The Dambusters Revisited

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SYNOPSIS. The British raid on the Möhne, Eder and Sorpe dams on the night of 16/17 May, 1943 caused the breaching of the 40m high Möhne and 48m high Eder dams and serious damage to the 69m high Sorpe dam. This paper considers the planning for the raid, model testing, the raid itself, the effects of the breaches and the subsequent rehabilitation of the dams.

Whilst the subject is of considerable historical interest it also has significant contemporary relevance. Events following the breaching of the dams have been used for the calibration of dambreak studies and emphasise the vulnerability of road and railway bridges which is not always acknowledged in contemporary studies.

INTRODUCTION

In researching this paper the authors have been very struck by the human interest in the story of English, German and Ukrainian people, whether civilian or in uniform, who participated in some aspect of the raid or who lost their lives or homes. As befits a paper for the British Dam Society, this paper, however, concentrates on the technical questions that arise, leaving the human story to others.

This paper was prompted by the BDS sponsored visit, in April 2009, to the Derwent Reservoir by 43 members of the Association of Friends of the Hubert-Engels Institute of Hydraulic Engineering and Applied Hydromechanics at Dresden University of Technology. There is a small museum at the dam run by Vic Hallam, an employee of Severn Trent Water. The museum commemorates the construction of the dam and also the raid, since the RAF practised at Derwent reservoir.

Like the Möhne Dam in the Ruhr Valley the Derwent Dam has two towers which were used by the bomb aimers to gauge their distance from the target (the towers are the same distance apart as those on the Möhne Dam).

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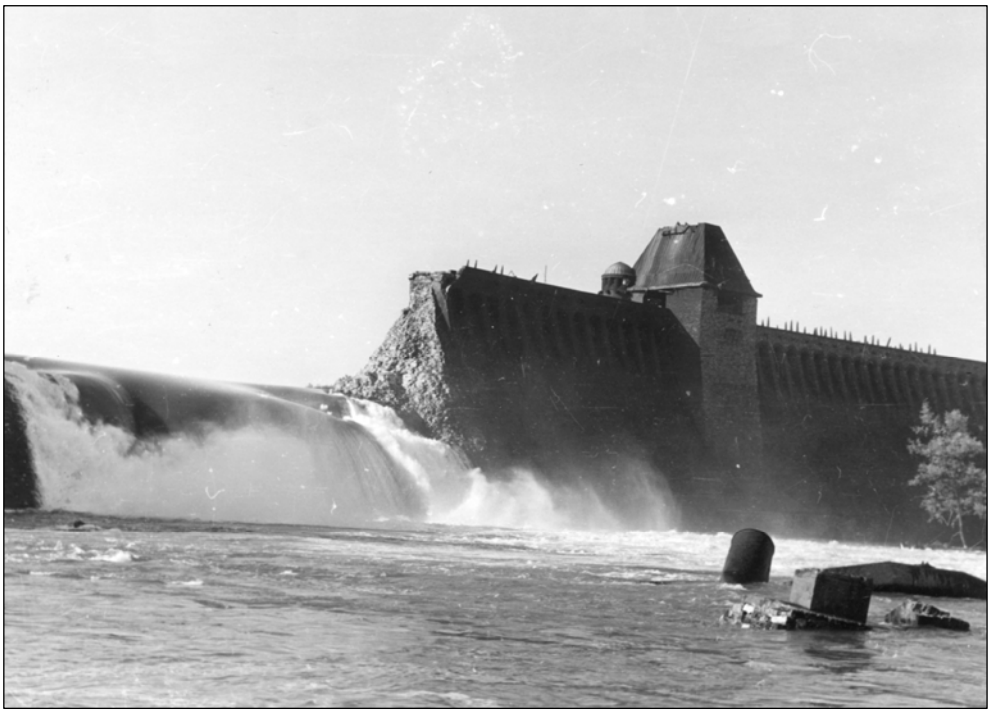

Figure 1. The Möhne Dam after breaching (Ruhrverband)

Four dams were attacked on the night of 16/17 May, 1943 while the reservoirs were full of water after the winter. The principal dams attacked were the 40m high Möhne Dam constructed of cyclopean masonry, the 48m high Eder dam also built of cyclopean masonry and the 69m high Sorpe dam which was earthfill with a reinforced concrete core. The 51m high Ennepe dam was unsuccessfully attacked by a single aircraft. The weight of explosive used in the final version of the Upkeep bomb was 2,950kg set to explode at a depth of 9.7m. The modified Lancaster bombers flew at a dangerous height of only 18m, controlled by spotlights on the water and at a speed of 380 km/hr.

The bombs were cylindrical in form and were rotating at 500rpm anticlockwise when viewed from the right (The idea of imparting backspin to the bombs was suggested by George Edwards, the Vickers Experimental Manager who was a keen cricketer). The backspin imparted lift of about 12.3kN to the bomb during its passage through the air reducing the effective weight by about 30 percent. The most significant aspect of the backspin was, however, to increase the effective forward speed of the aircraft and thus reduce the impact angle from 8.6 degrees to below the critical angle of 7 degrees needed for the bomb to bounce. At the Möhne and Eder dams the

bombs bounced over the surface of the water and over two anti-torpedo nets[1] before hitting the dam wall and sinking close to the dams.

The Möhne dam was attacked by five aircraft, the fourth of which produced a direct hit and breached the dam releasing most of the 135 Mm^3 of water in the reservoir. The Eder dam was attacked by three aircraft, the third of which produced a direct hit and breached the dam releasing most of the 202 Mm^3 of water in the reservoir. The Sorpe dam was attacked by two or three aircraft flying along the axis of the dam. It was briefly overtopped and damaged but not breached.

Eight aircraft were lost; 53 airmen were killed and three taken prisoner

The failure of the Möhne and Eder dams caused widespread devastation downstream. There were 1,294 killed and missing including 749 foreign forced workers, most of whom came from the Ukraine.

A total of 343 houses were destroyed or badly damaged, while 52 factories were destroyed or badly damaged and another 73 suffered lesser damage. 34 railway and road bridges were destroyed or badly damaged with 12 suffering lesser damage.

The dams were repaired fairly quickly. The repairs at the Möhne dam were completed on 3 October, 1943.

PLANNING FOR THE RAID

Since 1937 the UK Air staff had recognized the importance of the dams (particularly the Möhne and Sorpe) and had been seeking ways of destroying them. These efforts intensified after the outbreak of war in 1939.

It is interesting to note that there was early concern in Germany about the possible vulnerability of their dams; on 29 August 1939 Just Dillgardt (Mayor of Essen and Chairman of the Ruhrtalsperrenverein (Ruhr Reservoirs Association)) drew the attention of military authorities in Műnster to the vulnerability of "the large dams in southern Westphalia". He said that a vast outflow of water from the Möhne reservoir would deprive the population of four to five million of water and that all mines and coking plants would suddenly cease work owing to lack of industrial water supply.

[1] There were no anti-torpedo nets at the Eder Dam as the Germans thought that the terrain would preclude an attack.

It is also interesting to note that in 1940 the Germans considered attacking Derwent and Howden dams near Sheffield which were later used by 617 Squadron in training for Operation Chastise.

Barnes Wallis (born 26 September 1887 at Ripley in Derbyshire; died 30 October 1979 aged 92) was the central figure in planning the attack on the Ruhr Valley Dams. At the start of the war he was assistant chief designer at the aviation section of Vickers-Armstrongs at Weybridge. In October 1940 he asked the Ministry of Aircraft production for a copy of a report by W.T.Halcrow which concluded that the strong construction of the Möhne dam precluded successful attack. This opinion was repeated in Halcrow's report of May 1941 which said that "There does not appear to be any prospect of bringing about the failure of the dam as a whole with charges of the order of magnitude contemplated".

Figure 2. Sir Barnes Wallis (1887 – 1979)

CALCULATIONS, SCALE MODELS AND NANT-Y-GRO DAM

Notwithstanding pessimism about the likely success of a bombing raid, the perceived importance of the targets led to continued investigations inspired, in no small part, by Barnes Wallis. It was recognised from an early date that theoretical calculations using strain energy would need to be validated by model tests. To this end a 1/50 scale model of the Möhne Dam was constructed at the Building Research Station at Garston, near Watford, in November 1940 to January 1941. The model was 12.8m long by about 0.9m high and 0.6m thick at the base. It is still to be seen in the grounds of BRE. Once completed the structure was exposed to ten separate explosions of 56 gramme charges at distances of 0.3m to 0.9m but, although cracked,

the dam held. The 56 gram charges represented 50^3 x 56/1000 kg = 7,000 kg of explosive on the prototype.

Subsequent tests were carried out on another 1/50 scale model of the Möhne Dam at the Road Research Laboratory at Harmondsworth. There were, however, doubts as to the validity of scaling up the results from these small models and negotiations were, therefore, started with Birmingham City Corporation for the use of their disused 10.7 m high Nant-y-Gro dam which is on the right bank of Caban Coch reservoir near the town of Rhyader in mid-Wales. On 27 December 1940 Dr. R.E.Stradling, Chief Scientific Adviser to the Ministry of Home Security, visited Birmingham and secured permission to use the dam 'for experimental purposes', which might result in its destruction, with no requirement for 'reinstatement'. For calibration purposes a 1/10 scale model of Nant-y-Gro was constructed at Harmondsworth.

During spring 1942 tests were conducted at the Road Research Laboratory on the 1/10 scale models of the Nant-y-Gro dam. These models were subjected to scaled explosions at various distances from them. There was, however, an interesting development. The possibility of using contact charges had been informally discussed at an early stage of the experiments and discarded on account of the accuracy of bombing required. In late February or early March 1942 A.R.Collins decided to see if a contact explosion would breach one of the damaged models at Harmondsworth and was astonished to see pieces of mortar flung 9m away. This unscheduled contact explosion had an important effect on Wallis's thinking; Wallis later said that the bouncing bomb was invented solely to meet the requirements so convincingly demonstrated by this experiment.

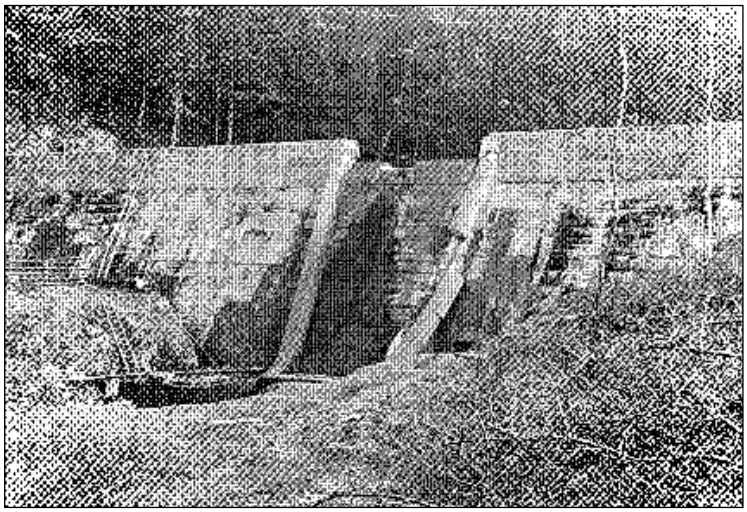

Figure 3. Nany-y-Gro dam (looking upstream) at the start of the testing programme. (Crown Copyright)

Nant-y-Gro Dam itself was destroyed by a contact explosion on 24 July 1942.

THE RAID

The raid was planned in great secrecy. In the end 19 modified Lancasters of 617 squadron from RAF Scampton took part in the raid led by Wing Commander Guy Gibson. Eight aircraft were lost.

The aircraft flew very low over the North Sea and Germany. It was a moonlit night and they had great difficulty avoiding flak and also high tension power cables (two aircraft crashed after hitting power cables). Eight of the 19 aircraft were lost.

One of the aircraft crashed near Gladbeck enabling the Germans to recover an undamaged Upkeep bomb. They studied this carefully and by 26 May (i.e. 10 days after the raid) they already had blueprints for their own bouncing bomb named 'Kurt'. This was never used but the British had to divert significant resources to defending British dams against attack with their own weapon. The reservoirs protected included Laggan, Caban Coch, Howden, Derwent and other reservoirs in the Sheffield area as well as Queen Mary Reservoir near Staines. High steel towers were erected beside the reservoirs with chains and hanging cables stretched between them to deter low-level attack. There were also searchlights, anti-aircraft guns and smokescreen apparatus.

MÖHNE DAM

The design of the Möhne Dam was based on the principles of Prof Dr.Otto Intze (1843 – 1904). He designed at least 12 masonry dams in his lifetime and 24 followed his methods.[2] The 'Intze type' dam was curved in plan with a radius of the valley width at the dam crest. It was designed as a gravity structure following the middle third rule. Any benefit of arching was neglected but assumed to provide an additional factor of safety. Uplift was not calculated but Intze took a number of measures to restrict its likelihood.

The Möhne dam was actually designed by Ernst Link who was an assistant of Otto Intze and who joined the Ruhr Reservoirs Association in 1904 – the year in which Otto Intze died on 28 December.

[2] A brief biography of Prof. Dr. Otto Intze is given on Page 177 of Dams and Reservoirs, Vol 19 No 4 of December 2009

The dam took four years to build and incorporated an ‘Intze wedge’ on the upstream side of the dam. This was a bank of clay and rockfill placed against the lower part of the dam to reduce internal uplift.

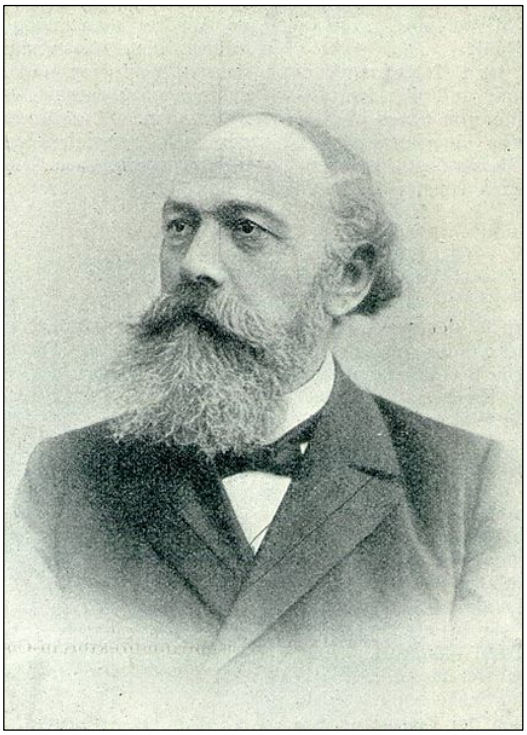

Figure 4. Prof Dr.Otto Intze (1843 – 1904).

EDER DAM

The Eder Dam was built between 1908 and 1914. It was a gravity dam of cyclopean masonry impounding a reservoir with a surface area of 11.8 km^2 and a capacity of 199.3 Mm^3, which made it the third largest reservoir in Germany. The design was linked to the name of Leo Sympher (1855 – 1924) who was a hydraulic engineer and one of the leading men of the German Waterways Administration.

The dam was intended for flood control and also for increasing the water flow in the Fulda and Weser Rivers and to supply water for the Mittelland Canal.

The attack in May 1943 caused a breach 70m wide and 22m deep and released a peak flow of 8,000 m^3/sec.

Owing to the rapid lowering of water level in the reservoir there were four sizeable landslips of the reservoir banks.

SORPE DAM

The Sorpe Dam was planned by Ernst Link and was built between 1926 and 1935. It contains 3,250,000 m^3 of earthfill and has a reinforced concrete core wall between 6m and 1.25m thick. The reservoir has a surface area of 3.30 km^2 and contains 70 Mm^3. There is power generation capacity of 7.44 MW at the dam.

The attack on 17 May 1943 inflicted only minor damage and two craters 12 m deep. However the RAF returned on several occasions so that a total of 11 bombs were dropped on the dam. On 15 October, 1944 they dropped five Tallboy bombs leaving behind only large craters. However in January 1951 there was a sudden and steady rise of seepage water (max 180 litres/sec) which contained soil fractions of up to 34 cm^3/litre. This internal erosion resulted in ground settlement of up to 1.4 m. The problem was attributed to bomb damage to the concrete core and led to grouting from the inspection gallery. During the repair of the dam there were 53,000m of boreholes; 4,350t of cement were used and 1,700t of clay as well as significant amounts of synthetic materials. The post-war difficulties at the Sorpe Dam, which lasted for a number of years, led to a major acceleration of construction of the new Henne Dam which is on another tributary of the Ruhr.

In 1958 the reservoir was drained for bomb damage repairs, in the course of which workers discovered an unexploded Tallboy bomb. On 6 January 1959 the whole village of Langscheid was evacuated while the Chief Bomb Disposal officer for Nordrhine-Westfalen, Walter Mietzke, and British Lieutenant, James M. Waters, jointly defused the 3.6m long bomb that still contained 2,500 kg of high explosive and a highly unstable acid fuse.

Figure 5. Bomb defused at Sorpe Dam in January 1959 (Ruhrverband)

Dr.Ing. Otto Kirschmer describes tests carried out in Germany in 1935 in connection with plans for a 118 Mm^3 reservoir near Pirna. Various models 3.0m high were attacked with charges of trinitrotolulene (TNT). The law of similarity for explosives is:

$$t^3 = a^3L$$

Where t is the depth of crater in metres
L is the weight of explosive charge in kg
a is a function of the type of earth and was 0.73 for non-cohesive sand of 0.02mm to 2mm

It was assumed in the experiments that the explosions occurred at a depth of 0.8m and that the craters had a natural slope of 36^o.

Otto Kirschmer's findings are reproduced below:

Table 1. Effect of different explosive charges on crater size

Explosive charge (kg)	0.2	100	250	500	1,000
Crater depth (m)	0.43	3.4	4.6	5.8	7.3
Crater diameter (m)	1.2	9.4	12.7	16.0	20.0

ENNEPE DAM

The Ennepe Dam[3] was a 51m high masonry dam with a convex curve into the reservoir. It was 330m long with a road over the top. It had circular gate towers 183m apart. Located 32km due south of Dortmund and 48km south-west of the Möhne Dam it held back 12.6 Mm^3 of water in the reservoir. The dam was built between 1902 and 1904.

REHABILITATION OF THE DAMS

On 2 October 1943 Hitler sent a telegram to the Ruhr Ensatzgruppe in Heidhausen expressing his particular thanks for the completion of repairs to the Möhne Dam. The repairs, using 18,000m^3 of masonry, had taken only 4½ months and were carried out by the Organisation Todt (OT), a Third Reich civil and military engineering group in Germany with about 2,000 forced-workers, mainly from Germany, Italy and Croatia.

A deep hole had been scoured out from the base of the dam immediately downstream of the breach. This was thought to have weakened the

[3] Sweetman (2002) makes a strong case that the fourth dam attacked was the Bever Dam not the Ennepe dam

foundations and a block of concrete, with a volume of 10,000 m^3, was constructed to support the downstream toe of the dam.

The repair of the dams and damaged infrastructure downstream required the diversion of 27,000 men from the construction of fortifications along the Channel coast (The Atlantic Wall) and thus made a positive contribution towards the Allied invasion via Normandy. 10,000 troops were also diverted to guard other dams in Germany.

DAMBREAK STUDIES

The flood wave caused by the breaching of Möhne Dam was bigger than any natural flood in the Ruhr Valley recorded before or since. Even though almost all relevant discharge gauging stations along the river had been washed away by the flood wave, it has been possible to use the available data for the calibration of dambreak flood waves.

CONCLUSIONS

Even after 65 years the Dambuster raid remains a controversial subject. It certainly gave a considerable boost to Allied morale, and was referred to two days later on 19 May, 1943 when Winston Churchill addressed a joint session of the US Congress. The Russians were also impressed. But it caused high loss of life amongst the aircrews and also amongst Ukrainian workers housed downstream of the Möhne dam. A considerable number of factories, many engaged in the production of munitions, were destroyed or seriously damaged but there was also a considerable amount of what is now termed “collateral damage” - 343 houses were destroyed or seriously damaged together with a number of farms. There were 545 German citizens killed or missing.

Objectives of the raid included the destruction of coal mines, coking plants and hydropower potential at the dams, as it seems that the Allies believed the hydropower capacity at the dams to be significant. There was, in fact, only 7 MW installed capacity (Otto Kirschmer says 4.8 MW) at the Möhne dam and 30 MW at the Eder with a further 7.3 MW at the Sorpe Dam. However the 140 MW Herdecke Pumped Storage Power Station on the River Ruhr was reported to have been flooded to a depth of 2.1 metres as a result of the breaching of the Möhne Dam. This station was not restored to full capacity until the end of 1945.

There was also a 115 MW Pumped Storage Plant at Hemfurth near the Eder dam which is reported to have suffered heavy damage. Notwithstanding the above the effect of the raid on power supplies to Ruhr industry appears to have been short-lived.

If, as had been intended, both the Möhne and Sorpe dams had been breached the effect on water supplies to the Ruhr valley would have been serious since 75 % of the water supply for the Ruhr conurbation came from these two dams. With the Sorpe Dam intact after the raid the disruption to water supplies was not great.

From the engineering point of view it was a significant achievement to breach such substantial structures as the Möhne and Eder dams. The failure to breach the Sorpe dam testifies to the robustness of the earthfill with a reinforced concrete core. Otto Kirschmer remarked that:

"Earth dams are safer from the point of view of deliberate damage than are masonry dams…….Dams of hollow construction are particularly vulnerable to deliberate damage".

He adds that "Reduction of water level by a few feet is sufficient in the case of both masonry and earth dams to ensure sufficient safety in case of danger of attack".

The swift repair of the dams is a tribute to German organisation. Photographs taken at the time show large numbers of workers from Italy, Croatia and Germany engaged in the task.

The downstream damage from the breaching of the Möhne and Eder dams has played a valuable part in the calibration of dambreak studies which are now such an important part of reservoir engineering.

ACKNOWLEDGEMENTS

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REFERENCES

British Intelligence Objectives Sub-Committee (1945), *Report on Dams and Hydroelectric Schemes in South West Germany*.

British Intelligence Objectives Sub-Committee (1945), *German Experimental Work on the Attack of Reinforced Concrete by Explosives and Projectiles and Inspection of the Möhne and Eder Dams*, September 1945.

Collins A.R. (1982), *The origins and design of the attack on the German Dams*, Proc ICE, Volume 73, Part 2, June.

Euler H (1999) *Als Deutschlands Dämme brachen*, Motorbuch Verlag, Stuttgart.

Franke P (Ed) (2001), *Dams in Germany*, Verlag Glückauf GmbH

Gibson, G. (1946), *Enemy Coast Ahead – Uncensored*, Crécy Publishing Ltd.

Halcrow W.T. (1941), *Results of Tests on a Scale Model Masonry Gravity Dam*, Report MAP/12, May.

International Commission on Large Dams (1974), *Lessons from Dam Incidents*, ICOLD, Paris.

Kirschmer O. (1951), *Destruction and Protection of Dams*, New Zealand Engineering, June.

Murray, I. (2009), *Bouncing-bomb Man*, Haynes Publishing

Sweetman, J. (2002) *The Dambusters Raid*, Cassell Military Paperbacks, London.