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Measurement of the Structural Response of a Large Scale Explosion Test Rig

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Measurement of the Structural Response of a Large Scale Explosion Test Rig

Prepared by

B G Technology

EXECUTIVE SUMMARY

It is important for safety engineers to be able to predict the effects that a gas explosion in an offshore module would have on the structure of the module involved. This report describes measurements of structural response of the large scale explosion rig at Spadeadam, carried out during part of a programme of large scale explosion experiments conducted by BG Technology under contract to the Health and Safety Executive (HSE). Measurements were made during seven tests and the data has been provided to the HSE for analysis.

CONTENTS

1. INTRODUCTION

When assessing the possible consequences of an explosion incident it is important to be able to estimate the effects of the overpressure pulse generated by the explosion on structures adjacent to, or containing the explosion. The effects of an overpressure pulse on a structure depends on the complex interaction of a number of factors including the:

- Characteristics of the overpressure pulse, magnitude, duration, rise time and shape.
- Characteristics of the structure, strength, shape and natural frequency.

This report describes measurements of structural response carried out during part of a programme of large scale explosion experiments conducted by BG Technology under contract to the Health and Safety Executive. The full programme of explosion experiments are reported elsewhere[1]. The structural response measurements were made on the test rig itself so that the results could be compared with the characteristics of the overpressures generated. The analysis of the structural response data is to be conducted separately by CREA consultants on behalf of the HSE and this report is limited to reporting the data only.

2. EXPERIMENTAL ARRANGEMENT

2.1 Test Rig

The large scale explosion test rig used in these experiments was originally constructed during the "Blast and Fire Engineering for Topside Structures Phase 2 " project managed by the Steel Construction Institute and subsequently used for the programme of explosion experiments for the HSE[1]. The rig was designed to represent, at full scale, the confinement and congestion within a typical offshore module containing items of process plant and pipework. The rig structure was designed and built to withstand significant explosion overpressures and allow for changes of module layout.

The design of the rig structure was based on a strong framework with beams on 4m centres onto which panels could be fitted to provide the required confinemnt. The design of the panels took advantage of previous experience obtained from the design and use of an explosion chamber at Spadeadam and the framework was designed to be capable of withstanding a static overpressure of 3.5 bar within the rig. In order to securely anchor the test rig, the main framework was fixed to steelwork which was embedded in a thick concrete test pad.

A mezzanine deck, comprising of a steel support frame covered with serrated open bar grating, was located at mid-height throughout all of the test rig and was designed to be similar to those found in typical offshore modules.

During all the experiments described in this report the test rig was 28m long, 12m wide and 8m high. All of the walls were open and about one third of the roof was also open with the remainder confined, the floor was all confined. The rig configuration is shown in Figure 1.

2.2 Test Conditions

Structural response measurements were made during seven of the 45 experiments conducted for the HSE[1], the experimental conditions of the seven tests are summarised in Table 1. It can be seen that the first six experiments were carried out in nominally the same test conditions, i.e. natural gas/air mixture with an equivalence ratio of approximately 1.08 and ignition at the west end of the test rig. The final experiment was conducted with stoichiometric propane/air mixture, water deluge and ignition near the centre of the rig.

3. INSTRUMENTATION

The instrumentation within the test rig was located at positions whose co-ordinates are given in Tables 2 to 4, using a co-ordinate system with its origin at the inside south west corner of the rig, see Figure 1.

3.1 Overpressure Measurements

Overpressure measurements were made at 42 positions inside the test rig (PI1-PI42). The locations of these transducers are given in Table 2. Three of these transducers (PI40-PI42) were located close to some accelerometers (see Section 3.2 below) as shown on Figures 2a and 2b. This was to allow correlation of the pressure pulse against the response of the structure.

The overpressure measurement were carried out using PCB type M102A06 pressure transducers with in-built F.E.T. amplifiers. The specification of these transducers is:

Pressure range:	0 - 35 bar
Resonant frequency:	>500 kHz
Response time:	1µs
Nominal Sensitivity:	145mV/bar
Linearity:	1%

The sensitive faces of the transducers were nominally flush to the floor, roof or side surface in which they were mounted, and they were covered with a layer of silicon grease and aluminium foil, to reduce the effects of thermal radiation on the transducer measurements.

The transducers were connected by coaxial cable to amplifiers close to the rig. There the signal was amplified to maximise its quality, before transmitted to the control room and recorded on transient recorders.

3.2 Accelerometers

16 accelerometers were fixed to the test rig at 6 positions to measure the acceleration of various rig components during the explosion tests. The accelerometers used during these experiments were Endevco type 751-10 and 752-10 transducers. The specification of these transducers is shown overleaf:

Range	500g
Frequency Response	1 to 15,000 Hz
Resonant Frequency	50 kHz
Nominal Sensitivity	10mV/g
Linearity	1%

At each position where accelerometers were located, the acceleration was measured in 2 or 3 axes. To achieve this, the accelerometers were stud mounted in PCB 080B10 tri-axail mounting blocks which were stud mounted to the structure. Figure 3 shows details of the mounting. The accelerometers were protected as far as possible from the effects of flame and overpressure by steel covers sealed with silicon rubber.

The accelerometers were connected by coaxial cable to amplifiers close to the rig to maximise signal quality, before being transmitted to the control room and recorded on transient recorders.

3.3 Linear Displacements

Four linear displacement transducers were mounted at two locations (see Table 4) on the rig structure measuring the deflection of the structure along the X and Y axes. The two locations were chosen to allow comparison between the linear displacements and accelerations measured. The linear displacement transducers used were Penny and Giles type HLP350, the transducers were attached between the rig and strong steel columns, as shown in Figure 4. It should be noted that it was recognised in placing these transducers, they were not being fixed on a rigid base. This may have influenced the measurements made.

The transducers were energised using a power supply close to rig, the signal from the transducers being taken back to the control room by twisted pair cable and recorded on transient recorders.

4. RESULTS

Data was recorded during all seven of the tests conducted during this final phase of the HSE funded 'Explosions in Full Scale Offshore Module Geometries'[1]. The data is included with this report in electronic format on CD-ROM.

5. SUMMARY

Measurements of the structural response of the large scale explosion rig have been made during seven full scale experiments. Measurements of the displacement and acceleration of a number of components were made, combined with additional overpressure measurements. The data has been supplied in electronic format for analysis by CREA consultant for analysis as directed by the HSE.

6. REFERENCES

1. EXPLOSIONS IN FULL SCALE OFF SHORE MODULE GEOMETRIES
Evans, J.A., Johnson D.M. and Lowesmith B.J., (Work Carried Out under Contract to the HSE, MaTSU/8847/3522), R2422, May 1999.

7. APPENDIX A - TABLES

Table 1

Test Conditions for Explosion Experiments in Which Structural Response Measurements were made.

Test no.	Fuel	Equivalence ratio	Ignition position (m)			Deluge
			X	Y	Z	
HSE39	Nat. Gas	1.12	0.4	6	2	None
HSE40	Nat. Gas	1.09	0.4	6	2	None
HSE41	Nat. Gas	1.05	0.4	6	2	None
HSE42	Nat. Gas	1.09	0.4	6	2	None
HSE43	Nat. Gas	1.06	0.4	6	2	None
HSE44	Nat. Gas	1.08	0.4	6	2	None
HSE45	Propane	1	13.5	5	0.4	Full Area

Table 2
Pressure Transducer Positions

Pressure transducer	X Co-ord (m)	Y Co-ord (m)	Z Co-ord (m)	Pressure transducer	X Co-ord (m)	Y Co-ord (m)	Z Co-ord (m)
PI-1	0.8	0.5	0	PI-22	18	8	4
PI-2	6	0.5	0	PI-23	27.5	6	4
PI-3	12.5	0.5	0	PI-24	0.5	11.5	4
PI-4	22	0.5	0	PI-25	10	11.5	4
PI-5	27.5	0.5	0	PI-26	18	11.5	4
PI-6	0.5	6	0	PI-27	27.5	11.5	4
PI-7	9	6	0	PI-28	0.8	0.8	8
PI-8	14	6	0	PI-29	13.9	1.7	8
PI-9	21	6	0	PI-30	26.1	1.7	8
PI-10	27.5	6	0	PI-31	6.9	3.3	8
PI-11	0.5	11.5	0	PI-32	19.2	8.7	8
PI-12	12.3	11.5	0	PI-33	1.1	11.1	8
PI-13	27.5	11.5	0	PI-34	12.8	11.2	8
PI-14	0.5	0.5	4	PI-35	26.1	11.3	8
PI-15	4.5	0.6	4	PI-36	12	11.2	4
PI-16	12	0	5.5	PI-37	12	10.4	4
PI-17	12	0.5	4	PI-38	12	9.6	4
PI-18	22	0.5	4	PI-39	12	8.8	4
PI-19	27.5	0.5	4	PI-40	11.8	8	6.1
PI-20	10.2	4	4	PI-41	12.2	8	6.1
PI-21	0.5	7	4	PI-42	14	4	7.9

Table 3

Accelerometer Positions

Position	Accelerometer	Axis	Co-ordinates (m)		
			X	Y	Z
AX1	1	X	12	0	4.45
AY1	2	Y	12	0	4.45
AX2	3	X	12	-0.4	8.3
AY2	4	Y	12	-0.4	8.3
AX3	5	X	12.15	8	6
AY3	6	Y	12.15	8	6
AX4	7	X	14	4	8.3
AY4	8	Y	14	4	8.3
AZ4	9	Z	14	4	8.3
AX5	10	X	28	4	4.45
AY5	11	Y	28	4	4.45
AZ5	12	Z	28	4	4.45
AX6	13	X	28.4	4	8.3
AY6	14	Y	28.4	4	8.3
AZ6	15	Z	28.4	4	8.3

Table 4

Linear Displacement Transducer Positions

Linear displacement transducer	Axis	Co-ordinates (m)		
		X	Y	Z
LD-1	X	11.84	-0.52	4.29
LD-2	Y	11.84	-0.52	4.29
LD-3	X	28.52	4.17	4.28
LD-4	Y	28.52	4.17	4.28

8. APPENDIX B - DIAGRAMS

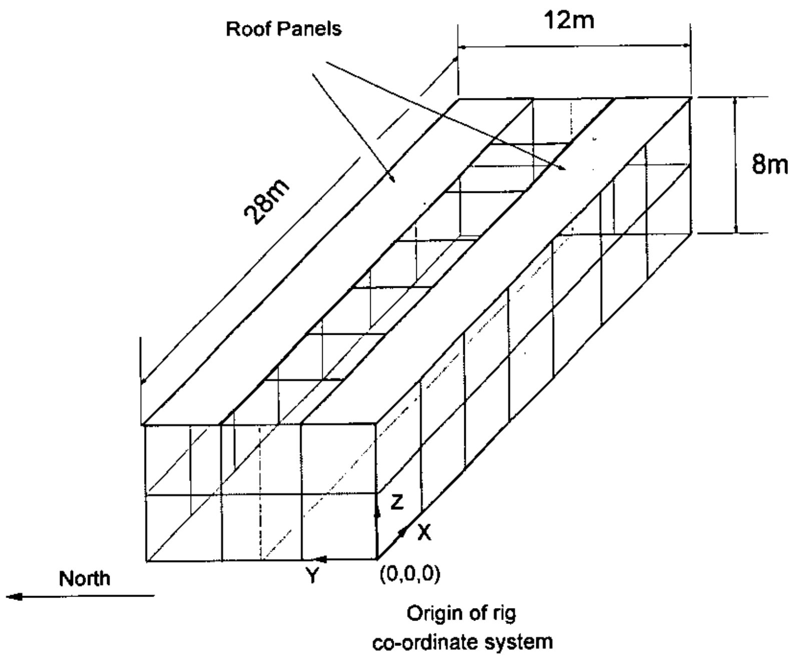

Figure 1 - Test rig configuration

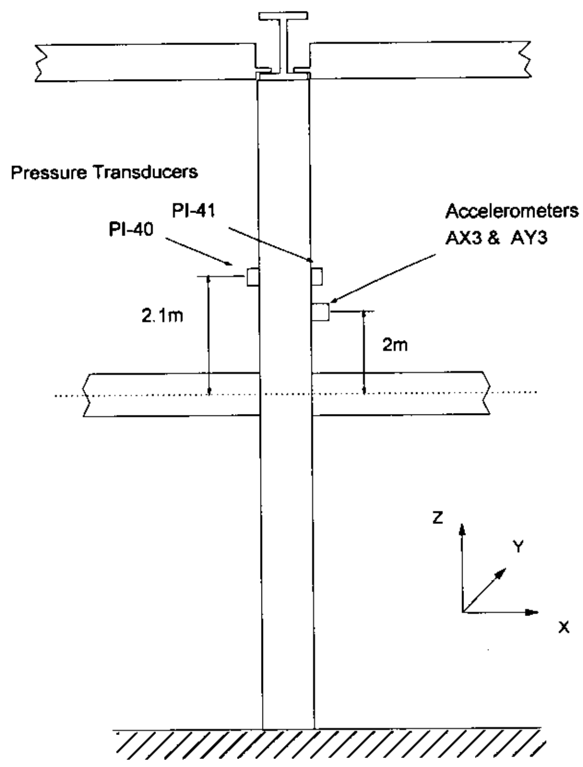

Figure 2(a) - Positions of pressure transducers PI-40 & PI-41 and associated accelerometers.

Contents

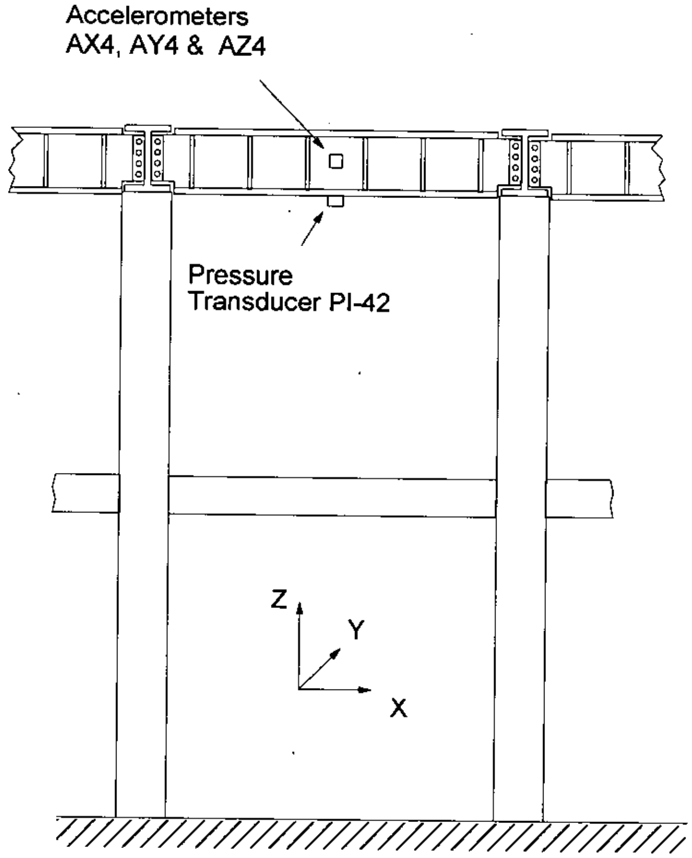

Figure 2(b) - Position of pressure transducer PI-42 and associated accelerometers.

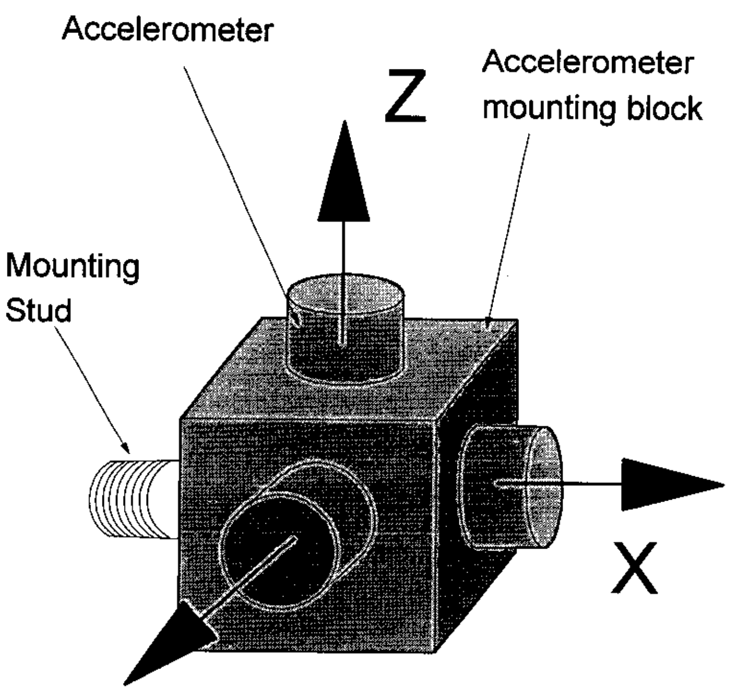

Figure 3 - Triaxial accelerometer

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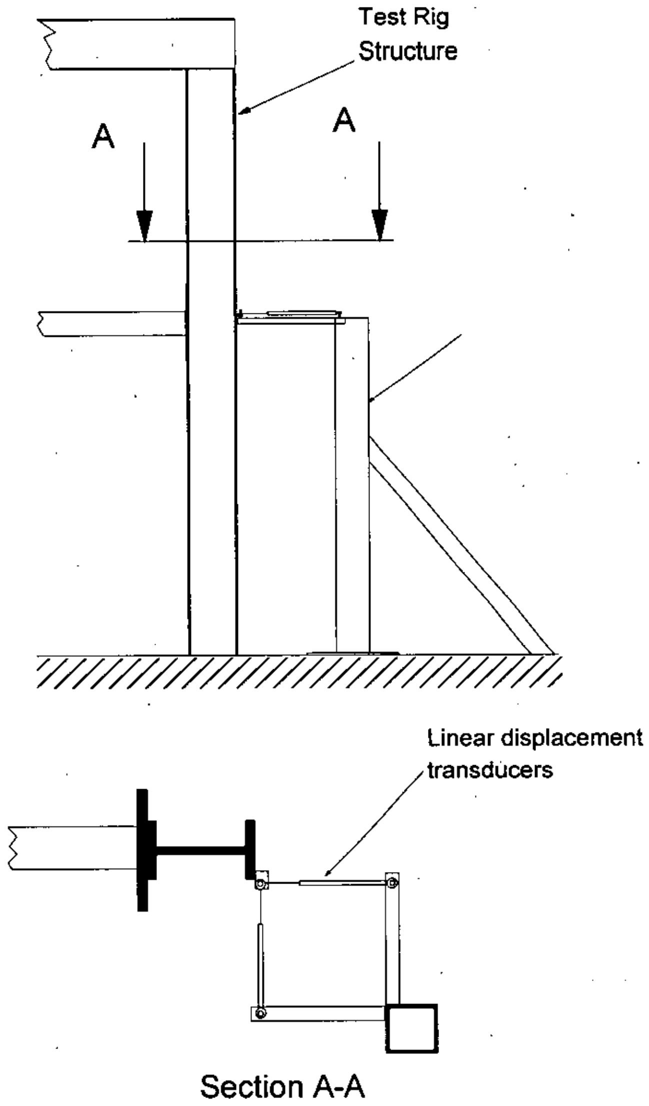

Figure 4 - Linear displacement transducer mounting

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