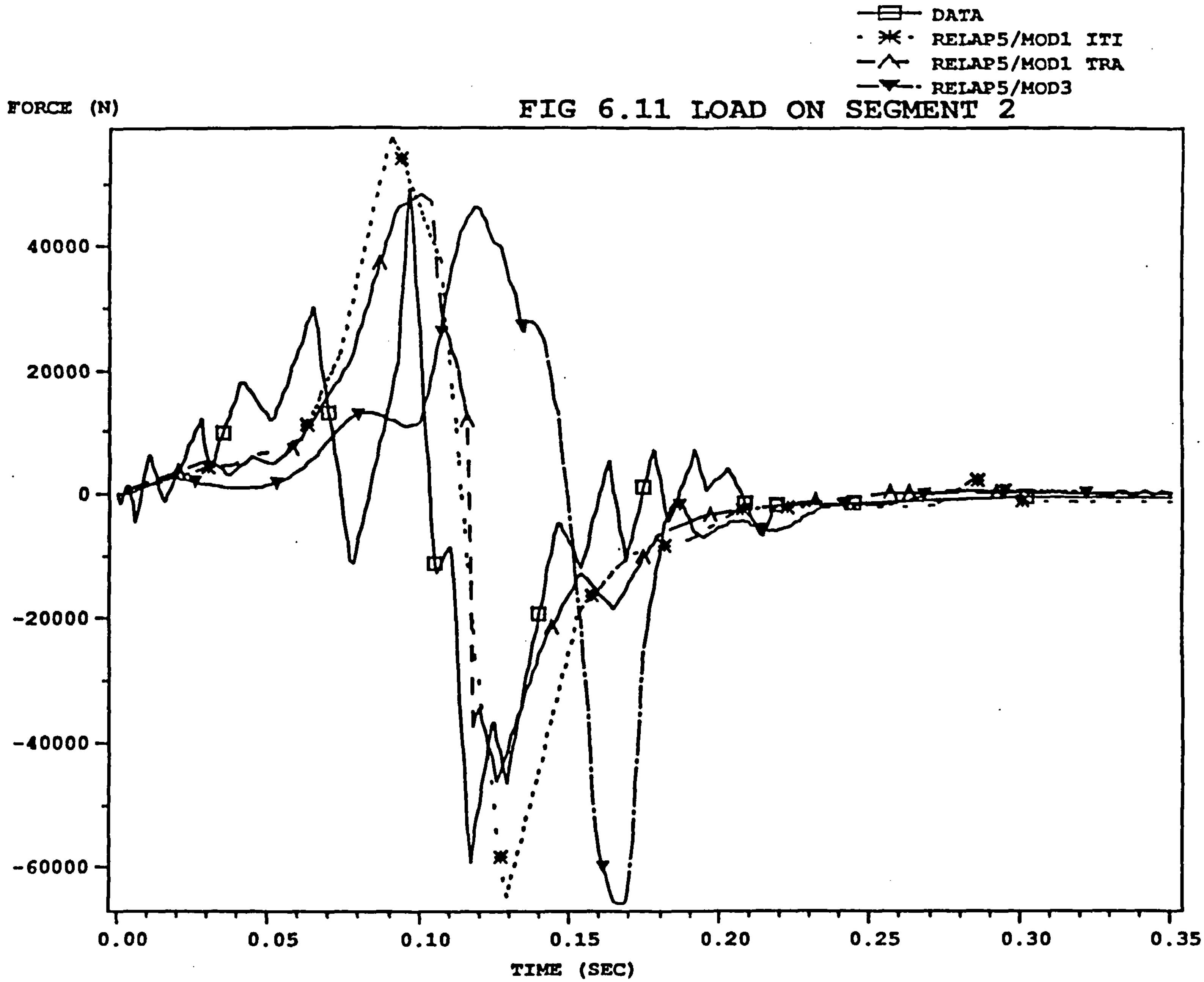
RELAP5/MOD3/V5M5 23/07/90
CE TEST NO.917. CASE 4

FIG 6.9 PRESSURE AT PT102




RELAP5/MOD3/V5M5
23/07/90
CE TEST NO.917. CASE 4
DATA
RELAP5/MOD1 ITI
RELAP5/MOD1 TRA
RELAP5/MOD3
FORCE (N)
FIG 6.10 LOAD ON SEGMENT 1
20000
15000
10000
5000
0
-5000
-10000
-15000
-20000
-25000
-30000
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
TIME (SEC)

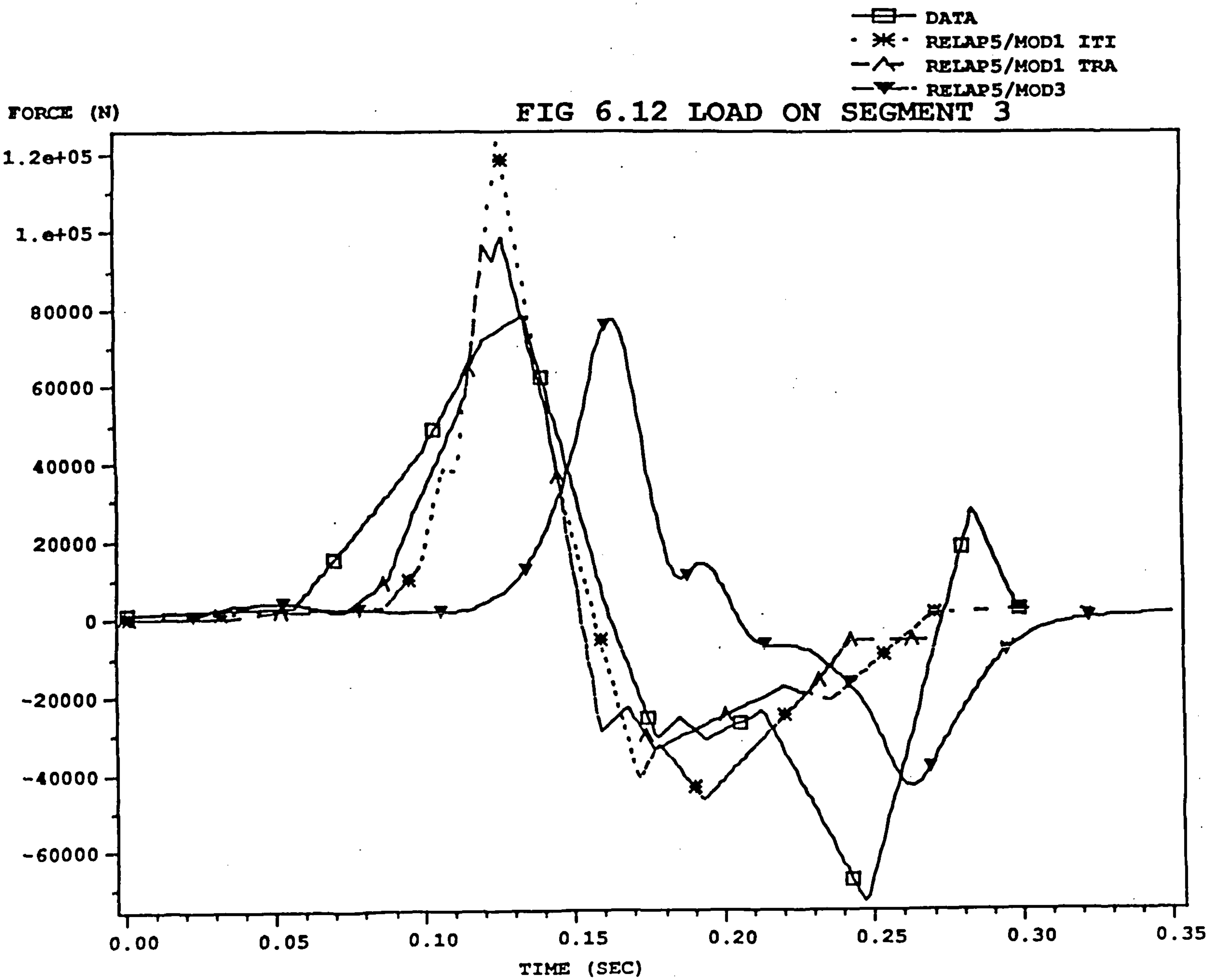
RELAP5/MOD3/V5M5 23/07/90
CE TEST NO.917. CASE 4



RELAP5/MOD3/V5M5 23/07/90

CE TEST NO.917. CASE 4

FIG 6.12 LOAD ON SEGMENT 3



RELAP5/MOD3/V5M5 23/07/90
CE TEST NO.917. CASE 4

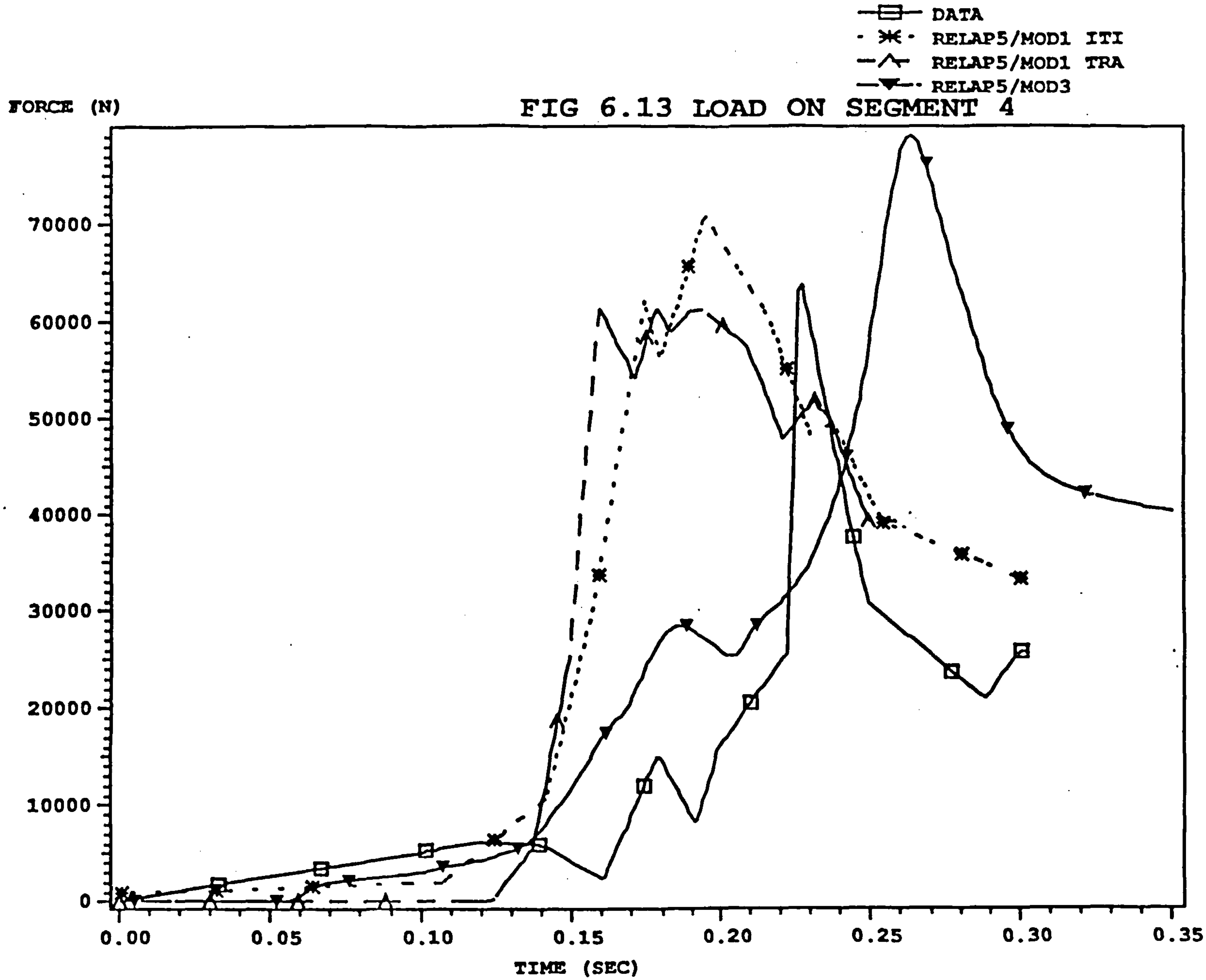
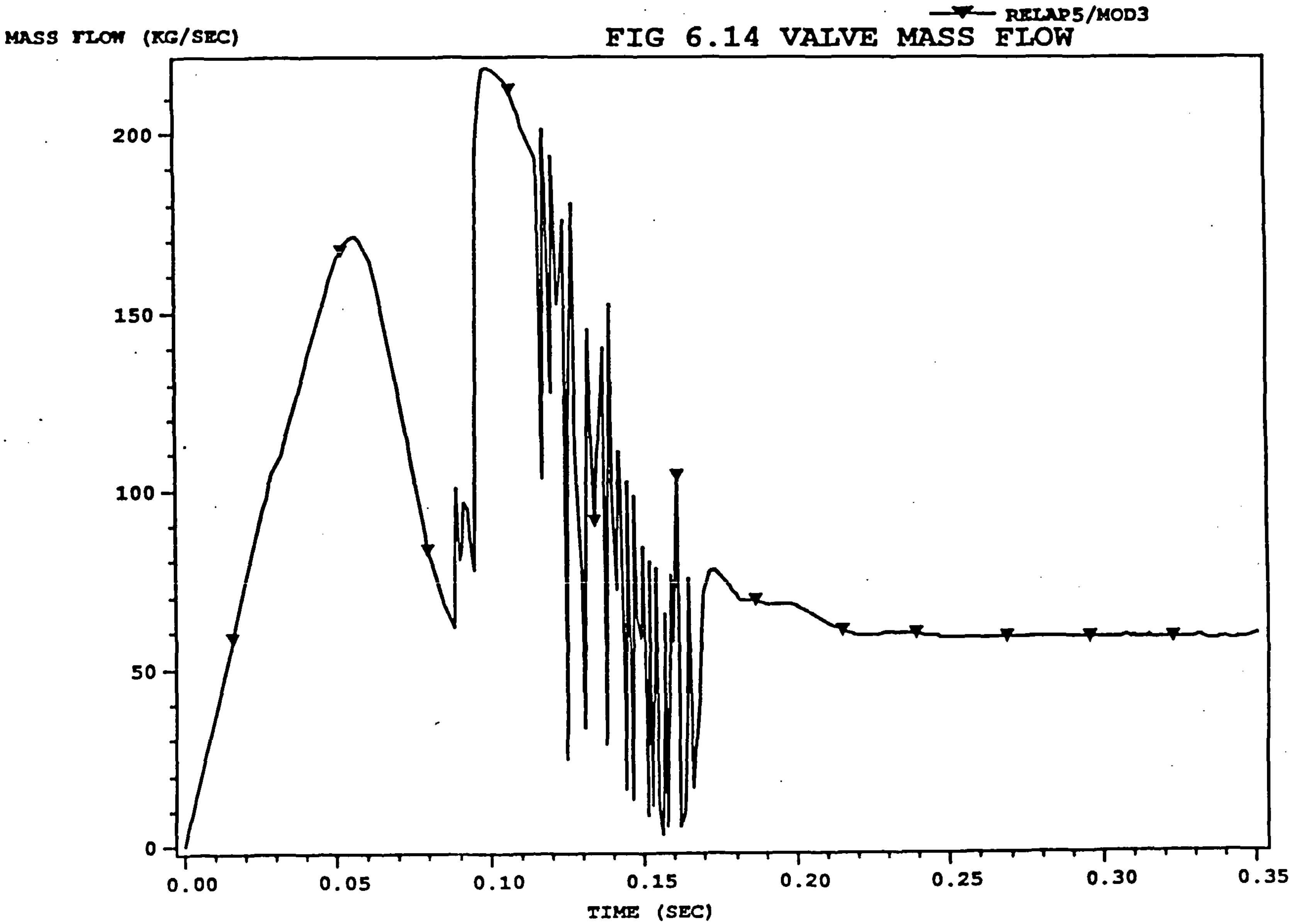


FIG 6.13 LOAD ON SEGMENT 4

RELAP5/MOD3/V5m5 23/07/90
CE TEST NO.917. CASE 4

FIG 6.14 VALVE MASS FLOW



6.1.7. Results of a fully choked solution downstream the valve (CASE 9)

Some changes have been introduced in MOD3 for the choking model (ref. 10). The improvements consisted on smoothing the transition from the subcooled to the two-phase choking model and elimination of a coding error. Although it is still recommended not to use the choking model in succesive junctions, a trial was made to study the slug evolution using the choking model at all junctions downstream the valve, as it was tried for MOD2. As a result, the liquid slug remained still in the first volumes downstream until t = 0.2, when the code failed. Recommendation of not using the choking option downstream the valve is made again.

6.1.8. One velocity solution in RELAP 5/MOD3 (CASE 10)

One-velocity analysis has been repeated with MOD 3 as it was done with MOD2 to assess the effect of interphase drag coefficients. Results are presented in Table 6.2 referred to as case 10. Although it is not shown in that table, the load peak timing is quite similar to the RELAP 5/MOD1 results proving that MOD1 solution was very close to one speed calculation. However the peak values are not equivalent, the differences arising from a different valve discharge due to the changes in the choking model in RELAP 5/MOD3.

7. Run statistics

The simulation has been performed on a computer APOLLO 10020 running with a UNIX operating system.

The requested time step for the whole calculation was 0.0002 sec yielding 1803 attempted advances (14 repeated) for the transient time of 0.35 sec (run statistics are taken from case 4).

The time step history as a function of the transient time is presented in Fig. 7.1 as well as the Courant time step. Figure 7.2 shows the CPU time performance.

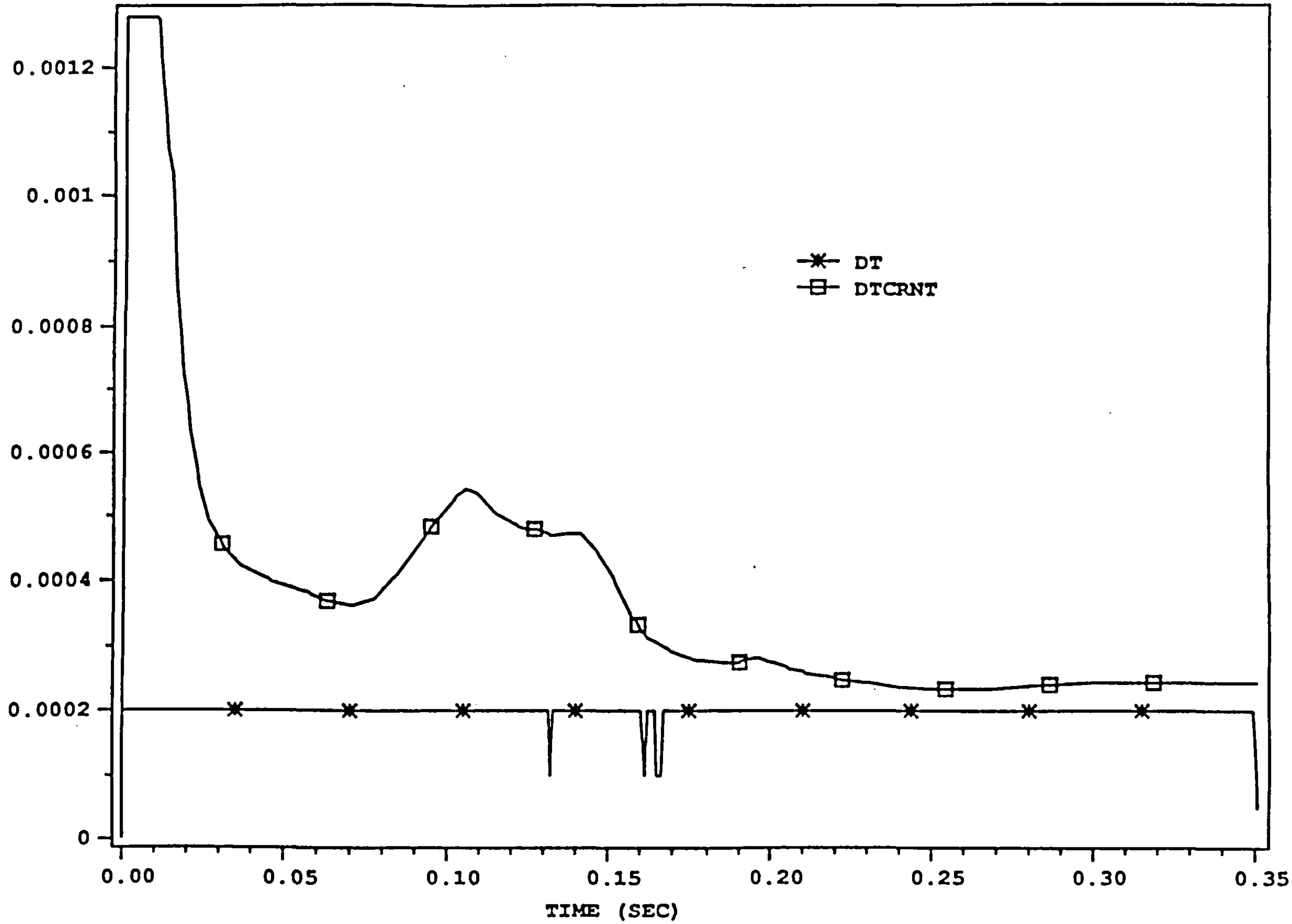
The code performance PF = (1000*CPU)/(N*DT) is (1000*463)/(118*1789) = 2.19 ms/step/volume.

In case 4 heat transfer to the pipe walls is not accounted for.

RELAP5/MOD3/V5m5 23/07/90

CE TEST NO.917. CASE 4

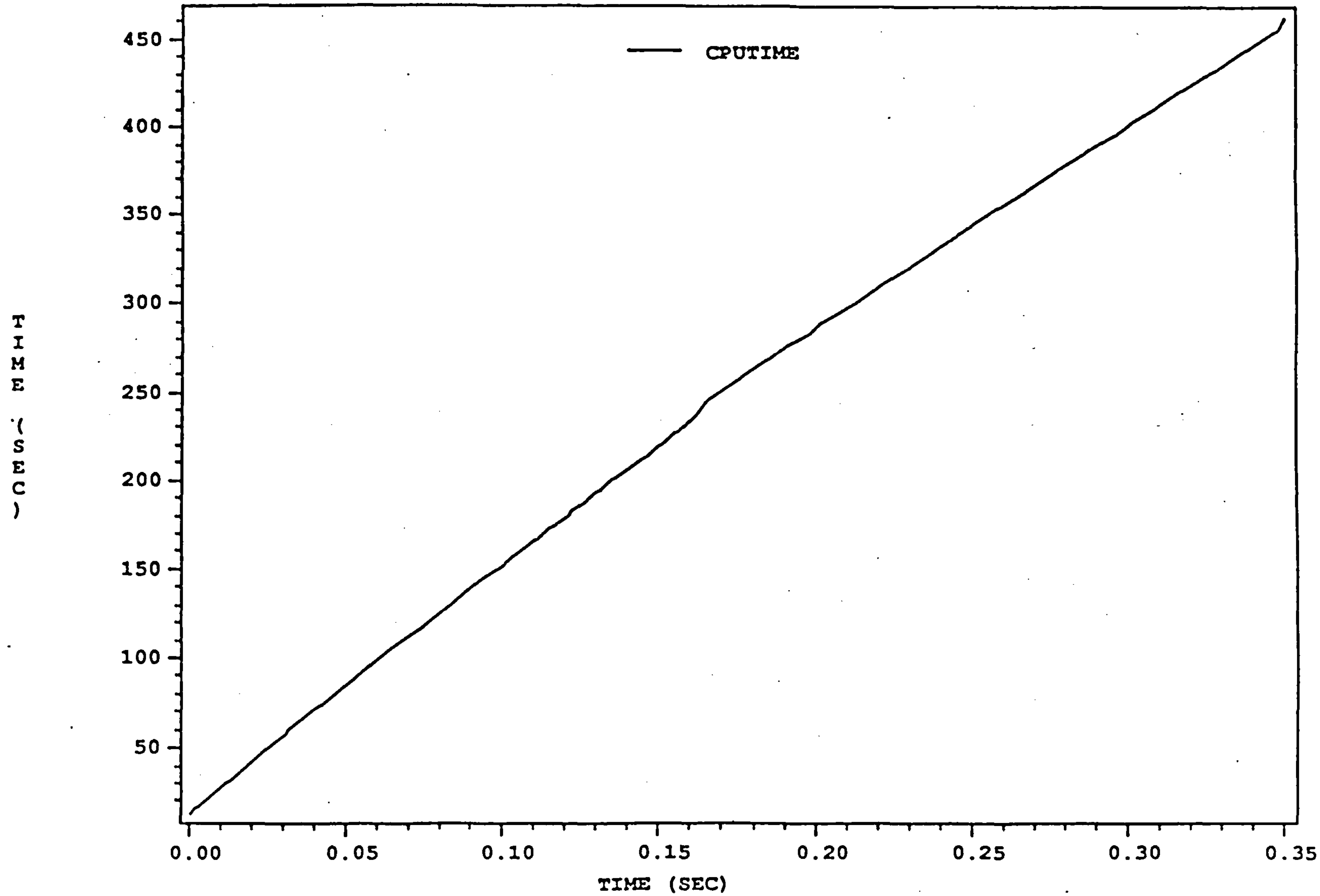
FIG 7.1 ACTUAL AND COURANT TIME STEPS



RELAP5/MOD3/V5m5 23/07/90

CE TEST NO.917. CASE 4

FIG 7.2 CPU TIME ON APOLLO 10020



8. Conclusions

RELAP 5/MOD1 was validated by EPRI for the calculation of safety and relief value discharge piping hydrodynamic loads (ref. 4). Modelization guidelines were issued for a proper code application to this kind of calculations and are summarized as follows :

- control volumes must have a length between 0.15 and 0.3 m for a correct slug and pressure fronts tracking.
- time step must be limited externally to the material Courant limit (≅ 0.2 m sec)
- the no-chocking option must be imposed to all the junctions downstream the test valve
- heat transfer to pipe walls must be included; ten radial nodes suffice to yield a solution not dependent on noding detail
- cold water loop seals (< 100°C) should be located initially downstream the test valve.

The suitability of some of these guidelines has been checked for RELAP 5/MOD3/5M5. One additional guideline has been found suitable for RELAP 5/MOD3 calculations.

- pipe orientation (horizontal or vertical) should be taken into account for pipes downstream the valve.

The main conclusions that have been reached during the assessment process are the folowing.

1. For liquid loop seal discharges the effect of heat transfer to pipe heat structures need not be modeled for a correct evaluation of liquid discharge loads. The same conclusion was obtained for REALP 5/ MOD1.
2. RELAP 5/MOD3 underestimates the coupling between the liquid and vapour phases producing a lower liquid slug velocity than in the experiments. Although maximum values for the loads are quite comparable to the measurements, the loads are delayed in time.
3. The changes that have been introduced to the choking model in RELAP 5/MOD3 (inclusion of a transition zone between the subcooled and two phase flow regimes) produces a characteristic two-bump valve flow discharge that is reflected on the loads of the downstream piping.
4. From this assessment study, one can recommend to use the following options using RELAP 5/MOD3 :
   a. control volumes must have between 0.15 and 0.3 m for a correct slug and pressure fronts tracking.
   b. time step must be limited externally to the material Courant limit (≅ 0.2 m sec).
   c. the no-chocking option must be imposed to all the junctions downstream the test valve.
   d. heat transfer to pipe walls is not requiered to be included for water loop seal discharges.

e. cold water loop seals (< 100° C) should be located initially downstream the test valve.

The suitability of some of these guidelines has been checked for RELAP 5/MOD3. Some additional guidelines have been found suitable for RELAP 5/MOD3 calculations.

f. pipe orientation (horizontal or vertical) should be taken into account for pipes downstream the valve.

g. valve junction is modeled with the 2 velocity option.

5. Comparing the RELAP 5/MOD3 results for case 4, which corresponds to the recommended options above, and the experimental data (Table 6.2) it is observed that

   a. The positive forces agree with the measured forces and a margin of 10 % covers all experimental points.

   b. The calculated negative forces all exceed the measured forces except for segment 3, where the measured results exceed the calculated values by 80 %. However, the large negative measured value is probably due to the lower stiffness of the supports for this segment (ref. 11) and the same discrepancy was found for RELAP 5/MOD1 and ignored for its qualification. Hence, it is proposed to consider the RELAP 5/MOD3 results acceptable, with a suitable margin to bring the data in line with the RELAP 5/MOD1 results, and to estimate the negative forces on all segments.

9. References

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10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

This report presents an assessment study for the use of the code RELAP5/MOD3/5M5 in the calculation of transient hydrodynamic loads on safety and relief discharge pipes. Its predecessor, RELAP5/MOD1, was found adequate for this kind of calculation by EPRI. The hydrodynamic loads are very important for the discharge piping design because of the fast opening of the valves and the presence of liquid in the upstream loop seals.

The code results are compared to experimental load measurements performed at the Combustion Engineering Laboratory in Windsor (U.S.A.). Those measurements were part of the PWR Valve Test Program undertaken by EPRI after the TMI-2 accident.

This particular kind of transients challenges the applicability of the following code models

- Two-phase choked discharge
- Interphase drag in conditions with large density gradients
- Heat transfer to metallic structures in fast changing conditions
- Two-phase flow at abrupt expansions.

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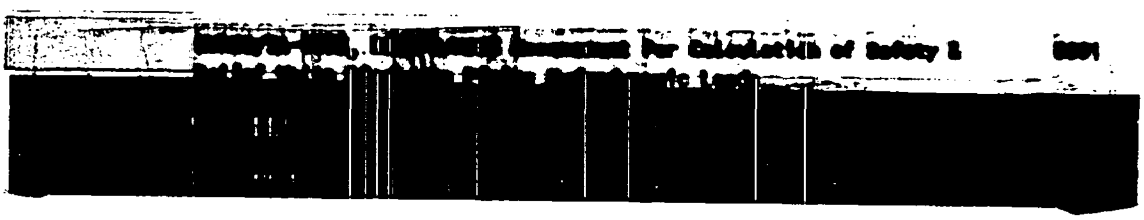

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