RESPONSE OF REINFORCED CONCRETE TARGETS TO IMPACTING SOFT MISSILES AN FRGMRT-UKAEA CO-OPERATION IN TESTS TO VALIDATE COMPUTER CODES AND SCALING LAWS

F. SAGE
UKAEA, Safety and Reliability Directorate,
Wigshaw Lane, Culcheth, Warrington, Lancashire WA3 4NE, United Kingdom

A. PFEIFFER
Gesellschaft für Reaktorsicherheit,
(GRS) mbH, Glockengasse 2, D-5000 Köln 1, Germany

This paper is concerned with the comparison of small scale model tests with large scale tests of soft crushable missiles impacting on reinforced concrete targets. It shows the need for very great care to get exact replicas of the models at the two different scales and demonstrates that if this is achieved the results of the small scale tests using micro concrete give a remarkable correspondence with the larger scale using full size aggregate.

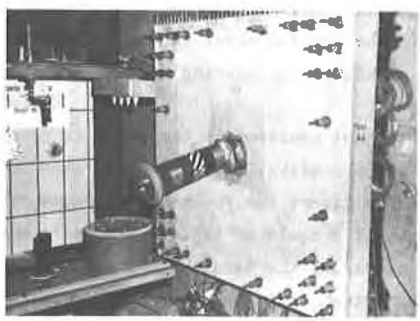

Figure 1. Foulness Test No 44

Figure 2. Meppen Test II/5

Figure 3. Foulness Test No 50
Front Face

1. INTRODUCTION

More than a year ago the UKAEA and the Federal Ministry of Research and Technology (FRG.MRT) started a very close co-operation, concerning the response of reinforced concrete to impacting soft missiles, then in anticipation of an agreement on nuclear safety and research a first phase of experimental work was started.

It was clear in the discussion that both sides already had a test programme in operation and that while many of the basic aims of both sides were the same such as the validation of their respective computer programmes the actual tests so far carried out were quite different with quite different aims in view. The German tests in Meppen on projects RS 149/165 used large scale targets with large amounts of shear reinforcement and soft tube shaped missiles, the main aim being to determine more exactly the structural response and safety margins of containment shells in case of an airplane crash. The British tests at Foulness on the other hand had a large number of much smaller targets (1/25 full size) and used the absolute minimum of shear steel relying on the concrete to carry the shear stresses and in addition to soft missiles gave growing consideration to hard missiles originating from internal accidents by the disintegration of components.

Three major points of interest emerged from this. The first was a general agreement that the most valuable information would be obtained from a target which the missile had just penetrated. If the missile perforated the target instrumentation on the back would be destroyed and if it did not penetrate the full strength of the target was still unknown. The second point was that it seemed desirable to make certain that the scaling laws are found valid and to check the possibility of parameter variations by comparing the restricted number of large scale tests with the smaller model tests. The third point of interest was the use of shear steel and its effect on the bearing capacity of the test slab and its effect if any on scaling.

In order to get a missile to just penetrate a target it is necessary to know fairly accurately the velocity of the given missile. With the programme for a large scale test at Meppen proceeding it was decided to divert the Foulness programme of work to construct three exact replicas of the Meppen test at a scale of 1:5.6. The tests would be made first with a missile velocity chosen not to penetrate the target but to bounce off giving deflection and load measurements etc. The second test would be made with a missile velocity chosen to give full perforation. From these two tests the third test would be carried out at a velocity chosen to give penetration. This was to determine the velocity at which the large scale missile at Meppen should be launched and to start demonstrating the effects of scaling.

Four tests at the large scale were planned for Meppen with varying amounts of shear steel. One test with full shear steel based on the usual German methods for the reactor structural analysis, the second with 75% of this shear steel, the third with 50% shear steel and the fourth with no effective shear steel at all but the thickness of concrete increased. Each of these tests to be preceeded at Foulness by two identical small scale tests, to establish the launch velocity of the missile at Meppen and to further vindicate the effects of scaling. Besides providing starting points for the validation of the various computer codes the object of these tests was therefore to give mutual confidence in small scale testing and the scaling laws and by co-operation on both sides to lay the foundations for a possible and more formally agreed co-operation in the longer term.

2. FIRST PHASE OF TESTING

It was possible to aim at a direct visible and therefore convincing comparison of the model and large scale test results so that discussions of an abstract numerical conversion process could be avoided. This required careful attention to detail and before the casting of any targets it was agreed that the crushing strength of the concrete, to be aimed for, in both Meppen and Foulness, should be 38 MN/m^2.

From previous tests at Foulness considerable experience had been built up of launching the missile using a sabot which was stripped off as the missile passed through a stripper plate. It was therefore decided to use this method for the tests with the model of the German type missile (tests 39 to 42 in Table I). Test 39 was successful but in the other cases with the increased velocity the missile was damaged at the stripper plate.

In test 39 the missile impacted on the centre of the panel and the concrete cover spalled from the impact area. On the rear face of the target there was some light radial cracking and a circular shear crack appeared at 200 mm radius. When the target was sectioned later, it revealed the full development of a shear plug which was held in position by the unbroken bending steel.

In test 40 the velocity was increased and damage to the target was similar to test 39.

In test 41 the missile velocity was 215 ms^{-1} and the damage to the panel appeared similar to test 39.

Test number 42 was a repeat of test 41 using the same panel that was used for test 41.

The missile attained a velocity of 220 ms^{-1} and was again damaged at the stripper plate. It penetrated the target to a depth of 27 mm and broke eight wires on the front face. The shear plug was completely formed and there was some scabbing on the rear face.

When test II/5 was carried out at Meppen the velocity of the missile was 236 ms^{-1} and it penetrated into the target. The front face reinforcement was broken, cover was stripped from the vertical bars on the rear face and much of the concrete in the shear plug had broken up and been forced through the rear face bending steel, three bars of which were broken.

A very careful search was then made for descrepancies and three main factors emerged. Under the laboratory conditions at Foulness a concrete strength very near to and slightly in excess of the 38 MN/m^2 was obtained while cores taken from the edge of the target at Meppen revealed that under these site conditions the concrete strength was 33 MN/m^2. Tests on the reinforcement taken from the front face of the Meppen target showed an ultimate tensile strength of 511 MN/m^2 against the 685 MN/m^2 of the Foulness models. (Note: These results were taken from single specimens.) A UK computer run indicated that when these factors were taken together with the increased velocity of the Meppen missile (236 ms^{-1}) the results were comparable. However, this did not meet the requirement of giving a readily discernible comparison and thereafter a better correspondence was strived for to establish the model technique as an independant tool besides computer codes.

A new method of launching the German type of missile was perfected at Foulness using two polyurethene rings for support in the barrel instead of a sabot. Two further small scale tests were arranged and the targets were cast taking great car to get the crushing strength of the concrete on the day of the test as near to the 33 MN/m^2 of the Meppen target as possible. In the event this was 32.7 MN/m^2 and the bending steel on the front face was changed so that the ultimate strength was very close to that in the Meppen target.

In test 43 the missile had a velocity of 229 ms^{-1} and it penetrated the panel 45 mm punching through the front steel as in the Meppen test. A shear plug was formed and deflection of the rear face and scabbing were very similar to the Meppen target. There was however no apparent failure of the rear face steel, which can be accounted for by the lower velocity of the missile in the Foulness test.

Test 44 was a repeat test of 43 as a check on repeatability of the results. In the event missile velocity, concrete strength, and target damage were all exceedingly close and the two tests were in fact almost identical and well within the limits to be expected from two separate tests of this nature.

The tests 39 to 44 are summarised in Table I for comparison and Figure 1 showing the Foulness test 44 and Figure 2 showing the Large Scale Meppen test II/5 clearly shows the degree of agreement achieved at the two different scales.

3. SECOND PHASE OF TESTING

From these encouraging results five further small scale tests (46 to 50 see Table II) at Foulness were planned, to preceed three large scale tests at Meppen. This was to check the effect of the use of shear steel and to further establish the validity of scaling.

In test 46 with 75% shear steel the concrete cover spalled from the impact area to a depth of 9 mm. There was slight scabbing and cracking of the rear face. The maximum deflection was 6 mm and the residual deflection was 4.5 mm.

In test 47 carried out one week later the missile velocity was increased to give approximately 7% increase in missile energy. The concrete cover spalled from the impact area to a depth of 10 mm there was slight cracking on the rear face. The maximum deflection was 7.3 mm and the residual deflection was 5 mm.

The comparable test at Meppen is test II/8 (Table III) damage to the target was similar and the residual deflection was 42 mm. (42/5.6 equals 7.5 mm model scale.)

In test 48 with 50% shear steel the target damage was similar to tests 46 and 47 with a maximum deflection of 6.7 mm and a residual deflection of 5 mm. In test 49 the missile velocity was increased to give approximately 14% increase in missile energy and the missile penetrated the panel to a depth of 37 mm. Some front face bending steel was broken a shear plug was formed with a large amount of scabbing of the rear face. The rear face bending steel remained intact and the maximum deflection was 31 mm with a residual deflection of 26 mm.

The comparable test at Meppen is test II/7 where the residual deflection was 113 mm. (20 mm model scale.)

In test 50 with 100% shear steel the missile penetrated the panel to a depth of 38 mm, some of the front bending steel was broken and there was a large amount of scabbing of the rear face. The maximum deflection was 26 mm and the residual deflection was 20 mm.

The comparable tests at Meppen is II/6 which had a residual deflection of 142.3 mm. (25.4 mm model scale.)

This is quite typical of this series of tests and the degree of agreement achieved can be seen by comparing Figure 3 with Figure 4 and Figure 5 with Figure 6.

4. THIRD PHASE OF TESTING

Two further small scale tests at Foulness were arranged to preceed one large scale test at Meppen partly with the object of continuing the checks on the validity of scaling but mainly with the object of giving a comparison between the effect of using shear steel or using a thicker concrete target panel with no effective shear steel.

In test 51 (Table II) the concrete cover spalled from the impact area for a depth of 6 mm. There was light cracking on the rear face and the maximum deflection was 1.5 mm with a residual deflection of 0.3 mm.

In test 52 a missile velocity of 250 ms^{-1} was aimed for to give a comparison with test 49. This would give a missile energy approximately 16% greater than for test 51. The concrete cover spalled from the impact area to a depth of 8 mm. There was light cracking on the rear face and the maximum deflection was 2.5 mm with a residual deflection of 0.5 mm.

The comparable test at Meppen is test II/10 where the reinforcement on the front face was just exposed with slight cracking on the rear face. The maximum deflection was 17 mm. (3.0 mm model scale)

5. CONCLUSIONS

Small scale models give results with a remarkable degree of correspondence with results from large scale models tending to prove the validity of scaling.

The small scale experiments are an highly effective tool to investigate the qualative and quantative orders of magnitude. It is desirable to support these by tests at as large a scale as possible to give added confidence and in those cases where it is necessary to check local existing safety margins more exactly.

A general factor to be researched is the fact that the damage in the small scale tests is slightly less than in the large scale. This might be due to the higher strain rate of the model targets which is not completely compensated for by the higher strain rate in the model missiles.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to Mr T P O'Brien and his colleagues at Foulness and to Mr H Heine and his colleagues at Meppen for their valuable help in carrying out this work.

REFERENCES

(1) Davies I Ll. Scaling laws applied to impact testing and computer assessments made to compare tests at two scales - Paper J8-1 SMiRT 5th Conference (Berlin 1979)

(2) Reich H. Experimental investigations to determine the kinetic ultimate bearing capacity of reinforced concrete slabs subject to deformable missiles - Paper J8-5 SMiRT 5th Conference (Berlin 1979)

(3) Jonas W. Approximate calculations of the impact of missiles onto reinforced concrete structures and comparison with test results - Paper J8-6 SMiRT 5th Conference (Berlin 1979)

Table I

Test No	Type of Missile	Weight of Missile KG	Velocity of Missile ms^{-1}	Target	Concrete Compressive Strength MN/m^2	UTS Wire MN/m^2	Yield Point of Wire MN/m^2
Foulness 39	1–5.6 scale of German soft missile	5.70	212	1–5.6 scale of German target	38.1 $\pm$ 1.5	Rear face 528 Front face 685	Rear face 470 Front face 626
Foulness 40	"	5.70	227	"	40.5 $\pm$ 0.8	"	"
Foulness 41	"	5.70	215	"	39.7 $\pm$ 3.55	"	"
Foulness 42	"	5.70	220	Repeat firing on target used for test 41	"	"	"
Meppen II/5	Full scale missile	1000	236	Full scale 6 m x 6.5 m x 700 mm RC Target	33 $\pm$ 0.2	Rear face 502 Front face 510	Rear face 436 Front face 440
Foulness 43	1–5.6 scale of German soft missile	5.745	229	1–5.6 scale of German target	32.7 $\pm$ 1.1	Rear face 528 Front face 511	Rear face 470 Front face 470
Foulness 44	"	5.745	229	"	32.7	"	"

Table II

Test No	Type of Missile	Weight of Missile KG	Velocity of Missile ms^{-1}	Target	Concrete Compressive Strength MN/m^2	UTS of Wire MN/m^2	Yield point of Wire MN/m^2
46	1/5.6 Scale of German missile	5.822	235	1/5.6 of German Target panel shear steel = 75% of maximum specified in German design (Model panel thickness 125 mm)	33.13 ± 1.52	Front Face 502 Rear Face 519 Shear steel 494	Front Face 446 Rear Face 466 Shear steel 423
47	"	5.855	242	As Test 46	33.6 ± 1.99	Front Face 502 Rear Face 519 Shear steel 494	"
48	"	5.770	234	As for Test 46 but shear steel reduced from 75% to 50%	32.01 ± 1.23	Front Face 502 Rear Face 530 Shear steel 508.4	Front Face 446 Rear Face 479 Shear steel 488
49	"	5.787	250	As Test 48	31.5 ± 2.67	Front Face 502 Rear Face 520 Shear steel 508.4	Front Face 446 Rear Face 471 Shear steel 488
50	"	5.881	260	As for Test 46 but shear steel increased from 75% to 100%	30.01 ± 0.95	Front Face 512 Rear Face 520 Shear steel 510	Front Face 463 Rear Face 471 Shear steel 470
51	"	5.792	233	1/5.6 of German Target panel but thickness increased to 161 mm and with no effective shear steel	36.81 ± 1.34	Front Face 512 Rear Face 542	Front Face 463 Rear Face 483
52	"	5.791	251	As Test 51	34.42 ± 1.6	Front Face 512 Rear Face 542	Front Face 463 Front Face 483

Table III

Test No	Type of Missile	Weight of Missile KG	Velocity of missile ms^{-1}	Target	Concrete Compressive Strength MN/m^2	UTS of Wire MN/m^2	Yield point of Wire MN/m^2
II/6	Tube shaped 6 m long by 0.6 m diameter	956	258	6 m x 6.5 m x 0.7 m thick with max shear steel specified in German design	33.5	Front Face 510 Rear Face 502 Shear steel 510	Front Face 440 Rear Face 436 Shear steel 440
II/7	"	940	225	As II/6 but shear steel reduced to 50%	33.0	As II/6	As II/6
II/8	"	990	236	As II/6 but shear steel reduced to 75%	33.7	As II/6	As II/6
II/10	"		245.6	6 m x 6.5 m x 0.9 m thick with no effective shear steel	33.8	As II/6 No shear steel	As II/6 No shear steel


Figure 4. Meppen Test II/6 Front Face


Figure 5. Foulness Test No 50 Rear Face


Figure 6. Meppen Test II/6 Rear Face