15/7/10

# Investigation Report

| | |
|---|---|
| Name(s) of Dutyholder(s) | Multiple: see below |
| Address(es) of Dutyholder(s) | Multiple: see below |
| Role of Dutyholder | Multiple: see below |
| Address/location of incident | Network Rail infrastructure at OS ref TQ 0051 8857: Engineer's Line of Route ELR: NAJ2 at Gerrards Cross between 6m 778 ch to 7m 59 ch |
| Date(s) of investigation | 30th June 2005 to date |

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Part A Investigation details

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## Part A – Investigation Details

**COIN case number** *(Give the master or trigger case number from COIN)*

4002328

**Matter under investigation** *(Give a brief summary of the subject of this report)*

The partial collapse of a structure being built over a two track passenger and goods railway line with trains operating at up to 75 mph. The structure comprising a three pin concrete arch 'tunnel' about 400 yards long, above which was being placed fill material whilst elsewhere on site steel erection for the supermarket was underway

**Date of incident** *(where applicable)*

30th June 2005

**Name of duty holder(s)** *(Give full name of legal entity)*

Jackson Civil Engineering Ltd

Chiltern Railway Co Ltd

Clark Construction (Tim Clark t/a)

Costain Ltd

White Young Green

Reinforced Earth Company

Macrete Ireland Ltd

Branlow Piling Solutions Ltd

PCE Ltd,

Tesco Stores Ltd

Gleeds Management Services

Atkins Rail

Carillion

Network Rail Infrastructure Ltd

Bureau Veritas BQI Ltd

**Role of duty holder(s)** *(Employer, principal contractor, etc)*

Jackson Civil Engineering Ltd – Principal Contractor

Chiltern Railway Co Ltd – Train Operating Company

Clark Construction (Tim Clark t/a) – Groundworks sub contractor to JCEL

Costain Ltd – store construction sub contractor to JCEL

White Young Green – overall designers, consulting engineers, Planning Supervisor (CDM)

Reinforced Earth Company – specialist 'tunnel' designers and suppliers

Macrete – manufacturers of the concrete arch segments

Branlow Piling Solutions Ltd – piling contractor

PCE Ltd – arch unit placement

Tesco Store Ltd - client

Gleeds Management Services – project manager for Tesco and equivalent of Clerk of Works

Atkins Rail – independent checking engineer for the permanent works

Carillion – oversight of safety of the railway to Rule Book provisions

Network Rail Infrastructure Ltd – Infrastructure Controller of the mainline national rail network

Bureau Veritas BQI Ltd – materials testing

**Address(es) of duty holder(s)** *(Include registered office address, Companies House registration number and company search (Annex 11) if a company, or NI number of individual when prosecution under consideration) (Insert COIN site ID number)*

Jackson Civil Engineering Ltd, 86, Jackson House, Sandyhill Lane, Ipswich, Suffolk, IP3 0NA

Chiltern Railway Co Ltd

Clark Construction (Tim Clark t/a), Brentford Grange Farm, Beaconsfield Road, Coleshill, Amersham, HP7 0JU

Costain Ltd, Nicholson Walk, Maidenhead, Berkshire

White Young Green Consulting Ltd, Elliot House, 130, Ber Street, Norwich, Norfolk, NR1 3AQ

Reinforced Earth Company, 7 Hollinswood Court, Stafford Park 1, Telford, Shropshire, TF3 3DE

Macrete Ireland Ltd. 50, Creagh Road, Toomebridge, County Antrim, Northern Ireland

Branlow Piling Solutions Ltd, Denzil House, Main Road, Yapton, West Sussex, BN18 0DW

PCE Ltd, Holly Lane Industrial Estate, Atherstone, Warwickshire, CV9 2RN

Tesco Stores Ltd, PO Box 400, Cirrus Building, Shire Park, Welwyn Garden City, Herts, AL7

1AB

Gleeds Management Services

WS Atkins

Carillion

Network Rail Infrastructure Ltd

Bureau Veritas BQI Ltd, Tower Bridge Court, 224-226, Tower Bridge Road, London, SE1 2TX

**Location details** *(Location of incident or other matter under investigation)*

At a point just south of Gerrards Cross railway station on the Birmingham Snow Hill to London Marylebone main line between 6m 77ch to 7m 59ch. Gerrards Cross station being at 7m 18 ch from Northolt Junction. The operational railway line in the bottom of a deep cutting was being 'covered' to allow trains to pass beneath a new Tesco supermarket being built between Packhorse Road Bridge and Marsham Lane Bridge in Gerrards Cross.

Line speed for passenger services operated by Chiltern Railways is 75 mph in both Up and Down Directions. Freight trains also operate on this line.

**Name(s) and address(es) of IP(s), DP(s)** *(Where applicable)*

None

**Name and full office address of lead HSE investigator** *(The lead HSE investigator is equivalent to the 'investigator' for the purposes of CPIA)*

Inspector of Railways, Office of Rail Regulation, c/o Health and Safety Executive, Lyme Vale Court, Parklands Business Park, Newcastle Road, Trent Vale, Stoke on Trent, ST4 6NW

**Names of other HSE investigators** *(Include the names of key HSE colleagues involved in the investigation)*

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|---|
| HM Specialist Inspector – Construction Engineering – Construction Engineering Specialist Team (South) – based in Luton<br><br>, HM Specialist Inspector – Construction Engineering – Construction Engineering Specialist Team (North) – based in Edinburgh |

**Name(s) and contact details for non-HSE investigators** *(Other investigating authorities and key personnel involved)*

| |
|---|
| HM Inspector of Railways, ORR, C/O Health and Safety Executive, Manchester<br><br>HM Inspector of Railways, ORR, c/o Health and Safety Executive, Birmingham<br><br>, HM Deputy Chief Inspector of Railways, ORR, 1 , Kemble Street, London, WC2B 4AN |

**Date investigation commenced**

| |
|---|
| 30th June 2005 |

**Criminal Procedure and Investigations Act 1996**

| | | | |
|---|---|---|---|
| **Investigator** | | **Officer in charge of Inv (SIO)** | |
| **Disclosure Officer** | | **Prosecutor** | |

**Brief Executive Summary**

*(This information should be copied from the mandatory investigation details note on COIN. Provide short summary of facts and any enforcement actions taken to date)*

A 'tunnel' (or rather 'covered way') was under construction over the 'live' double track main line at Gerrards Cross in Buckinghamshire. The project was to build the reinforced concrete 'tunnel' made out of sections that interlock at the crown of the arch. Then back fill to sides and over the top and then construct a supermarket with car park spaces for 325 off vehicles.

On the evening of the 30th June 2005, at about 19:30 hours, part of the 'tunnel' collapsed. The extent of the collapse was 29 off arch sections each weighing 22 tonnes and many thousands of tonnes of backfill. This blocked the 'live' railway line: i.e. trains were operating in both directions. Fortunately, nobody was injured though one train had just started off from Gerrards Cross station towards the 'tunnel' about 50 yards away whilst another in the opposite direction made an emergency brake application and stopped perhaps 250 yards short of the collapsed 'tunnel'. Each train carried around 50-70 passengers. So the potential was there for multiple fatalities; they were narrowly avoided.

The line was closed for seven weeks reopening on or around the 21st August 2005. There was much disruption to services and consequential loss of revenue etc. The 'tunnel' has been substantially redesigned (now a two pin rather than three pin arch structure) and work is in progress as at 15th July 2010 to complete the project using most of the original 'tunnel' sections but incorporated into the new design.

## Part B – Factual Report

### Description of the facts and circumstances leading to the accident/event

*This section should be confined to factual information, cross-referenced to relevant statements, documents, sketches or photographs. Provide a comprehensive account of the facts. Where conflicts of evidence exist do not comment on the merit of any particular version. Where appropriate, the account should be structured into sub-sections covering, for example:*

- *Plant, equipment and substances*
- *Systems of work*
- *Training, instruction and supervision*
- *Risk assessment*
- *Outcome and consequences, eg extent of any injury*

**Station and incident location:**

Gerrrards Cross is a well to do commuter town lying just north of the M25 motorway on the London Marylebone to Birmingham Snow Hill main line (ELR:NAJ2). This is the former joint GWR / GCR route that opened in the early years of the 20th century with Gerrards Cross station opening in April 1906.

The station which is operated by Chiltern Railway Co Ltd (leased from Network Rail Infrastructure Ltd) is located at 7m 18ch from Northolt Junction and had 829,000 passengers in the year 2005/06 (at the time of the incident to which this report relates). NB this is the year when the station had no passengers for seven weeks!

The station has two platforms and hence two roads – 'Up' and 'Down'. However, when built there were four roads through the station, two of which were 'through' roads. The extant roads are non electrified and aligned on a gentle reverse curve with max speed of 75 mph for through passenger (non stopping) trains. The route is also available to goods traffic.

Immediately to the east of the 'up' platform end there is a road over rail bridge known as Packhorse Road Bridge (Network Rail structure 31) and about 350 yards further to the east is a second similar bridge known as Marsham Lane Bridge (Network Rail structure 30). The double track line between these bridges is at the bottom of a 12m deep cutting with side slopes at 1:2 opened out when the line was built. The formation was and remains capable of accommodating four tracks.

**History:**

Many years ago, circa 1960, it was mooted that an office block could be built over the railway by the expedient of covering the tracks with a 'tunnel', backfilling and then constructing said building. Technically this is not a 'tunnel', rather a 'covered way'. Further attempts were made post 1990 to progress a similar project and Railtrack identified Tesco Stores Ltd as a partner to sponsor the scheme but this time for a supermarket. This involved construction of a covered way / 'tunnel' and supermarket / car park above the operational railway.. The green light for construction was given in 1998 by the then Secretary of State for Transport, John Prescott. This despite much local opposition.

Initially, the scheme was to be a two track affair but in 2001 following representations made by freight operators it was decided to 'future proof' the route such that it would become a 'tunnel' to accommodate four tracks. Due to the floor level and height of the proposed store needing to remain, the designer kept the crown of the arch at the same level as in the four track scheme.. The effect of maintaining the crown level whilst increasing the span was to

create a much flatter arch. This had implications for the design.

The basic design envisaged a single storey store of approximately 34,000 sq ft (Tesco Format 25 style), of steel frame construction, brick clad supported on large reinforced concrete foundations to spread the load over the 'tunnel', with a surface car park and access road for 325 vehicles. The 'tunnel' requiring 90,000 cu m of imported fill material to construct the above. Most of the fill material being brought to site by rail using an extended siding adjacent to the 'Up' line just west of the station itself. The tunnel is aligned in a NW-SE orientation with west being the country end and east being the London end. The approximate value of the contract was of the order of £25m.

**Chronology**

The information obtained indicates there were some key steps or stages in the project where decisions likely to affect railway safety were made. In chronological order these steps or stages were: -

- 1998 – 2001: feasibility studies: various options were considered including variation of arch dimension to span four tracks - an increase to the original two track spanning structure: this following objections from FOCs to the two track option.
- May 2001: the 'Form A' (outline design concept) submission for a four track span, which explains the design concept, was agreed with Railtrack by White Young Green (WYG) who were Tesco's consulting engineers.
- June 2001: a tender document incorporating the 'Form A' details for the scheme was issued to prospective tenderers as part of the first stage tender process, to narrow the field to four front runners for a Design & Build scheme: (a form of contract where the Principal Contractor accepts responsibility for the detailed design and construction of the project).
- 26 June 2001: Pre tender Health & Safety Plan issued by WYG
- 11 Feb 2002: Gleeds prepared a report on the first stage tender process, identifying four suitable candidates who then produced fully costed submissions for the second stage tender process, for a design & build scheme.
- 12 Feb 2002: Pre-tender Health & Safety Plan updated - by WYG
- 14 to 18 March 2002: All four second stage tenderers met with Railtrack to demonstrate their understanding of the scheme, discuss the site constraints, raise queries and confirm their mutual understanding of the project requirements.
- 20 May - 30 May 2002: Second stage tender process review completed. WYG & Gleeds joint report recommends negotiations commence with Jackson Civil Engineering Ltd (JCEL) as the preferred contractor for the project.
- 25 June 2002: A letter of no objection to concept of the project was sent by HMRI (HSE) as part of the RQTS process
- 27 Jan 2003: Network Rail appoint Carillion Rail for asset protection / possession management work at the site, in accordance with "Rule Book Requirements"
- 24 - 26 April 2003: contracts signed by Tesco to appoint Principal Contractor (Certas, JCEL's parent company); Planning Supervisor (WYG); Project Manager, Supervisor and Quantity Surveyor (Gleeds) and Independent Checker for Design - the 'Cat 3' checker (Atkins Rail )

- 25 April 2003: Tesco / Network Rail 'air rights' agreement signed defining safety obligations of both parties and specifically when Network Rail's approvals or acceptances were required. Tesco's responsibility for construction safety is confirmed in this document.
- April - May 2003: JCEL change the backfill design. Previously single source limestone (6N) - changed to limestone fill around the arch with mass fill of Incinerator Bottom Ash Aggregate (IBAA). Reinforced Earth Company (RECO)s check on the arch structure for this revision & WYG design check for foundation loads follows thereafter.
- May 2003: Site clearance and surveying starts
- June 2003: Piling work starts on the site
- Mar 2004: JCEL circulate arch backfill procedure, indicating a trapezoidal 6N sleeve placed first and followed by IBAA surrounding . Circulated to Gleeds and Network Rail's site team.
- contract extended by Network Rail for railway asset protection services.
- 29 July 2004: arch unit erection commences
- 13 Dec 2004: Arch backfill method statement issues by JCEL
- Jan - Feb 2005: Partial sanction by NR representative of arch method statement
- Jan 2005: Arch backfill starts on site
- 13 June - 28 June 2005: large Arch deflections reported by JCEL site engineers to JCEL site managers
- 28 / 29 June 2005: Platform for East Portal on the arch crown commenced
- 30 June 2005: East Portal concrete pump method statement issued
- 30 June 2005: at approx: 1930 hrs arch sections collapsed onto the operational railway line below

**Principal dutyholders involved: (inc witnesses)**

Tesco Stores Ltd were the client as owners and eventual operators of the store (*David*

Gleeds Management Services acted as Tesco Stores Ltd Project Managers, Quantity Surveyors and on site Clerk of Works equivalent.

Jackson Civil Engineering Ltd, Principal Contractor appointed by Tesco Stores Ltd

Costain Ltd were Jackson Civil Engineering Ltd's sub contractor to build the store

White Young Green Consulting Engineers appointed by Tesco Stores Ltd as overall designers and Planning Supervisors for the project

Reinforced Earth Company (RECO) were appointed by Jackson Civil Engineering Ltd to design and supply the reinforced concrete 'tunnel' sections

Atkins Rail were appointed by Tesco Stores Ltd to check design, calculations etc as independent 'Category 3 checker'

Macrete Ireland Ltd were contracted direct to Reinforced Earth Company to manufacture and deliver the 'tunnel' sections

Branlow Piling Solutions Ltd were appointed by Jackson Civil Engineering Ltd to design and install piles to support the structure

PCE Ltd were engaged as direct sub contractors to Jackson Civil Engineering Ltd to supply labour and plant to erect the 'tunnel' sections

Hanson Aggregates UK Ltd contracted by Jackson Civil Engineering Ltd to provide bulk fill materials to site

Clark Contracting (Tim Clark t/a) were bulk fill sub contractors working direct to Jackson Civil Engineering Ltd. [redacted]

Reynolds Installations, sub contract groundworks contractor but not known to whom

Bureau Veritas B&I Ltd were appointed by Jackson Civil Engineering Ltd to undertake materials testing including measuring compaction of bulk fill at site

Scott Wilson Consulting Engineers were appointed by Costain Ltd post collapse to provide a design solution for completion of the project

Network Rail Infrastructure Ltd own and maintain the railway infrastructure though do not operate passenger or freight services.

Carillion Transport dealt with oversight of safety of the railway to Rule Book provisions

Chiltern Railway Co Ltd: train operating company on the route including Gerrards Cross station.

**Tender Stage**

In May 2001 the design scope for a four track scheme was agreed with Network Rail using the 'Form A' sign off process. This is an important step because the designer is telling Network Rail that the chosen design concept incorporates various NR restrictions and constraints. In March 2002, a series of meetings chaired by WYG were held with eight prospective tenderers to explain the project. The space and access constraints of the site were described in the tender documents but meetings were held to ensure that these constraints were properly understood by the tenderers. This was to help them appreciate the risks and liabilities involved in progressing the design concept into a detailed design and then a built structure. These meetings were minuted.

of WYG confirmed that he was first involved in feasibility studies in 1990 and WYG, his employer, were involved in the early feasibility discussion for the project including the early two track options and the final four track option. In January 2002, helped his colleague of WYG prepare a tender presentation which showed a typical tunnel cross section and the construction process. He outlined the scheme

requirements including planning issues, site geology and method of construction. This included the backfilling requirements anticipated by the designer i.e full width and equal height either side of arch and it also included key constraints arising from railway operations. It was a two hour presentation fairly typical for a project of this size and scope at tender pre-selection stage. It also describes how piles and pile caps are to be constructed alongside the railway, how tunnel arch units are erected during track possession and how the tunnel arch fill is to be placed in layers either side of the tunnel..

Following the first stage tender process when the design concept was made clear, WYG invited a shortlist of four tenderers for second stage tender meetings, which included Network Rail personnel, to further clarify the scope and answer queries. The table below outlines some of the discussions extracted from these minutes-

| Date of meeting | Contractor + Personnel | Structural design type issue raised regarding the new 'tunnel' |
|---|---|---|
| 14 Mar '02 | **Skanska** | One raised - query about loading the outside of the erected arch units |
| 18 Mar '02 | **Costain–** | Four raised<br>1) installation of tunnel roof,<br>2) differential settlements between 'tunnel' and Packhorse Rd bridge<br>3) backfilling over erected arch units<br>4) discussion about alternative structural arch forms |
| 27 Mar '02 | **Jackson** | None raised |
| 28 Mar '02 | **Taylor Woodrow** | None raised – but confirmed they:<br>1) were happy with techniques + concepts,<br>2) were familiar with the RECO system, and seen other NR sites using it,<br>3) had reservation about other suppliers of alternative units. |

Ultimately Jackson were appointed in April 2003. There was around 12 months for the designers / contractors to appreciate the client requirements which would have been discussed at these tender meetings a year earlier.

Around May 2003, JCEL proposed partial use of IBAA fill as an alternative to WYG's original design and WYG assessed this change for compatibility with the foundation design. The effect of this change on the arch units was checked by RECO in about May 2003. WYG then incorporated JCEL's design alteration into the 'category 3' checking regime. This sequence of events, i.e. the changed backfill requirements and WYG's check on the foundations occurred very soon after JCEL's appointment as Principal Contractor during a value engineering exercise.

At the two stage tender process all of the tendering parties

- were informed about the project backfill requirements and
- had information at the tender stage to enable assessment of the risks involved in the work and
- had opportunity to discuss rail restrictions and rail safety risks and
- had time to consider the implications of the risks and restrictions when planning the work.

It was JCEL who chose the IBAA fill material as a design option to complete the project. Their

contract allowed them to do so.

Gleeds were involved in supporting Tesco's procurement during the two stage tender period and then administering the 'New Engineering Contract Form of Agreement' between Tesco and JCEL. Gleeds had no technical input into design and construction issues during the tender stages: their input was into programme and commercial matters only and advising Tesco on the same. Additionally, Gleeds understood that all design functions were controlled by JCEL after the latter's appointment by Tesco on 24 April 2003. Gleeds would have monitored the design activities for statutory acceptance by the likes of Network Rail as these represented key milestones in the project, but this was to measure the process for timeliness and adherence to the project programme. Gleeds limited role in the technical issues at the tender stages appears to be confirmed by the information obtained from Network Rail and WYG.

From the information contained in the tender meeting minutes, JCEL raised no queries at this stage and offered no alternative design proposals. Furthermore, in submitting a 'design and build' tender JCEL were accepting responsibility for managing the 'design' risks in the project. These risks would have included both safety and commercial risks.

**'Tunnel' design**

Overall the design of the 'tunnel' was undertaken by WYG incorporating a specialist reinforced concrete arch design developed by RECO and using their 'Tech Span' system developed by a sister company in Spain. Essentially, this three pin 'arch' design (two keyways at pile caps plus where male and female ends of units meet at the crown) consists of segmental pre-cast steel reinforced concrete sections that interlock together (50% lateral stagger at the crown, one to another). Each project is largely bespoke in terms of shape of the 'arch' and the associated geometry.

The 'Tech Span' system has been used on the Continent for around 25 years and was introduced into the UK in the early 1990's. It has been used in many applications though primarily for 'tunnels', culverts and the like. In the UK notable jobs include the Channel Tunnel rail link and the 'tunnel' giving access to Terminal 5 at Heathrow.

Erection of the concrete reinforced sections and subsequent back filling arrangements are included in RECO's Construction Manual entitled Tech Span Construction Manual Spanish Crown Joint dated 29th October 2002 and its subsequent addendum dated October 2004. The purpose of the addendum was to ensure that the backfilling arrangements complied with the Specification for Highways Works – Series 600. Copies of both the Tech Span Manual and its addendum being given to Jackson Civil Engineering Ltd.

When erection of the sections is complete backfilling commences with compaction to the required specification. Asymmetrical backfill loading is a factor that influences instability in all arch structures.The 'Tech Span' system appears to be particularly 'sensitive' to asymmetric loading. The 'Tech Span' manual emphasises the need to control the backfilling operation to ensure that there is no differential between backfill levels of greater than 500mm from side to side.

Continuing on the 'sensitivity' aspect, of RECO states "The design intended backfilling sequence leads to the crown deflecting above its initial position. As the backfill is placed on the arch, the backfill to the sides provides restraint and the arch deflects downwards close to the design position. If backfill is not placed as the design intended, as in this case, this restraint will be reduced and the deflections increased. The result of this will be to increase the stresses in the structure and reduce the overall factor of safety of the design".

RECO had no on site role, never visited the backfilling operations and according to [redacted] were unaware that the backfilling arrangements were contrary to their Design Intent.

In this project the "tunnel' to be constructed measured 324m in length (Packhorse Road

bridge (ch 941.162) to a few metres short of Marsham Lane bridge (ch 1261.69)) and has been constructed wide enough to span four railway tracks (as above). This span is at the upper end of 'Tech Span' projects. The concrete sections were manufactured by Macrete Ireland Ltd for RECO and went directly to a near to the site holding yard, by road. There were a total of 343 sections, each weighing 21.5 to 22 tonnes (those under the store itself having more steel reinforcement) to cover a span of 20 metres with a height from rail level to intrados of 8.5m to allow for possible Overhead Line Electrification in the future. Each concrete section measuring 1824mm wide x 350mm thick. Required concrete strength was 50 N / sq mm. The sections were founded on a pile cap on either side below which are 1,100 off, 450mm diameter cast in situ concrete piles extending down 8.5m on each side of the 'tunnel'.

Drawings, specifications etc were provided by RECO to Macrete Ireland Ltd and the former sent one of their employees ( ) every month to monitor quality etc. Information from his inspections confirming that the precast units were compliant has been obtained by HSE.

It should be noted that at the outset only '6N' (a limestone quarried, crushed stone material) was envisaged but this was changed to a mix of '6N' and any material that met '1A' specification and Incinerator Bottom Ash Aggregate (IBAA) was chosen as presumably a cost saving measure.

JCEL proposed this alternative backfilling arrangement to the original design in May 2003. They circulated their fill placement procedure (working method) to Network Rail and Gleeds in March 2004. The project drawings showed a "sleeve"of '6N' material around the tunnel, with an alternative bulk fill elsewhere.

The fill placement procedure prepared by JCEL indicated that the trapezoidal sleeve of 6N material around the arch would be placed first along the length of the tunnel. This would then be followed at a later stage by IBAA fill over and around it. This document was not sent to the designers.

The designer's intention was that all backfill materials should be placed across the 'full width of the excavation'. The two methods of backfilling were therefore inconsistent with one another (see drawing 2101 rev F).

Backfill arrangements were discussed between JCEL, WYG and RECO about this change. JCEL who initiated the change, then had to manage the delivery of the changed "design" under the terms of their contract. We are not aware of any calculations undertaken prior to the collapse for the loading situation created by placing a trapezoidal sleeve first and IBAA later. This was not part of Atkins category 3 independent check either. (The density of IBAA is less than that of 6N). Atkins Rail confirmed that Cat 3 checks did not include any intermediate stages of construction.

**Site events:**

Following a successful tender (lowest of all by some margin, approx £3m), Jackson Civil Engineering Ltd started work at Gerrards Cross around May 2003. Initial work was site clearance and surveying. HMRI approval was obtained for the project under the Railways and Other Transport Systems Regulations 1994: HMRI being an Inspectorate within HSE until April 2006.

HMRI's "approval" referred to in the paragraph above was actually a "no objection" letter in accordance with the ROTS Regulations and it was issued on 25 June 2002. This "no objection" letter was based on the ROTS submission which for this scheme was the' Form A' document and supporting information prepared by WYG in Jan 2001. The 'Form A' document is an important step in the project, as this submission confirmed to Network Rail and others involved that the concept design for the arch structure as described therein, could be built within certain constraints thus:

- it would span the railway to carry the proposed loads emanating from the client requirements
- provide adequate clearances for rail traffic
- could be built subject to some important Network Rail restraints e.g. site access
- complied with Railway Group Standards

The same document also confirmed that as Tesco's expert advisor, the consulting engineers WYG, had done enough research to justify the statement of intent in the 'Form A'. This is a very important principle from the point of view of the approach by the engineers concerned, as the 'Form A' submission set the technical boundaries of the project.

The 'Form A' submission confirms in part 2.9 that the design concept proposed had no unusual features, the technical standard for the design is BD37/88 (Department of Transport Bridge Design Standard) and in Section 9.1 there are no departures from the technical standards stated. This indicated to Network Rail that the design concept contained well known features and presented no unusual risk.

A resubmission of the 'Form A' is mandatory if the detail design, design implementation and construction phases result in deviations from the original 'Form A' parameters. No revised 'Form A' was ever submitted. It is not clear if the change in fill material would be sufficient to require a further 'Form A'

Referring to the concept design stage described in the 'Form A' documents it should be noted acceptance was required by senior engineers at various levels in Network Rail's organisation. Additionally in this case, acceptance by the local Highway Authority was also required. This means that at least three engineers outside the WYG / RECO team were satisfied that at this stage, prior to detail design and construction, the concept design was buildable. These senior engineers were (Network Rail Territory Civil Engineer), (Network Rail Principal Asset Manager for Structures) and Senior Bridge Engineer, Bucks County Council) and they would not have given their acceptance to the 'Form A' submission lightly. Their signatures are on the 'Form A'.

It is important to note that a reviewing engineer would not sign any acceptance of the 'Form A' submission:

- If he had any doubts about the concept design
- Until any queries had been clarified or explained.
- Until technical requirements or constraints were complied with

Thus, in the information collected we see that Messrs. [redacted], engineers from Network Rail, raised many issues about the design concept in the 'Form A' submission. They sought clarification on all these matters before acceptance was given.

Piling works were undertaken by Branlow Piling Solutions Ltd and commenced in June 2003 but were suspended as Network Rail Infrastructure Ltd had not approved temporary works proposals. This was obtained in November 2003. By February 2004, 478 off piles had been installed (22% out of 2,200 off) but discussions re pile reinforcing continued during 2004. The dispute centring around the derailment loading and the amount of reinforcing required in the piles.

Works later recommenced and had progressed to such an extent that the pile caps had been constructed allowing erection of the reinforced concrete 'tunnel' sections to begin on the 29th July 2004, concluding in June 2005.

PCE Ltd who undertook the erection had previous experience of the 'Tech Span' system. Erection took place at night in full engineers possession of the line ('T3') using an LR1160 crawler crane working to their own method statement. In short, following inspection by the PCE Site Foreman (and JCEL), each section (they all passed though a few had minor damage such as spalling) was craned into position using proprietary lifting points. After the

first four units were installed there was no need for temporary support as each section was interlocked at the crown through 50% of the section width. Each section having a stainless steel end plate (either male and female) at the crown. Shims at the bottom of each section were used in the keyway (100mm deep x 575 wide) as necessary, as well as steel wedges at the rear. Each section was checked that it was erected to previously installed lines and every fifth one by theodolite to ensure the top was not creeping out of line.

The longitudinal stitch beams on the extrados measured 250mm x 312.5mm tied the sections longtitudonally. PCE Ltd did not grout the keyways and had nothing to do with the longitudinal stitch beam on the extrados of the crown or the bulk filling.

PCE felt that apart from poor ground conditions / lighting on occasion there appeared to be no problems with the ercetion of the concrete sections.

Backfilling commenced in January 2005 and was undertaken by Clark Construction C . This is a local company based in Amersham. They have around 35 employees (inc staff). Their contract with JCEL was to backfill and compact within the cutting using material supplied by JCEL. Initially, although two grades of material ('6n' and '1A') were required, it was envisaged that they would be from a single source and would both be crushed limestone. The source was with a quarry with a railhead. A proposal was advanced to use Incinerator Bottom Ash Aggregate for the '1A' grade material. This was supplied by rail from Rainham in Essex'. IBAA is a less dense 'man made' waste product supplied by Hanson Aggregates UK Ltd.

Prior to the backfill operation commencing in January 2005, a 'Fill Material Placing Procedure and Sequence' document had been issued by [redacted] of JCEL dated 23/03/04 (ref 4107/dt/AE/016) - Appendix L. In essence, this said that the fill should start with '6N' making an annulus around the tunnel working from west to east. Once complete, IBAA filling would start at the east and move west. There was to be a haul road to eastern end on a 1:10 grade.

To execute this procedure a method statement, serial number 4107/MS/044 dated 8th December 2004 was prepared and Section 9.0 Methodology is particularly relevant. It was prepared by of JCEL along with of Clark Construction signed off by of JCEL. (The basis for the method statement were WYG and RECO drawings, 'Tech Span' manual and Addendum and the Civil Engineering Works Specification). It was 'accepted' by (Design Project Engineer) for Network Rail. Though Network Rail had no site role they were involved in supervision of working methods as far as asset protection of the railway from contractors activities were concerned, in accordance with Rule Book requirement 'GCRT8000' sections 'T2' and 'T3'. The 'Form C' sign off process for site temporary works was also in place. All method statements having to be 'accepted' (demonstrated by form 'G2') by Network Rail. In this instance reviewed and rejected the above method statement asking the question on form G2 "will fill be placed to a uniform level across the full width of a cross section or will it ramp up or down locally at the arch in order to maintain the correct fill level differential between the north and south sides". He ultimately accepted the method statement when he was given to understand that the fill would be placed up and brought up across the full width of the cross section.

The back fill method statement was never sent to WYG nor RECO though according to certain aspects were discussed with RECO who did a design check. All method statements were stored centrally in the site offices and available to anyone who had cause to need them.

The method statement required '6N' and then 'IBAA' materials to be placed either side of the tunnel sequentially. There must at no time be a differential between sides greater than 0.5m in height. The '6N' being placed in 100mm layers using a 13 tonne tracked excavator and then compacted using a vibrating compactor in accordance with clause 610/5 of the Highways Specification. states "So effectively we worked to the Highways Specification whether that actually says that in the method statement I'm not sure unless I read right through but that certainly was the intention and that's how the contract was set

up..." This is specified in the Civil Engineering Specification produced by WYG.

A Bomag 120 roller being used to compact materials over 2m away from the tunnel. Material will be built up in layers to the crown with the leading and trailing edges sloped to ensure it remains stable. 1.5M of compacted material required over the tunnel so that the dump trucks can be used. IBAA will be deposited by dump trucks and levelled using a D6H bulldozer towing a roller behind for compaction. The leading edge of the fill must be a minimum of 10m from the leading edge of the tunnel. Steve Christian says "the intention was to place all the 6N which is what I call engineering fill around the tunnel and then to fill in with IBAA". This appeared to be mainly due to delivery and site storage restrictions: two different materials from two locations by train (and lorry) and not much site storage area.

It is not clear exactly how the fill should progress in the method statement. The use of the word 'sequentially' is ambiguous.

Information indicates that the backfilling method chosen from the start appeared to be a '6N trapezoidal sleeve' around the arch with IBAA fill later, not brought up full width as the WYG specification required.

The presence of the unrestrained trapezoidal sleeve of '6N' construction, (the sequence adopted at the site) is significant. Tesco's expert report refers to "unprecedented departures" from the intended design, language that suggests a gap between the backfilling practice around the arch on site compared to good practice.

The three points mentioned above and the trapezoidal fill issue generally need taking into account when judging the management systems on this project.

[redacted] though seems certain when he says "I have no doubt that it allowed us to build it the way we did in terms of putting '6N' or type A material over the 'tunnel' on its own, absolutely no doubt. So there's nothing on that drawing that indicates to me I, we needed to fill it in to the full cutting width right the way up the tunnel". Further, he states that he believed the way the method statement says the work to be done was correct.

Was the above method statement the right method statement for this 'sensitive' structure?

The specification did not require any deflection monitoring of the 'tunnel' sections as to their relative positions during and post backfill though there does appear to be the need for monitoring of 'settlement plates'. Indeed [redacted] was unaware that WYG requested 'tunnel' crown monitoring during backfill in March 2005. He doesn't know if any results were so passed nor can he recall if his own engineers [redacted] gave him the information - they said they gave it to him or [redacted]. Similarly, [redacted] was also unaware of any requirement in the contract for fill / post fill monitoring.

In the information WYG confirm that they requested deflection monitoring of arch units following discussions with RECO, mainly to compare actual deflections with theoretical ones.

Moving onto the monitoring situation. The information indicates that when JCEL eventually did monitor the units for deflections the results were ignored. Some very large deflections (> 150mm) did not result in any action by JCEL site management. Thus, had the works been completed without collapse, large areas of the structure would have been in a condition not foreseen by its designers and hence well outside its design parameters, Nobody on site was aware of this situation at the time it occurred.

The information does reveal JCEL's view of the structure. Its construction was like a 'big culvert' according to [redacted] Nothing in the information from WYG or RECO indicate they specifically emphasised to JCEL the sensitive nature of this structure.

**Practicalities of fill operations:**

Placement of fill commenced in January 2005 with '6N' initially and then IBAA which were primarily supplied to site by train using the extended turn back siding to the west of the station. Trains being unloaded by 360 deg excavator feeding a conveyor taking the material under Packhorse Road bridge to site. Here it was initially deposited by long reach plant to the opposite side of the 'tunnel' but this was very slow and so a 'field conveyor' was then used (Accepted by Network Rail). Once a cover of 1.5m had been achieved over the crown of the tunnel, it was JCEL's understanding that this would allow Volvo A30 dump trucks over the 'tunnel' and thereby speed up deposition.

An annulus ring was created around the concrete 'tunnel' sections to a profile shown on the drawings. It was compacted by light compaction plant and then larger plant (Bomag 120) further from the 'tunnel' (between 1 and 2m) and then larger towed plant elsewhere. The method statement emphasised that the maximum differential between heights of fill side to side must be no greater than 500mm. Once the '6N' had been compacted to the required profile at base, sides and crown of tunnel they then deposited the IBAA which was spread and compacted using a towed roller. in his second PACE account towards bottom of page 13 says "The intention was to place all the '6N' which is what I call engineering fill around the 'tunnel' and then to fill in with IBAA". This appears to be because of the restricted nature of the site, restrictions on type of deliveries per week and lack of storage accommodation for materials? The backfill being 6N from PHRB to ch 1100 and then filled with IBAA and then carried on in same vein to Marsham Lane bridge.

The method statement involved the placement and compaction of two different materials at different times. The Highways Specification Series 600 Earthworks at page 9 para 4 states "Embankments and other areas of fill shall, unless otherwise required in the contract, be constructed evenly over their full width and their fullest possible extent". When questioned about this anomaly and considered that it was not feasible to compact the two different materials at the same time to the same extent and that the correct procedure was to compact one, then bench into the edge, place and compact the second material to complete the filling operation. RECO's addendum was written to achieve compliance with the Highways Specification.

Compaction specifications were detailed in the contract with Clark Contracting dated 24th February 2005. They were also given by JCEL relevant drawings and a copy of a RECO document entitled Tesco Store – Gerrards Cross, Construction Manual Addendum, Backfilling and Compaction, dated October 2004. Clark Contracting took their instructions exclusively from JCEL. Their foreman was who dealt principally with (General Foreman) of JCEL who gave them their instructions.

Overseeing the backfill from JCEL's point of view was (Site Engineer). He never saw the method statement prior to the tunnel collapse. He looked for it but could not find it. (To be fair they had a central copy available in the Site Offices). So he interpreted the drawings and was briefed by a colleague who was leaving for Australia. This resulted in compliance with the method statement. not aware of the Highways Specification Series 600 documents existence though he had seen RECO's 'Tech Span' manual and addendum. was concerned that Clark Contracting not fully aware of backfilling process but no action taken by Site Agent).

of Clark Contracting believed that his staff followed the method statement though he had no personal knowledge and he did not hear to the contrary.

of Clark Contracting always received his instructions verbally from of JCEL. He did have a copy of the backfilling method statement. He says that when he took charge on 4th April 2005 some of the backfill was in place and he carried on as per the method statement along with his Clark Contracting staff of of Reynolds Installation. says his men created a "ring" (trapezoidal profile) around the tunnel of 6N before the IBAA was brought up in 1,000mm lifts on either side consistent with the maximum 500mm differential in height restriction. This was benched into the '6N' using the dozer and then compacted. Thus, there

was a sleeve of '6N' around the tunnel and between it and the embankment edges was a bulk fill of IBAA. IBAA also being deposited over the tunnel to finished level. This was how the job appeared to proceed until the 29th June 2005. Hence, the method statement was apparently being followed but this was not in accordance with the Highways Specification Series 600 Earthworks.

Some time in early to mid June 2005, (JCEL Senior Engineer) asked (JCEL Engineer) to check the intrados levels at east and west portals. The west was lower than its design position by 125mm (tolerance of 25mm to 30mm) and was roughly the same at the other end. There was no fill over the tunnel at Marsham Lane portal. He double checked from a different location with the same result. He passed his results to who passed them on to either of JCEL. Nothing resulted. Similarly, and JCEL Engineer) had also checked the 'tunnel' crown levels (before 10th June 2005) and at the east end it was 147mm lower than shown on a WYG drawing. They reported this to but they were not too concerned as they "thought it might be a tunnel geometry problem". Further on the 28th June 2005 asked to take further crown level measurements. This he did resulting in 191mm low at the west end and 179mm low at the east end. This was reported to but n/k by what they did with the information.

In the afternoon of the 29th June 2005, told and a (who worked also for Clark Contracting) that an access 'road' (level area) to site a concrete pump was required on top of the tunnel. The concrete pump was coming to site on 1st July 2005: no method statement for the fill aspect was prepared though and the JCEL engineers discussed the pump's position. The pump was for use with a mass pour at the Marsham Lane end of the site as required by Network Rail who didn't want reinforced earth but rather mass concrete at the east portal. '6N' covered the 'tunnel' at this point. The access road consisting of spreaded fill – presumably IBAA. It was to be about 30m long – to the protection boards. Positioning of the place where the pump was to be sited was marked out by at the request of This was to be as far back from the east portal as possible and central over the crown of the 'tunnel' to feed both sides. Actual measurements were 34m back from the portal as the pump had a 32m boom. This was done a number of times as deposition of the IBAA would obliterate the sprayed markings. said he didn't know the depth of the IBAA at the pump position due to changes in depth of fill since he last checked!

told that the sides of the 'tunnel' were not up to level with fill. reiterated the need for access road for the pump and that they could return to side backfilling later says he "did what I was told". corroborates this account. However, in his PACE interview has a differing view on this aspect in that he assumed that Clark Contracting would fill in the sides before going over the top with the fill. (JCEL Project Manager) in his PACE interview is categorical that he told to get the sides filled in when he saw the access road going in on top of the 'tunnel': see next but one paragraph below.

In effect the top was covered with IBAA for the platform and the sides were not backfilled. This is contrary to the method statement prepared for the works by (JCEL) and Clark Contracting) above. aw that the backfill was not going as per the method statement but it didn't seem to register "I did spend an awful lot of time walking past it, walking round it" but did not forcibly tell to get the sides filled in. So presumably assumed the sides would be brought up, that he didn't get them brought up when he saw it throughout the day and that he didn't communicate properly with A series of photos taken by (HMRI) shows the IBAA being shy at the sides of the 'tunnel' and are commented upon by his gives credence to the '6N' around the tunnel with IBAA on the top but missing from parts of the sides. never thought the tunnel would collapse even with the extra IBAA on the top of the tunnel.

In the afternoon of the 30th June 2005, (JCEL Project Manager) went out to site to get some photographs for a magazine. He took the very last photos of the tunnel standing at about 15:00. He spoke to enquiring as to what was going on atop the 'tunnel'. Stewart Bamford told him that he had been instructed to do the work by of JCEL: ie build the access road and then backfill the sides. was content according to but reminded the latter to backfill the sides as soon as the top road was finished. Again corroborates this account. says that normally they would have backfilled the sides of the tunnel with IBAA before placing IBAA on the top of the 'tunnel'. takes a contrary view and is categoric when he says he told them to get the sides filled in immediately though he did not check that his instructions had been carried out.

(Project Manager) of Costain Ltd was in charge of the store construction itself - they were direct sub contractors to JCEL. They had no part in the 'tunnel' construction or backfilling. noted that '6N' had been placed around the 'tunnel' section roughly opposite his site offices. He thought it was perhaps a metre thick all around and had been placed there up to a week before the collapse. He saw a dozer on the 30th June 2005 spreading IBAA over the top of the 'tunnel' though there was minimal IBAA over the '6N' on the sides of the tunnel. The haul road to the end of the site was compacted IBAA. There was no fill above the haul road between the sides of the tunnel and the embankment. also noted that they were having problems with IBAA in that there was nowhere to store it! This is corroborated by of Reynold Installations who states" I thought it was odd that there was not much at the sides whereas in the main body of the site the sides had been filled in before the top of the tunnel was covered". Incidentally, he never saw a method statement for backfilling or compacting though the latter is what he was doing on the date of the collapse - simply asked to do it by of Clark Contractors. He says that was nearly always out and about the site corroborates the above lack of IBAA at the sides of the '6N' in the area from the car park to the protection boards.

Volume 1 Specification for Highways Works – Series 600 Earthworks at page 9, para 4: "Embankments and other areas of fill shall, unless otherwise required in the Contract. be constructed evenly over their full width and their fullest possible extent....."
(Consulting Engineer with WYG) confirms this requirement was part of the project specification. WYG were last on site on the 10th June 2005 and had no site role throughout. Their contract specifically excludes this.

It should not be forgotten that apart from trains beneath the backfilling operation there were also contractors working in the 'tunnel': eg Carillion staff working on catch pits and a supervisor. They exited about 16:00 when the 'tunnel' lighting became faulty.

The access road for the pump was finished about 16.15 on the 30th June 2005 and then backfilling of the sides commenced and continued to about 17:45. There was no sign of distress when they left though earlier (23rd to 28th June)

Earlier a 4' wide section of '6N' had been dug out on the south side roughly where the 'tunnel' collapsed. This was roughly at the interface between what collapsed and what stood. This was to repair a leak. (We have been unable to track down the contractor's operative (employed by Walsh) who was involved in this aspect of the works). It was backfilled as it was later decided that this might unbalance the 'tunnel' in terms of asymmetrical side loading.

On the evening of the 30th June 2005, at approximately 19:30 / 19:35 hours a 'tunnel' over the railway line at Gerrards Cross partially collapsed such that many thousands of tonnes of concrete arch structure and fill material fell onto and totally blocked the two track railway line. Fortunately, this heavily used commuter line did not have trains on it when it collapsed but two trains on the 'Down' and the 'Up' roads were in the immediate vicinity.

The 'Down' train was the 19:03 ex London Marylebone to Stratford passenger service (reporting number 2W62) comprising 165037 (three vehicles). It departed the previous stop at

Denham Golf Club at approximately 19:29 and due to stop at Gerrards Cross at 19:33. North of the M25 the train was doing around 55-60mph before braking in the usual manner for Gerrards Cross. After coming around a curve at about 50 mph the driver noted he could not see through the tunnel and placed the brake into full emergency such that the train stopped 250-300 yards before the eastern portal entrance to the tunnel. The driver seeing mud and rubble in the tunnel. During the emergency braking a STOP broadcast came over his Cab Secure Radio. Marylebone IECC (Signalling Centre) contacted the driver by Cab Secure Radio to ensure that the train had stopped and that protection was in place for the train. The driver placing detonators between the train and the tunnel entrance – signal protection being provided by the IECC. After 30 minutes or so the train reversed to Denham Golf Club and the 50-70 passengers terminated their rail journey that evening. The last train through the 'tunnel' on the 'Down' Line was the 18:58 service ex Marylebone.

The 'Up' train was the 17:40 Stratford on Avon to London Marylebone passenger service (reporting number 1H97) and had departed Banbury at about 18:30. It was booked to stop at Gerrards Cross at 19:31 but was approximately one minute late on arrival. The driver thought that there was a lot of dust upon his arrival. Passengers arrived and left and the driver noted a green aspect on signal ME116 at the platform end – just before Packhorse Road bridge. The train set off but at about 5 mph the driver thought something was wrong. He used a full service brake and stopped behind signal ME116. He contacted Network Rail Control using the Cab Secure Radio emergency line. He told them what had happened and then placed a TCOD (Track Circuit Operating Device) on the 'Down' line. He then contacted Marylebone IECC from the Signal Post Telephone at ME116 informing them of the situation. He then obtained authorisation to set his train back the few yards into the 'Up'platform at Gerrards Cross station. The 40-60 passengers got off the train – there was no guard as this was a DOO service (Driver Only Operation). This service train had a forward facing camera and the relevant discs were subsequently copied and given to HSE.

The weather at the time was that rain had just started to fall and hence the rails were wet.

It transpired that 28 off sections (marked as N115 to N129 inclusive on the north side with S116 to S129 inclusive on the south side) had initially collapsed below the proposed car park area towards the eastern portal (ch 983 to 1010) onto the railway along with approximately 15,000 tonnes of fill material. A further section collapsed overnight resulting in the collapse of in total, 14 units on the north side and 15 sections on the south side. The fill profile over the adjacent damaged units that did not collapse (though were later removed in a controlled manner) shows approx 2.5m fill over the crown with 2m to 2.5m at the haunches. The access road sloping down on the north side from west to east.

A further 16 units were subsequently removed due to damage etc. Hence, the initial collapse area was about 90' long and then increased to 138'.

Nobody was hurt. The line remained closed to all traffic until reopening on the 21st August 2005.

The report entitled Gerrards Cross Tunnel Collapse - Review Document Final Issue dated 12/08/05 signed off by [redacted] (Managing Director) of JCEL and [redacted] of WYG is of interest as follows:

Page 15, para 10:

"Network Rail's view on the cause of the collapse was inadequate fill material around the arch haunches compared to the fill directly over the crown. In their opinion this was a classic mode of failure, with the arch deflecting under the weight of the backfill over the crown with insufficient fill to the sides to resist the forces. Consequently plastic hinges formed at the haunches and this allowed the crown pin to snap through or dislocate and resulted in collapse."

The report's own view on page 16 is

"The units failed by creating a plastic hinge on the concrete units at the quarter point".

The post incident analysis section at 4.0 on page 19 highlights various non conformances with specification: level differences of up to 35mm between adjacent units, lateral gaps of up to 30mm, spalling of concrete, cusping, external to internal cracking. None of these are considered significant by RECO but no mention of how all together in combination may have affected the structure.

Further, on page 20, crown levels are between 123mm and 281mm below those indicated at design stage. On average these are 250mm lower in the loaded area and 150mm lower in the unloaded area. Predicted deflection limit under dead load of 40mm. [redacted] says "you can't control the crown level".

Chord lengths for concrete sections varied between 25 and 30mm shorter than specification which would in itself lead to a 55mm lowering of the crown level. However, the following paragraph on this page seems to indicate sections "conformed to the geometric tolerances for chord length" In essence, they appeared to be correct in the Macrete QA documentation but were short at site. This aspect (as to why) does not appear to have been investigated by anyone.

The report states on page 23

"there was a requirement to maintain the access to the east portal which prevented the laying of IBAA fill fully on the haunch areas to both north and south sides of the tunnel. IBAA material, however, continued to be placed and compacted over the tunnel arch leading to an overload of materials on the arch units". Indeed, [redacted] (RECO) design analysis report of 12/08/05 (appendix to this report) states at 3.0 Back Analysis of Tunnel Unit Loadings located at collapse (last para) "The results of the back analysis show that the arch units either side of the collapse were subjected to load effects at the limit of the design capacity of the concrete section. The stresses in the reinforcement exceeded the yield stress of the steel. Given the comments above, especially those concerning the amount of fill above the crown in the collapse zone, it can be concluded that the failure arose from the formation of plastic hinges at the quarter points as a direct result of the loading imposed by the backfill".

Another pertinent point to note from this report is the contents of Appendix 'OO', prepared by Atkins Rail for JCEL's report dated 12th August 2005. The contents have been agreed by RECO and WYG. It concerns the theoretical Adequacy Factors (AF) extant on site at the completion of the '6N' filling operation by JCEL.

Referring to p1 Addendum A of Appendix 'OO', there is a "Table of Adequacy Factors - Historic and up to end of completion of Phase 1( Load Relief) Stage." This table shows adequacy factors for the whole length of the structure from chainage 942 to 1218 for various loading situations. Of interest to the investigation team is the loading situations described below:

**chainage 1100-1218:** Loading cases B1, total cover over tunnel extrados = 3.3 m (base run) - on completion of '6N' capping, AF = 0.733 and final condition prior to phase 1 works AF = 0.727

**chainage 1050-1100:** Loading cases B2, total cover over tunnel extrados = 2.8 m (base run) - on completion of '6N' capping AF = 0.609 and final condition prior to phase 1 works AF = 0. 639

**chainage 970-1030:** The collapse area itself had Adequacy Factors( AF) of 0.437- 0.520.

Other areas of the arch structure still standing had AFs values varying from 0.733 - 0.609 and in engineering codes structural stability requires AF values > 1. The practical meaning of

these numbers to an engineer is that between chainages 1050 - 1218 the arch units were not code compliant: ie they were outside their design envelope for some period prior to the collapse on the 30th June 2005.

It should be noted that in an earlier draft of this report dated 29th July 2005, the Executive Summary was present whilst in the final report it was not present: it states in the opening paragraph (1.01)

"The Engineering Team review has concluded that the cause of the collapse was due to the placing of too much Type 1A fill over the area of the crown of the tunnel prior to placing and compacting sufficient material in the area of the tunnel haunches adjacent to the north and south site access roads towards the east end of the site. This overloading induced excessive moments within the arch leading to formation of plastic hinges at approximately quarter points in the precast arch units, thereby inducing collapse.

There is no evidence of any other contributory factors.

The filling operation in the area of collapse was a departure from JCE's planned fill regime. The departure was unique to this area. Elsewhere from PHRB to ch 1028 JCE adhered to their planned fill regime and did not place IBAA on the crown of the tunnel until sufficient haunch support was in place".

Further at (1.04) it states "The joint producers of this report endorse the Executive Summary..." Seems to indicate that it was a joint WYG / JCEL production but in the Validity Statement at front of the document it is stated that "this report has been compiled for Jackson Civil Engineering Ltd by White Young Green Rail...".

Further, according to Atkins Rail (post collapse) said that the 'tunnel' should have fallen down if we (JCEL) backfilled it in the way they did. Atkins report however indicates that the tunnel was not code compliant.

of RECO says:

"The tunnel collapsed because the crown was overloaded and there was insufficient backfill to the sides to maintain it. This induced excessive bending moments at the quarter points of the arch structure leading to the formation of plastic hinges and subsequent collapse".

**Health and safety management** *(Where appropriate and to the extent not covered above, describe the health and safety management system before the incident, including any arrangements between duty holders that are relevant to the investigation)*

**Preventative measures taken by the duty holder(s) AFTER the incident** *(Describe the measures taken post event to secure compliance. State where measures taken resulted from HSE intervention (including enforcement action)*