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Containment for petroleum products – lessons learnt from Buncefield, UK

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A massive explosion and fire at the Buncefield oil terminal in Hertfordshire, UK on 11 December 2005 caused significant damage to the terminal and neighbouring buildings. Significant environmental damage was also caused by leakage of petroleum products and contaminated firewater through failed secondary containment bunds and tertiary containment measures. Since the groundwater was contaminated over an area in excess of 1 ha, the incident was defined as a major accident to the environment. This paper highlights the civil engineering lessons learned from a review of the Buncefield incident, which should help to improve the safety and environmental protection of oil storage depots worldwide.

1. Introduction

The Buncefield terminal in Hertfordshire, UK was a collection of fuel storage tanks, known as a tank farm, and associated incoming and outgoing supply pipelines and equipment to fill road tankers.

Following normal practice the storage tanks were provided with ‘secondary containment’, either singly or in groups of tanks, in the form of concrete-walled bunds on either concrete or compacted clay bases. These were intended to contain any unintended escape of petroleum products and other pollutants – such as day-to-day spillages or following an incident – until such time as remedial action could be taken.

The terminal was built in the late 1960s, came into operation in 1968 and was extended and modified several times, most recently in 2002. It consisted of three establishments run by Hertfordshire Oil Storage Ltd, British Pipeline Agency Ltd and BP, all of which were ‘top tier’ operators operating under the Control of Major Accident Hazards (Comah) Regulations 1999 (HMG, 1999). The emergency plans drawn up for the site correctly foresaw fire incidents and failure of the bund walls, so additional ‘tertiary containment’ measures were provided to store spillages.

A major incident occurred at the Buncefield terminal on the site operated by Hertfordshire Oil Storage at around 6·00 a.m. on Sunday 11 December 2005. A large initial explosion from tank T912 in bund A, itself containing three tanks, was followed by a series of smaller explosions and a fire, which affected 22 fuel storage tanks and seven bunds (HFRS, 2006) (Figure 1). This included six tanks on the adjoining site operated by British Pipeline Agency, which were also involved in the fire.

As well as the structural damage from the blast wave following the explosion, the fire then destroyed most of the site and generated large clouds of black smoke, which dispersed over southern England and beyond as the fire raged for 5 days. The Hertfordshire Fire and Rescue Service attended the incident and had enormous difficulty tackling the fires, which has been well documented. Escape of fuels, water and foam from the bunds was a significant added complication for the fire and rescue service, as was the realisation that emergency plans to use some bunds as remote secondary containment did not work as the bunds had become damaged by heat from the fire.

It was not until 31 December 2005 that the fire was sufficiently under control to allow the fire and rescue service to leave site

Figure 1. Buncefield plant on fire on 11 December 2005 (courtesy Royal Chiltern Air Support Unit, http://www.buncefieldinvestigation.gov.uk/images/gallery/casu02big.jpg)

permanently, only returning every 6 h to reapply foam. The site was formally handed back to the operators on 5 January 2006. A total of 53 Ml of 'clean' water and 786 000 l of foam concentrate were used to control the fire, collectively termed 'firewater'.

Unfortunately, the bunds did not fulfil their intended function of containing the escaping fuel and firewater until they could be safely removed. Large quantities escaped from various bunds, comprising both old and new designs. Some bund failures were inevitable, as the severity of the fire in places had caused the concrete to decompose and steel to melt. At other locations, where the fire was not as intense, both good and bad practices were identified.

The tertiary containment also failed, resulting in contamination of the groundwater over an area in excess of 1 ha, meaning that the incident was defined as a major accident to the environment. The European Commission was notified as required by clause 21 (1) and part 1 of schedule 7 of the Comah Regulations 1999 (HMG, 1999).

The authors were engaged as expert witnesses by the Competent Authority (Environment Agency, Health & Safety Executive and Scottish Environment Protection Agency) in the context of criminal prosecutions of Hertfordshire Oil Storage and British Pipeline Agency for breaches of health and safety regulations and failing to follow industry standards and best practice guidance – see HSE (2011). The issues addressed concerned the suitability and fitness for purpose of the secondary containment bunds and tertiary containment drainage site profiling in preventing the escape of petroleum products into the environment.

The reports identified issues with the design, construction and maintenance of the secondary and tertiary containment systems at Buncefield. The lessons gained have been captured in the Buncefield Standards Task Group report on the incident (BSTG, 2007) and the Competent Authority's report (CA, 2011). It has also led to the revision (led by the co-author) of Ciria report 164 (Mason *et al.*, 1997), the main industry guidance on bunds, to Ciria C736 (Walton, 2014).

2. Site layout and bund construction type

At the time of the incident, Hertfordshire Oil Storage west consisted of five bunded areas (A to E) each containing various numbers of storage tanks and other equipment. The general arrangement of the terminal is shown in Figure 2.

To the east was the British Pipeline Agency main bund, containing five main tanks, followed by the Hertfordshire Oil Storage east site (bund F). To the north was the British Pipeline Agency tank 12 site, containing a single tank, the largest on the site, and a firewater lagoon provided to the east of the bund for tertiary containment. Inside the bunds, each tank stood on its own concrete ring beam, with fill provided beneath the tanks themselves.

The construction of the bunds varied with the year of construction. Bunds A, B and C were built in 1990 and comprised concrete walls and floors. Bunds D and E were built earlier, in approximately 1966, and comprised concrete walls with a clay base covered with stone chippings. The main bund was built as part of the original site, dating back to the 1960s. Consistent with other older bunds at the site, the main bund had reinforced-concrete walls and a clay/soil base. The walls had been refurbished by British Pipeline Agency shortly prior to the incident, with extensive cutting back and repair to corroding reinforcement in the walls.

The tank 12 bund was newly rebuilt in 2002 to increase the bund capacity to meet current recommendations for freeboard, based on the size of the primary containment tank. The design included reinforced-concrete walls and a reinforced-concrete floor slab.

3. Performance of secondary containment bunds

A bund is normally considered to be a facility (including walls and a base) built around an area where potentially polluting materials are handled, processed or stored in a primary containment system (e.g. a storage tank), for the purpose of containing any unintended escape of material from that area until such time as remedial action can be taken (Mason *et al.*, 1997).

Traditionally, bunds have been built from a variety of materials including concrete-filled reinforced blockwork, compacted earth walls and bases, and reinforced concrete. For Comah sites containing petroleum products, the choice of construction material is much more limited, based on satisfactory performance in a fire. The material choice narrows to earth bund or concrete bund construction or, as is commonly found with older facilities, earth bases with concrete walls.

The requirement is that all materials achieve an impermeability to the contained liquids equivalent to a material of 1 m thickness with a permeability coefficient of 1×10^{-9} m/s, which is deemed by industry to represent best containment practice for clay liners (Mason *et al.*, 1997). These requirements apply not only to the materials of the walls and bases, but also to the ancillary materials used to build the bunds, including joints and pipe penetrations.

The minimum period of containment is recommended as 8 days, allowing sufficient planning time following an incident to arrange measures to deal with the escape. This means that to contain liquids such as fuel oils and firewater, the bunds should be designed and built as a liquid-retaining structure. If the contents are corrosive to the bund materials, then additional protection may be needed.

3.1 Construction materials

The impermeability requirement for walls and bases is easily met by properly designed reinforced concrete to a water-retaining code of practice. For this reason, the much reduced land take compared with the sloping sides of earth bunds, and the longer life, mean reinforced concrete is usually the first choice for bund material in petroleum storage situations.

Traditionally, reinforced concrete would have been designed to BS 8007 (BSI, 1987a) or its predecessors, but this is now within the scope of the Eurocode BS EN 1992-3 (BSI, 2006a). Concrete to the requirements of BS 8007 (BSI, 1987a) would be based on C28/35 compressive strength to BS 8500 (BSI, 2006b) and, where used externally, will contain entrained air to prevent freeze–thaw damage – although for bunds within buildings this is not necessary. A C28/35 concrete should easily achieve a permeability coefficient of 1×10^{-11} m/s, meaning that when used at the normal thickness of at least 150 mm, the impermeability require-

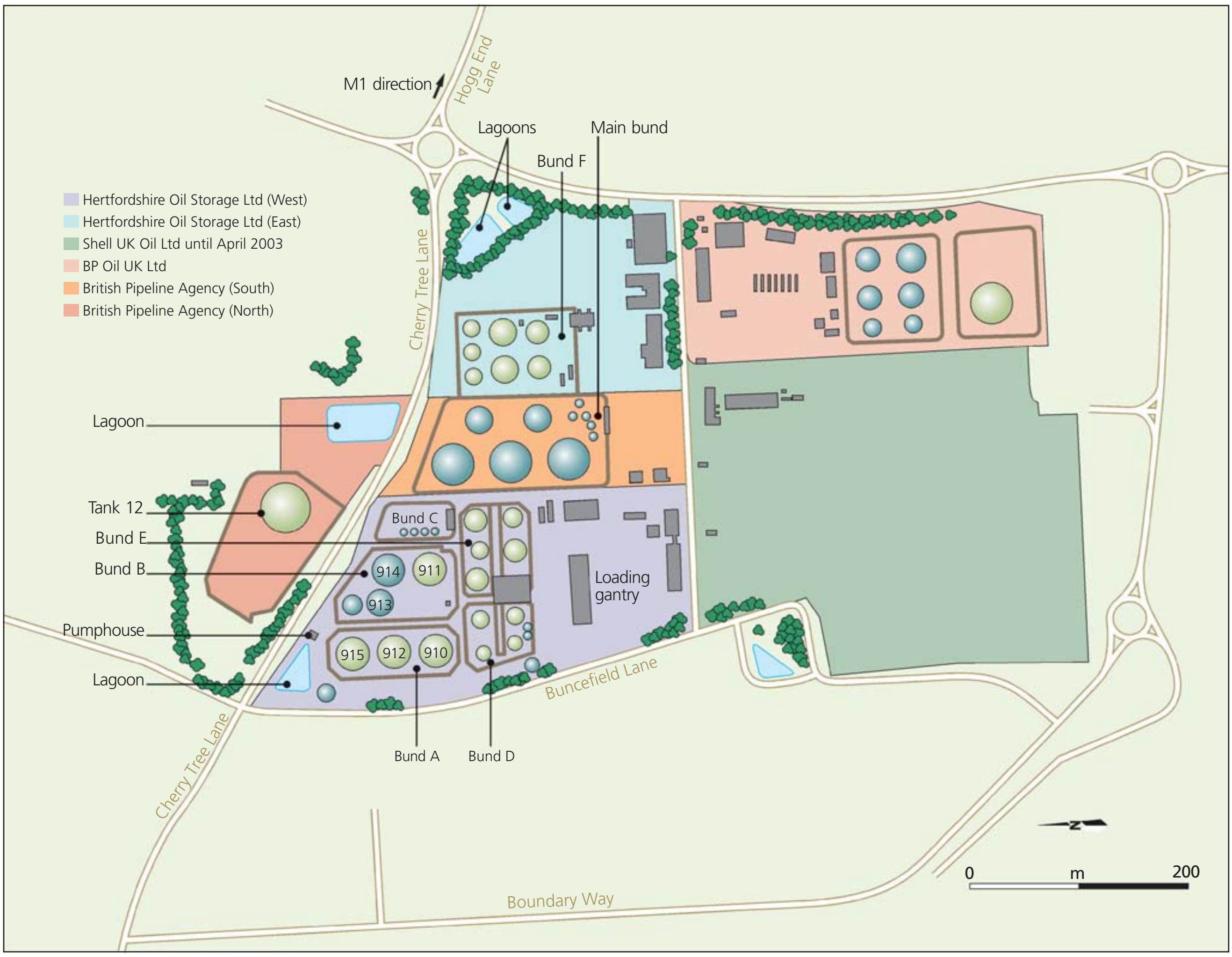


Figure 2. Buncefield site layout

ments for a bund will easily be met provided there are not significant cracks in the walls or slabs.

The design of concrete to retain liquids provides sufficient reinforcement to ensure that stresses due to structural loads or long-term shrinkage do not produce excessively wide through-cracks in the structure. Traditionally, BS 8007 (BSI, 1987a) has based the design on cracks of less than 0·2 mm width. BS EN 1992-3 (BSI, 2006a) refines the design approach and considers hydrostatic pressures acting and likely crack movements in service, but in principle offers a similar design solution for the base of a 1·5 m high bund wall or a concrete slab base to a bund.

Non-structural cracks, including restrained thermal cracking, plastic cracking and other causes attributable to construction practices, can lead to through-cracks that are substantially above 0·2 mm and, to meet the containment requirements, these cracks will need to be sealed. Further guidance on the causes of non-structural cracks, their prevention and rectification is given in TR22 (The Concrete Society, 2010).

Following the Buncefield incident, the authors examined the performance of the concrete bunds with respect to the best practice design criteria that applied at the time of the original construction, as well as any changes in legislation that may have required the operators to take actions in maintaining or upgrading the secondary containment. While the concrete walls and slabs and earth bases generally performed very well, there were a number of issues relating to bund joints and various types of penetration through the walls and slabs that failed.

3.2 Bund joints

Ciria report 164 (Mason *et al.*, 1997) provided specific and diagrammatic advice on the design of reinforced-concrete bund joints in walls and slabs that are normally provided by the designer to prevent stresses in the concrete from causing uncontrolled cracking that could lead to leakage. It discussed the design of three types of joint – contraction joints, expansion joints and construction joints. More recent terminology refers to movement joints, tied joints and construction joints, and this will be used here.

Where planned movement is expected to occur in a wall or slab, joints in a bund structure to contain liquids should have de-bonded dowels to prevent out-of-plane movement and have a water stop to prevent water passing through the joint. An example of a suitable design for a dowelled and water-stopped joint in a slab is shown in Figure 3(a).

Tied joints are provided with continuous reinforcement across the joint and are not intended to open significantly. Tied joints are normally vertical joints in slabs or walls and may be formed at a planned break in pouring, requiring formwork. Best practice is that such joints should also have water stops to prevent leakage.

Construction joints, found in the kicker joint to a bund wall, are normally horizontal and, like tied joints, will also have continuous reinforcement across them. The old concrete will normally be prepared by high-pressure water-blasting or mechanical needle-gunning to remove laitance and contamination, before saturating the surface, priming it with a grout mix and then pouring the next load of concrete. Water stops are not normally needed in these joints if the work is done conscientiously, but often they are provided and are recommended for bunds.

The material used for water stops needs to be determined based on risk considerations. Some guidance is given in section 2·124 of the *Civil Engineering Specification for the Water Industry* (CESWI; UKWIR, 1998) about polyvinyl chloride (PVC) and rubber water stops. With the potential for an incident involving burning fuels, the water stops may need to be fire resistant as well as resisting the fuels themselves and be capable of retaining firewater. As identified in Ciria C736 (Walton, 2014), hydrophilic water stops may be unsuitable as they are not designed to swell in the presence of petroleum fuels.

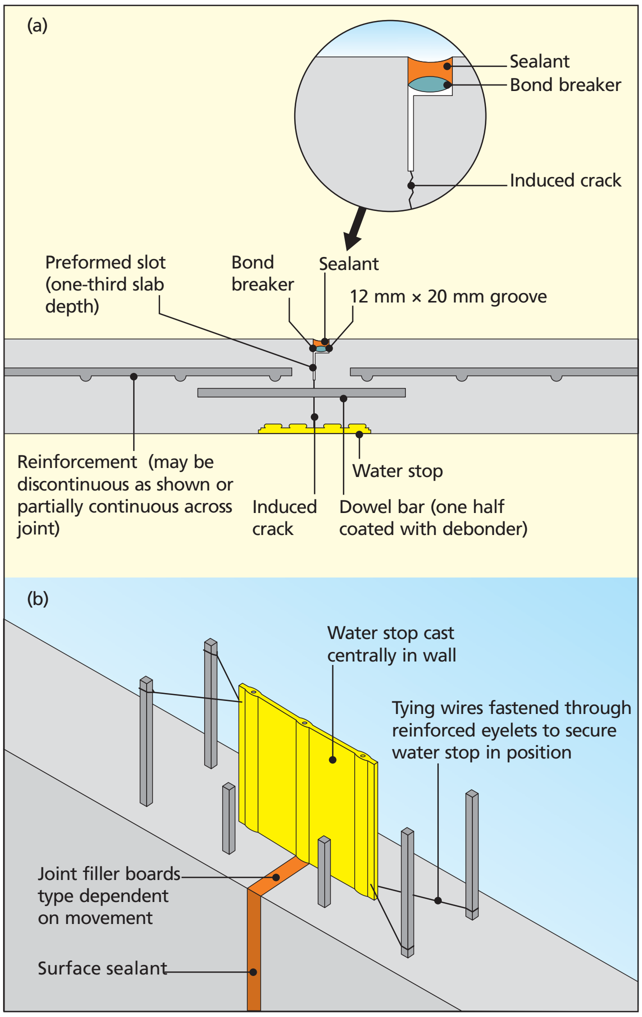


Figure 3. Movement joint details after Mason *et al.* (1997): (a) in a slab and (b) in a wall

The original bunds D and E had earth bases and concrete walls. The walls had PVC types of 'dumb-bell' water stops in the centre, similar to Figure 3(b), along with dowels. Metal plates had subsequently been installed over the joints on the inside surface of the walls during a refurbishment programme. The plates had over-sized holes to allow for movement when bolted into position and were sealed to the concrete surface with mastic. The plates appeared to protect the joints from the direct effects of radiation during the fire and no instances of melted PVC water stops or failed plates were found in the sections examined. Bunds D and E performed well in retaining products and firewater during the incident.

Bunds A, B and C, built more recently, also had concrete walls and earth bases. However, while the wall joints had dowels, they did not have water stops and performed particularly badly. Thioflex 600 or Geocel was applied as a surface sealant over the movement or tied joints. Neither of these sealants is resistant to fire. The absence of water stops meant that the construction of these joints did not conform to the relevant standards at the time for a water-retaining structure.

Bunds A and B were reported to have leaked during periods of rain, and a programme of refurbishment had been planned to upgrade bunds A, B and C. However, no upgrading had been carried out at the time of the incident and these bunds leaked extensively as the sealant was consumed by the fire, allowing fuel, foam and firewater to flow onto the site roadways.

The main bund was built in the 1960s and had concrete walls and an earth base. A corrugated copper sheet water stop was provided across each joint in the centre of the wall, which was a standard waterproofing detail of the time. These sheets functioned well – even though this bund was exposed to a bund pool fire and tank fires, the joints performed well and did not leak significantly (see CA, 2011).

Figure 4 shows the location of core 6 in the western main bund wall, in the vicinity of a joint. The copper sheet is partially visible in the upper part of the picture. Although this joint showed extensive spalling, it performed well in retaining liquids during the fire. The concrete repairs to the wall also performed well and showed no signs of significant delamination.

The British Pipeline Agency tank 12 was the latest bund construction at the site and comprised concrete walls and base slab. Built in 2002, the original specifications required a liquid-retaining structure, citing BS 8007 (BSI, 1987a) and CESWI (UKWIR, 1998). However, British Pipeline Agency failed to manage the project to ensure that changes made during the design and build project were properly assessed (CA, 2011).

The bund walls were built with simple vertical butt joints, formed by casting against a compressible filler material between the sections, with sealant material gunned into the visible top and sides of the joint. Some joints were positioned at corners, at either obtuse 30° or 90° corners. The base slabs similarly did not have any water stops provided at either movement joints or tied joints.

Figure 4. Main bund joint (with core sample 6 cut through it)

As a consequence of the lack of dowels and water stops, the joints in the tank 12 bund walls leaked extensively during the incident, with the shallow angles forcing the walls out of plane when heated by the burning fuels

The only waterproofing was a mastic sealant poured into a groove formed by casting the concrete against a compressible filler material. This single bead of sealant was the only measure preventing escape of liquids from the bund. At tied joints, where the reinforcing fabric reinforcement ran continuously across the joint, joint sealant did not appear to be provided. This construction did not conform to any recognised standard for the containment of water or fuel within bunds. BS 8110 (BSI, 1985) and BS 8007 (BSI, 1987a) indicate that dowels and water stops are required at movement joints to prevent out-of-plane movement and leakage at these locations. As a consequence of the lack of dowels and water stops, these joints leaked extensively during the incident (Figure 5), with the shallow angles forcing the walls out of plane when heated by the burning fuels. This allowed fuel, foam and firewater to leak out of the bund.

3.2.1 Core samples

To ascertain the effect of the fire on the concrete bund walls and floor, nine core samples were taken from bund D/E, the main bund and the tank 12 bund. These core samples were examined by petrographic methods to establish the depth of the heat-affected zones, and grouped into three bands by temperature of exposure: above a temperature of 300°C the cement phases begin to decompose and a significant loss of strength occurs; above 600°C substantial weakening of the concrete occurs and it is no longer structurally useful; above 900°C the calcareous components disintegrate (The Concrete Society, 2008). A summary of the findings with respect to the heat-affected depth is provided in Figure 6, with a selection of core photographs shown in Table 1.

Figure 6 shows that, based on the samples taken from the walls of bunds D and E and the tank 12 bund, the concrete had generally performed well in the fire in terms of resistance to heat. Generally, the heat-affected zone (>300°C) was less than 60 mm, with two notable exceptions: in core 3 (bund D/E) and core 11 (tank 12) the 300°C depth (dark blue bars) was 118 mm and 182 mm respectively, with the depth of substantial structural weakening (>600°C) at 70 mm and 110 mm respectively (brown bars). Given that PVC will melt at temperatures of around 200°C and the walls are typically 300 mm in thickness, this evidence suggests it is marginal whether PVC would have been exposed to temperatures sufficient to melt it during the most severe exposure to heat from this fire in the tank 12 bund, had it been used as a water stop.

Concrete comprising the base slab of the tank 12 bund generally appeared to be unaffected by the fire, with escaping fuel and then firewater protecting the concrete from direct heat exposure. However, one location had substantial darkening and lifting near to tank 12 itself. Cores 9 and 10 were taken from this bay of concrete (bay M in the tank 12 bund), an area which may

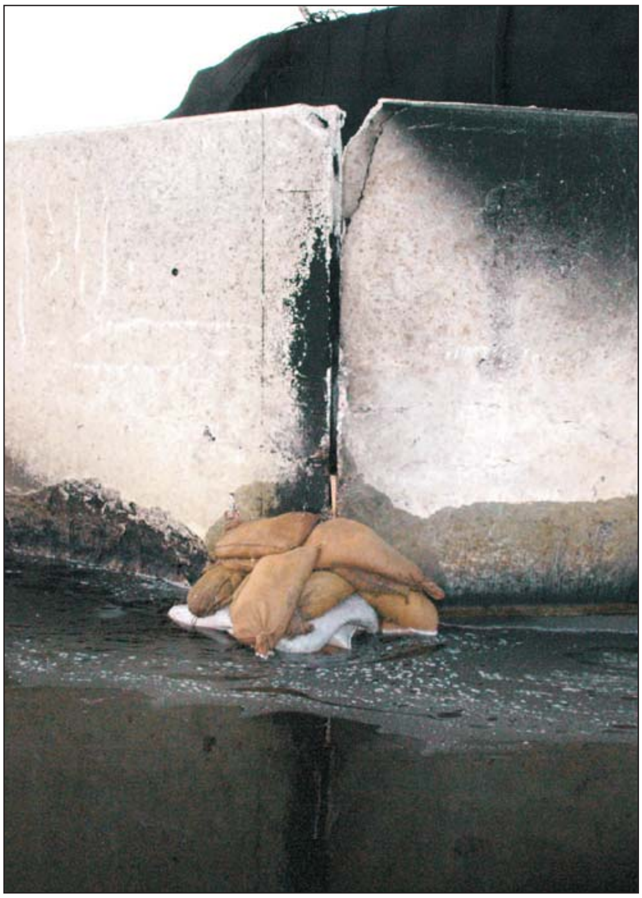
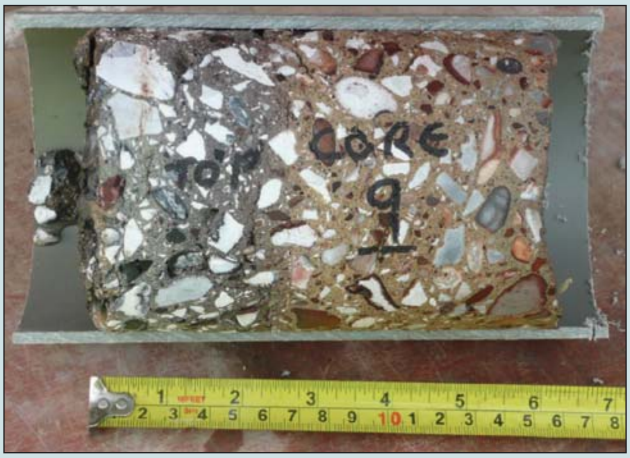


Figure 5. Obtuse angle butt joints at tank 12

Core 2B: taken through the wall of bund E, showing very little heating damage to the concrete and no evidence of damage to the polyvinyl chloride water stop.

Core 8: taken through a repaired area of main bund showing laminar striations in the outer 50 mm of the wall, but generally very good performance for the sprayed concrete material.



Core 9: taken from the floor to tank 12 bund under an area suspected of receiving a jet of burning fuel. 70 mm thick light grey zone exhibits extreme heating.

Table 1. Examples from core examinations extracted from the Buncefield site and then sent for petrographic examination

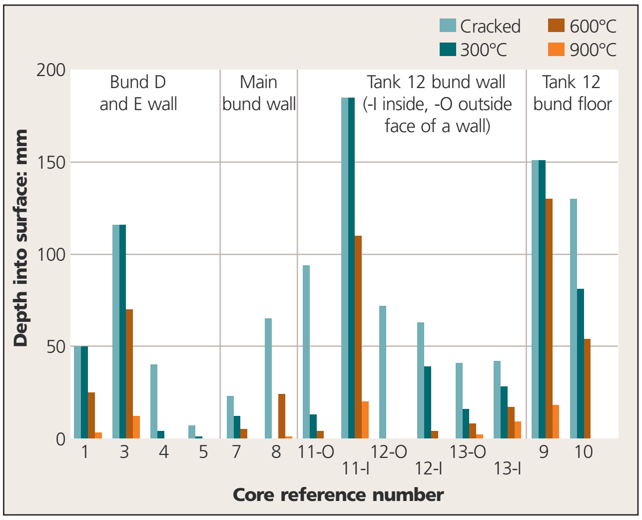


Figure 6. Heat-affected depths into the concrete bund surfaces

Figure 7. Fire-damaged reinforced concrete floor at tank 12 bund

have been under a jet of escaping fuel. The petrographic examination revealed the concrete had been heated to very high temperatures and for a considerable depth. Nearly the full thickness (130 mm) of the 150 mm slab had been heated to above 600°C; the full depth was weakened by the fire effects and the outer 18 mm reached temperatures above 900°C.

The lifting of the slab in bay M was probably the result of expansion in the flint gravel coarse aggregate in the upper part of the floor slab, which undergoes a phase change at 573°C accompanied by 5% increase in volume (The Concrete Society, 2008). This expansion would create stresses in the outer fibres of the concrete and cause the area to curl and lift. An example of the damage observed to the bund floor is given in Figure 7.

3.3 Bund penetrations

A large number of pipe penetrations were observed through the bund walls and through the floor of the tank 12 bund floor slab that were not sealed effectively. Good practice from the Health and Safety Executive (HSE), issued some 7 years before the incident states (HSE, 1998: p. 33)

> The integrity of the bund wall may be put at risk if pipework and other equipment are allowed to penetrate it. If it is necessary to pass pipes through the bund wall, for example to the pump, then the effect on the structural strength should be assessed. Additional measures may be needed to ensure that the bund wall remains liquid tight.

Despite these recommendations, many of the bunds had pipes penetrating through the walls and the tank 12 bund, newly built, had penetrations through the floors. Failures at these points meant the bunds could not retain liquids.

Some penetrations appeared to be retrofitted, with the top of the wall cut back, the pipes installed into over-sized holes and the concrete reinstated, whereas others were original installations. Generally, the pipe penetrations were not sealed into the wall with puddle flanges, as would be normal for a water-retaining structure, and failed in several different ways.

For walls, some pipe penetrations were in over-sized holes and provided with a flexible ‘bellows’ arrangement that was intended to provide a liquid-proof seal between the pipe and bund wall, so allowing differential thermal movement between the concrete wall and the steel pipe. Unfortunately, the flexible bellows were not adequately fire resistant and were consumed by the fire, leaving a substantial gap through which fuels floating on firewater could escape (Figure 8). In addition to being damaged by fire, it is possible that the bellows could also have been damaged by the vapour cloud explosion.

In cases where the pipes were a closer fit, passing through walls and floors, only sealant had been provided to prevent leakage, which proved not to be resistant to fire. Where pipe penetrations had been retrofitted, thermal movement of the pipe or heating of the concrete led to failure of the wall around the pipe penetrations, most probably because the re-cast concrete used to close the opening in the wall was not tied in by properly anchored reinforcement.

Figure 8. Bund pipe penetrations (lacking puddle flanges)

Figure 9. Leaking tie-bar holes in tank 12 bund (at lower part of bund)

The best precaution with regards to service penetrations through bund walls is to avoid them whenever possible, and to route the services over the bund walls. If pipe penetrations are deemed essential, it is industry practice, as indicated for example by section 3·4·4 of BS 8000-15:1990 (BSI, 1990) and section 16 of BS 8005-2:1987 (BSI, 1987b), that puddle flanges should be provided to ensure an adequate seal around pipe penetrations through concrete structures, as recommended post-Buncefield (BSTG, 2007).

3.4 Tie-bolt holes

A significant amount of leakage was observed from tie-bolt holes within the British Pipeline Agency tank 12 bund (Figure 9), which added to ‘Lake Buncefield’. Tie bolts had been used to secure the formwork together at low level, so gripping the kicker formed off the perimeter beam. This is normal practice to establish a good seal against the kicker concrete, where the bolts pull the two sides together. However, the method used was not appropriate for a water-retaining structure, because the bolts comprised debonded lengths of threaded steel in a plastic sleeve that were pulled out and re-used.

For example, section 4·30 of CESWI (UKWIR, 1998) states that, ‘Tie bolts which form a continuous hole through a structure designed to retain an aqueous liquid will not be permitted’. The contractor building the tank 12 bund wall appeared to have removed the tie bolt and sealed over the surface with a plug of

Flexible bellows around pipe penetrations were consumed by fire, leaving a substantial gap through which fuels floating on firewater could escape

Inadequate site profiling and drainage led to uncontrolled release of product and firewater into the environment

mortar, giving the appearance of a sealed hole that proved not to be resistant to heat from the fire. There were some indications prior to the incident that the tie-bolt holes were weeping rainwater, but no actions had been taken to investigate or address the leakage before the incident occurred.

Commonly available on the market are leave-in tie-bolt fittings that are cast into the concrete. The tie bolt is then removed from each side, with the fitting blocking the passage of water through the wall. Alternatively, special rigs can be used that do not need low-level tie bolts: Figure 10 (redrawn after Ciria report 164 (Mason *et al.*, 1997)) shows a shuttering arrangement for a reinforced-concrete bund wall, with formwork panels supported by props or braces. Such formwork would have avoided tie bolt holes altogether.

4. Performance of tertiary containment

The Control of Industrial Major Accident Hazards Regulations 1984 (HMG, 1984), in place at the time of the construction of bunds A–C, set a requirement to limit the consequences of major accidents to persons and the environment, which may include tertiary containment if such a measure is required to bring the risks down to the as low as reasonably practicable (Alarp) level.

However, there was large and uncontrolled release of product and firewater into the environment during the incident, due to inadequate site profiling and drainage arrangements (Figure 11).

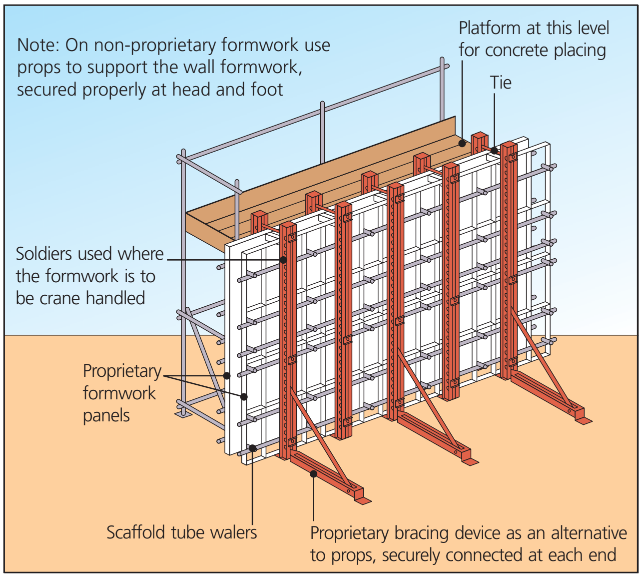


Figure 10. Shuttering for reinforced concrete bund wall after Mason *et al.* (1997)

Figure 11. Escape of product and firewater from Buncefield bunds

The topography of the site encouraged liquid run-off to the north of the Hertfordshire Oil Storage West site, down Cherry Tree Lane and beyond, past the roundabout into Hogg End Lane and as far as the M1 motorway bridge, several hundred metres away (CA, 2011).

The Hertfordshire Oil Storage surface drainage arrangements were provided using perforated pipes; road drainage was provided using storm water sewer pipes. The drainage design (pipe diameters and gradients) was generally consistent with the requirements for rain water collection, rather than the collection of any firewater or petroleum products. There was thus limited capacity to accommodate the flows from a sudden release of petroleum product in case of bund failure.

The existence of vitrified clay perforated pipes as drainage channels within Hertfordshire Oil Storage West indicated that the drainage system was not suitable for the transmission of petroleum products in case of a loss of secondary containment. In addition, the existence of soakaways on site was not consistent with the requirements for the safe capture of petroleum products.

It was known to Hertfordshire Oil Storage that when the west site lagoon was full of rain water, the water backed up to the fire pump-house and flooded it. Prior to the incident, this flooding risk was controlled by pumping water out of the lagoon into bund A, and then on to bund B if required (by way of the fire drenching system). This procedure was not possible after the explosion on 11 December 2005, since the relevant power and communication cables were no longer in operation, rendering the measures ineffective.

A number of recommendations had been made to Hertfordshire Oil Storage to improve the tertiary containment, but these recommendations had not been implemented at the time of the incident.

5. Conclusions

Hertfordshire Oil Storage, British Pipeline Agency and three other parties were prosecuted and fined £9·8 million for their part in failing to provide adequate precautions to prevent major accidents between 18 November 2001 and 12 December 2005. The companies also accepted responsibility for allowing polluting

There should have been a realistic chance of minimising the release of firewater, foam and petroleum products into the environment if the bunds, drainage and site profiling had been better designed

matter – firewater, chemicals and fuel – to enter the chalk aquifer under Buncefield. Full details of the verdicts are given by HSE (2011).

It was recognised that in places the fires were so severe that concrete and steel reinforcement had melted, so some failures in the bunds were inevitable. However, with the large volumes of firewater and foam used to tackle the Buncefield fire (53 Ml of 'clean' water and 786 000 l of foam concentrate), there should have been a realistic chance of minimising the release of firewater, foam and petroleum products into the environment, if the bunds had not leaked so extensively, if the drainage system had been appropriate and if the site had been profiled appropriately.

A number of recommendations for updating safety and environmental standards for fuel storage sites have been made by the Buncefield Standards Task Group (BSTG, 2007). A new version of Ciria report 164 (Walton, 2014) has been published incorporating these findings and providing detailed guidance on evaluating existing bunds for adequacy and fitness for purpose.

In summary, the key technical points include the following.

- Design bund walls and floors as a water-retaining structure to BS EN 1992-3 (BSI, 2006a) or equivalent, using best practice from the water industry (e.g. UKWIR, 2011).
- Ensure all bund walls and floors have properly designed and carefully built joints, with central water stops that should be stainless steel sheet in the highest risk category sites.
- Avoid through-wall tie-bolt methods for fixing formwork and use cast-in types or suitable framing.
- Do not route pipework through the concrete floor slabs.
- If it is not possible to avoid pipework passing through bund walls, then provide proper puddle flange connections to form a watertight seal.
- Set up a regular inspection maintenance regime as befits any safety-critical element of the facility.
- For existing facilities, carry out a baseline survey to find out how bunds have been built and whether there has been a change in use/risk; if deficient, address any shortfall by extending or upgrading the secondary and/or tertiary containment.

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What do you think?