Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 63 (1991)

Artikel: Environmental impact of the disposal of channel tunnel spoil

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DOI: https://doi.org/10.5169/seals-48501

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Environmental Impact of the Disposal of Channel Tunnel Spoil

Environnement et dépôt des matériaux d'excavation du tunnel sous la Manche

Umwelteinfluss der Abraumdeponien des Aermelkanaltunnels

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SUMMARY

After an extensive study of potential disposal sites for over 7 million m^3 of rock, disposal in lagoons behind a new sea wall was chosen for UK spoil and pumping it as a slurry behind a dam in a dry valley for the French. The paper describes the reasons for these choices and some of the studies carried out to assess the impact of spoil disposal upon the environment. Such studies are essential for projects of any magnitude in an increasingly environmentally conscious world.

Environnement et dépôt des matériaux d'excavation du tunnel sous la Manche

Résumé

Une étude détaillée des sites potentiels pour le dépôt de plus sept millions m3 de roches a été entreprise. Une solution de dépôts dans des lagunes derrière une nouvelle digue a été choisie du côté anglais alors qu'une solution de pompage derrière un barrage à l'intérieur des terres a été retenue du côté français. L'article décrit les raisons de ces choix et quelques études réalisés pour évaluer l'influence des dépôts de matériaux d'excavation sur l'environnement. De telles études sont essentielles pour des projets majeurs dans un monde devenant de plus en plus respectueux de l'environnement.

Umwelteinfluss der Abraumdeponien des Aermelkanaltunnels

Zusammenfassung

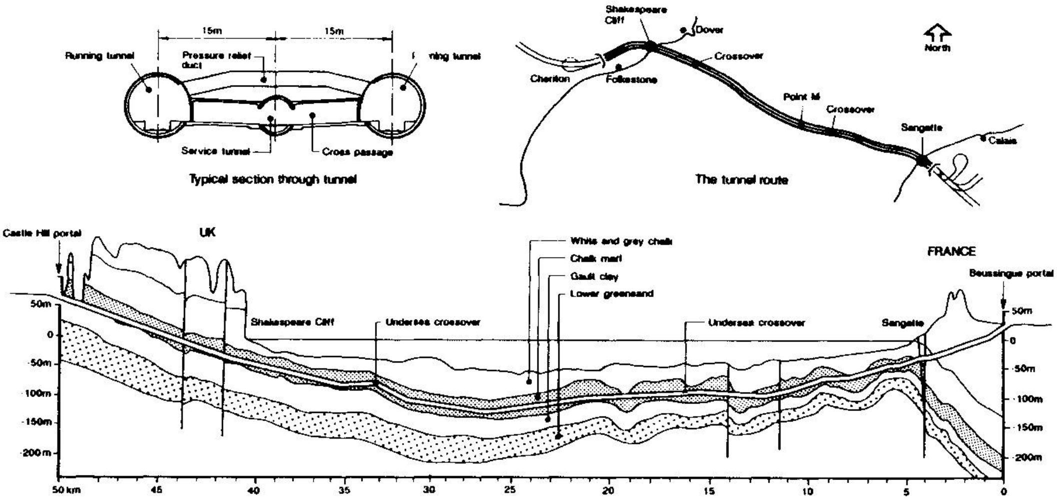
Nach einer extensiven Studie der möglichen Lageanordnungen von über 7 Millionen Kubikmeter Fels wurde im Vereinigten Königreich eine Anordnung in Lagunen hinter einem neuen Seedeich gewählt, während es in Frankreich als Schlämme hinter einen Damm in eine trockene Schlucht gepumpt wurde. Der Artikel beschreibt die Gründe für diese Entscheidungen und einige Studien über den Einfluss der Abraumlagerung auf die Umwelt. Derartige Studien sind in einer zunehmend umweltbewussten Welt sehr wichtig für Projekte jeder Grösse.

1. INTRODUCTION

The Channel Tunnel rail link runs between the Cheriton and Sangatte terminals on the UK and French sides respectively (see Figure 1). The construction of the two 8.4m outside diameter running tunnels and the 5.4m outside diameter central service tunnel requires the removal of over 7 million m^3 of insitu Cretaceous Lower Chalk of Chalk Marl. The Marl is mainly calcite but in places contains up to 40% clay. The total quantity of spoil to be disposed of is greater as excavation fractures the rock, producing bulking. Depending on the method of disposal and subsequent treatment, $1m^3$ of insitu rock can be represented by $1.3m^3$ to $1.7m^3$ of spoil.

Before and during the passage of the Channel Tunnel Act through the UK Parliament many options were examined for spoil disposal, including filling of redundant chalk and gravel pits and reclamation for port development. All the advantages and disadvantages were examined including transport mode and distance, disruption, noise and pollution as well as the financial implications. On the UK side it was finally agreed that most of the spoil should be transported by conveyor and disposed of behind a new sea wall in front of existing sea defences at the toe of Shakespeare Cliff. The area reclaimed would be used as the working site and subsequently as a recreation/conservation area, with a small area allotted for the tunnel cooling plant. The remainder of the spoil was to be taken through the completed service tunnel as fill for the Terminal site.

On the French side, the decision was taken not to use the spoil in any way but to pump it as a slurry behind a new dam at Fond Pignon. The French disposal volume was therefore proportionally greater than the UK because of different method of disposal.



<u>Fig 1</u> Plan, geological cross-section and section through the tunnels

2. SELECTION OF THE DISPOSAL SITES

In 1986 the British and French Governments awarded the Channel Fixed Link concession to the Channel Tunnel Group France Manche. After the award the Group separated into Eurotunnel (ET), who are now the Concessionaires, and an association of contractors, Transmanch Link (TML), who are entirely responsible for constructing and commissioning the Channel Tunnel Project, including driving the tunnels.

Tunnelling required the removal of over 7 million m^3 of insitu rock, some 4.6 million m^3 coming from the UK side. ET's UK Submission Scheme proposed that most of the UK spoil would be used to create a working platform at Shakespeare Cliff, with some spoil going to raise levels of the Cheriton Terminal site leaving the site for the remainder of the spoil to be decided.

Alternative sites for the remaining spoil were examined by the Surplus Spoil Working Party (SSWP), set up under the Chairmanship of Kent County and included representative from local District Councils, British Rail, and nature conservancy authorities. In all the SSWP examined 70 potential spoil sites against general criteria eg. spoil acceptance rates and environmental impact as well as technical aspects including modes of transport.

The majority of the sites were disused mineral excavations in Kent, within 2 km of a railway line. Piped transfer of the slurrified spoil was considered and rejected on geographical and environmental grounds (on the French side this proved to be the most appropriate method). Road transport was not considered as KCC wished to restrict heavy construction traffic even to deal with the inevitable peaks in spoil production. The local environment was examined in some detail, as were specific spoil disposal activities that could impinge on the above, eg. the generation of a fine slurry and dust, noise etc.

The SSWP finally shortlisted three sites to be investigated further, Lappel Bank (a mudflat in the River Medway), St James Lane (a narrow disused chalk pit) and a dry chalk valley at West Hougham, which lies in an Area of Outstanding Natural Beauty (AONB). After this intensive study the Government decided that, on balance, an extension to the construction platform at Shakespeare Cliff was preferable to any of the above.

The platform at Shakespeare Cliff is the working site from which six tunnels were driven, three towards France and three back inland towards the Cheriton Terminal. The inland drives were 8.1 km long and the marine drives were programmed to be 22 km long, meeting the French marine tunnels on the French side of the Channel mid point. All the marine tunnel spoil was to be deposited at Shakespeare Cliff together with the service tunnel spoil from the land drive. Once the land service tunnel was completed it would then be filled out with a 9km conveyor to take the 1 million m^3 of land drive spoil to Cheriton.

Filling, in addition to that available from the tunnels, was required at Cheriton and various sources were examined including spoil from the Kent coal field. However, it was decided that, mainly on environmental grounds regarding the transport of filling materials, it would be preferable to use dredged sand from the Goodwin Sands. Because of the success of this operation, which involved the dredging and depositing in a near-shore by barge which then, pumped to a head of 60 m over a distance of in excess of 7 km and its beneficial effect on the construction programme for the terminal, it was decided to obtain all the 2.75 million m^3 from this source. This of course left a problem of what to do with the surplus tunnel arisings. Again numerous schemes were studied, including the dumping/disposal outside UK territorial waters. However, a parallel study of the cooling capacity requirements for the Tunnels had shown that cooling was required about 1 month and not as originally envisaged, 1 year, after completion. While the cooling buildings might have been sited in the centre of the Shakespeare platform, this was not acceptable to the planners and it was agreed, after much debate and a full environmental assessment, to site the buildings near the access adits at the east end of the site. Thus, an additional spoil lagoon (number 5) was required at Shakespeare Cliff and the spoil destined for Cheriton was used to fill it.

3. SPOIL PROPERTIES AND DISPOSAL

The tunnels are driven through Cretaceous Lower Chalk or Chalk Marl, consisting of mainly calcite but, lower down, up to 40% clay. Typically a sample might contain 10% quartz, 60% calcite and 30% smectite. As such it is a good tunnelling medium in that it is both competent and relatively easy to excavate. Indeed, tunnels by Col. Beaumont over 100 years ago and a trial tunnel in the early 1970's showed this to be the case. It was always envisaged that the UK tunnels would go more than halfway across the Channel and thus, for the Shakespeare platform, the approved volume of UK rock to be excavated allowed the tunnels to go 2 km further ie through 3.42 million m^3 of rock to point M, up to a maximum of 3.76 million m^3.

It was originally envisaged that spoil would be produced at a peak average rate of about 14,000 tonnes/day for a 24 hour 7 day a week operation. This was equivalent to an individual tunnel advance rate of about 200 m/week. In reality the running tunnels have been achieving about 320 m/week and peaking at 380 m/week. This is considerably more than the planned rate and it is fortuitous that the Shakespeare Cliff site was chosen as transport elsewhere would have been difficult for this production rate.

Tunnelling from the full faced boring machines produces spoil ranging in size from 75 mm downwards, with the majority being in the 35-55 mm range. It was known that handling the spoil, would lead to its degradation and the marine spoil would have a chloride content of 6000 mg/l (brackish) to 20,000 mg/l (saline).

In both the French and UK tunnels spoil is transported from the tunnel face in trains and tipped into receiving bunkers at pit bottom. At Shakespeare Cliff the bunkers feed a conveyor bringing spoil to the surface where an overland conveyor transports it to a radial spreader for distibution. All conveying equipment is designed with a capacity of 2400 tonnes/hour ie. twice the hourly average production rate. The radial spreader has, however been little used, with most of the spoil being transported from the end of the tunnel conveyor by lorry, each lorry placing up to 55 m^3/hour. It was also planned that only the top 4 m of spoil would be compacted in 1 m layers, but greater depths have been compacted both to reduce the overall volume and improve the ground conditions.

Trials in the UK examined the Chalk's "bulking factor" ie. its increase in volume after excavation and transport. Initially the results both at Barrington Quarry near Cambridge and within the works as they proceeded, indicated that with some compaction, bulking factors of between 1.2 and 1.25 could be achieved, but the overall factor has proved to be is nearer 1.37 ie. as originally envisaged.

On the French side spoil is transported by train to the main access shaft behind the shoreline at Sangatte. Here, water is added and it is pumped some 700 m behind a earthfill dam situated in a small dry chalk valley called Fond Pignon. The spoil contains some 50% of saline water when deposited and 20% after consolidation. The estimated final bulking factor of 1.67 has again proved to be low and, because of this and additional spoil quantities, the dam has had to be raised twice rather than the once planned.

4. DISPOSAL SITE DESIGN AND ENVIRONMENTAL IMPACT STUDIES

4.1 Shakespeare Cliff Platform

The 1986 Channel Tunnel Act allowed the construction of the working platform and lagoons at Shakespeare Cliff but limited construction to the seabed fronting 100 year old rail sea defences where the cliffs behind had 'greened'. On either side wave action and erosion ensured the cliffs were 'white' and this balance was not to be changed.

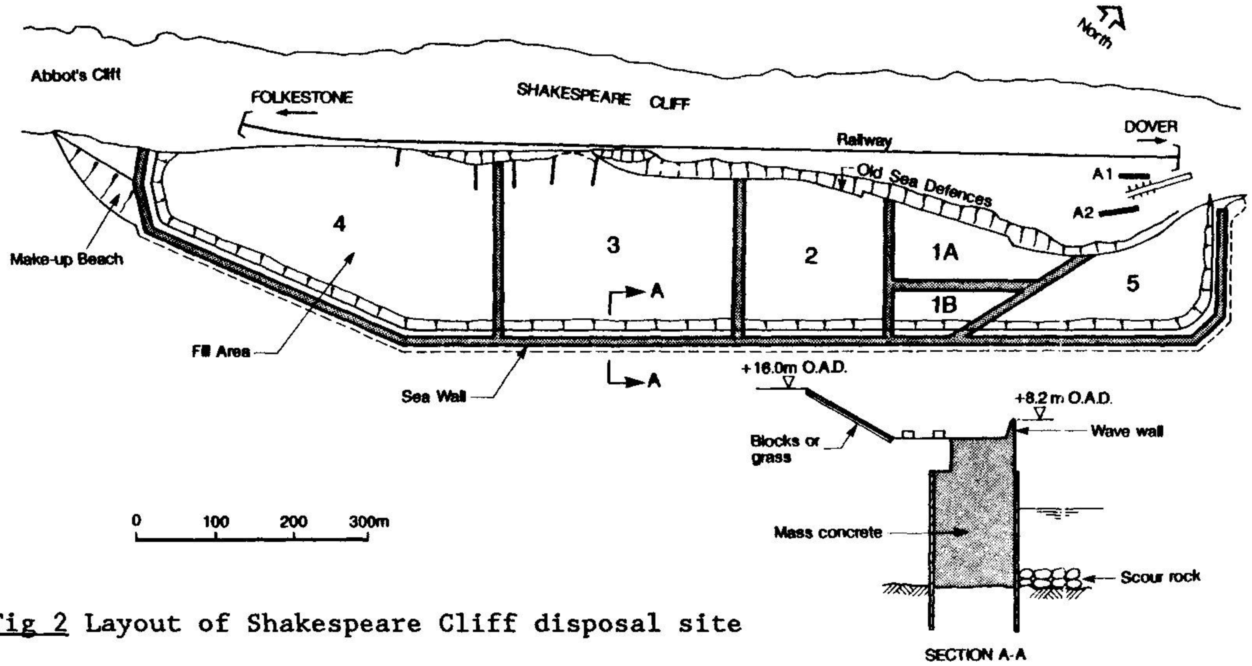


Fig 2 Layout of Shakespeare Cliff disposal site

For tunnelling to begin there had to be a disposal area and because of delays in obtaining final planning approval, TML built temporary lagoons within the agreed main lagoon area. As most tunnel construction activity was to take place at Shakespeare, it was also essential to reclaim it rapidly to provide working space.

A seawall of piled cells filled with mass concrete to 7 m Above Ordnance Datum (AOD) going from cliff to cliff (see Figure 2), which has taken over 3 years to construct, protects the spoil. On top of the mass concrete is a 1.2m wave wall along the front edge and behind at a 13.5 m wide zone of wave energy absorbing structures running up to a level of 8.5 m AOD, with grassed blockwork or 'reinforced' grass extending to the profiled platform which has an average level of 16 m AOD. A blanket of 4t scour rock protects the toe of the seawall.

Spoil could not be placed in the open sea and tunnelling could not wait for the completion of the 1.8km seawall. Thus, a series of crosswalls had to be built from the shore to the new seawall as it progressed, ensuring spoil was only placed in closed lagoons. In total there are five lagoons with the temporary lagoons forming part of lagoon 1 (see Figure 2). The capacity of lagoons 1 to 5 are 510,000m^3, 811,000m^3, 1,387,000m^3, 1,606,000m^3 and 712,000m^3 respectively, giving a total of 5,026,000m^3 covering a seabed area of 393,000m^2. Boreholes, together with seismic and bathymetric surveys were carried out as part of the design, together with piling trials. Noise levels were also measured on top of the cliffs and in the adjacent village of Aycliffe for the various types of piling hammer used.

Lagoon water is expelled, as filling proceeded, or with ingress from groundwater, or rainfall or due to wave overtopping. It was essential therefore to ensure that the dispelled water was clean and the first crosswall was essentially a long settling tank into which flocculating agents could be added, if necessary. However, the temporary piled lagoon walls filled with gravel proved so successful in filtering water, that all the subsequent crosswalls were gravel filled and were used as access roads. The final lagoon has a filtration cell and, as with all the lagoons, the discharge water has been cleaner than that in the surrounding sea.

Throughout construction silt concentrations have been monitored both in the lagoons and the sea using optical pHOX meters, which measure turbidity in mg/l formazin equivalents. Lagoon water levels were also measured. For example the lagoon 4 water level was raised by about 0.6 m in May 1990 and while the turbidity of the lagoon water was higher than in April, it was lower in the sea. Figure 3 shows lagoon turbidities higher than the sea (but discharged water was not) but the lagoon results were affected by algal blooms.

Suspended solid concentrations were also measured at 3 depths in the coastal zone at two stations at either end of the platform and there were sediment sampling stations in deep water off Folkestone and Dover. The purpose of these was to establish the ambient levels of suspended sediment concentrations in the coastal waters and to identify the dependence of natural concentrations on variation of tide and waves. The six inshore pHOX meters recorded continuously and pumped samples were also taken to assist in calibration. Nunny type NBT82 samplers monitored concentrations at the deep water stations, which also included recording Aanderaa current meters. The samples showed that while calcite predominated, the make-up of the suspended solids was different from the spoil, containing more quartz, kaolinite and illite.

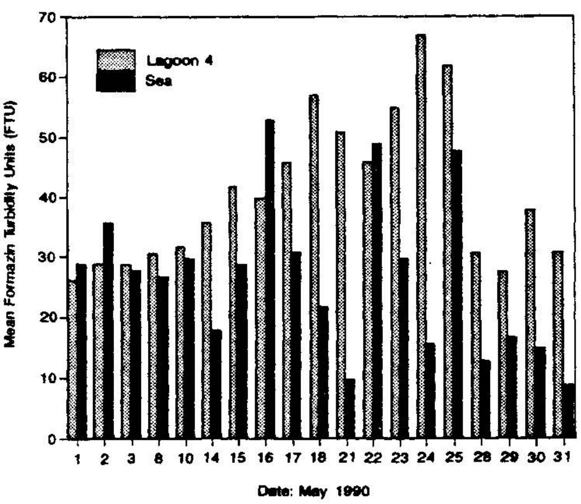


Fig 3 Turbidity, Lagoon 4

While wind derived storm conditions were used initially to establish the seawall design conditions, a wave rider buoy was installed for a period of two years during construction and its results were also used to assess variations in suspended loads. Sediment concentrations were shown to be dependent on tidal level and while correlation was achieved, the spread of concentrations within wave energy and persistence classes remained wide. Typically standard deviations reached 75% of the mean for wave heights of <1.5 m improving to 50% or less for higher waves. Concentrations normally were between 50 and 100 mg/l, peaking at about at about 600 mg/l and 400 mg/l in the coastal zone and offshore respectively.

The Channel Tunnel Act contained provision for the protection of Dover Harbour, which lies just over 2 km to the east of the platform. It was therefore decided to examine the movement of spoil in the event of a catastrophic failure of the seawall. There is a net transport of water eastwards up the Channel into the North Sea and the mathematical model studies showed that while spoil would pass Dover Harbour, little would enter to cause siltation. Also, the environmental impact of such a failure would be relatively small as there would be a rapid dilution and spreading of the spoil.

The existing intertidal and sublittoral flora and fauna, which are relatively limited due to the exposure and type of seabed, have been the subject of long term monitoring and skilled eye surveys. Some 97 intertidal species of seaweed were recorded at Shakespeare in 1989 compared with 94 in 1988 and the benthic faunal survey showed a general reduction in diversity for the same period. The conclusion reached was that the changes seen were as expected in areas such as this where the seabed is highly variable and no effects from the platform construction could be observed.

Cliff stability has also been studied and, as Table 1 shows cliff erosion rates behind the existing platform are surprisingly very similar to those exposed to the sea, the mean rate being 0.1 m/year. Erosion does however lead to spectacular failures of these 100m high cliffs and a failure to the west of the site on 26 January 1988 moved same 6000 m^3 of rock, which was pushed out into the sea in the form of a semi-circular dam. A nearby failure in 1912 moved same 50,000m^3 of rock and the largest failure has been estimated at about 200,000m^3. Clearly, such failures inject considerable quantities of chalk into the coastal zone as is evidenced by the boulder strewn foreshore.

Table 1 Summary of cliff top recession rates

Location	Cliff length m	Sea defence	retreat m/yr	Range of slopes
West end of Abbot's Cliff Tunnel	100	Seawall	0.40	1 in 1.1 to 1 in 0.7
Abbot's Cliff to 1912 rock fall	525	Shingle Beach	0.13	1 in 1.1 to 1 in 0.7
1912 rockfall to west end of sea walls	550	Bare chalk platform	0.08	1 in 1.1 to 1 in 0.5
Sea walls to Abbot's Cliff Tunnel	225	Seawall	0.10	1 in 1.2 to 1 in 0.9
Abbot's Cliff Tunnel to Akers Steps	1250	Railway platform and Seawall	0.12	1 in 1.1 to 1 in 0.7
East of Akers Steps	1000	Shingle Beach	0.06	1 in 0.7 to 1 in 0.4

The monitoring of plant and animal life has not been limited to the sea but has included studies of the unique chalk cliffs and downs. Seeds of over 35 plant species have been collected by Wye College for reseeding the new platform, most of which will be kept as a nature reserve on completion of construction. Seeding trials for the platform and the upper slope protection are proceeding.

Studies of the wave conditions and beach gravel movements have shown that the net littoral drift is from west to east up the Channel. While the potential for movement is large the actual quantities moved in the littoral zone are small due to the limited supply of gravel. The net accretion updrift of Dover Harbour is some 3,000 m^3 annually and the construction of the Shakespeare platform in up to 6 m of water (below low water) would disrupt this drift. Studies indicate that it would take over 100 years before littoral drift was re-established.

To assist littoral material to by-pass the platform a beach and groyne are to be built at its west end with its extent limited because of the unique geological exposures which might be covered by a more extended beach. The beach level variation in up to 30 beach sections have been monitored since the start of the project but recently have been concentrated on Dover West Beach (downdrift of the platform). While significant changes have been seen, these are thought to be due to seasonal changes, cliff falls (which act as substantial groynes) and significant events such as the 16 October 1987 storm, rather than to the presence of the platform. Provision has been made in the Channel Tunnel Act for ET to repair 100 m of beach adjacent to Dover Harbour's Admiralty pier, should erosion be seen during the 120 year lifetime of the project.

4.2 Fond Pignon Dam

The approach of the French Planning Authorities is different from those in the UK and the choice of a land fill site negated the need for the extensive marine environmental studies seen on the UK side. However, many studies, an local fauna and flora and groundwater were undertaken.

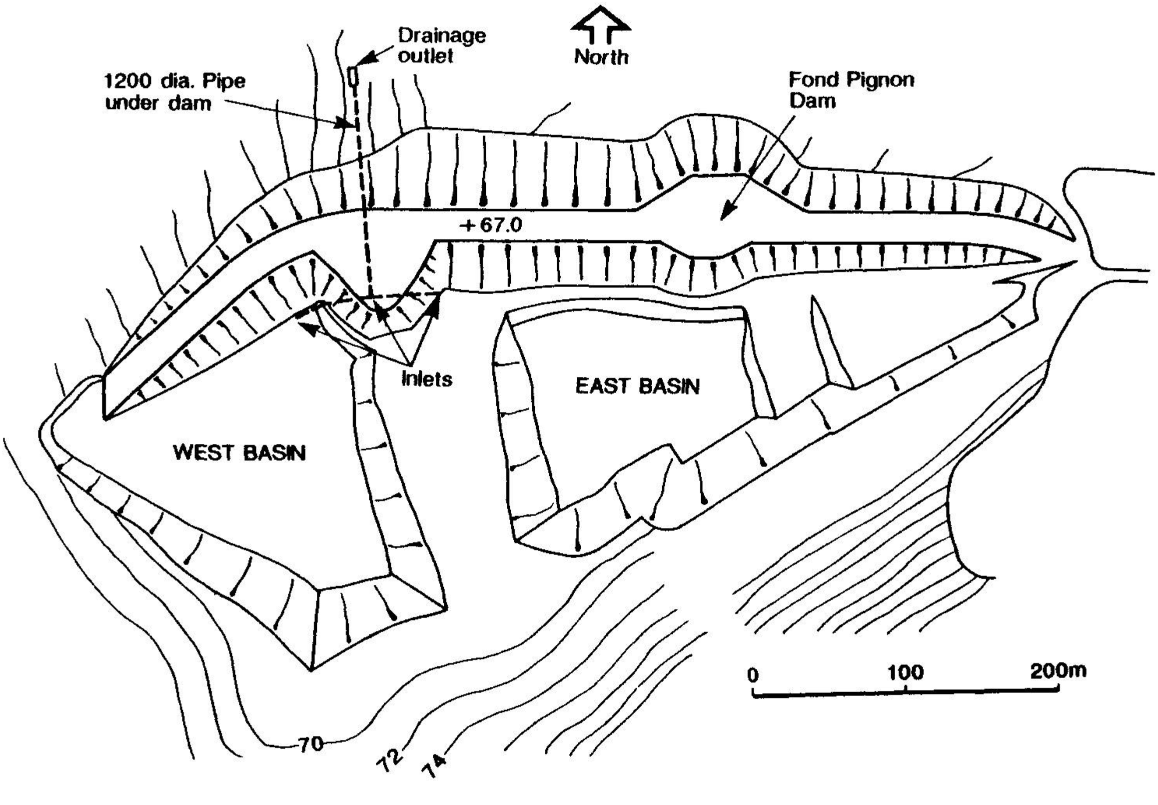


Fig 4 Fond Pignon disposal site

One reasons why TML at Sangatte opted to pump the chalk spoil in a slurry was the nature of tunnelled rock. As Figure 1 shows, part of their tunnelling was in White Chalk and there are a number of major faults (reaching the seabed) through which the tunnels must pass. Also, in general their depth of weathering was greater. Thus, the generally wetter spoil is taken by train to the very large access shaft behind the cliffs at Sangatte and then crushed and turned into a slurry before being pumped to the Fond Pignon site, which lies in a small dry chalk valley, 700 m from the shaft. Originally it was intended that the dry spoil from the drives on the landward side of the access shaft would be sent to the terminal but, for reasons of economy and programming, all spoil went to Fond Pignon.

The planned volumes of insitu spoil excavated on the French side was 2.82 million m^3 and, with a bulking factor of 1.67 the Fond Pignon dam was designed to retain 4.71 million m^3. The reservoir was designed to retain materials with a water content of between 40% and 60% and allow the exuded water from the chalk slurry to be discharged and reused.

The retention reservoir is divided into two areas by a bund roughly perpendicular to the earthfill dam (see Figure 5) which covers two old underground blockhouses. The intention was to construct the dam in two phases, the first about 19m high to provide initial storage of up to 1.4 million m^3 and then to monitor behaviour of the spoil and obtain a bulking factor. The second phase would raise the dam a further 9 m to 11 m, depending on circumstances. It has however been necessary to raise the dam further still because of the better than programmed French tunnelling rates and a higher bulking factor. The dam design was subject to the approval by Comité Technique Permanent des Barrages (Permanent Technical Committee for Dams). However, as it is not a large dam, it was not covered by Decree No 68450 of 16 May 1968 regarding monitoring and warning of downstream populations (there are none in any case) or the statutory order of 11 September 1970 regarding the flood wave.

The comprehensive programme of geotechnical investigations carried out to ensure the project was technically feasible included 15 water testing wells. Pumping spoil required a water content of about 50% when deposited and 20% after consolidation. Seepage studies show that salt concentrations in adjacent ground, greater than 10% of the original concentrations, only inside a 1200 m wide belt between the dam and the sea. This area is well away from any water catchment and should have no effect on potable water quality. Two wells sunk downstream allow groundwater levels and quality to be monitored.

On completion the area will be landscaped and replanted by species similar to that of the surrounding countryside. Replanting trials are underway at present.

5. CONCLUSION

The paper describes some, but not all, of the studies that have been carried out both in terms of the design and to examine the environmental impact of the schemes for spoil disposal. For the Shakespeare Cliff platform alone there have been over 40 studies and many more studies have been carried out on the terminal areas, including archaeological digs.

It might be thought that too much effort has been put into the environmental studies but, while they have been considerable, their costs are normally small compared with the size of the project.

The Channel Tunnel studies have led to a limiting of any potential environmental impact the project might have. They have also advanced knowledge and understanding of the environment and, importantly, re-assured all statutory authorities and the general public that the early assumptions regarding the impact of the works were indeed correct.

During the course of the work every effort was made to obtain the agreement and co-operation of not only the authorities but the general public as well as. ET have held regular "Environmental Forums" at which the progress of the work and the various studies are described and discussed and copies of reports are sent to the relevant interested parties. The general public's interest in the project is high and catered for at ET's Exhibition Centre, which has received about 350,000 paying visitors annually since it opened in September 1988.