Main Index

NORWEGIAN SOCIETY OF CHARTERED ENGINEERS

NORTH SEA FLOW METERING WORKSHOP

13 - 15 October 1987

Stavanger Forum, Stavanger

DEFLECTION OF ORIFICE PLATES AT HIGH DIFFERENTIAL PRESSURE

by

Jim Fulton	BPC
Erling A. Hammer	UiB
Audun Haugs	CMI

3.3

Norwegian Society of Chartered Engineers
Department of Further Education

North Sea Flow
Metering Workshop

Stavanger Forum, Stavanger
13 -15 October 1987.

Deflection of Orifice Plates at High Differential Pressure

by

Jim Fulton BPC
Erling A. Hammer UiB
Audun Haugs CMI

SUMMARY

This paper describes the work carried out at Chr. Michelsen Institute in Bergen to investigate experimentaly, the deflection of orifice plates under varying Differential Pressure (DP) conditions.

The project was sponsored by Statfjord Division, and involved the construction of a full scale test rig with components identical to those used on meter stations in the Statfjord Field.

The purpose of the test was to prove that the theoretical formula used by "Jepson and Chipchase" to calculate orifice plate deflection, was equaly valid when applied to actual offshore equipment, and thence to establish the actual levels of measurement uncertainty at flow conditions up to 1000 mbar.

INTRODUCTION

During the latter part of 1985. Mobil (MENI) as operator for the Statfjord Fied. started Gas Sales to buyers in the UK and Germany.

Metering of the gas was achived by four DANIEL gas metering stations, one on platforms A and C, and two on platform B (one of which was dedicated to UK gas export).

The configuration and capacity of each of these meter stations is shown in table 1.

TABLE 1. Statfjord meter station capacity.

Station	No of Tubes (Runs)	Capacity / Tube (Mm3/Day)	Station Capacity (Mm3/Day)
A	3	3.8	7.6
B	2	5.7	5.7
C	2	5.7	5.7
UK	2	3.8	3.8

During the early months of gas export, Mobil had on occations problems in meeting daily gas delivery requirements, owing to the limited capacity of their meter stations.

Such problems were generaly caused by one or more of the following factors:

- reservoir management demands (i.e. priorytising export from one platform only).
- unplanned shutdowns
- planned shutdowns

The options which were considered for resolving this capacity problem were:

1. Installation of additional meter tubes on all platforms.
2. Use the spare meter run.
3. Increasing the range of the DP cells.
4. Increasing orifice plate Beta Ratio's.

Option number 1. was evaluated but rejected because of cost, weight and space restrictions.

Option number 2. could be used in the short term, but would jeopardise the reliability and maintainability of the meter stations.

Option numbers 3 and 4 could be easily applied, but would contravene existing NDP regulations which limit DP to 500 mbar and Beta Ratios to 0.6.

Of these four options, the most attractive (from an operating standpoint) was 3., if approval could be obtained from the appropriate Norwegian and British authorities.

With that thought in mind, Mobil approached CMI, early in 1986, to inquire about the possibility of undertaking full scale test to investigate the deflection of orifice plates under flow conditions exceeding 500 mbar.

If it could be established, that the amount of deflection at high DP was less than 1% and that the mass flow measurement error was less than 0.1% then Mobil felt that they would have a good chance of obtaining relaxation from current authority requirements.

TECHNICAL BACKGROUND

Present regulations for fiscal gas metering, both in Norway and the United Kingdom, require that the range of the differential pressure for orifice plate measurement in fiscal metering systems to be limited to 500 mbar and 0.6 Beta Ratio. In the United Kingdom, however, Department of Energy guidelines provide allowance for exceeding the 500 mbar limit. if the total orifice plate deflection is less than 1%, and the mass flow measurement error is less than 0.1%.

In November 1985 MOBIL Gas Dispatch Centre carried out a calculation study into increasing the Differential Pressure measurement of all the gas metering systems on the Statfjord platforms. This increase was required to improve the operational flexibility of gas sales from the Statfjord field.

The orifice plate deflection calculations were based on a formula given by Messr. Jepson and Chipchase in a paper published in the Journal of Mechanical Engineering in 1975.

The Jepson and Chipchase formula allows calculation of both deflection and associated flow error for various Beta Ratio plates. The original research was carried out by the British Gas at their Killingworth research station in The North East of England, and utilized plates mounted rigidly between flanges. This experimental work however, involved working at differential pressures from 0 - 120 mbar. (Figure 1.)

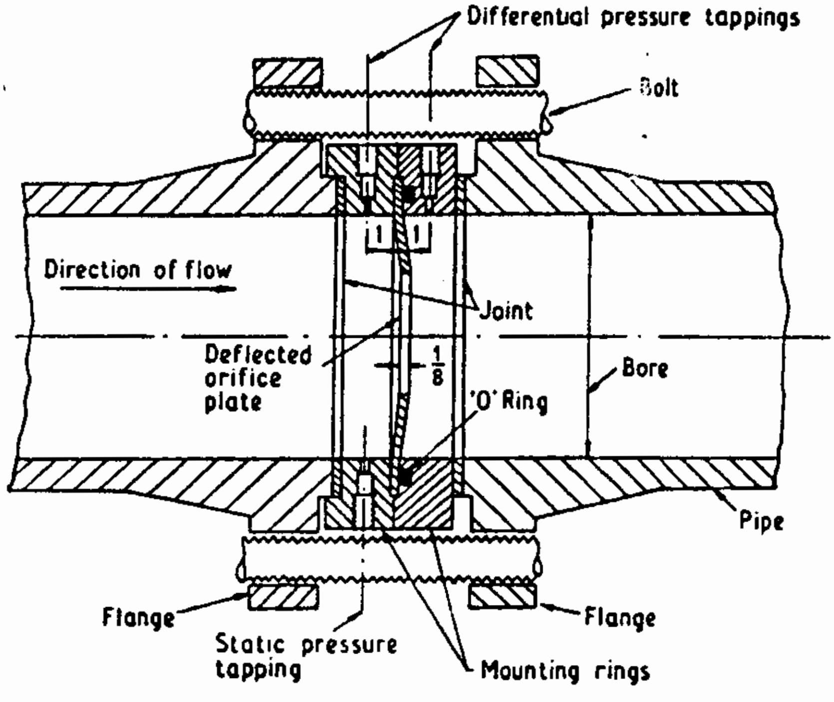

Figure 1. Jepson and Chipchase
Orifice-plate fixing arrangement.

The orifice fittings used in the Statfjord gas metering stations are DANIEL Senior Carriers. The seal rings used in these orifice carriers are made of stainless steel and comply fully with ISO 5167, Rev. 80. These seal rings do not provide the same rigid mounting as obtained for the flange mounted plates tested by Jepson and Chipchase. It was therefore of great interest to verify if the Jepson and Chipchase formula is equally valid for the type seal rings used offshore, and operating at differential pressure up to 1000 mbar.

THE TEST RIG

A test rig was designed to simulate as far as possible the conditions found on offshore gas meter stations, and comprised the following main parts: (Figure 2)

- Air reservoir and supply source.
  To ensure a controlled air pressure during the tests, a buffer tank with regulated input pressure control was devised.

- 10 inch nominal bore piping.

- DANIEL 10 inch junior orifice carrier.
  Pipe and carrier were fitted and flanged using offshore grade material.

- Restriction tube.
  To achieve a differential pressure of 1000 mbar across the orifice plate under laboratory conditions, it was necessary to restrict the air flow through the orifice plate.
  A restriction tube was centered in the 10 inch pipe, leaving only a small clearance (0.8 mm) between the tube and the orifice plate bore.

- Deflection and DP measurement devices.
  The DP measurement device was a FOXBORO 823DP d/p Cell TRANSMITTER, and the deflection measuring devices were of the TESATRONIC type linear measuring device.

  (A patent for the rig has been applied for.)

Figure 3. shows the transducers used for deflection measurements, and also indicates placement of these transducers (4) on the orifice plate under test.

The DP-cell and the deflection measurement transducers were connected to a DATA 6000 data logger, capable of logging more than 2000 samples at high speed to internal memory, from each input channel in parallel, during a test run (approx. 1 minute).

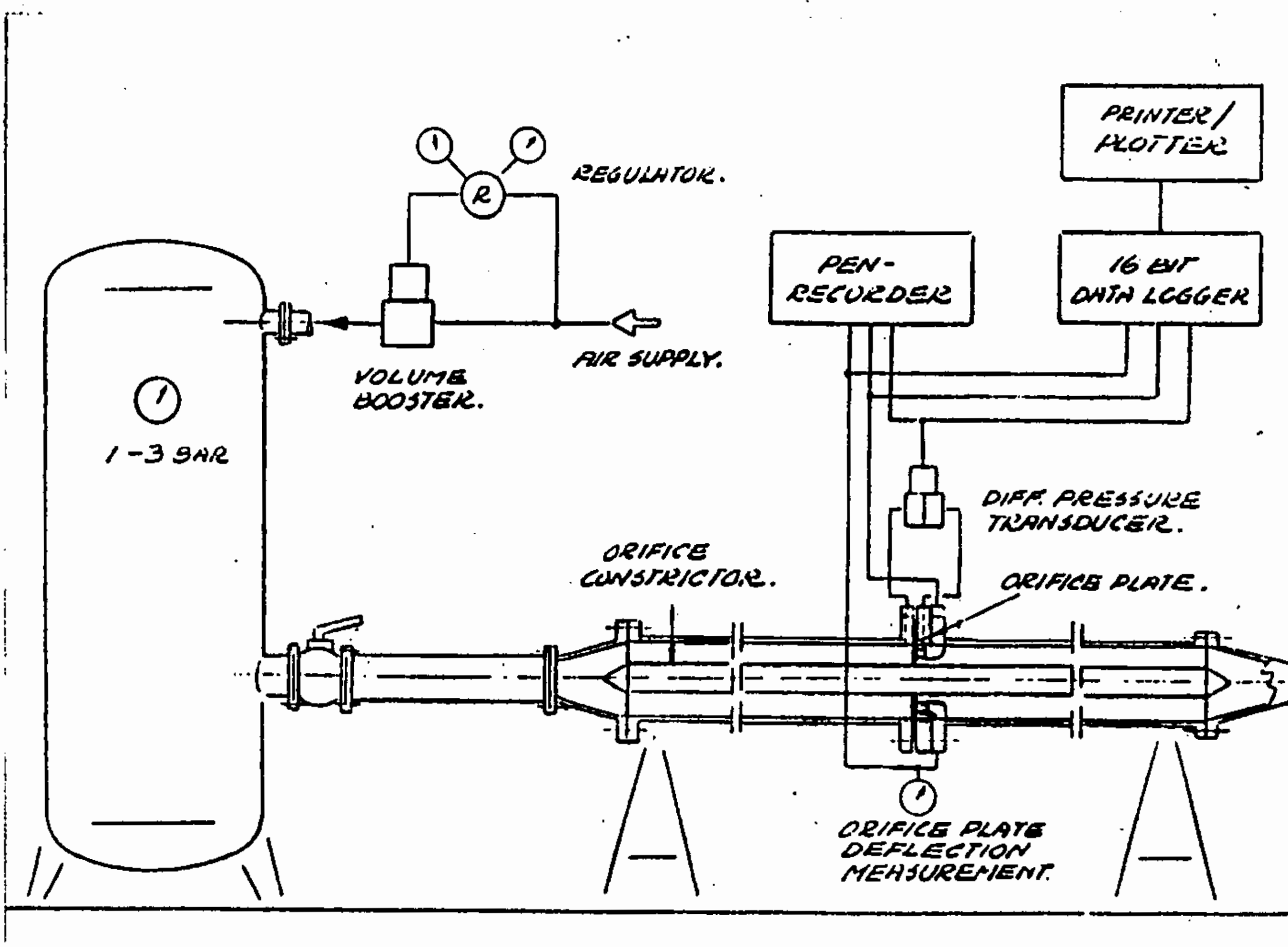

Figure 2. General arrangement of test rig.

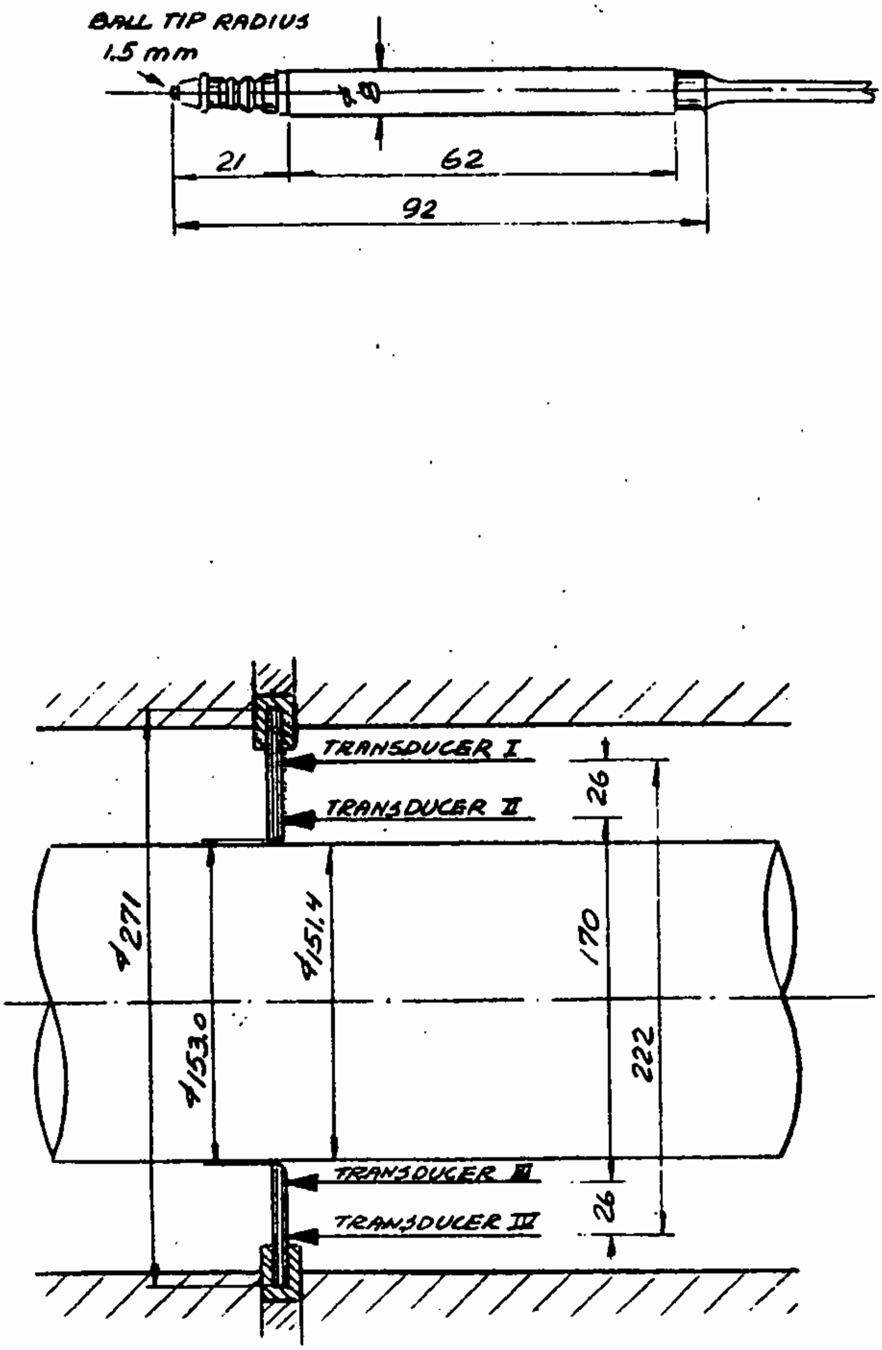

Figure 3. Displacement transdusers - Details.

After each run, data from the data logger was transferred to a Hewlett Packard 9816 series 200 desktop computer, for data processing and presentation of tables and graphs.

A sketch showing the theoretical deflection form of the orifice plate is shown in Figure 4. The displacement value Ymax was derived during the test by linear interpolation under the assumption of flat plate theory.

TESTS PERFORMED

Tests were carried out with a combination of 3 seal rings, each of a different type, and 3 orifice plates with different properties. Figure 5. illustrates how the seal rings fitted into the carrier.

Each combination was tested 4 times, twice with increasing d/p (0 - 1000 mbar) and twice with decreasing d/p (1000 - 0 mbar).

Referring to Figure 2., the following was done before each of the above tests:
- Buffer tank pressure was set to establish 1000 mbar across the orifice plate, with Pressure Regulating Valve fully open.
- Data logger was "armed".

Test run - Increasing method (0 - 1000 mbar):
- Pressure Regulating Valve was fully closed.
- Air valve between buffer tank and pipe was fully open.
- Trigger signal to data logger and opening/closing device on Pressure Regulating Valve.

The data logger now started to collect data, while the Pressure Regulating Valve was slowly turning to fully open. The opening/closing devise was set to fully open the the valve within the timespan of the data logging period (approximately 1 minute). The d/p cell signal and the transducer signals were all stored in the data logger memory, for further processing.

Test run - Decreasing method (1000 - 0 mbar):
- Pressure Regulating Valve was fully closed.
- Air valve between buffer tank and pipe was fully open.
- Trigger signal to data logger and opening/closing device on Pressure Regulating Valve.
- Shut of air supply to buffer tank.

In this case the opening/closing device was set to open the valve at maximum speed. When the Pressure Regulating Valve was fully open, the air supply to the buffer tank was shut of. The pipe pressure started to drop, and the d/p cell signal reached zero within the timespan of the data logging period (approximately 1 minute).
The d/p cell signal and the transducer signals were all stored in the data logger memory, for further processing.

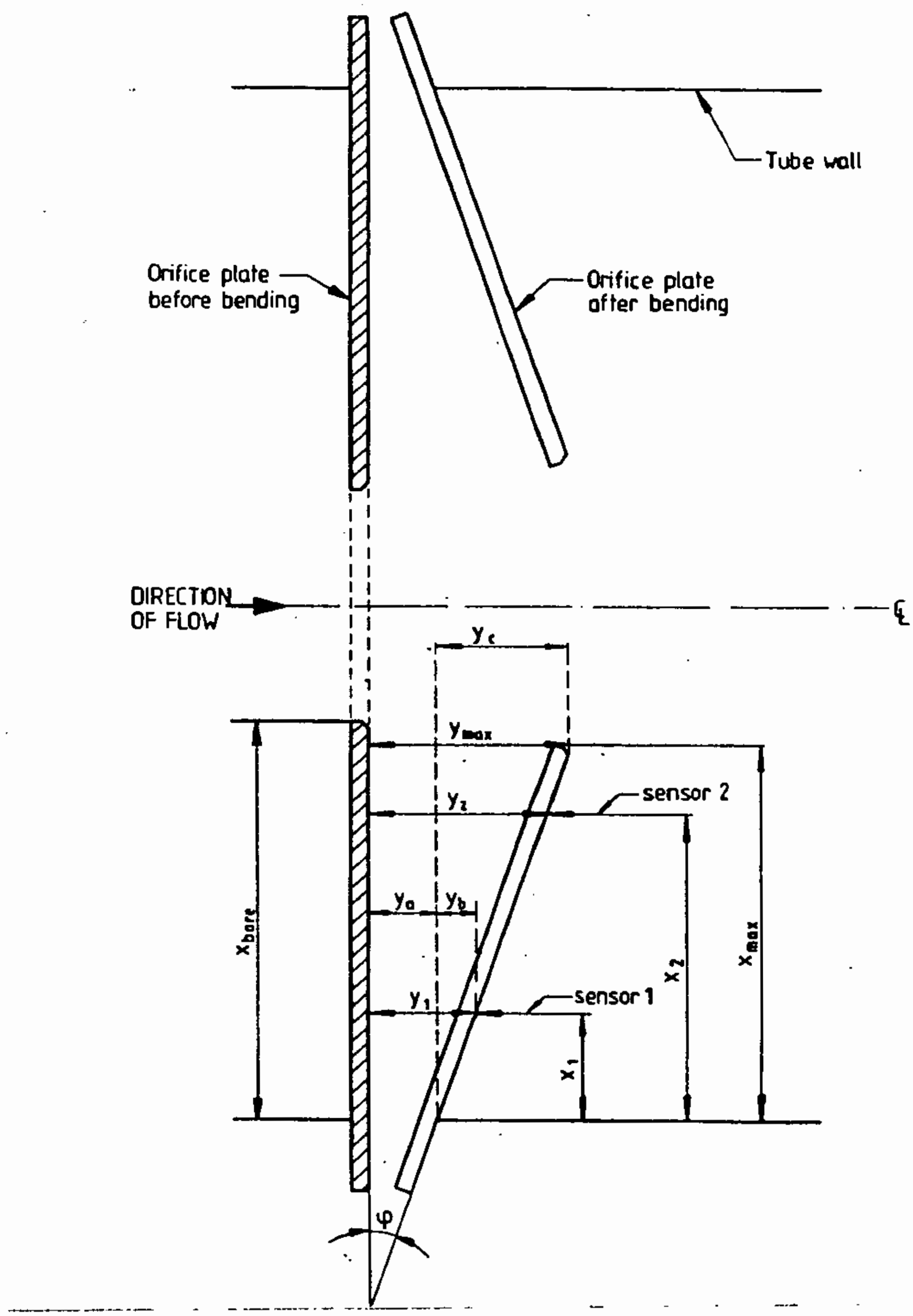

Figure 4. Principle of plate deflection measurement.

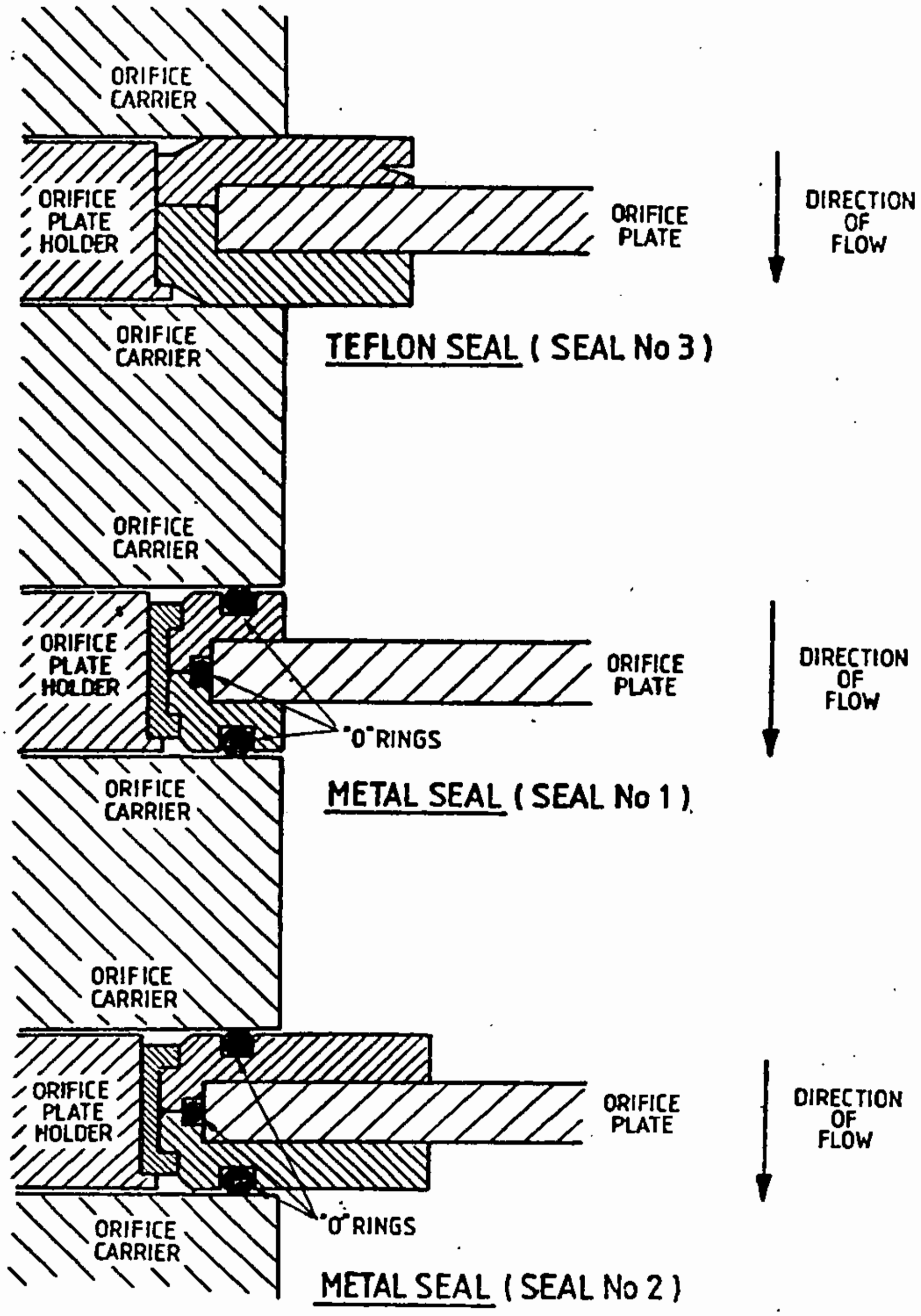

Figure 5. Different seal ring arrangements.

RESULTS

Three different orifice plates where tested (ESAS-M076 6.177mm thick, ESAS-M075 6.197mm thick, DANIEL-95685 6.475mm thick), each of them mounted in three different seal rings.(Metal-316S/S 256mm I/D, Metal-316S/S 224mm I/D and Teflon 224mm I/D, all from DANIEL).

Some examples of the graphs of orifice plate deflection, measured and calculated according to Jepson and Chipchase, are presented in the Figures 6, 7, 8, 9 and 10.

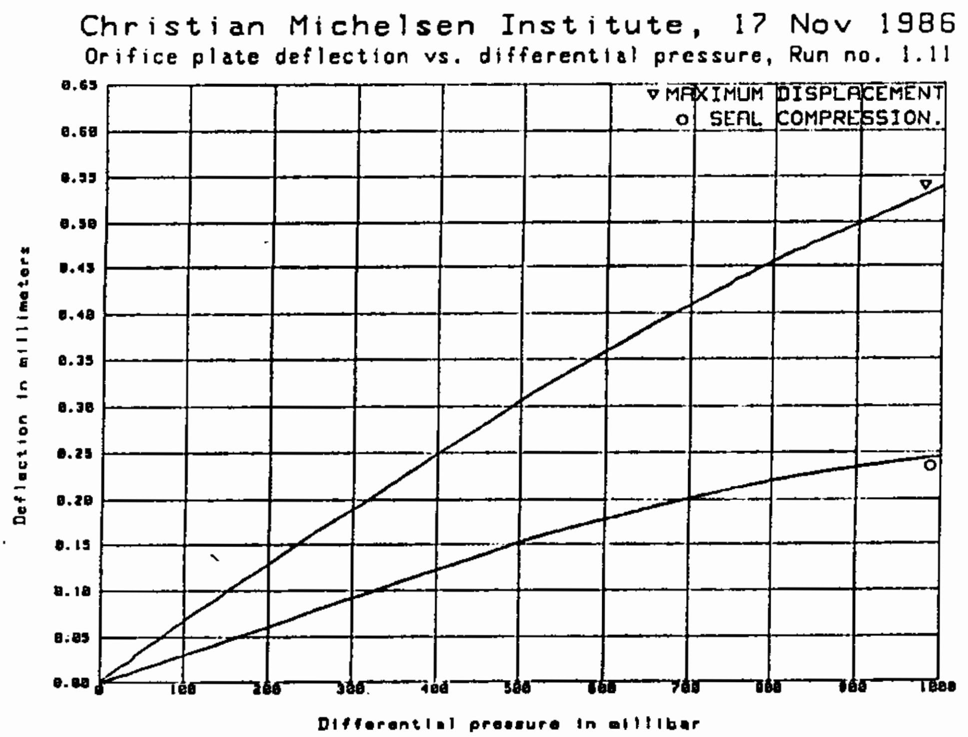

Figure 6. Measured deflection of M076-ESAS plate mounted in metal seal 316 S/S, 256mm I/D. (Run 1.11)

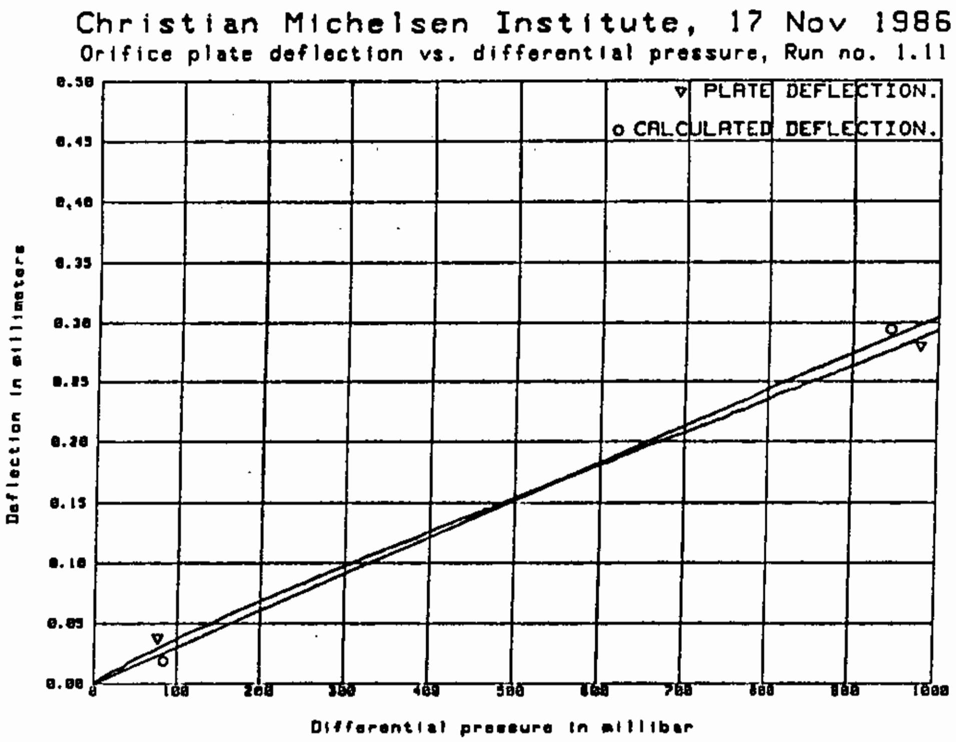

Figure 7. Measured and calculated deflection of M076-ESAS plate mounted in metal seal 316 S/S, 256mm I/D. (Run 1.11)

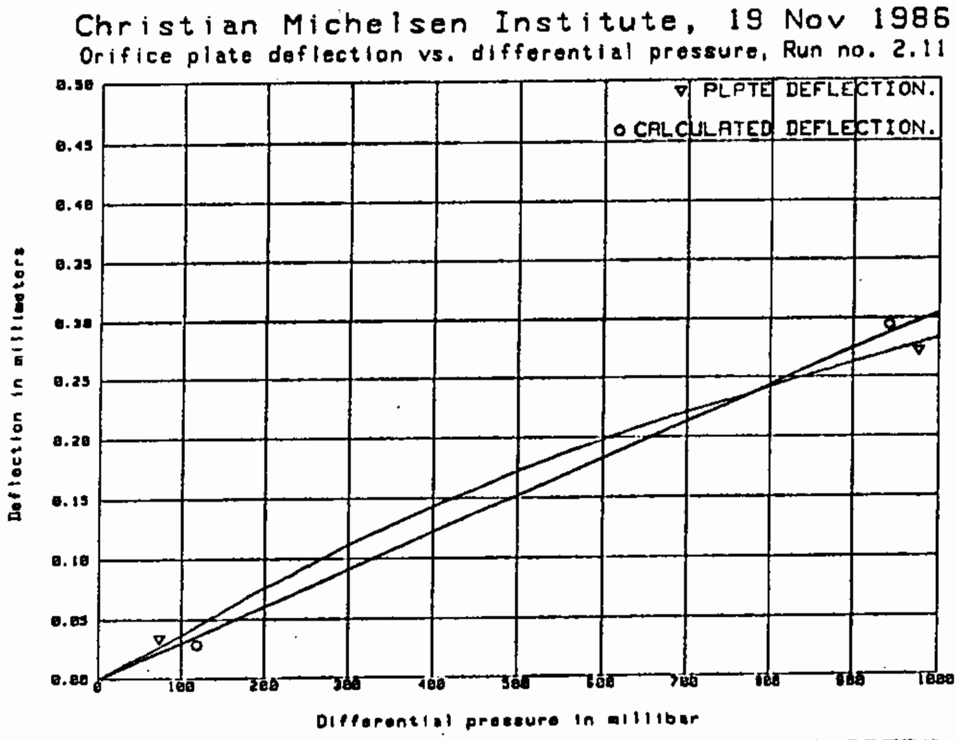

Figure 8. Measured and calculated deflection of M076-ESAS plate mounted in metal seal 316 S/S, 244mm I/D. (Run 2.11)

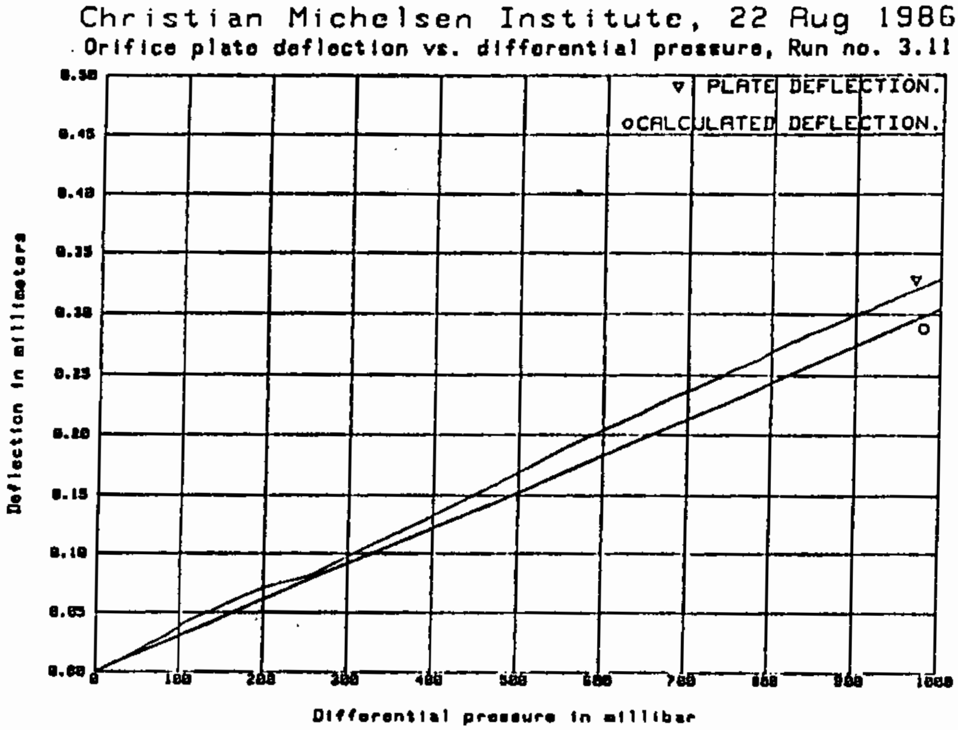

Figure 9. Measured and calculated deflection of M076-ESAS plate mounted in Teflon seal, 224mm I/D. (Run 3.11)

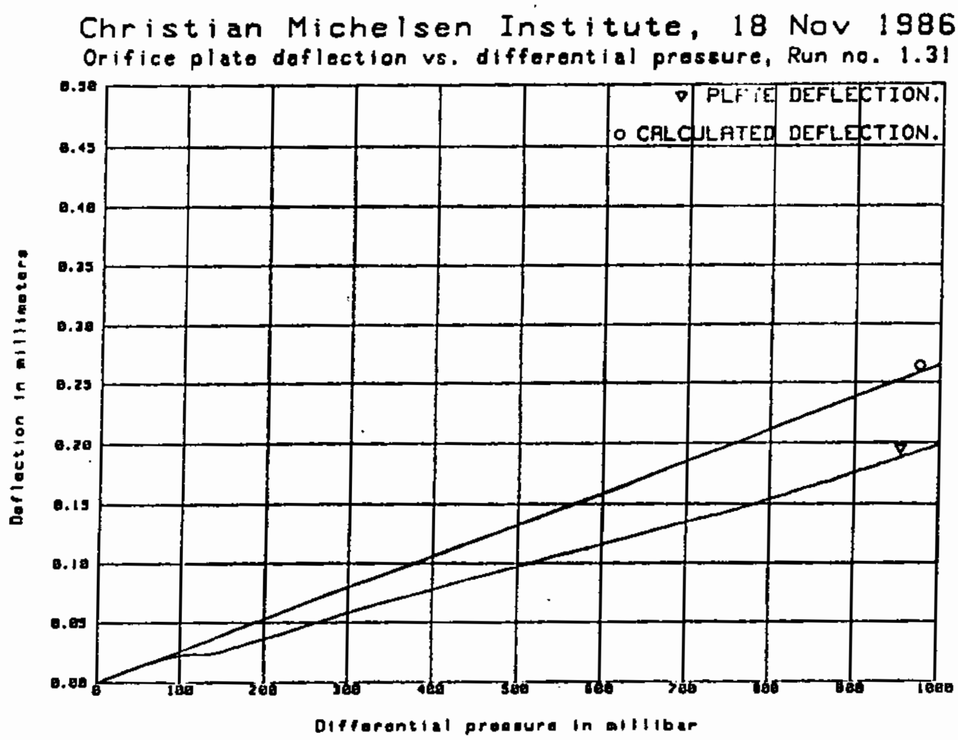

Figure 10. Measured and calculated deflection of 95658 - DANIEL plate mounted in metal seal 316 S/S 256mm I/D(Run1.13)

The results from our measurements are summarized in table 2.

Table 2.

RESULTS

COMPARISON OF ACTUAL DEFLECTION AGAINST THEORETICAL DEFLECTION

SEAL RING	ORIFICE PLATE		
	ESAS (6.177 THICK)	ESAS (6.197 THICK)	DANIELS(6.475 THICK)
1. METAL 256 MM I/D	VERY CLOSE TO THEORETICAL DEFLECTION	20% LESS THAN THEORETICAL DEFLECTION	20% LESS THAN THEORETICAL DEFLECTION
2. METAL 224 MM I/D	CLOSE TO THEORETICAL DEFLECTION (± 10%)	33% LESS THAN THEORETICAL DEFLECTION	40% LESS THAN THEORETICAL DEFLECTION
3. TEFLON 224 MM I/D	15% GREATER THAN THEORETICAL DEFLECTION	15% GREATER THAN THEORETICAL DEFLECTION	CLOSE TO THEORETICAL AT 1000 MILLIBAR, 15% GREATER AT 500 MILLIBAR

CONCLUSION

From the results of the tests it could be seen that each seal ring/orifice plate combination performed in a different way. Of the three seal rings however, the following comments can be made:

Seal Ring 1. (Metal 256mm I/D)
It was the only seal ring which matched the orifice plate carrier.

Seal Ring 2. (Metal 224mm I/D)
The inside diameter of the seal ring protruded into the carrier bore, giving additional support to the orifice plates. The results obtained from this seal ring were repeatable, although significant seal movement was experienced at low DP, owing to use of old "O"-rings.

Seal Ring 3. (Teflon 224mm I/D)
The inside diameter of the seal ring protruded into the carrier bore, initially providing additional support to the orifice plate. On repeated tests this support was much less evident, due the plastic deformation of the Teflon.

Whilst the results from Seal Ring 2 and 3 are most interesting, such seals would not have been used in a similar offshore metering station, because their inside diameter protrude into the bore of the carrier.

In conclusion however, the results of the tests (with particular reference to Seal Ring 1.) have established the following:

1. The Jepson and Chipchase formula for orifice plate deflection under high differential pressure, will give a worst case result if the orifice plate is used with a metal seal ring.

2. Increases in the thickness of standard orifice plates do not significantly reduce orifice plate deflection.

3. As DP increases (max 1000 mbar) the Jepson and Chipchase formula will increasingly predict a deflection value in excess of the actual value.

4. The use of Teflon seal rings will generally give less overall plate displacement (i.e. seal ring + orifice plate), but may give an orifice plate deflection 15% greater than that calculated by using the Jepson and Chipchase formula.

SUMMING UP

Although the tests described in this paper were motivated by operational needs, the consequence of our findings have probably more impact in the future design of new meter stations.

If for example authority approval was obtained to operate meter stations at DP levels up to say 1000 mbar, the potential savings for the industry could be enormous in terms of:

- Weight Savings
- Equip. Cost Savings
- Operating Cost Savings
- Spares Cost Savings

ACKNOWLEDGEMENT

The authors of this paper would like to express their sincere thanks to the following parties for their assistance during the execution of the project:

Dr. Bob Peters	DANIEL Industries
G. G. Brown	MOBIL
M. Marshall	Consultant

REFERENCES

1. International Standard ISO 5167 Rev. 1980.
Measurement of fluid flow by means of orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full.

2. P. Jepson R. Chipchase
"Effect of Plate Buckling on Orifice Meter Accuracy"
Journal Mechanical Engineering Science, Vol 17 No 6 1975.

3. Norwegian Petroleum Directorate 1984
Regulation for fiscal measurement of gas produced in internal waters, in Norwegian territorial waters and in the parts of the Norwegian Continental Shelf which subject to Norwegian sovereignty.

4. Audun Haugs et al:
"Orifice Plate Deflection Measurement"
Final Report
CMI - No 861204-1, 1986.